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**Proceedings of
International Scientific and Professional Conference
“ALFATECH “
Smart Cities and modern technologies**

Belgrade,
February 28th 2025



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Proceedings of Conference

Proceedings of International Scientific and Professional Conference “ALFATECH” Smart Cities and modern technologies

February 28th 2025, Belgrade, Serbia

Publisher:

ALFA BK University, Belgrade, 2025

For publisher:

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Prepress:

MSc. Stefan Popović MSc.

Danilo Strugarević

The press:

GLAMURKraljevo, Kraljevo, Serbia

Circulation: 250 copies

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Proceedings of Conference

ALFATECH 2024

**International Scientific and Professional Conference
“ALFATECH “
Smart Cities and modern technologies**

Belgrade, Serbia February 28th
2025

Organizer:

Faculty of Information Technologies, ALFA BK University, Belgrade, Serbia
Faculty of Mathematics and Computer Science, ALFA BK University, Serbia
Faculty of Technical Sciences in Čačak, University of Kragujevac, Čačak, Serbia

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Supported by:

The Ministry of Science, Technological Development and Innovation of the
Republic of Serbia.

The conference is part of the project “Smart cities and modern technologies”

No: Y02/2023

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International Scientific Conference "ALFATECH – Smart Cities and modern technologies"

28.02.2025.

Alfa BK University, Bulevar maršala Tolbuhina 8, Belgrade

CONFERENCE PROGRAM

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Time	Activity	Moderator	Location
9:30 - 11:00	Registration of participants		University Hall
11:00 - 11:30	Opening Ceremony	Jovan Veselinović Milan Gligorijević Mihailo Jovanović	A 1
11:30 - 12:30	Plenary Session 1 Dušan B. GAJIĆ, Blockchain Applications in the Development of Smart Cities Jovana MIHAILOVIĆ, From Network to Smart Cities, the Role of Mobile Operators in Urban Development, ICT product programming manager, A1 Serbia Hanyao TAO, Empowering Governments with AI-powered Smart City Solutions on Huawei Cloud, Senior Manager of Huawei Cloud, Huawei Kosta VESELIĆ, Smart Building Concepts, Informatika AD	Milan Gligorijević Vladimir Mladenović	A 1
12:30 - 13:00	Coffee Break&Koktel		University Hall
13:00 - 14:30	Plenary Session 2 Nikola GLIGORIJEVIĆ, Integration of Drones for Intelligent Crowd Counting in the Safe City Concept Mladen GLIGORIJEVIĆ, AOP and PSIM platforms, TeleGroup Ivan Vulic, Digital infrastructure of smart cities: Possibilities and challenges, Executive Director of the Institute of High Technologies Vlatom Predrag NIKOLIĆ, Smart City Solutions Within the BK Tesla Project, BK Tesla High Technology Park Snežana ĐORIĆ-VELJKOVIĆ, Modern Technologies for Innovative Urban Water Management in Smart Cities Dejan BLAGOJEVIC, Mapping of Heat Underground Infrastructure in Smart Cities – Resource Control	Milan Gligorijević Vladimir Mladenović	A 1
14:30 - 15:00	Coffee Break&Koktel		University Hall
15:00 - 16:30	Session 3 - selected papers - part 1	Stefan Popović Aleksandar Stokić	A 1
16:30 - 16:45	Coffee Break&Koktel		A 1
16:45 - 18:00	Session 3 - selected papers - part 2	Stefan Popović Aleksandar Stokić	A 1



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15:00 - 16:00	Panel discussion - Benefits and challenges of applying modern technologies from the aspect of sustainability in business practice.	Violeta Dimić	A 4
14:30 – 17:00	Poster Session	Milan Brkljač	K 2

Activity	Topic	Presenters
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	Peak Loads Reduction Optimizing Strategies in District Heating System – Case Study Of Maribor	Etjan KIRALJ, Filip KOKALJ
	The Role of Organizational Culture in the Onboarding Process in Four Small IT Companies: A Qualitative Study	Maja GABOROV, Željko STOJANOV, Mila KAVALIĆ, Verica GLUVAKOV, Igor VECŠTEJN
	Leadership in Smart Cities: Emotional Intelligence as a Driver of Smart City Ecosystem Transformation	Jelena VUKONJANSKI SRDIĆ, Bojana MILIČIĆ, Katarina PAVLOVIĆ
	Using Machine Learning Techniques for Age Prediction Based on PPG Signal Analysis	Mirjana TOMIC, Stevan JOKIC, Nenad GLIGORIĆ, Ana KOVAČEVIĆ, Branislav GERAZOV
	Digital Transformation of Education: The Impact of Generative AI on Programmer Training	Egor CHEGLOV, Andrey PESTUNOV, Olga SHVETS
	The Model of a Smart Education System: Gamification of Teaching Through Digital Dialogue	Momčilo RANĐELOVIĆ, Radoje JEVTIĆ, Jovan NIČKOVIĆ, Dragan VUČKOVIĆ
	Smart City Challenges: Prioritization Methods	Aybeyan SELIM, Mimica MILOŠEVIĆ, Dušan MILOŠEVIĆ
	Global Location Coding (Universal Geographical Indicator System)	Dejan DJUKIC, Stefan POPOVIC, Snezana OCOKOLJIC
	Implementing Network Policies in Kubernetes	Sava STANISIĆ, Vladimir MLADENOVIC
	Contemporary Machine Learning in Smart Cities: A Review of Quality, Measurability, Explainability, Privacy, and Security	Anja DELIĆ, Jelena KOVAČ, Nevena GLIGOROV, Branislav S. RISTIĆ, Marko GORDIĆ, Radovan TUROVIĆ, Dinu DRAGAN, Dušan B. GAJIĆ, Veljko B. PETROVIĆ
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		ŠARČEVIĆ, Dragan Vučković
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	A Computationally Implemented Method for Assessing Air Pollution in Urban Traffic Based on Traffic Density Analysis	Nikola Stefan ĆIRKOVIĆ, STANIĆ, Katarina KARIĆ

Poster Session	Development of Educational Information Systems in Smart Cities with the Application of Artificial intelligence	Ana BAŠIĆ, Dejan VIDUKA, Ana-Marija VUKIĆ
	Using Machine Learning Techniques for Age Prediction Based on PPG Signal Analysis	Mirjana TOMIC, Stevan JOKIC, Nenad GLIGORIĆ, Ana KOVAČEVIĆ, Branislav GERAZOV
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Personalization of learning in smart cities: using AI technologies to create adaptive educational platforms

Ildar SHAIKHISLAMOV, Andrey PESTUNOV, Olga SHVETS

Abstract: This article considers an urgent problem of personalization of learning in the context of the development of smart cities, where educational processes should be not only effective, but also adapted to the individual needs of students. The authors present an innovative adaptive educational platform developed using advanced artificial intelligence (AI) and machine learning technologies. The platform analyzes students real-time data, including their academic achievements, preferences and learning styles, to offer personalized learning trajectories. The main goal of the research is to demonstrate how AI technologies can be integrated into smart city education systems to improve learning and inclusion. The platform uses machine learning algorithms to automatically customize learning materials, allowing for individualized learning experiences for each student. This not only improves the learning process, but also reduces the workload of teachers, freeing up their time for more creative and strategic tasks. An important aspect of the study is the integration of the platform into the infrastructure of smart cities. The authors emphasize that such technologies not only improve educational processes, but also contribute to the sustainable development of the urban environment. The platform helps optimize the use of educational resources, reduce the cost of education and provide equal access to quality education for all individuals, regardless of their social status or physical capabilities. In conclusion, the article proposes new approaches to the organization of educational processes in smart cities based on AI technologies. The presented platform shows potential for scaling and implementation in various educational institutions, which makes it an important tool for shaping the future of education. The authors also discuss possible challenges associated with the implementation of such technologies, including data privacy and ethical issues in the use of AI, and suggest ways to address them.

Keywords: personalization of learning, smart cities, artificial intelligence, adaptive education platforms, machine learning, inclusive education.

1 INTRODUCTION

In an era marked by the dynamic advancement of technology and the exponential growth of urbanization, the concept of smart cities is getting increasingly more prominent. Education, as a vital component of social infrastructure, necessitates adaptation to these evolving conditions. The personalization of learning, grounded in artificial intelligence (AI) and machine learning (ML) technologies, unveils new prospects of developing adaptive educational platforms (AEPs) capable of accommodating the individual needs of students.

Traditional educational paradigms, characterized by a uniform approach to learning, exhibit significant limitations within the context of the modern socio-cultural environment. The failure to account for individual cognitive styles, disparities in the level of prior training and motivational preferences decreases student engagement, deteriorates academic performance and increases attrition rates. The implementation of AEPs, based on the principles of intelligent data analysis, presents a promising direction for addressing this issue.

This study explores the feasibility of integrating adaptive educational platforms (AEPs), underpinned by artificial intelligence (AI) and machine learning (ML) technologies, into the infrastructure of smart cities. The objective is to

examine the potential of such platforms for the dynamic analysis of student data, the generation of individualized learning trajectories, and, consequently, the enhancement of efficiency, accessibility, and inclusivity of education within the urban environment. This research is geared towards the development and experimental validation of an innovative AEP model, as well as the evaluation of its potential impact on key indicators of learning effectiveness within the context of a smart city.

To achieve the objective, the following tasks are addressed:

1. Development of algorithmic and software solutions for AEP to collect, process, and analyze student data, as well as generate individualized learning trajectories;
2. Conduct an experimental study to evaluate the impact of the AEP on indicators of student performance, engagement, and satisfaction, as well as on reduce the workload on teaching staff;
3. Investigate and determine the optimal strategies for integrating the developed AEP into the existing smart city infrastructure, with due account of educational institutions, online resources, and other relevant components of the urban ecosystem;
4. Analyze ethical and social aspects of AEP implementation, including data confidentiality,

algorithmic bias, and ensure equal access to educational resources.

This research requires a comprehensive methodological approach, particularly:

- machine learning methods for analyzing student data and identifying patterns that determine their cognitive characteristics and preferences,
- statistical analysis methods for assessing AEP effectiveness and identifying statistically significant differences between experimental and control groups,
- modeling and simulation methods for analyzing the impact of various AEP parameters on the overall performance and stability,
- expert assessment methods for identifying potential risks and problems associated with AEP implementation, as well as developing strategies to minimize them.

Ildar SHAIKHISLAMOV, Andrey PESTUNOV, Olga SHVETS

2 DEVELOPMENT OF AN INNOVATIVE ADAPTIVE EDUCATIONAL PLATFORM

Within the scope of this research, an innovative AEP was developed, intended for personalized learning within the context of smart cities. The key objective was to create a scalable and flexible system capable of adapting to the dynamically changing needs of students and integrating into the existing smart city infrastructure.

2.1 Platform Architecture

The AEP is designed on a modular principle for flexibility and scalability. The platform comprises the following main functional modules:

1. Data Collection and Processing Module: This module supports collection of data about students from various sources, including online questionnaires, test results, data on academic performance, and behavioral patterns. Machine learning algorithms are used to process and normalize the collected data.

2. Content Adaptation and Individualized Learning Trajectory Generation Module: This module is responsible for the dynamic adaptation of educational content and the formation of individualized learning trajectories, taking into account the unique needs, goals, interests, and cognitive characteristics of each student. Based on the analysis of data obtained from the Data Collection and Processing Module, the system automatically adjusts the complexity, format, and pace of delivery of educational material to build the optimal sequences of educational elements to fit individual educational goals and learning styles. A multilayer perceptron (MLP) with a categorical cross-entropy loss function and an Adam optimizer is used to implement adaptive learning, allowing for dynamic

adjustment of learning parameters depending on student progress and feedback.

3. Interactive Communication Module: Provides interactive communication of students with the platform, providing opportunities for feedback, consultations with teachers, and exchange of experience with other students.

4. Gamification Module: To increase student engagement and motivation in AEP, including elements of competitiveness, rewards, and goal-achieving incentives.

2.2 Integration with Smart City Infrastructure

One of the key advantages of the developed AEP

is its ability to integrate with the smart city infrastructure, which will optimize the use of educational resources and give equal access to quality education for all individuals.

Integration of the AEP with urban services and databases will:

- automatically adapt curricula to the needs of the labor market and the requirements of employers,
- supply information to students about available educational resources, events, and employment opportunities in the city,
- optimize the logistics of the educational process, considering the transport infrastructure and geographical location of students,
- support students with special needs by providing access to specialized resources and services.

2.3 Results of Experimental Validation

The results of the experimental validation of the developed AEP indicate its high efficiency and prospects. Students who followed individualized educational routes demonstrated a 20% increase in academic performance compared to the control group. In addition, 90% of the experiment participants expressed a high degree of satisfaction with the platform and a willingness to recommend it to other students. There is also a significant decrease in the churn rate to 0, which indicates a high degree of student engagement in the educational process.

3 INCLUSIVITY, ETHICAL ASPECTS, AND DEVELOPMENT PROSPECTS OF ADAPTIVE EDUCATIONAL PLATFORMS

3.1 Inclusivity and Equal Access to Education

One of the key aspects of AEP implementation is to ensure inclusivity and equal access to quality

education for all individuals, regardless of their social status, physical capabilities, or geographical location. AEPs allow adapting curricula and materials to the individual needs of each student, creating conditions for successful learning regardless of the initial level of training and cognitive characteristics.

As a further development of the study, it is proposed to develop special AEP modules and functions to support students with special educational needs, including:

- adaptive interfaces that adjust font size, color gamut, and contrast for students with visual impairments,
- interactive exercises and tasks with alternative methods of information input (voice input, gesture control) for students with motor impairments.

3.2. Ethical Aspects of Artificial Intelligence in Education

The introduction of AI technologies into educational processes is associated with a number of ethical challenges that require serious attention and the development of appropriate regulatory frameworks. Data confidentiality, algorithmic bias, and ensuring transparency of decision-making are of particular relevance.

This study proposes the following measures to ensure the ethical use of AI in AEP:

- strict data protection protocols, including encryption of information, restriction of access to personal data, and

ensuring the consent of students to the use of their data for educational purposes,

- regular audit of machine learning algorithms to identify and eliminate potential biases and discriminatory effects,
- transparency of AEP decision-making to provide students with the opportunity to understand how their individual learning trajectories are formed and what factors influence content adaptation,
- feedback and appeal mechanisms that allow students to challenge AEP decisions and receive advice from qualified professionals.

3.3. Prospects for the Development of Adaptive Educational Platforms

Adaptive educational platforms are a dynamically developing area in which new technologies and approaches are constantly emerging. In the future, further improvement of AEP can be expected due to:

- integrating with other aspects of the smart city, such as smart homes and transport systems, which will

create even more personalized and contextualized learning routes, - using data on student movement to adapt curricula to their geographical location and interests,

- developing new machine learning algorithms that take into account the individual characteristics of students based on the analysis of large amounts of data obtained from various sources,
- creating virtual educational assistants capable of providing students with individual support and consultations in real time.

3.4 Challenges and Limitations

Despite significant AEP potential, the existing challenges and limitations should be taken into account. These include: - high costs of AEP development and implementation, requiring significant investments in infrastructure and personnel training,

- the need for constant updates and adaptation of AEP to the changing needs of students and the labor market, - the risk of digital inequality, when access to quality education using AEP will be limited for certain groups of the population, - problems related to data protection and confidentiality of information about students.

To overcome these challenges, a comprehensive approach is required, including effective funding mechanisms, open standards and protocols for data exchange, as well as widespread efforts to educate the population about the benefits and risks of AEPs.

CONCLUSION

This work contributes to the development of the theoretical and practical foundations of personalized learning in the context of smart cities and is important for the formation of an innovative educational environment with improved quality and accessibility of education for all members of society.

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UDK: 37.091.3:004.8

DOI:

10.46793/ALFATECHproc25.004C

Original scientific paper

Digital Transformation of education: the impact of generative AI on programmer training

Egor CHEGLOV¹, Andrei PESTUNOV², Olga SHVETS³

Abstract: With the development of generative artificial intelligence (AI), students are increasingly using it to solve programming tasks. This leads to changes in the educational process and requires revision of traditional teaching methods. The study analysed the patterns of AI usage, its advantages and disadvantages, and identified key differences between code written manually and generated by neural networks. Possible approaches to the integration of AI into the learning system are considered in order to increase the effectiveness and ensure the objectivity of knowledge assessment.

Keywords: code generation; digital transformation; generative AI; knowledge assessment; programmer training; programming education; teaching methods integration.

9056 1 INTRODUCTION

With the advancement of generative artificial intelligence (AI), students have gained access to computational tools that facilitate the automation of academic tasks across various disciplines. The 2023 study conducted by researchers from Darmstadt University of Applied Sciences (Germany), sampling over 8,800 students, examines the prevalence and domains of AI in education. The findings indicate that more than 63% of respondents incorporate AI-driven

technologies into their learning processes. The adoption rate is notably higher among students in engineering disciplines (75%), followed by those in the natural sciences (71%), humanities (61%), and medical fields (52%) [1].

Programming is one of the academic disciplines most closely associated with AI. The integration of AI into programming education presents both advantages and disadvantages [2]. Generative AI facilitates the development of solutions by autonomously producing accurate and comprehensible program code, thereby significantly reducing the time and computational resources required to complete assignments. However, the incorporation of generative AI into the educational process has sparked extensive debate among educators and researchers.

On the one hand, AI can function as a personalized assistant for students, providing explanations of algorithms and guiding the development of complex software structures, as well as systematically organizing and presenting information in an accessible format [3]. On the other hand, concerns have been raised that relying on generative AI may diminish students' motivation for independent problem-solving and impede the advancement of critical and creative

thinking skills, potentially leading to a decline in overall knowledge acquisition [4].

This raises several critical questions: does the use of generative artificial intelligence (AI) pose a threat to the educational process? Can it facilitate a deeper understanding of complex topics by freeing up time for analysis and creativity, or, conversely, does it deprive students of essential hands-on experience?

The objective of this study is to examine students' experiences in utilizing generative AI for solving programming-related learning tasks. The research aims

to identify the distinctive characteristics and patterns of AI usage among students from various academic backgrounds, thereby providing a more comprehensive understanding of how AI integration influences the educational process in the context of programming instruction.

Additionally, this study includes an analysis of an electronic programming course hosted on the university's Learning Management System (LMS). Universities commonly employ the CodeRunner plugin for the automated assessment of students' solutions [5].

Traditional teaching process often assumes that a teacher plays both roles: teaching and checking. In such a situation, the second (checking) role may dominate over the first one and the student may fall into some sort of confrontation with the teacher. Automatic systems such as CodeRunner take the checking role by themselves and the teacher becomes an ally with the student. Their common goal is to overcome all checking barriers of the automatic system. The teacher doesn't help his student directly, but tries to help him (her) to handle the problem.

However, GAI (generative AI) may spoil these educational process model by creating temptation of

exploiting it in order to solve the problem with the help of GAI instead of the teacher. There exists a difference between the teacher's and the GAI's help. The teacher is able to provide the student with the partial solution and the student would try to reach the final one. But GAI will elaborate the final solution at once and the student will be satisfied with that, thus, eliminating the teaching effect.

Thus, the study explores the challenge of detecting generative AI usage in academic assignments and proposes methods for identifying such cases within an automated verification environment.

2 RESEARCH METHODOLOGY

This study investigates the perceptions and experiences of students utilizing various generative AI models to complete programming tasks. To facilitate data collection, a structured questionnaire was designed, combining both quantitative measures and open-ended questions to capture qualitative insights.

The survey was administered to students enrolled in programming-related disciplines, including "Fundamentals of

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Algorithmizing and Programming" (secondary vocational education), as well as "Programming," "Programming Languages," and "Programming of Discrete Structures" (bachelor's degree programs). Participation was voluntary and anonymous. A total of 61 students participated, comprising 29 students from secondary vocational education programs and 32 students from bachelor's degree programs.

In addition, the study incorporated 100 tasks of basic complexity from an electronic course, organized into eight thematic blocks. The experimental procedure involved simulating the behaviour of a student who copies the task description from the LMS and inputs it into a generative AI model. The AI-generated solution is then submitted to an automated testing system for verification without modification. In case of failure, the student iterates the process by submitting clarifying queries to the AI model until the solution passes the tests successfully.

3 SURVEY RESULTS

According to the results of the survey, 34 students (55.7%) reported possessing only basic programming knowledge, while 11 students (18%) indicated that they were learning programming for the first time. Another 11 respondents (18%) self-assessed their skills as confident in one programming language, and only 5 students (8.2%)

stated that they are proficient in multiple programming languages.

In their self-assessment of algorithmic knowledge, 47.5% of respondents acknowledged a lack of familiarity with this area, while 42.6% of respondents indicated that they were acquainted with basic algorithms, such as brute force or bubble sort. Only 6 students (9.8%) reported proficiency in more advanced algorithms, such as binary search, quick sort, or Euclid's algorithm.

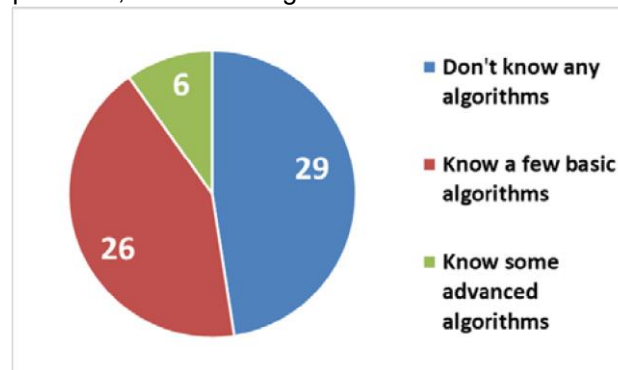


Figure 1 How would you rate your algorithms knowledge?

An analysis of the responses revealed two distinct groups based on the students' level of proficiency in programming and algorithms. Among those with limited or basic programming knowledge, the use of generative AI was most prevalent due to challenges faced after several unsuccessful attempts to complete tasks independently (67%)

and the need to debug their own code (65%). In contrast, students with more advanced programming skills in one or more languages were more likely to turn to AI due to poor understanding of task conditions or the meaning of the problem (44%) and a lack of motivation to solve the task independently (38%). Additionally, both groups expressed a desire to obtain optimized solutions (13.3% of the total respondents).

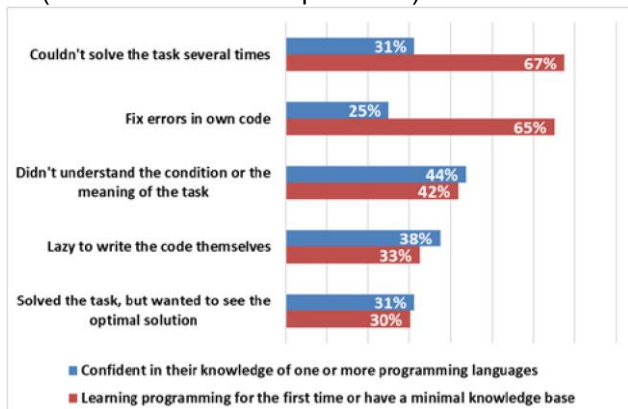


Figure 2 What is your main reason for using generative AI?

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An analysis of the frequency of AI usage revealed that 73.8% of the respondents use it 1–3 times per week, 16.4% use it daily, and 9.8% use it 4–5 times per week.

The students identified several significant advantages of using generative AI in programming tasks. The most frequently mentioned benefits included time-saving, reported by 82.2% of respondents, and assistance in mastering new and complex algorithms, cited by 74.2%. Additional benefits highlighted by students included faster and improved learning processes, more accessible and comprehensible explanations and solutions compared to traditional teacher-provided explanations, as well as increased self-confidence and enhanced motivation to learn.

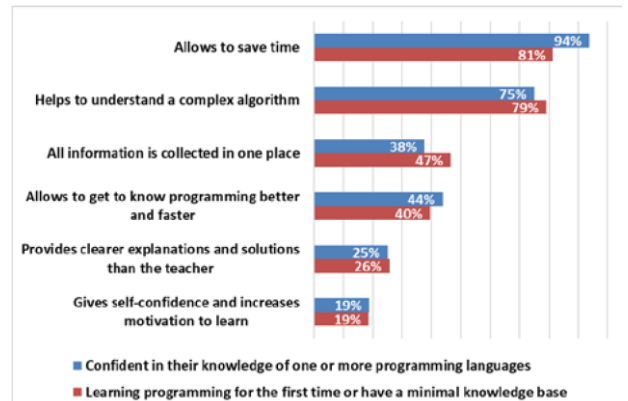


Figure 3 What advantages can you identify from using generative AI?

While a small percentage of students (2.9%) did not perceive any disadvantages in using generative AI for programming tasks, the majority identified several notable negative aspects. Entry-level students with minimal programming knowledge most frequently

pointed out the inaccuracy of the generated code (72%) and the risk of overreliance on AI (44%), which they believed weakened their algorithmic thinking abilities (35%). Students with more advanced knowledge also highlighted frequent inaccuracies in the generated solutions (88%) and the issue of AI misinterpreting their requests, which often led to misleading results (50%). Other disadvantages noted by respondents included a perceived lack of creativity and variability in problemsolving.

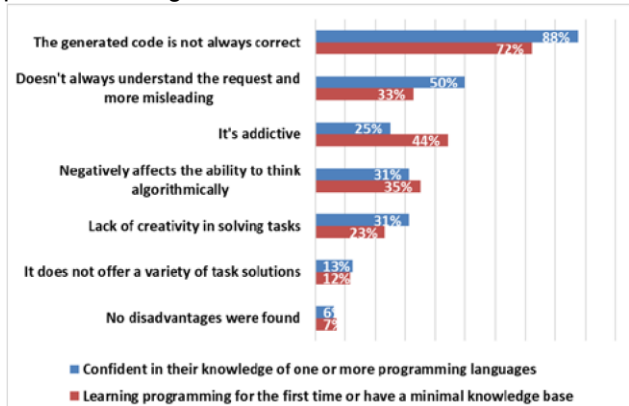


Figure 4What disadvantagescan you identify from using generative AI?

The survey results suggest that the majority of students (61%) require multiple clarifying queries to obtain a correct solution from generative AI, although 34% of respondents reported successfully resolving the task on the first attempt. These findings may indicate that many students have not yet developed the skills to accurately formulate queries to AI and tend to simply copy the task description and submit it without modification.

Furthermore, the survey revealed that students rarely present AI-generated solutions as their own work (only 11%). Instead, they use AI primarily to improve their own solutions: 43% of respondents integrate part of the generated code into their projects, and 46% modify the proposed code before submitting it for evaluation.

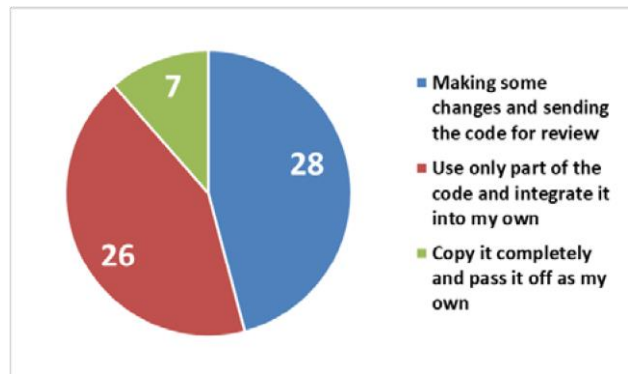


Figure 5How do you use the AI-generated code?

The questionnaire also aimed to identify which generative AI models' students utilize, including ChatGPT, Gemini, YandexGPT, GigaChat, DeepSeek,

Telegram-based chatbots, ChatInfo, and generative AI integrated into development environments. The obtained data served as the foundation for the second phase of the study.

One of the primary objectives of this study was to identify the differences in problem-solving approaches between generative AI models and students. While an experienced instructor can typically distinguish between independently written and externally generated code, the challenge lies in training an automated system to detect such instances and respond appropriately in real time.

Generative AI adheres strictly to the programming standards, ensuring consistent code formatting and comprehensive comments—an approach that is uncommon among most students. Furthermore, AI-generated solutions often incorporate advanced programming language features that are not typically covered at the initial stages of learning, which may raise suspicions during the assessment of student work. Additionally, variations in variable naming conventions can serve as an indicator of AI involvement: while AI tends to assign names based on the semantic meaning of the variable's contents, students are more likely to use abstract or inconsistent naming patterns.

The identification of AI-generated code can be facilitated through various quantitative and qualitative metrics. Execution speed and memory consumption serve as fundamental indicators, as AI-generated code is often optimized for performance.

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This optimization stems from the efficient utilization of built-in programming language functions and advanced algorithms. In contrast, student-written code may exhibit higher memory consumption due to redundant variables or inefficient data structures.

Additional quantitative metrics indicative of GAI usage include features that are less commonly observed in student solutions, such as the frequency of inline comments, function definitions (including lambda functions), try-except blocks, and list comprehensions.

Furthermore, qualitative metrics can provide deeper insights into AI-generated code characteristics. These include adherence to programming style standards, the average length of variable and function names, Halstead Difficulty, which quantifies cognitive complexity in code comprehension, and Cyclomatic Complexity, a metric that assesses algorithmic complexity by measuring the number of linearly independent execution paths. The integration of these metrics enables a more comprehensive analysis of code provenance and aids in distinguishing between human-written and AI-generated solutions.

4 CONCLUSION

The findings of this study provide an opportunity to evaluate the feasibility of integrating generative AI into the educational process. On the one hand, AI can serve as a tool for personalized student support, adapting to their level of proficiency and individual learning needs. On the other hand, its widespread use may adversely affect the development of independent problem-solving skills and critical thinking. These results highlight the necessity for further research on AI integration in education, with a particular focus on developing methodologies that foster precise problem formulation skills and promote the effective use of AI as an educational aid without diminishing students' cognitive engagement and motivation for independent work.

The analysis conducted in this research can serve as a basis for the development and integration of advanced software modules designed to detect AI-generated code or establish new principles of formulating the problems conditions in order to limit the extent of using GAI by the student while solving the problems. One potential implementation is a neural network embedded within the LMS, which would enable the automated identification of both AI-generated code and instances of code reuse among students. Furthermore, such a system could offer personalized recommendations for code optimization and refactoring, while also facilitating the implementation of individualized learning trajectories, thereby enhancing the adaptability and overall efficacy of programming education.

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Peak loads reduction optimizing strategies in district heating system – case study of Maribor

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Abstract: District heating systems provide centralised heat generation and efficient distribution in urban environments, enhancing energy efficiency and mitigating local uncontrolled emissions. Nonetheless, district heating is influenced heavily by fluctuations in energy prices, environmental and climate issues, and the necessity of maintaining reliable operations during the heating season. These systems often depend on continuously functioning equipment to meet fundamental heating requirements, while peak demands are addressed with supplementary flexible heat sources. This frequently results in system oversizing, elevating operating expenses and inefficiencies. An effective strategy to mitigate peak demand challenges is heat consumption shifting, which reallocates energy usage more uniformly over the day. Shifting heat demand from peak hours to times of lesser consumption enhances overall system efficiency and diminishes the necessity for extra peak-load capacity. This method can be very advantageous in current district heating networks without necessitating significant infrastructure modifications.

A simulation of heat load shifting was performed on the district heating system of the City of Maribor. The research employed altered heat consumption patterns to examine the viability of load shifting and its effects on system performance. The results indicate that optimised energy distribution may augment operational stability, decrease expenses, and boost sustainability.

Keywords: district heating system; energy efficiency; heating schedule; optimization

1 INTRODUCTION

District Heating Systems (DHS) play a crucial role in providing heat to urban areas by enabling efficient heat distribution and supply through centralized heat production. Despite their numerous advantages, DHS face challenges related to fluctuating energy prices, environmental and climate issues, and ensuring reliable operation.

One of the biggest challenges for modern DHS is peak loads, which occur during periods of highest heat demand. The thermal power profile exhibits a characteristic daily consumption pattern, marked by pronounced peaks and periods of lower demand. In the early morning hours, there is a sharp increase in thermal power due to rising heating needs at the start of the day. This increase reaches a peak before gradually stabilizing at slightly lower levels throughout the morning and afternoon. The late afternoon often brings a second pronounced peak, linked to additional energy consumption before the system begins to settle in the evening. During the night, heat demand drops significantly as consumption decreases to a minimum due to lower requirements and the shutdown of certain systems. This daily cycle repeats consistently, with peaks aligning with periods of higher consumer activity. Such a pattern presents opportunities for optimization, such as peak shaving and a more even distribution of thermal power during periods of lower demand.

The DHS in the Municipality of Maribor ensures a reliable, sustainable, and energy-efficient heat supply. The system is managed by the public utility company Energetika Maribor d.o.o. (ENMB), which provides heating to households, public institutions, and commercial buildings through a modern distribution infrastructure. The operation of this complex system is governed by the System Operating Instructions for the District Heating Distribution System (SON) [1]. The SON document regulates all aspects of system management, operation, and development while also defining the rights and obligations of all consumers, designers, and system operators. As the district heating provider, Energetika Maribor must continuously meet DHS requirements, ensuring that heat supply parameters such as temperature and pressure comply with agreed-upon standards, which prescribe specific temperature regimes. To manage peak loads, ENMB currently utilizes thermal storage units, which allow excess heat to be temporarily stored during low-demand periods and used during peak demand periods.

The main objective of this study is to explore options for smoothing production peaks in the DHS of ENMB. One potential solution is modifying the heating regime and implementing a continuous heating approach. To this end, a simulation of load shifting in the DHS of ENMB was conducted. The study examined an alternative heating pattern and its impact on heat production. The simulation was performed for three representative days during the heating season, selected based on historical outdoor temperature data:

- **Case A** represents a very cold day,

- **Case B** represents a moderately cold day, and
- **Case C** represents a warmer-than-average day within the heating season.

For each of these three cases, modified consumption profiles were created and compared with actual historical data.

It is expected that the adjusted heating regime will reduce morning peaks, helping to lower the strain on production facilities during these periods, as the need for a sudden heat supply in the early hours will be diminished.

1.1 District heating substations

District heating substations are a key component of DHS, as they serve as the connection between the distribution network and end users. A district heating substation consists of heat exchangers, control valves, measuring devices, and circulation pumps, which ensure the transfer of heat from the high-temperature water network to the secondary circuit that heats the building's interior spaces. District heating substations play a crucial role in this study, as the entire heat production process is dictated by their operation. In a way, a district heating substation can be seen as a mirror of consumer demand.

There are two operational modes for district heating substations: flow-through (continuous) and non-flow-through (intermittent) operation.

Flow-through district heating substations (FTDHS) maintain a constant flow of the heat transfer medium, specifically hot water. The water continuously circulates through the district heating substation, meaning that the temperature profile of the district heating substation closely matches that of the distribution network.

Non-flow-through district heating substations (NFTDHS), on the other hand, do not allow a constant flow and only activate flow at specific times. The term "activation" refers to the moment when the valve in the district heating substation opens, allowing the primary district heating water flow to pass through the heat exchanger. This typically occurs between 5:30 and 6:30 AM. As a result, the temperature profile of a non-flowthrough district heating substation shows a distinct peak, reflecting the sudden increase in temperature when heating begins.

In the DHS of ENMB, the number of flow-through and nonflow-through stations is approximately equal. The idea behind this study is to simulate a transition to an exclusively flowthrough heating regime.

Figure 1 illustrates the temperature profile for a flowthrough district heating substation's supply temperature and the corresponding temperature at the heat source outlet. The district heating substation's profile follows that of the heat source but with a slight time lag and lower temperature values. The time lag is caused by heat transport delays, while the lower temperatures result from heat losses in the distribution network. The presented profile represents the actual data for a typical day during the heating season.

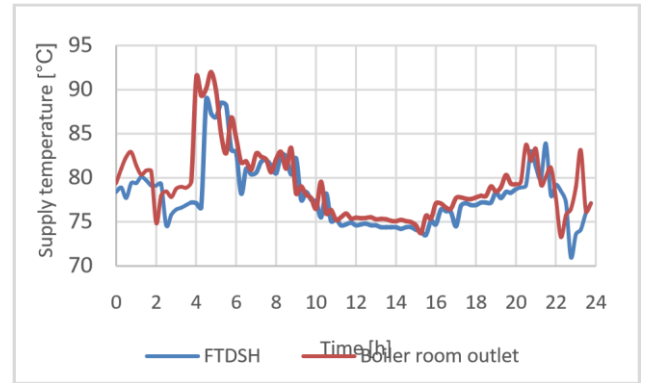


Figure 1 Temperature profile for a flow-through district heating substation

Figure 2 once again illustrates the supply temperature of the district heating substation and the water temperature at the heat source outlet. However, this time, it depicts a district heating substation operating in a non-flow-through heating regime. The data corresponds to the same day analysed in Figure 1, allowing for a direct comparison. The profile reveals a significant difference, with a distinct activation and deactivation moment clearly visible. This is expressed as a sharp temperature peak in the early morning hours, when the district heating substation is activated, followed by a steep drop in the evening, when the system is deactivated.

In non-flow-through heating systems, buildings operating under this regime maintain a reference temperature of 0 °C overnight, which in practice means that heating is entirely inactive during this period. As a result, users cannot adjust indoor temperatures using radiators or other heating devices during the deactivation period, as they do not reach the necessary operating temperature.

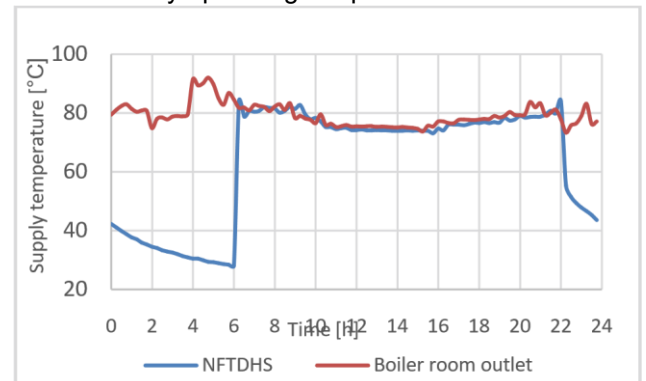


Figure 2 Temperature profile for a non-flow-through district heating substation

2 METHODS

To reduce complexity, the analysis is limited to the heating season, covering the months from November to March. This period is characterized by low temperatures, during which the primary heat source is the Jadranska boiler plant, which is also physically separated from the boiler plant on the left bank of the Drava River during this time. As a result,

the analysis is focused solely on this boiler plant, as it dictates heat production during the specified period.

The database includes 251 district heating substations, comprising all stations for which relevant data is available for the analysis. The key variables considered in the study are outdoor temperature, thermal power, supply temperature, return temperature, and thermal energy, all of which were continuously monitored throughout the analysis. Historical data was collected at 30-minute intervals over the past two years, ensuring a comprehensive dataset for evaluation.

Due to the large volume of data, the district heating substations were grouped into logical categories based on their location within the city. Instead of analysing each station individually, they were organized into data subsets – sub databases (SD). In total, 12 groups were formed, but only 11 were considered relevant for the analysis.

2.1 Interdependencies between the analysed variables

Determining the interdependencies between the analysed variables is crucial for understanding the behaviour of the entire district heating distribution system. Theoretically, the correlations between these variables could be described mathematically using well-known equations from the fields of heat transfer and fluid mechanics. However, in practice, these relationships often do not hold precisely due to multiple influencing factors, which affect each variable differently. As a result, the interactions between variables are not always constant.

To gain a better understanding of real-world system behaviour, one possible approach is to construct a correlation matrix of influencing factors, which provides a structured representation of these interdependencies. A correlation matrix is a table that displays the correlations between multiple variables within a dataset. The correlation analysis was conducted using a correlation matrix, where the relationships were quantified using the Pearson correlation coefficient, which ranges from -1 to 1. A value of 1 indicates a perfect positive correlation, meaning that an increase in one variable results in a proportional increase in another. Conversely, a value of -1 represents a perfect negative correlation, where an increase in one variable leads to a proportional decrease in the other. A value of 0 signifies the absence of a linear relationship between variables.

To generate the correlation matrix, we used the Python programming language along with appropriate libraries to develop the necessary code [2][3][4][5]. This code calculates the Pearson correlation coefficient for every possible combination of variables in the dataset. Additionally, two filtering constraints were applied to improve data quality. First, missing and anomalous values were excluded from the calculations. Second, rows containing values that deviated by more than three standard deviations from

the mean were also removed, as these outliers often result from data entry errors or anomalies during data collection.

The correlation matrix for one of the district heating substations is shown in Figure 3. Each field in the matrix represents the Pearson correlation coefficient for a specific pair of variables, determined at the intersection of a column and a row. For example, Figure 3 reveals that the Pearson coefficient between flow rate and thermal power is 0.77, indicating a strong positive correlation – as the flow rate increases, thermal power also increases. On the other hand, outdoor temperature and thermal power exhibit a negative correlation, which is expected, as lower outdoor temperatures lead to an increased demand for thermal power, consistent with the fundamental equation for calculating thermal energy.

Correlations vary more than expected for each district heating substation, especially in relation to outdoor temperature. Prior to data processing, a strong dependence of variables on outdoor temperature was anticipated. However, the resulting table did not indicate promising correlation values, as they were generally low and highly diverse. A similar variability was observed in a study [6] that focused on energy consumption forecasting. This variability was one of the key reasons why it was necessary to simplify the analysis with specific assumptions.

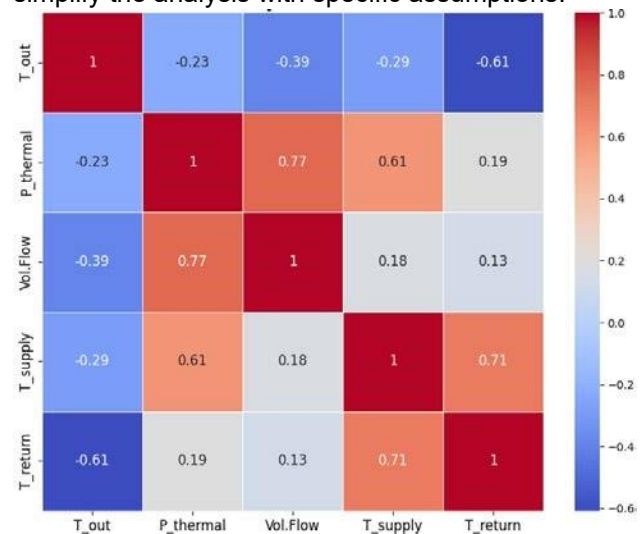


Figure 3 Correlation matrix for one of the district heating substations

Another important factor to highlight is the mutual influence of buildings. When multiple district heating substations serving neighbouring buildings activate simultaneously, it causes an increase in local heat demand, which can affect surrounding district heating substations in different ways. This is especially true for stations located toward the end of pipeline networks, where heat distribution may be less stable.

Table 1 presents Pearson correlation coefficients for the dependency between various variables and the thermal power output of selected district heating substations (101, 105, 305, 405, 510, 712). The thermal power (P_T) represents the amount of thermal

energy delivered to consumers over a given period, expressed in megawatts [MW]. It is a key parameter in analysing district heating substation loads and optimizing heat distribution. The demand for heating is strongly influenced by outdoor temperature (T_{OUT}), expressed in degrees Celsius [$^{\circ}\text{C}$]. Lower outdoor temperatures increase the demand for thermal power, as more energy is required to maintain the same indoor heating levels.

Another crucial parameter in heat transfer is the volumetric flow rate (V), which represents the amount of water that flows through the system per unit time [m^3/h]. A higher volumetric flow rate enables the transfer of a larger amount of heat at the same temperature difference. The supply temperature (T_{SUP}) refers to the temperature of the heat transfer medium as it enters the heating system, while the return temperature (T_{RET}) represents the temperature of the medium as it exits the system, both expressed in degrees Celsius [$^{\circ}\text{C}$].

Table 1 Pearson correlation between variables and thermal power

P_T	101	105	305	405	510	712
T_{OUT}	-0.23	-0.2	-	-0.15	-0.43	-
			0.096			0.72
V	0.77	0.82	0.92	0.97	0.25	0.55
T_{SUP}	0.61	0.64	0.6	0.67	0.74	0.47
T_{RET}	0.19	-0.8	-0.76	-	-0.77	-
				0.014		0.98

2.2 District heating water transport times

Determining transport times is crucial for analysing the connection between the heat source and district heating substations. The most pronounced response of district heating substations occurs during the morning peak, when the heat source must rapidly supply the required thermal energy. At this time, a sharp increase in temperature at the heat source profile is clearly visible, and with a delay, the peak also appears in the district heating substation profile. This delay represents the transport time which is the time it takes for a unit of heat to travel from the source to the station. Analytically, transport time can be calculated if the pipe cross-section, hot water density, pipeline length, and mass flow rate are known, as derived from Equation (1).

$$tt_{cc} = \frac{AA * \rho * LL}{mm} \quad (1)$$

Since the calculation of transport time based on flow rate depends on numerous external factors, such as pipeline branching and network complexity, the analysis employs a method that determines the delay between the temperature peaks at the heat source and the district heating substation. The approach assumes that the heat unit reaching its maximum at the source is the same unit that later reaches its maximum at the district heating substation, albeit with heat losses and a time delay. By identifying these

temperature peaks, it is possible to determine the transport time. A graphical representation of this concept for analysing transport times is shown in Figure 4, with the transport time being labelled as T_t .

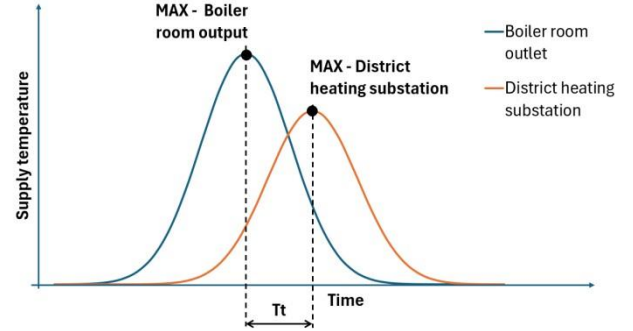


Figure 4A graphical representation of the transport time concept

For a more precise analysis, time-series data is often smoothed. Traditional filters, such as the moving average and moving median, reduce noise but also truncate peaks, which can affect results. Therefore, this analysis uses the SavitzkyGolay filter (SG filter), which is based on polynomial approximation using the least squares method. This filter effectively preserves the shape of the temperature profile while reducing noise without losing important information, making it widely used in spectroscopy, audio processing, medical analyses, and other fields.

2.3 Heat consumption time shift

Energy flexibility can be defined as the ability to shift energy flows over time to adapt to operational constraints and objectives [7]. Lowering temperature levels in the network reduces peak loads, meaning temperature peaks are mitigated, allowing the system to operate more efficiently in a base load operation mode.

Base load operation of heating equipment is the most favourable heat production regime, as boilers and heating plants operate at a relatively constant load without being subjected to sudden power fluctuations. This results in lower maintenance costs and extended equipment lifespan. In parallel, this presents an opportunity to integrate continuous heating and heat load shifting within the network.

The goal of continuous heating is to ensure more stable heat production while reducing sudden peaks in heat demand. If buildings are heated continuously, the system encounters a smaller temperature difference during peak demand periods, which in turn reduces the amount of heat that needs to be supplied at those times.

To maintain thermal comfort for consumers, the same total amount of heat must still be delivered, meaning that heat must be stored or supplied during periods of lower demand. This process is known as heat load shifting. The idea is to increase thermal power during low-demand periods (before the morning peak) and reduce it during high-demand

periods, ultimately leading to a lower maximum daily power requirement for production facilities. This redistribution of load from peak-demand to low-demand periods is illustrated in Figure 5 [8].

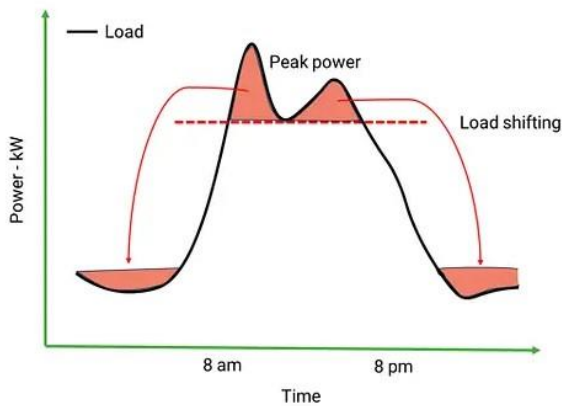


Figure 5 The redistribution of load from peak-demand to low-demand periods

2.4 Additional energy demand

Peak loads cannot be reduced solely by shifting heat consumption; it is also necessary to consider the fact that continuous heating results in higher overall energy use. While the peak load itself is lower, the assumption of continuous heating means that heat losses always occur, leading to an increase in total thermal energy consumption for space heating.

To estimate the magnitude of this additional energy demand, an analysis was conducted on two identical residential buildings. These buildings share identical architecture and a connected heating capacity of 175 kW. These buildings were chosen as ideal candidates for evaluating additional energy consumption, as one building operates under a continuous heating regime, while the other follows an intermittent heating regime.

The analysis utilized two identical buildings located in the same area with the same connected power capacity, allowing for a reliable comparison of heat consumption. This comparison provides a solid estimate of additional energy use, though the final consumption figures are also influenced by occupant behaviour, renovation levels, and other factors that are difficult to quantify precisely.

A historical consumption analysis based on data from 2023 and 2024 revealed that over the course of one month, specifically January, the building with continuous heating consumed 20 % more thermal energy. The difference was particularly pronounced towards the end of the month, when outdoor temperatures dropped further. This significant increase in consumption exceeded initial expectations set before the analysis. Consequently, this additional energy consumption was accounted for in the modification of heating profiles, serving as one of the key assumptions in further simulations.

2.5 Assumptions

Before modifying the profiles, it was necessary to define key assumptions and simplifications applicable to all cases. These assumptions are based on historical data and relevant literature. The analysis is limited to the heating season, covering the period from November to March, as this is when heat production is at its peak and all district heating substations are actively consuming heat. The study focuses exclusively on energy for space heating, while energy for domestic hot water preparation is excluded, as it is not relevant for this analysis.

The district heating substations are grouped into 12 subgroups, each representing a specific district within the Municipality of Maribor. The number of district heating substations in each subgroup varies based on geographical location and the specific heating demands of each area.

For the simulation, three representative scenarios were defined, corresponding to typical days during the heating season:

- **A very cold day (A)** with the lowest average outdoor temperature (T_{OUT}),
- **A cold day (B)** with an average T_{OUT} around 0°C , and
- **A milder day (C)** where T_{OUT} is higher than the seasonal average.

During the modification of profiles, the increased energy consumption caused by higher indoor temperatures during low-demand periods was accounted for, as it leads to greater heat losses. Peak reduction and load redistribution were adjusted based on the specific characteristics of each profile, ensuring realistic adaptations.

By redistributing heat demand, the operating mode of district heating substations also changes. Flow-through stations allow for a continuous flow, whereas non-flow-through stations do not, requiring their profiles to be adjusted to a flow-through regime. As a result, the modified profile shows a gradual increase in power before the peak, while the original profile shows zero thermal power before activation.

Transport times were determined based on flow-through stations, as they provide a more accurate representation of heat transfer dynamics. Non-flow-through stations interrupt the primary flow, making it more difficult to estimate transport times. When aggregating modified profiles, transport times were adjusted with appropriate time shifts for each subgroup. The principle of maintaining the total amount of heat delivered was upheld in the profile modification process. While peak loads were reduced, the heat was redistributed, and additional heat losses due to the changed regime were incorporated into the modified profile. As a result, the modified profile includes a higher total energy consumption compared to the original one.

Since some stations had incomplete or unavailable data, missing power values were replaced with virtual district heating substations to enable accurate total load calculations and ensure realistic heat production estimations. The total heat

supplied by the district heating substations was adjusted to match the system's annual efficiency rate of 86,5%, which is the efficiency standard for the district heating system operated by ENMB.

2.6 Profile modification

A dynamic model was developed in the Python programming language using the Dash module, which enables visualization and interactive graph manipulation for heat consumption redistribution. The model allows users to define the start and end times (hh:mm) for two peak demand periods and two reduced demand periods. One period is designated for morning peaks, while the other accounts for potential increases in afternoon consumption. For each period separately, it is possible to reduce peak loads by a specified percentage. The model lowers values in the selected time based on the defined percentage reduction. If power at a given time interval is represented by $P(t)$, then the reduced power $P_{\text{reduced}}(t)$ at a specified reduction level (expressed as a percentage) is defined as shown in Equation (2).

$$PP_{rrrrrrrrccrrrr}(tt) = PP(tt) * 1 - \frac{1}{100}zz \quad (2)$$

If it falls within a peak demand period, the corresponding heat consumption value is reduced. The amount of energy reduced is then stored and summed, after which it is evenly redistributed across the selected low-demand period. Thus, if a time point falls within a high-demand period, the corresponding thermal power value is decreased. Conversely, during lowdemand periods, the power is increased by the redistributed amount. When reducing thermal power, the saved energy is calculated, and this energy is then allocated to intervals with lower heat consumption. The energy savings can be expressed mathematically as shown in Equation (3).

$$EE_{ssssssrrrr} = \sum_{tt \in pprrrsppss} PP(tt) - PP_{mmmmrr} (tt) * \Delta tt \quad (3)$$

The saved energy must be redistributed during low-demand periods to achieve a smoother and more balanced profile. The redistribution is performed linearly, based on the total duration of the low-demand periods. If the low-demand periods contain n intervals, the additional power $P_{\text{additional}}$ is defined as shown in Equation (4).

$$\begin{array}{l} EE\textit{ssssssrrrr} \\ PP\textit{ssrrrrraattaammaassaa}(tt) = aa*\Delta tt, tt \in \textit{rrrrrrrrrrccrrrr} \\ \textit{rrrrmmssaarr} \end{array} \quad (4)$$

$P_{\text{additional}}$ represents the power added to the thermal power values during low-demand periods, resulting in the increased power profile $\square_{\text{increased}}(t)$.

Additionally, a Gaussian mathematical filter was implemented to further smooth the modified profile.

Equation (5). Without filtering, sudden fluctuations were observed, as noise from the original profile was transferred to the modified profile. To achieve a cleaner and more refined result, this filter was applied. In this case, a Gaussian filter was chosen instead of the previously used Savitzky-Golay (SG) filter. The Gaussian filter proved to be simpler and more effective, primarily due to its easier control of smoothing intensity using the parameter σ , which defines the width (or intensity) of smoothing. With the Gaussian filter, the smoothing intensity can be adjusted more directly, whereas the SG filter requires manipulation of two parameters, making fine-tuning more complex. The final modified profile, denoted as

$\square_{\text{mod}}(\square)$, consists of the reduced power profile $\square_{\text{reduced}}(\square)$ and the increased power profile $\square_{\text{increased}}(\square)$, which appear within their respective periods. This profile is then smoothed using SG filter as shown in Equation (5). $PP_{ssmmmmmmmtt hrrrr}(tt) = \sum_{pp} PP_{mmmmrr}(tt - pp) * GG(pp, \sigma\sigma)$ (5)

$G(k, \sigma)$ represents the Gaussian function with an offset μ and a standard deviation σ , as defined in Equation (6).

$$G_G(k, \sigma) = \frac{1}{\sqrt{2\pi}\sigma} * e^{\left(-\frac{pp2}{\sigma^2}\right)} \quad (6)$$

3 RESULTS

Profile manipulation is performed using a custom-developed tool that operates based on the described equations. The software tool is supported by libraries that enable the use of existing code functionalities. To use the tool, the user must upload a file containing thermal power data for the selected day. The file is structured so that each column contains data for a specific SD subgroup. The user must define 4 time intervals, specifically: two peak demand periods and two low-demand periods.

For each period, both start and end times must be specified. Additionally, the percentage reduction of peak demand (z) must be defined, which can vary between the two peak periods.

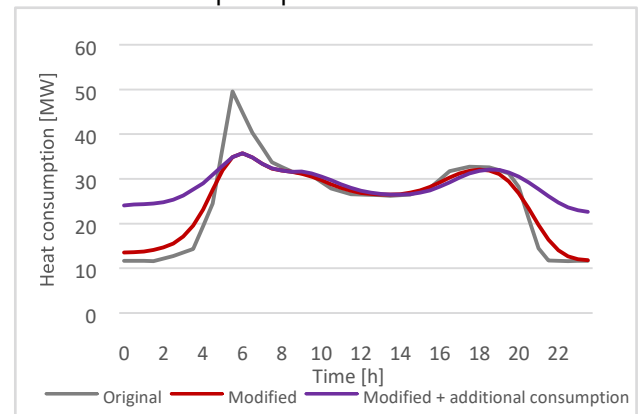


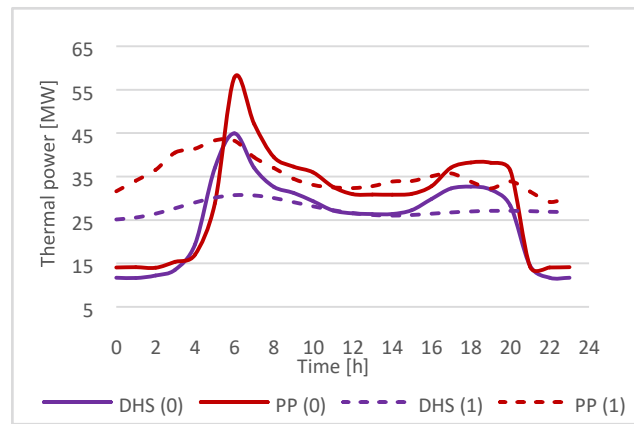
Figure 6 The modification process

The graph in Figure 6 illustrates the modification process applied to the hourly thermal power profile. The original and modified profiles contain the same total amount of consumed heat over a single day. From a mathematical perspective, this means they have the same area under the curve. The total heat consumption increases only when the modified profile incorporates additional energy consumption, which is added exclusively during low-demand periods. This approach best describes the transition from mixed heating regimes to a fully flow-through heating regime. It is important to emphasize that this represents only a modified heat consumption profile, not the heat production profile, which is discussed in the following chapter. **3.1 Profile modification**

For each analysed day, it was necessary to generate a modified production profile that corresponded to the adjusted heat consumption profile. The modified profile was based on the assumptions outlined previously in this paper. Based on this, the total amount of heat for each scenario was determined. The total heat supplied needed to be 86.5% of the energy produced at the source, reflecting the system's efficiency. However, since the sum of the thermal energy of all district heating substations did not meet this condition, virtual district heating substations were introduced to achieve the correct balance between production and consumption.

Once the balance was properly adjusted, the next step was the modification of individual subgroups, ensuring that heat consumption was properly redistributed. The modified subgroups were then summed, resulting in an overall increase in total heat consumption due to the additional energy use incorporated in the assumptions. The final summed profile of the modified subgroups thus represented the new thermal power demand profile. Since different district heating substation groups have different transport times, their profiles needed to be shifted accordingly to account for heat transport delays to the consumption points.

In the final step, system efficiency between the production sources and district heating substations was accounted for. The modified profiles were divided by the efficiency factor, ensuring that the necessary production values were correctly reflected. The total sum of the modified profiles ultimately represented the new production profile PP (1), which served as the foundation for planning the new base load operation of the heating plants. The process is visually represented in Figure 7.

**Figure 7** Process of determining the new thermal power profile for the production

3.2 Heat production

The production structure of the Energetika Maribor group consists of hot water boilers, combined heat and power (CHP) units, solar collectors, and a high-temperature heat pump (HTHP) located at the Pristan boiler plant. However, the solar collectors and HTHP were not considered in this analysis. In the previous sections, we defined the new heat demand profile. Based on this new profile, an operational plan was developed to ensure that the heating plants meet the revised thermal requirements. As a result, three operational plans were created one for each analysed scenario (representing a different typical heating day).

At the Jadranska unit, various heat and power generation devices are installed, including hot water boilers, gas engines, and solar collectors.

The thermal energy supply is provided by four hot water boilers:

- LOOS 12 with a total thermal capacity of 12 MW,
- LOOS 18 with a thermal capacity of 18 MW,
- UT-HZ 1 and UT-HZ 2, each with a thermal capacity of 26 MW.

For combined heat and power (CHP) generation, gas engines are used:

- TOM 1 (one gas engine) with 2,58 MW of thermal power and 3 MW of electrical power,
- TOM 2 (four gas engines) with total 8,904 MW of thermal power and total 9,859 MW of electrical power. Thermal storage tanks also play a crucial role, as they can be used to increase base load energy production and manage peak loads. In Figure 8 and 9, these storage tanks are labelled with H and indexed with "in" and "out", indicating charging or discharging operations.

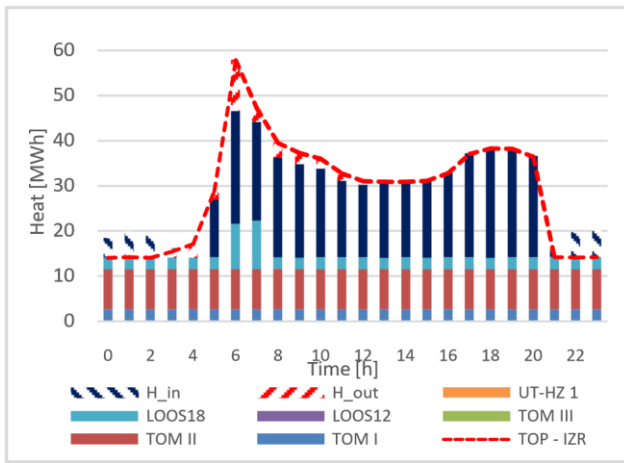


Figure 8Original operational regime

Figure 8 represents the original operational regime. The red dashed line (TOP-IZR) represents the heat demand profile that must be met to comply with the System Operating Instructions (SON). This profile exhibits a distinct morning peak, which was primarily covered by the UT-HZ 2 boiler. The required thermal power fluctuates between 10 MW and 57 MW.

Figure 9 illustrates the operational plan developed for the modified heat consumption profile. This plan was manually designed, with a focus on meeting the hourly heat demand specified by the modified profile. The most notable difference appears in boiler operations—in the modified scenario, the boilers would produce 44% more MWh of thermal energy. Consequently, this would lead to higher internal electricity consumption and increased natural gas usage. The rise in thermal energy production is a result of both the higher overall heat consumption described in previous sections and the redistribution of demand over time.

A key achievement of the modification is the reduction of peak power, which was successfully lowered by 14 MW. However, the average and minimum achieved thermal power levels are higher in the modified operational plan. A similar effect was observed in the other two scenarios, where peak reduction was also achieved but required higher average and minimum thermal power levels. Additionally, peak reduction was influenced by outdoor temperature. At higher outdoor temperatures, the reduction in peak load was smaller. This can be attributed to the nature of peak loads, which tend to be more pronounced at lower temperatures, as heat demand rises more sharply in colder conditions.

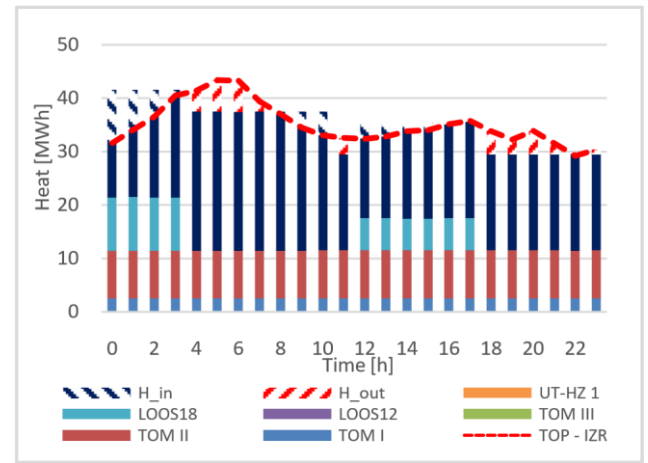


Figure 9Operational plan developed for the modified heat consumption profile

The characteristics of the new modified operational plans, compared to the original ones, can be analyzed using a load duration diagram. These diagrams provide a clear visualization of peak loads, which, although infrequent, have a significant impact on the system. Ideally, we aim for a more uniform distribution of loads over time. The diagram illustrates load curves for all scenarios, showing a substantial reduction in peak loads and a much more balanced profile. In the original load curves, the direct influence of outdoor temperature on system load is evident. Scenario C (the warmest day) places significantly less strain on the system compared to Scenario A (the coldest day), where heat demand was highest. In the diagram shown in Figure 10, dashed lines represent modified operational regimes, while solid lines depict the original (real) profiles.

In the economic comparison of individual scenarios, the focus was primarily on the daily financial outcome, which is determined by costs (as described in the previous subsection) and revenues. Revenues consist of sold heat, electricity, and received operational support for CHP (SPTE) units. Although the modified operational regime resulted in a better financial outcome, this was achieved at the cost of additional energy consumption, which was supplied to consumers. The key question of the master's thesis is whether the additional revenue was sufficient to at least offset the increased heating costs. For CHP units (SPTE), there were no significant differences, as both scenarios operated within the base load range, justifying this conclusion.

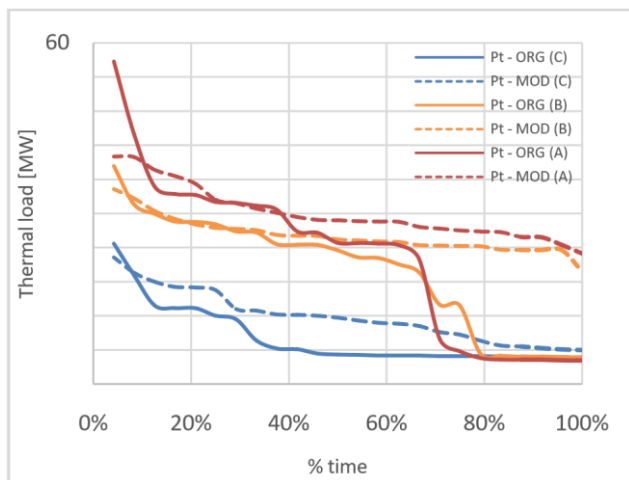


Figure 10 Load duration diagram

However, at the boiler room, a higher amount of heat was produced to compensate for additional losses caused by continuous consumption. The additional heat produced represents a cost that must somehow be covered. Although consumers pay for the produced heat, it would not be justified to pass the cost of additional heat generation directly onto them, as they do not benefit from it directly. From this perspective, the extra produced heat could be considered an additional expense. Therefore, it is crucial to examine the savings in production, which could potentially be leveraged to reduce or offset this additional cost. A notable difference was observed at the boiler plant, where the modified operational regime resulted in a slightly better outcome, as the boilers produced a higher quantity of heat.

4 DISCUSSION

As part of this study, a method for peak load smoothing was examined using heat load shifting and the creation of new operational regimes, where continuous heating was assumed. The analysis steps included a literature review, data acquisition and processing for district heating substations, data analysis, and the formulation of assumptions based on the collected data.

The main challenges in data processing involved handling missing and erroneous values, visualizing data graphically, and determining transport times. Throughout the calculation and analysis process, Python programming was used, enabling automated

data processing and complex calculations. Following the data analysis, new heat consumption profiles were created, based on existing thermal power profiles and the adopted assumptions. Using these modified consumption profiles, corresponding operational plans were developed. These were then compared with the existing ones from both a technical and an economic perspective.

In the modified profiles, additional heat consumption was assumed, based on an analysis of two identical buildings with different heating regimes. It was determined that during the heating season, a flow-through system requires an average of 20 % more thermal energy. This additional energy consumption was incorporated into the profile modifications, resulting in a greater amount of heat being produced.

From an economic standpoint, this is beneficial for the boiler plant, as it means more heat is sold, leading to better daily financial results. However, the additional energy also results in increased emissions and higher heating costs for consumers. While the final analysis confirmed an expected cost increase for consumers, the study also explored the possibility of cost compensation.

It is anticipated that such simulations will become increasingly relevant in the future, due to ongoing transformations in the energy sector, including changes to network regulations, the transition to renewable energy sources, digitalization, and potential legislative adjustments, all of which may introduce new challenges for the energy industry.

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UDK: 351.777.6

DOI:

10.46793/ALFATECHproc25.01

6S Original scientific paper

AIR POLLUTION – CASE STUDY Podgorica UB

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Abstract: In December 2024, the EU defined new rules of air quality standards by cutting allowed limit values. Five years' data about air pollutants, PM_{2.5}, PM₁₀, and SO₂, are extracted from the measuring station in Podgorica – Podgorica UB. Analysis of the data is presented. The study used classical statistical analysis and machine learning K-mean and K-medoid methods to classify data and to make conclusions about air quality and air pollutants in Podgorica.

Keywords: Statistics, data analysis, K-mean, K-monoid.

1 INTRODUCTION

The European Union (EU) is striving to deliver cleaner air by reducing pollution levels for both short-term and long-term exposure. On October 23rd, 2024, the European Parliament adopted a new directive defining limits and models for calculating values for air pollutants [1]. Concrete, the revised Ambient Air Quality Directive updates air quality standards, lowering the allowable levels for twelve air pollutants: particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide (NO₂) and nitrogen oxides (NO_x), sulphur dioxide (SO₂), ozone (O₃), carbon monoxide, benzene, benzo(a)pyrene, arsenic, cadmium, nickel, and lead [2]. Lowering these values improves both the lives of people and the environment since it forces polluters to modify their operations to these levels.

Additionally, the World Health Organization (WHO) has guidelines for measuring the limits of certain air pollutants, including carbon monoxide, nitrogen dioxide, sulphur dioxide, ozone, and particle matter (PM_{2.5} and PM₁₀) [3]. It is estimated that exposure to polluted air causes millions of deaths and leads to loss of health. The ecosystem of the world and our lives are negatively impacted by air pollution. [4].

Data on pollutants produced over the previous five years by the Podgorica UB monitoring station of the Environmental Protection Agency of Montenegro were used in the study. Data on the pollutants SO₂, PM_{2.5}, and PM₁₀ are gathered by this station. [5]

In order to identify the source of pollution, we perform exploratory analyses using statistical analysis, data visualization, and machine learning clustering approaches. We make use of the RStudio IDE and the R programming language.

1.1 Data

Cleaning the extracted data is the first step in the process. The rows that have a NA (not available) are also removed, and all nonnumeric data is altered (" <2 " is altered by 1.9, and " <5 " is altered by 4.9). We discovered that much of the data for 2021 was missing after this data modification. Data from the years 2020–2024 were chosen. Figure 1 shows the results of transforming data by adding columns for the year and month.

The month and year are taken from the first column of the row data (the first column represents the data collection time).

Date <chr>	SO2 <dbl>	PM10 <dbl>	PM2.5 <dbl>	year <chr>	month <chr>	day <chr>
15.01.2020 13:00	26.6	59.1	46.4	2020	01	15.01.2020
15.01.2020 14:00	23.5	40.5	31.0	2020	01	15.01.2020
15.01.2020 15:00	27.2	36.5	27.7	2020	01	15.01.2020
15.01.2020 16:00	29.8	45.3	35.4	2020	01	15.01.2020
15.01.2020 17:00	15.0	99.4	90.6	2020	01	15.01.2020
15.01.2020 19:00	9.3	186.9	151.0	2020	01	15.01.2020
15.01.2020 20:00	11.2	237.9	194.5	2020	01	15.01.2020
15.01.2020 21:00	10.1	391.5	317.2	2020	01	15.01.2020

Figure 1 Data - 30,618 entries, 6 total columns

Visualisation of data are presented on Figure 2.

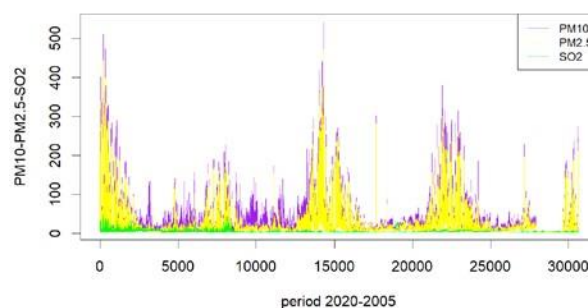


Figure 2 Visualization of data.

2 STATISTIC DATA ANALYSIS

Summary of the pollutants' data values are presented in Figure 3 (minimum, 25% quartile, median, average value, 75% quartile and maximum).

SO ₂		PM ₁₀		PM _{2.5}	
Min.	: 1.90	Min.	: 4.90	Min.	: 4.90
1st Qu.	: 2.30	1st Qu.	: 9.10	1st Qu.	: 6.40
Median	: 3.70	Median	: 15.50	Median	: 10.40
Mean	: 4.36	Mean	: 28.82	Mean	: 21.06
3rd Qu.	: 5.40	3rd Qu.	: 30.30	3rd Qu.	: 17.90
Max.	: 47.60	Max.	: 541.00	Max.	: 471.70

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Figure 3 Summary of data.

2.1 SO₂

Sulphur dioxide (SO₂) is a gaseous air pollutant that is mainly produced by the combustion of fuels (power plants, internal combustion engines, manufacturing, oil refining, diesel engines, etc.). SO₂ causes harmful effects on the lungs (difficulty breathing, chest tightness, inflammation of the airways, etc.) [6]. According to the new EU directive [1], it is recommended that the level of SO₂ higher than 50 µg/m³ should not be exceeded more than 18 times during the year. Our data shows a maximum value of 47.6 µg/m³, and no hours over the 2020–2024 timeframe had a greater value. Podgorica is therefore in very good shape with relation to the SO₂ pollution.

2.2 PM_{2.5} and PM₁₀

A variety of chemical species are mixed together to form particulate matter in the atmosphere. These particles vary greatly in size, shape, and chemical composition and can contain inorganic ions, metal compounds, elemental carbon, organic compounds, and compounds from the earth's crust. For air quality, their diameter is important. The diameter of PM_{2.5} is 2.5 microns or less, and PM₁₀ is 10 microns or less. PM_{2.5} contains a fraction of PM₁₀. [7].

Their correlation in our data is positive and it is greater than 0.97 with 95 percent confidence interval [0.9732772, 0.9744332].

On the Figure 4 are presented mean values of PM₁₀ and PM_{2.5} per months for the 2020-2024 period.

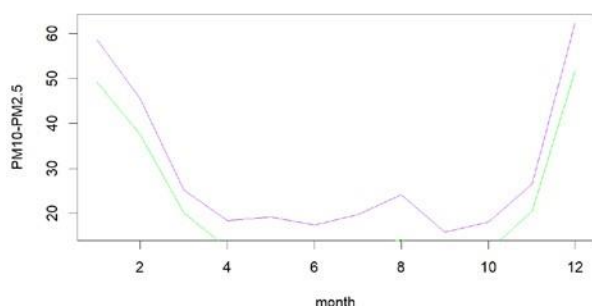


Figure 4 Average values of PM₁₀ and PM_{2.5} per months

Premature mortality, acute and chronic bronchitis, asthma episodes, emergency room visits, respiratory symptoms, limited activity days, and other negative health effects have been linked to both short-term and long-term exposure to PM_{2.5} and PM₁₀.

According to the new EU directive [1], we find the number of days per year with PM₁₀ values greater than 45 µg/m³ (reccomendation is not to be exceeded more than 18 times per calendar year) and annual mean

values (reccomendation is 20 µg/m³). The data are presented in the Table 1:

Table 1 Number of days and annual mean PM₁₀ values per year

PM ₁₀	2020	2021	2022	2023	2024
days >45 µg/m ³	55	23	53	58	46
Annual average	32.57	32.82	32.98	28.59	22.38

Also, according to the new EU directive [1], we find the number of days with PM_{2.5} values greater than 25 µg/m³ (not to be exceeded more than 18 times per calendar year) and annual mean values (reccomendation is 10 µg/m³). The data are presented in the Table 2:

Table 2 Number of days and annual mean PM_{2.5} values per year

PM _{2.5}	2020	2021	2022	2023	2024
days >25 µg/m ³	65	31	42	88	69
Annual average	23.08	27.06	19.18	23.02	17.66

We can observe from Tables 1 and 2 that there are significantly more particulate matter particles in the air in Podgorica than what the new EU directive recommends.

The most likely source of the air pollution is what we are searching for.

3 CLUSTERING DATA

Clustering is an unsupervised machine learning technique that discovers similar data across rows, grouping such data into the same group. Less similar data are grouped into different groups.

Here, we employ the K-mean and K-medoid clustering techniques. Using a distance metric, they both separate the data into distinct groups. Reducing the sum of squared distances between data points and their respective cluster centroids (mean of the cluster) is the goal of the K-means algorithm. In order to minimize the total absolute distance between data points and their respective cluster medoids (the cluster median), the K-medoid algorithm is used. K-medoid is less sensitive to outliers compared to K-means. [8].

Only PM₁₀ and PM_{2.5} data will be used after the SO₂ data has been analyzed. We also exclude the year, month, and day columns because these clustering techniques are sensitive to categorical data.

Column *Date* is also excluded. Thus, we have two columns in the data frame at the end: PM10 and PM2.5.

For both methods, the number of clusters must be predetermined. An explicit approach for determining the ideal number of clusters does not exist. Here, we use within cluster sums of squares (wss) method [9]. Figure 5 shows the results of utilizing the R *fviz_nbclust* function for determining and visualizing the optimal number of clusters. We therefore selected three clusters.

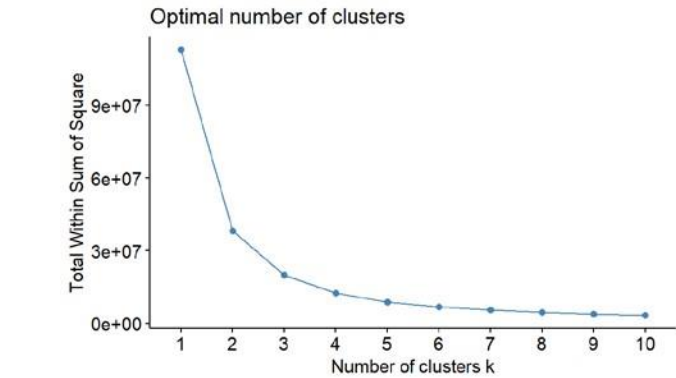


Figure 5 Number of clusters using wss method.

Figure 6 and Figure 7 show K-mean and K-monoid clustering with 3 clusters.

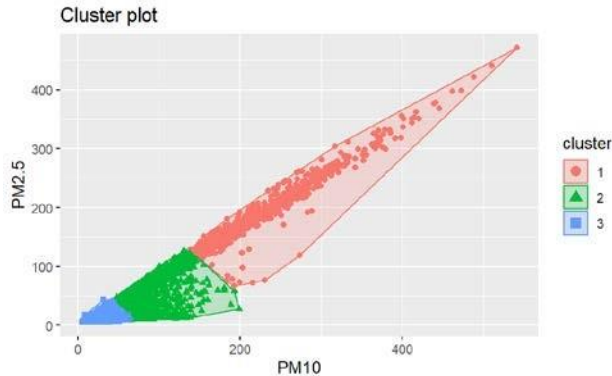


Figure 6 K-mean clusters

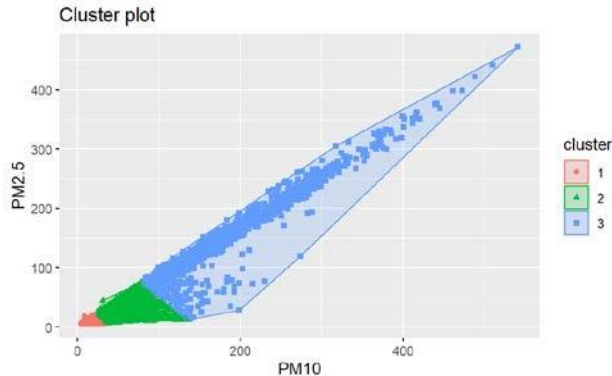


Figure 7 K-medoid clusters

The disparity in clusters is predicted because the median is smaller than the mean, for both PM10 and PM2.5 data. We may infer that there are fewer large values, but those values have a significant influence on air pollution, since the third quartiles of the summary

data (Figure 3) are significantly smaller than the highest values.

The six-level yearly PM2.5 and PM10 pollution scales are developed by the WHO. We incorporate two columns that contain categorical data (values ranging from 1 to 6) according to PM2.5 or PM10 readings and the relevant EU regulatory thresholds. The barplots look like what's in Figure 8.

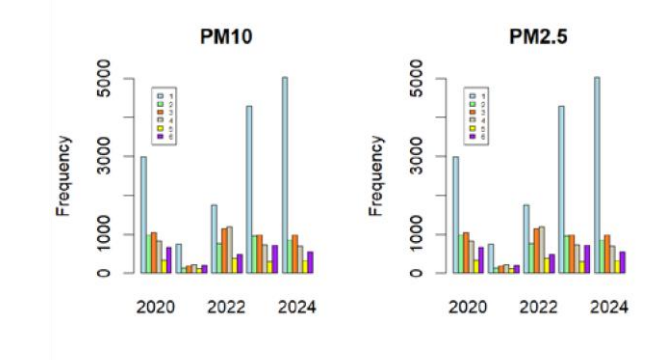


Figure 8 Frequencies of data per year

The most likely cause of the air pollution in Podgorica is what we are now searching for. A significant periodicity may be seen in the higher numbers, according to the visualization of our data in Figure 2. We created Figures 9 and 10 by clustering the PM2.5 and PM10 data independently, then joining the clusters with the monthly data. The K-mean method is used.

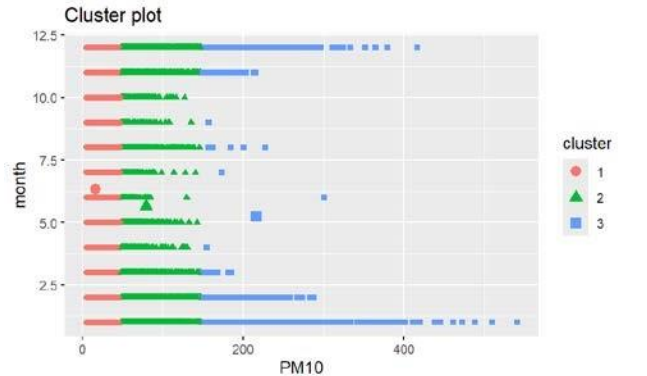


Figure 9 Clustering PM10 data and months

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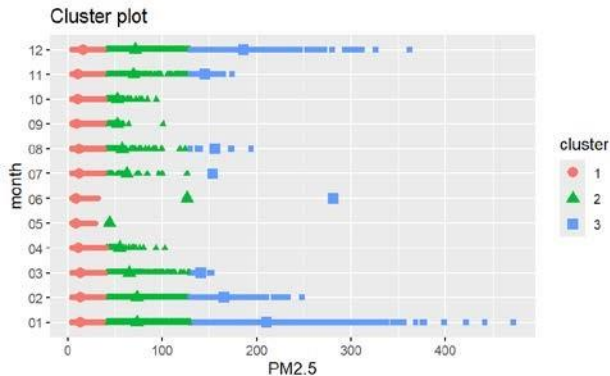


Figure 10 Clustering PM2.5 data and months

From these figures we can see that months with critical, high level, PM10 and PM2.5 data is extreme in the November, December, January and February.

3 CONCLUSION

According to the new EU air pollution directive, two conclusions can be drawn from historical air quality data generated by the Environmental Protection Agency of Montenegro's Podgorica UB monitoring station:

- In Podgorica, the measured SO₂ air pollutant is within the advised range for the 2020–2024 timeframe.
- In Podgorica, measured levels of PM_{2.5} and PM₁₀ air pollutants are higher than the advised threshold for the 2020– 2024 timeframe.

Podgorica residents are exposed to PM_{2.5} and PM₁₀ particulate matter for longer than is advised by a

5 REFERENCES

- [1] Directive (EU) 2024/2881 of the European Parliament and of the Council of 23 October 2024 on ambient air quality and cleaner air for Europe (recast)
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- [4] See <https://www.who.int/teams/environment-climate-change-andhealth/air-quality-energy-and-health/health-impacts>
- [5] See <https://www.epa.org/me/vazduh/>
- [6] See <https://www.epa.gov/so2-pollution/sulfur-dioxide-basics>.
- [7] See <https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health>

recent EU directive. The contaminants' yearly average levels are also higher than what the directive suggests.

The months of November, December, January, and February have particularly high measured levels of PM₁₀ and PM_{2.5} particulate matter. This city's heating season is represented by these months. All year long,

the measured SO₂ levels fall within the allowed ranges. Thus, the primary cause of air pollution in Podgorica can be attributed to heating fuels.

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Smart City Challenges: Prioritization Methods

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Abstract: Substantial shifts in our way of life prompt us to consider creating smarter, more sustainable cities. The construction of smart cities has become increasingly popular in both systematic studies and international policies. The research seeks to identify the main barriers to smart cities by reviewing the existing literature and consulting with subject-matter experts. In order to identify the most significant obstacle category and rank certain challenges within the categories to the development of smart cities in Serbia and the surrounding area, this investigation also attempted to prioritize the barriers. The foundation for all planned actions in the administration of the urban environment, including its sectors and infrastructure, is the Fourth Industrial Revolution and digitization. Multi-criteria decision-making (MCDM) has used the following fuzzy logic techniques to identify key indicators that are pertinent preconditions for the creation of a smart city: triangular and trapezoidal fuzzy analytic hierarchy process (FAHP) and triangular and trapezoidal interval type-2 fuzzy sets (IT2FS). The creation of a legislative and strategic framework for the Smart City platform, its implementation in the post-COVID-19 era, and the standardization of ICT and ICT management have been identified as the prominent indicators based on six groups of criteria and a significant number of sub-criteria.

Keywords: Smart city, FAHP, IT2FS, MCDM, algorithm ranking

1 INTRODUCTION

Over the past 20 years, smart city development has gained significant attention in worldwide policies and systematic research [1-3]. According to this study, a smart city is a modern, technologically sophisticated area with a certain level of intelligence that addresses different social, technical, and economic facets of development using smart computing techniques to create better infrastructure components and services [4-6].

Despite being the epicentres of education, research, and culture, cities are more frequently referenced negatively than rural places. They are in the public eye mostly because of the issues with metropolitan settings, such as being the top energy consumers and environmental polluters [7]. A major factor in the concentration of people in cities is the rising demands of modern man in terms of comfort, a high standard of living, and financial stability. This process encourages people to migrate to economically developed areas and from rural to urban areas, even beyond the borders of the country where they previously resided. Among the issues that metropolitan regions face are the effects of the ongoing urbanization process, disregard for environmental preservation, and irrational resource usage, some of which jeopardize environmental quality [8]. Strict lifestyle modifications have forced us to think of creative solutions for building a more sustainable civilization that can endure the

quick changes in our surroundings. A key component of guaranteeing sustainable progress is qualitative management founded on sustainable strategies, accountability, transparency, public engagement, emissions reduction, energy efficiency, waste management, and mobility [9]. One step in that direction is the Smart City concept. As one of the non-exclusive layers

in contemporary social policy conduction, circular economy, and urban development, smart cities are a topic of interest to both scientific academics and modern society. All planned actions in managing urban environments, their sectors, and infrastructure require the Fourth Industrial Revolution and digitization. Information-communicative technologies (ICT) are becoming a key tool in developing future technical patents and smart grids due to the quest for solutions that will expedite the monitoring of urban operations, enhance infrastructure systems, and simplify daily activities.

The world has turned into a global marketplace where nations compete with one another in terms of technical product innovation and sustainability, human capital, scientific advancements, and robust businesses. The Smart City model differs from nation to nation based on various economic, social, and political considerations. Many developing countries are still far from having strategies that accurately implement the Smart City concept in future urban development, despite developed nations taking pride in inventions that use sensors and artificial intelligence, require virtually no manual human control, and extensively use available resources [10,11].

The pandemic has altered our perspectives on sustainable future development and our goals for developing sustainable living spaces.

This study looks at the potential applications of artificial intelligence in creating smart cities. It offers a theoretical summary of the most recent scientific findings about creating and using the Smart City concept, fostering a conversation about potential obstacles. Using multi-criteria analysis, the study attempts to pinpoint important indicators as essential preconditions for the development of smart cities. We decided to use triangular FAHP, triangular IT2FS, trapezoidal FAHP, and trapezoidal IT2FS as fuzzy logic techniques because of the problem's multidimensionality and complexity.

The selection of barriers was made through literature and inputs received from experts. Prioritizing the barriers is a decision problem involving various criteria and sub-criteria.

The remaining sections of the paper are structured as follows: Section 2 presents the related literature on smart cities and highlights the barriers to smart city development. Section 3 discusses the solution methodology along with the research

framework. Section 4 illustrates the data analysis and results. Section 6 provides conclusions, limitations, and directions for future research

2 LITERATURE REVIEW

This section illustrates the literature linked to smart cities, and identifies the barriers related to smart cities development. **2.1 Smart City Concept: From Idea to Reality**

The idea of a "smart city" was originally introduced in the 1990s to focus on the implications of information and communication technology for better infrastructures and network upgrades. Thanks to the widespread use of information technologies, cities are empowered to develop essential services for safety, health, governance, and delivery [12,13]. The California Institute for Smart Communities investigated how to turn a city into a smart city and the degree of information technology used in smart cities to help policymakers design smart city networks [14,15].

The Smart City movement links urban ideas with recent scientific and technical advancements to provide fresh answers to current urban issues in response to the mounting challenges of urbanization. The idea was initially raised in relation to "growing cities in a smart way" and advocating for the "compact city" model to avoid the agglomeration of metropolitan areas and foster environmental consciousness [16].

When thinking about a smart sustainable environment, technological developments have pushed the boundaries. The use of innovative solutions has become a good tool for collecting information that would help uncover current urban problems. In 1994, the term "smart" was linked to the city, the center from which sustainability must be derived [17]. The idea has expanded since the EU began utilizing the "smart" label to qualify sustainable urban development projects in 2010 [18].

The European Commission launched plans for smart cities in 2010 as an important and logical project. These plans support four aspects of cities: transportation, power, heating and cooling systems, and construction [19].

Because the term "smart" is interconnected and utilized in many facets of contemporary life, smart devices, smart apps, smart roads, smart phones, smart lights, and smart buildings have become commonplace. The value of libraries as public institutions has been undermined by internet searches [20]. At the same time, sensors in cell phones provide us with information about weather and weather conditions, free parking applications, public transportation arrival times, and less congested routes [21].

The European Commission has also supported proposals for "smart cities" to increase community energy efficiency and green transportation [22]. In [23],

six essential components for a smart city were proposed. These include economics, mobility, environment, people, living, and governance.

According to the Pan-European research project Intel Cities (2009) [24], the development of smart cities depends on efficient governance. According to an analysis of various definitions and practices of smart cities worldwide [25], the majority of smart cities heavily rely on mobile infrastructure and services. Given Serbia's growing urban population and rising service quality, scholars and decision-makers must have a solid grasp of smart cities and the associated challenges.

One of the fundamental responsibilities of a smart city is to use cutting-edge technologies to make urban surroundings more sustainable. The term "smart city" is interpreted differently in the literature; it no longer refers to entities that are entirely reliant on contemporary technologies but rather to a type of sustainable city with a well-defined planning strategy, excellent management, effective citizen-government communication, and an "intelligent" approach to resilience and self-improvement [26]. Generally accepted [27], "the city can be considered smart" when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and high quality of life, with a wise management of natural resources through participatory governance."

Several writers and researchers define a smart city as:

- a worldwide movement that emerged concurrently with the Fourth Industrial Revolution and was mostly represented in the scientific domain of spatial planning and urbanism [28];
 - a city, usually of medium size (100-500k inhabitants) [22], created by various actors: government, public-private partnership, investors, IT and other types of companies, scientists, but also the citizens themselves;
 - a sustainable system that enhances the quality of life in the areas of infrastructure management, transportation, energy, urban water, and building [29];
 - a product of the Internet of Things (IoT) platform, which enhances current urban environments through the use of big data, artificial intelligence platforms, sensors, and applications [30];
 - a livable urban environment resistant to changes [10].
- The following categories can be used to organize technological advancements in the creation of a Smart City across several facets of daily life [31,32],

2.2 Barriers of smart cities development

Based on earlier research, this study identified 35 major barriers to the development of smart cities. With experts' consultation, it categorised these barriers into six key categories. The various categories and associated barriers are represented in Table 2.

3 SOLUTION METHODOLOGY

determine the importance and weight of the barriers associated with smart cities and their categories.

3.1 Triangular and trapezoidal fuzzy numbers and analysis

Table 1 Identifying indicators of challenges in the development of smart cities

<i>Challenges indicators</i>	<i>Challenges sub-indicators</i>
Governance (G)	Lack of a legislative and strategic framework of platform and cooperation and coordination between the city's operational networks (G ₁) Unclear ICT management vision, the need for standardization of ICT management (G ₂) Political instability (G ₃) Lack of trust between the governed and government, Poor private-public participation (G ₄)
	Insufficient development entrepreneurship and innovation (E ₁) Lack of adequate ICT sector development and job opportunities within it (E ₂)
Economic (E)	Higher funding for design and implementation of local and national smart solutions and initiatives (E ₃) Higher commercialization of innovative technologies assessment (E ₄) Higher technology competition on the national and international market (E ₅) Higher external funding for the Smart City platforms (E ₆) Lack of competitiveness (E ₇) Higher operational and maintenance costs (E ₈)
Livability (L)	Greater personal security (L ₁) More affordable housing (L ₂) Accessible utilities, resource availability and infrastructure equipment (L ₃) Job opportunities for all (L ₄); Improvement of health, education, tourism and culture sectors (L ₅) Geographical diversification problems (L ₆) Social integration (L ₇)
Citizens (C)	A greater degree of community awareness (C ₁) A high level of education and qualification (C ₂) A readiness to try new things (C ₃) Demonstrated flexibility, creativity, and public confidence in modern solutions (C ₄) Greater civic engagement (C ₅) Increased awareness of ethnic and social diversity (C ₆)
Mobility (M)	Insufficiently integrated ICT infrastructure (M ₁), Innovative transport scheme that prioritizes non-motorized vehicles (M ₂), Domestic and international accessibility (M ₃)
Surroundings (Environment) (S)	More consideration of sustainability (S ₁) Monitoring quality and protecting the environment continuously (S ₂) Recycling in urban areas (S ₃) Higher renewable energy source utilization (S ₄) Construction of energy-efficient and smart facilities (S ₅) Not enough the reduction in energy usage linked to the development of new technologies (S ₆) Not enough natural resource protection and management (S ₇)

This exploratory study aims to build a theoretical foundation in the context of smart cities. To achieve the goal, AHP gives each variable a numerical priority. However, AHP has its limitations, which are as follows:

- The issue of priority shifts or rank reversals brought on by modifications to variables or options
- The idea is that elements exist independently.
- Subjectivity and human bias in opinions when making pairwise comparisons
- Consensus measure

To overcome the aforementioned drawbacks, our research methodology employed triangular and trapezoidal fuzzy AHP and interval triangular and trapezoidal fuzzy AHP. Fuzzy AHP makes it possible to

In addition to the crisp numbers utilized in the Analytic Hierarchy Process (AHP) method [33–35], this study uses triangular and trapezoidal fuzzy numbers when applying the Fuzzy Analytic Hierarchy Process (FAHP) methodology [36, 37].

A unique fuzzy set $FF = xx, \mu_{FF}(xx), xx \in \mathbb{R}$, is a fuzzy number, and $\mu_{FF}(xx): \mathbb{R} \rightarrow [0, 1]$ is a continuous function.

$TT = (aa, mm, rr)$ is the notation for the triangular fuzzy

number (TFN), and its membership function is:

$$\frac{xx-aa}{mm-aa}, \quad xx \in (aa, mm)$$

$$\mu_{FF}(x) = \begin{cases} \frac{u-x}{u-m}, & x \in (m, u) \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

Trapezoidal fuzzy numbers (TrFN), represented by $MM = (aa, mm^{aa}, mm^h, rr)$, are employed in the trapezoidal FAHP method [38].

$$\mu_{FF}(xx) = \begin{cases} \frac{xx - aa}{mm^{aa} - aa}, & xx \in (aa, mm^{aa}) \\ \frac{rr - xx}{rr - mm^h}, & xx \in (mm^h, rr) \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

If $mm^{aa} = mm^h$, the trapezoidal fuzzy number MM is reduced to the triangular fuzzy number MM .

The triangular fuzzy number MM is obtained by reducing the trapezoidal fuzzy number MM to $mm^{aa} = mm^h$.

Table 2. The laws for operations for an arbitrary two trapezoidal fuzzy numbers

Operation	Expression
$MM_1 \oplus MM_2$	$(aa_1 + aa_2, mm_{1aa} + mm_{2aa}, mm_{1h} + mm_{2h}, rr_1 + rr_2)$
$MM_1 \ominus MM_2$	$(aa_1 - rr_2, mm_{1aa} - mm_{2h}, mm_{1h} - mm_{2aa}, rr_1 - aa_2)$
$MM_1 \odot MM_2$	$(aa_1 \cdot aa_2, mm_{1aa} \cdot mm_{2aa}, mm_{1h} \cdot mm_{2h}, rr_1 \cdot rr_2)$
$MM_1 \oslash MM_2$	$(aa_1/rr_2, mm_{1aa}/mm_{2h}, mm_{1h}/mm_{2aa}, rr_1/aa_2)$
$ppMM_1$	$(ppaa_1, ppm_{1aa}, ppm_{1h}, ppr_1)$
aa MM_1	$aa_1, mm_{1aa}, mm_{1h}, rr_1$

Similar definitions apply to the operations for triangular fuzzy numbers. The fuzzy set

$$GG = (xx, rr), \mu_{GG}(xx, rr) \forall xx \in XX, \forall rr \in I_{xx} \in [0, 1],$$

$$0 \leq \mu_{GG}(xx, rr) \leq 1$$

is the definition of a type-2 fuzzy number (T2FN), where I_{xx} represents an interval in $[0, 1]$. When $\mu_{GG}(xx, rr) = 1$ is the membership function, interval type-2 fuzzy numbers (IT2FN) are a particular case of T2FN. The trapezoidal IT2FN number MM is represented with:

$$MM^{UU}: HH_1(MM^{UU}), HH_2(MM^{UU}), MM^{LL}; HH_1(MM^{LL}), HH_2(MM^{LL}),$$

(Figure 1)

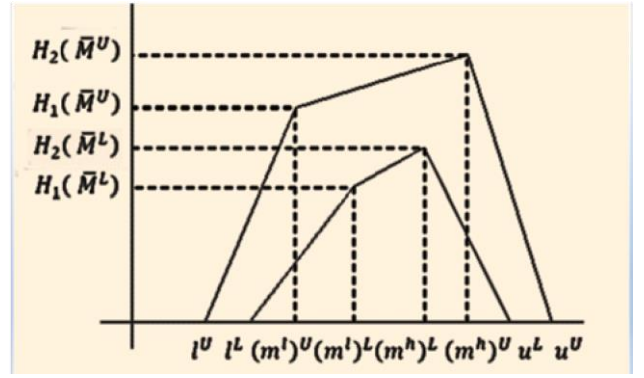


Figure 1 Graphical representation of trapezoidal IT2FS where $MM^{UU} = (aa^{UU}, (mm^{aa})^{UU}, (mm^h)^{UU}, rr^{UU})$ and $MM^{LL} =$

$(aa^{LL}, (mm^{aa})^{LL}, (mm^h)^{LL}, rr^{LL})$ are TrFNs, while $HH_1(MM^{UU}), HH_2(MM^{UU}), HH_1(MM^{LL})$ and $HH_2(MM^{LL})$ represent the middle left and right vertex heights of the upper and the lower trapeze, respectively.

Heights $HH_1(MM^{UU}), HH_2(MM^{UU}), HH_1(MM^{LL})$ and $HH_2(MM^{LL})$ belong to the interval $[0, 1]$.

For two trapezoidal IT2FNs,

$$MM_1 = MM_1^{UU}; HH_1(MM_1^{UU}), HH_2(MM_1^{UU}), MM_1^{LL}; HH_1(MM_1^{LL}), HH_2(MM_1^{LL})$$

and

$$MM_2 = MM_2^{UU}; HH_1(MM_2^{UU}), HH_2(MM_2^{UU}), MM_2^{LL}; HH_1(MM_2^{LL}), HH_2(MM_2^{LL})$$

arithmetic operations are given in Table 3.

Table 4 provides the linguistic descriptions of triangular and trapezoidal IT2FN fuzzy numbers.

Table 3. The laws for operations for an arbitrary two interval trapezoidal fuzzy numbers

Addition	$MM_1^{UU} \oplus MM_2^{UU}; \min HH_1(MM_1^{UU}), HH_1(MM_2^{UU}), \min HH_2(MM_1^{UU}), HH_2(MM_2^{UU}),$ $MM_1 \oplus MM_2 =$ $MM_1^{LL} \oplus MM_2^{LL}; \min HH_1(MM_1^{LL}), HH_1(MM_2^{LL}), \min HH_2(MM_1^{LL}), HH_2(MM_2^{LL})$
Subtraction	$MM_1^{UU} \ominus MM_2^{UU}; \min HH_1(MM_1^{UU}), HH_1(MM_2^{UU}), \min HH_2(MM_1^{UU}), HH_2(MM_2^{UU}),$ $MM_1 \ominus MM_2 =$ $MM_1^{LL} \ominus MM_2^{LL}; \min HH_1(MM_1^{LL}), HH_1(MM_2^{LL}), \min HH_2(MM_1^{LL}), HH_2(MM_2^{LL})$
Multiplication	$MM_1^{UU} \odot MM_2^{UU}; \min HH_1(MM_1^{UU}), HH_1(MM_2^{UU}), \min HH_2(MM_1^{UU}), HH_2(MM_2^{UU}),$ $MM_1 \odot MM_2 =$ $MM_1^{LL} \odot MM_2^{LL}; \min HH_1(MM_1^{LL}), HH_1(MM_2^{LL}), \min HH_2(MM_1^{LL}), HH_2(MM_2^{LL})$
Division	$MM_1^{UU} \oslash MM_2^{UU}; \min HH_1(MM_1^{UU}), HH_1(MM_2^{UU}), \min HH_2(MM_1^{UU}), HH_2(MM_2^{UU}),$ $MM_1 \oslash MM_2 =$ $MM_1^{LL} \oslash MM_2^{LL}; \min HH_1(MM_1^{LL}), HH_1(MM_2^{LL}), \min HH_2(MM_1^{LL}), HH_2(MM_2^{LL})$
Scalar multiplication	$kMM_1 = ppMM_1^{UU}; HH_1(MM_1^{UU}), HH_2(MM_1^{UU}), ppMM_1^{LL}; HH_1(MM_1^{LL}), HH_2(MM_1^{LL})$
<i>n</i> th root	${}^{aa}MM_1 = \left(\sqrt[n]{\bar{M}_1^U}; H_1(\bar{M}_1^U), H_2(\bar{M}_1^U) \right), {}^{aa}\bar{M}_1^L; H_1(\bar{M}_1^L), H_2(\bar{M}_1^L)$

Crisp	TFN	Upper TFN with high	Lower TFN with high	TrFN	Upper TrFN with highs	Lower TrFN with highs	Linguistic variables
1	(1,1,3)	(1,1,3;1)	(1,1,2;0.9)	(1,1,1,3)	(1,1,1,3;1,1)	(1,1,1,2;0.9,0.9)	Equally important (E)
2	(1,2,3)	(1,2,3;1)	(1.5,2,2.5;0.9)	(1,1.5,2,5)	(1,1.5,2.5,3;1,1)	(1.5,1.75,2.25,2.5;0.9,0.9)	Intermediate value (I ₁)
3	(1,3,5)	(1,3,5;1)	(2,3,4;0.9)	(1,2,4,5)	(1,2,4,5;1,1)	(2,2.5,3.5,4;0.9,0.9)	Weakly important (W)
4	(3,4,5)	(3,4,5;1)	(3.5,4.4,5;0.9)	(3,3.5,4.5,5)	(3,3.5,4.5,5;1,1)	(3.5,3.75,4.25,4.5;0.9,0.9)	Intermediate value (I ₂)
5	(3,5,7)	(3,5,7;1)	(4,5,6;0.9)	(3,4,6,7)	(3,4,6,7;1,1)	(4,4.5,5.5,6;0.9,0.9)	Fairly important (F)
6	(5,6,7)	(5,6,7;1)	(5.5,6,6.5;0.9)	(5,5.5,6,7)	(5,5.5,6,7;1,1)	(5.5,5.75,6.25,6.5;0.9,0.9)	Intermediate value (I ₃)
7	(5,7,9)	(5,7,9;1)	(6,7,8;0.9)	(5,6,8,9)	(5,6,8,9;1,1)	(6,6.5,7.5,8;0.9,0.9)	Strongly important (S)
8	(7,8,9)	(7,8,9;1)	(7.5,8,8.5;0.9)	(7,7.5,8,9)	(7,7.5,8,9;1,1)	(7.5,7.75,8.25,8.5;0.9,0.9)	Intermediate value (I ₄)
9	(7,9,9)	(7,9,9;1)	(8,9,9;0.9)	(7,9,9,9)	(7,9,9,9;1,1)	(8,9,9,9;0.9,0.9)	Absolutely important (A)

Table 4TFN, TrFN and interval type-2 fuzzy scale for the triangular and trapezoidal IT2FN with linguistic variables

3.2 Fuzzy Hybrid Model object.As an expansion of T1FS, Zadeh [40] also presented fuzzy set type-2 (T2FS). More degrees of uncertainty can be The theory of fuzzy sets is introduced in [39], who also conveyed by T2FS, which produces more reliable results and discusses the imprecision and ambiguity of human language makes it possible to model uncertain environments and thought. A fuzzy set also called a type-1 fuzzy set (T1FS), appropriately. We introduced the interval type-2 fuzzy ~~set~~ IT2FS represents a class of objects on a continuum of membership and the usual T2FS type. This set has a larger degree of grades. It is distinguished by a membership function that uncertainty than T1FS but allows for significant calculation allocates a membership grade between 0 and 1 to every reduction,

resulting in more reliable and accurate findings [41,42].

The algorithm as it is explained below:

Step 1: Create the fuzzy evaluation matrices AA (formula (3)) in the manner described below for each preference criterion that is taken into consideration:

$$= \begin{bmatrix} 1 & SS_{12} & \dots & SS_{1aa} \\ \frac{1}{SS_{12}} & 1 & & \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{SS_{1aa}} & \frac{1}{SS_{2aa}} & \dots & 1 \end{bmatrix} \quad (3)$$

SS_{aaii} , aa , $ii = 1, 2, \dots, aa$ is a crisp number in the AHP method or corresponding triangular fuzzy number, trapezoidal fuzzy number, triangular IT2FN and trapezoidal IT2FN in fuzzy AHP. Step 2: Use the method to investigate the consistency of fuzzy evaluation matrices. The CI for matrix consistency is $CCII =$

$\lambda_{\max} - \frac{mm_{aa}^{ssxx} - 1}{aa}$, consistency ratio $CCCC = \frac{CCII}{CCII^{max}}$. The value $\lambda_{\max}$ represents the maximal eigenvalue of the comparison crisp matrix AA . The matrix's dimension is n , and RI is the known random index. The comparison matrix is consistent if CR is less than 0.1 and the estimates of the criteria's relative importance are deemed acceptable.

Step 3: Use the following formula to determine each row's geometric mean:

$$rr_i = [a_{i1} \odot a_{i2} \odot \dots \odot a_{ina}]^{\frac{1}{n}}, i = 1, aa \quad (4)$$

Step 4: Determine the fuzzy weights assigned to each criterion.

$$ee_{ii} = rr_i \odot [rr_1 \oplus rr_2 \oplus \dots \oplus rr_{aa}]^{-1}, ii = 1, aa. \quad (5)$$

Step 5: The defuzzified values in the FAHP procedures are obtained using the center area approach. In the case of triangular fuzzy number, the defuzzified value is $\frac{1}{4}(aa + 2mm + rr)$. When a trapezoidal fuzzy number, the defuzzified value is $\frac{1}{4}(aa + mm^{aa} + mm^h + rr)$. For the triangular IT2FN, the

defuzzified value is $\frac{1}{8}aa^{UU} + rr^{UU} + aa^{LL} + rr^{LL} + 2HHTT^{UU}mm^{UU} +$

$2HHTT^{LL}mm^{LL}$ and for the trapezoidal IT2FN, the defuzzified value is $\frac{1}{8}aa^{UU} + rr^{UU} + aa^{LL} + rr^{LL} + HHMM^{UU}((mm^{aa})^{UU} +$

$(mm^{rr})^{UU}) + HHMM^{LL}((mm^{aa})^{LL} + (mm^{rr})^{LL})$.

4 DATA ANALYSIS AND RESULTS

The techniques described in Section 3 will be used in this section. The linguistic expressions presented in Table 2 are used to assess the importance of each criterion and sub-criterion. Expert-derived fuzzy matrices of comparison of criteria and sub-criteria are provided in Tables 5 through Table 11. Based on the obtained value of $CR < 0.1$, one can conclude that all comparison matrices are consistent

Table 5 Comparison matrix of criteria

	G	E	C	L	M	S
G	E	I_1	W	W	I_2	I_2
E	$1/I_1$	E	I_1	I_1	W	W
C	$1/W$	$1/I_1$	E	I_1	I_1	I_1
L	$1/W$	$1/I_1$	$1/E$	E	I_1	I_1
M	$1/I_2$	$1/W$	$1/I_1$	$1/I_1$	E	E
S	$1/I_2$	$1/W$	$1/I_1$	$1/I_1$	$1/E$	E

Table 6 Comparison matrix of sub-criterion G

	G ₁	G ₂	G ₃	G ₄
G ₁	EI	I_1	W	W
G ₂	$1/I_1$	EI	I_1	I_1
G ₃	$1/W$	$1/I_1$	E	I_1
G ₄	$1/W$	$1/I_1$	$1/E$	E

Table 7 Comparison matrix of sub-criterion E

	E ₁	E ₂	E ₃	E ₄	E ₅	E ₆	E ₇	E ₈
E ₁	EI	I_1	I_1	W	I_2	I_2	F	F
E ₂	$1/I_1$	E	E	I_1	W	W	I_2	I_2
E ₃	$1/I_1$	$1/E$	E	I_1	I_1	W	I_2	I_2
E ₄	$1/W$	$1/I_1$	$1/I_1$	E	I_1	I_1	W	W
E ₅	$1/I_2$	$1/W$	$1/W$	$1/I_1$	E	E	I_1	I_1
E ₆	$1/I_2$	$1/W$	$1/W$	$1/I_1$	$1/E$	E	I_1	I_1
E ₇	$1/F$	$1/I_2$	$1/I_2$	$1/W$	$1/I_1$	$1/I_1$	E	E
E ₈	$1/F$	$1/I_2$	$1/I_2$	$1/W$	$1/I_1$	$1/I_1$	$1/E$	E

Table 8 Comparison matrix of sub-criterion L

	L ₁	L ₂	L ₃	L ₄	L ₅	L ₆	L ₇
L ₁	E	I_1	I_1	W	I_2	F	F
L ₂	$1/I_1$	E	E	I_1	W	I_2	I_2
L ₃	$1/I_1$	$1/E$	E	I_1	I_1	I_2	I_2
L ₄	$1/W$	$1/I_1$	$1/I_1$	E	I_1	W	W
L ₅	$1/I_2$	$1/W$	$1/W$	$1/I_1$	E	I_1	I_1
L ₆	$1/F$	$1/I_2$	$1/I_2$	$1/W$	$1/I_1$	E	E
L ₇	$1/F$	$1/I_2$	$1/I_2$	$1/W$	$1/I_1$	$1/E$	E

Table 9 Comparison matrix of sub-criterion C

	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇
C ₁	E	I_1	W	W	F	S	E
C ₂	$1/I_1$	E	I_1	I_1	I_2	I_3	$1/I_1$
C ₃	$1/W$	$1/I_1$	E	E	W	F	$1/W$
C ₄	$1/W$	$1/I_1$	$1/E$	E	W	F	$1/W$
C ₅	$1/F$	$1/I_2$	$1/W$	$1/W$	E	W	$1/F$
C ₆	$1/S$	$1/I_3$	$1/F$	$1/F$	$1/W$	E	$1/S$
C ₇	E	I_1	W	W	F	S	E

Table 10 Comparison matrix of sub-criterion M

	M ₁	M ₂	M ₃
M ₁	E	I_1	I_2
M ₂	$1/I_1$	E	W
M ₃	$1/I_2$	$1/W$	E

Table 11 Comparison matrix of sub-criterion S

	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇
S ₁	E	I ₁	W	W	I ₂	F	S
S ₂	1/I ₁	E	I ₁	I ₁	W	I ₂	I ₃
S ₃	1/W	1/I ₁	E	E	I ₁	I ₂	F
S ₄	1/W	1/I ₁	1/E	1/E	I ₁	W	F
S ₅	1/I ₂	1/W	1/I ₁	1/I ₁	E	I ₁	I ₂
S ₆	1/F	1/I ₂	1/W	1/W	1/I ₁	E	W
S ₇	1/S	1/I ₃	1/F	1/F	1/I ₂	1/E	E

The ranking results by triangular FAHP (1), trapezoidal FAHP (2), triangular IT2FS (3), and trapezoidal IT2FS (4) fuzzy logic techniques of the most important challenge indicators are shown in Figure 2.

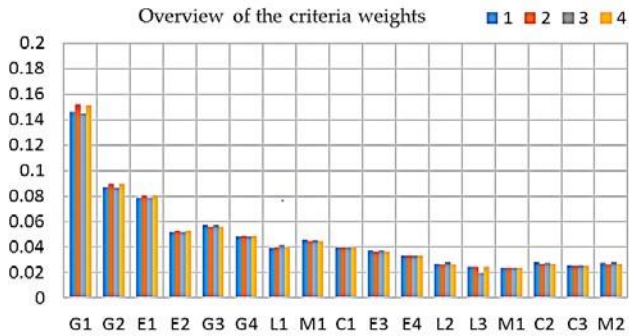


Figure 2 Weights of key indicators of challenges to the development of smart city

The comparative application of FAHP methods, triangular and trapezoidal, and corresponding hybrid IT2FS methods in the field of smart city development highlights the following indicators that are potentially the most significant barriers to change:

- The absence of a platform's strategic and legal framework, as well as collaboration and coordination among the city's operational networks;
- The need for ICT management standardization and an unclear ICT management vision;
- Insufficient development of entrepreneurship and innovation;
- Lack of adequate ICT sector development and job opportunities within it;
- Political instability;
- Lack of trust between the governed and government, Poor private-public participation;
- A greater degree of community awareness;
- Greater personal security;
- Higher funding for design and implementation of local and national smart solutions and initiatives;
- Higher commercialization of innovative technologies assessment.

5 CONCLUSION

In this paper, we explore the possibilities for developing smart city models, considering the obstacles to their development and the possibilities for overcoming them. The theoretical background primarily explains the most important aspects and challenges of smart cities in our country and the surrounding area. In terms of the applied methodology, the contribution lies in the comparative application of triangular and

trapezoidal FAHP methods and the corresponding hybrid IT2FS methods in creating a platform of challenges for developing smart cities. In addition to the pandemic, globalization, environmental catastrophes, and general overpopulation require human society to think and live more intelligently. The study identifies important prerequisites for a smart city, including key barrier indicators. The primary dominant indicators, derived from many sub-criteria and six groups of criteria, were: The lack of cooperation and coordination between the city's operational networks and a platform's legal and strategic framework; the necessity of standardizing ICT management and the lack of clarity in its vision; inadequate growth in innovation and entrepreneurship; inadequate job opportunities and development in the ICT sector; and a state of political instability. Transparent regulatory frameworks and clearly defined objectives can create opportunities for the development of smart cities. Based on findings about the primary indicators, this study may serve as the foundation for future research initiatives.

Acknowledgements

This work was realized with the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, the contract on research work of the Faculty of Electronics of the University of Nis in 2025, reg. number 45103-65/2024-03/200102.

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Modern Technologies for Innovative Urban Water Management in Smart Cities

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Abstract: The efficient usage of resources is essential to the development and operation of smart cities, with recent technologies playing a pivotal role. In particular, advanced electronics and digital innovations are transforming energy and water management, integrating clean technologies and promoting sustainability. Smart sensors, IoT networks, and automated systems enable real-time data collection and analysis, allowing for predictive maintenance, timely interventions, and optimized resource allocation. Leading-edge technologies such as AI-powered analytics and machine learning models enhance decision-making processes by providing actionable insights for urban management. Additionally, blockchain technology can ensure secure data exchange, while 5G connectivity facilitates faster communication between devices, improving the overall productivity of urban systems. These advancements are increasingly integrated into the infrastructure of newly developed smart cities built with technology at their fundamental. At the same time, in many cities of Europe the existing infrastructure is retrofitted with smart solutions to improve their operations. This study will examine these achievements and point out two possibilities of their potential application in cities of Serbia, as well as Bosnia and Herzegovina. The goal is to systematize the ways in which modern electronic technologies are involved for sustainable water management, intelligent urban infrastructure, and resilient urban development.

Keywords: Smart cities, sensors and systems, water management.

1 INTRODUCTION

The aspiration to a better quality of life in urban areas, combined with the population growth, have led to the emergence of new concepts in the development and management of the city, as well as the application of novel technology and new solutions. Further, climate change significantly influences both the quantity and quality of water resources, with these effects being mainly pronounced in urban areas. Given that more than half of the global population currently resides in cities, with this number expected to increase, the optimization of resource utilization is becoming increasingly important, particularly in terms of the efficient consumption of energy and water [1]. As a result, there is an increasing focus on adopting innovative solutions and modern technologies associated with smart city development.

The development of the smart city concept, through the implementation of integrated systems, optimizes water management efficiency with the aim of reducing consumption. Beyond individual solutions in various areas of conventional water management (WM), these innovative systems enhance comprehensive WM within the urban water cycle, ultimately leading to intelligent WM [2-7]. Moreover, in a smart city, intelligent technologies complement and improve existing infrastructure and technologies for water management across the entire urban system. This is achieved through the use of real-time integrated

information and electronic components and systems, such as sensors, monitors, Geographic Information Systems (GIS), remote sensing, and other contactless intelligent tools in urban area [7].

Existing water management practices in smart cities align with at least five Sustainable Development Goals (SDGs) of the 2030 Agenda: ensuring healthy lives and promoting well-being (Goal 3); providing access to sustainable water and sanitation management (Goal 6); improving inclusive, safe, and resilient cities (Goal 11); ensuring sustainable consumption and production patterns (Goal 12); and combating the impacts of climate change (Goal 13) [8]. Numerous programs and projects funded by global, regional and national institutions promote progress in improving the water conservation and control [8-12], often through the development of digital service tools to improve specific segments (e.g., water supply or stormwater management) while simultaneously fostering technologies for public engagement in water management.

The aim of this study is to investigate the applied modern technologies in water management and required devices necessary for their application. The research of functional practices in selected smart cities of Europe can be useful for highlighting strategies potentially applicable in the cities of Serbia, as well as Bosnia and Herzegovina.

2 TECHNOLOGIES FOR INOVATIVE URBAN WATER MANAGEMENT

Smart cities from the list of global smart cities, more than a third of which are in Europe, were chosen for the

analysis [14]. In addition to already existing cities where new technologies are applied to improve citizens' quality of life, a city initially established as a smart city was also selected. Additionally, the study also considers emerging smart cities that are rapidly integrating digital solutions to address urban challenges, such as sustainability, mobility, and public services, aiming to transform their infrastructures into fully interconnected ecosystems.

2.1 Milton Keynes, United Kingdom

Milton Keynes was founded almost 65 years ago as a smart city. Thanks to advanced thinking and technological integrations, a synergy has been created between water supply, waste water treatment and storm water management, optimizing the use of resources and increasing the overall efficiency of the system.

The innovative solutions applied in Milton Keynes include: smart water meters, data collection, analysis, and predictive modelling, advanced leak detection technologies, smart irrigation systems, grey water recycling systems, public engagement and education, UV system devices are presented in Fig. 1. planning for water supply [15]. These solutions and applied

such as data loggers, IoT (Internet of Things) gateways, edge computing devices, and cloud-based servers are integral to this system.

Advanced leak detection technologies are used to minimize water losses. This is achieved through the application and integration of acoustic sensors and satellite images. These technologies enable rapid identification and repair of leaks within the water distribution network, enhancing overall efficiency. Key electronic devices include acoustic leak detectors, satellite sensors, handheld monitoring devices, and smart pressure monitoring valves.

Smart irrigation systems are used for precise irrigation scheduling. This is achieved through the utilization of sensor-driven smart irrigation systems combined with weather forecasts. Such approach reduces water waste and optimizes water use for green spaces and agricultural purposes. The systems rely on soil moisture sensors, weather monitoring stations, automated irrigation controllers, and communication modules for remote management.

Grey water recycling was achieved through the

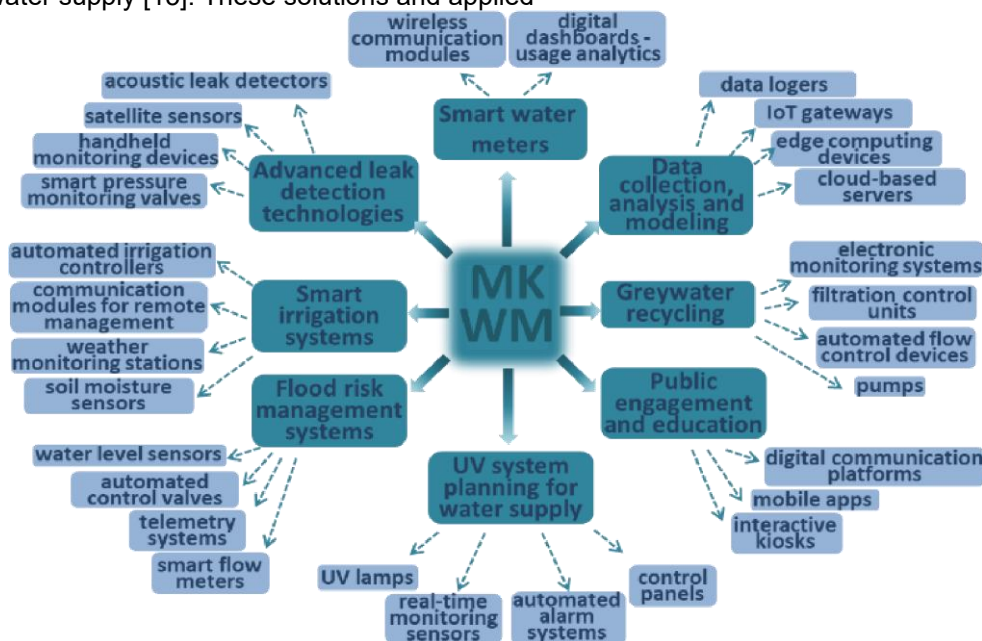


Figure 1 Innovative solution elements for water management in Milton Keynes and applied devices

recycling, flood risk management Smart water meters enable real-time monitoring of water consumption. These devices provide valuable data to both consumers and water management authorities, fostering efficient water usage and early detection of abnormal consumption patterns. These meters are typically equipped with wireless communication modules for data transmission and are integrated with digital dashboards that provide usage analytics.

Data collection, analysis and predictive modelling are allowed by sophisticated data analytics platforms. Predictive modelling helps in efficient forecasting and management of water demand, allowing the city to proactively address potential supply issues. Devices

establishment of nine dedicated grey water recycling centres. These centres collect and treat wastewater from sinks, showers, and various appliances, repurposing it for landscape irrigation and toilet flushing. The recycling process is supported by electronic monitoring systems, pumps, filtration control units, and automated flow control devices.

Flood risk management systems are used to mitigate these risks. The city employs decentralized stormwater management solutions, also known as Sustainable Urban Drainage Systems. These systems manage rainwater effectively and reduce the burden on conventional drainage networks. Electronic components such as water level sensors, automated

control valves, smart flow meters, and telemetry systems are used to monitor and regulate stormwater flow.

Public engagement and education are used to promote sustainable water management practices. Milton Keynes actively engages with residents and businesses through educational programs and public awareness campaigns. These initiatives encourage the adoption of eco-friendly behaviours and community participation in water conservation efforts. Digital communication platforms, mobile apps, and interactive kiosks play a role in these engagement efforts.

UV System Planning for Water Supply is a notable example of innovation. This novelty in water management is the analysis and forecasting of water demand using devices based on the application of ultraviolet waves. The city has developed predictive models based on five different scenarios for population growth and regulatory changes in the construction of new residential buildings. These models assist in optimizing water supply infrastructure and ensuring resilience in the face of urban expansion. Electronic components used in UV systems include ultra violet lamps, control panels, real-time monitoring sensors, and automated alarm systems for maintenance notifications.

The advanced management approach in Milton Keynes and the integration of advanced technological solutions have made it a benchmark for sustainable and intelligent water management in urban environments. By leveraging smart technologies and innovative systems and devices, the city shows how efficient management of water resources can contribute to the creation of a sustainable and resilient urban ecosystem.

2.2 Barcelona, Spain

In Barcelona, the transformation towards smart city started 35 years ago and further developed according to the 2012 model, which ensures efficient services for all citizens across various levels of urban management through information and communication technology. The core concept behind the model is managing the city as a "network of networks" [16]. The model encompasses 12 sectors, including environmental protection, mobility, energy, water, and public open spaces, each defined by specific programs and projects. For most sectors, in Barcelona is employed a three-layer technological structure: (i) Sensors installed throughout the city, connected via the Sentilo platform [17]. (ii) City OS platform: Aggregates and analyses data from various applications. (iii) Open user platform: Facilitates data sharing and analysis results [16].

In the domain of water management, or "smart water," as often emphasized in smart cities, Barcelona introduced remote control technologies in the mid-2010s. These included the management of public green space irrigation, the operation of public fountains, and two networks supplying hot water to 64 buildings. The annual savings attributed to smart water technology during that period were estimated at \$58

million [16]. Today, Barcelona is one of the global leaders in smart water management, leveraging various novel technologies across numerous sectors,

Innovative technical systems for water management in Barcelona involve several integrated solutions aimed at optimizing water usage and reducing operational costs. One key initiative is the deployment of a comprehensive sensor network to monitor water levels, flow rates, and leakage detection in real time. These sensors are strategically placed across the water distribution network and connected to the Sentilo platform [17], which allows for centralized data collection and analysis.

Additionally, in Barcelona are utilized smart irrigation systems in its public green spaces. These systems rely on soil moisture sensors (Fig. 2) and weather data to determine the optimal amount of water needed, significantly reducing water wastage. Remote control units enable city managers to adjust irrigation schedules and monitor the system's performance from a central dashboard. The implementation of this technology has led to more efficient water use and healthier urban greenery.

Public fountains in the city are also equipped with smart control systems that monitor water quality, detect malfunctions, and optimize operating hours. These systems are managed remotely, allowing for immediate response to any issues and contributing to significant maintenance cost reductions.



Figure 2 Smart irrigation unit with water level sensor in Barcelona
(source: ajuntament.barcelona.cat)

Another notable innovation is the use of advanced metering infrastructure for residential and commercial water consumption. Smart water meters provide real-time data on water usage, helping both utility providers and consumers to identify and address inefficiencies. These meters are connected to the City OS platform, enabling detailed consumption analytics and the development of predictive maintenance strategies.

The electronic devices essential for these solutions, include IoT-enabled sensors (such as flow meters and soil moisture sensors), communication modules (for real-time data transmission), and smart controllers for automated irrigation and fountain management. The data from these devices is aggregated and analysed through cloud-based platforms, allowing for actionable insights and informed decision-making.

The holistic approach of Barcelona to smart water management demonstrates the potential of combining

advanced technology with data-driven strategies to create a more sustainable and efficient urban environment [18]. The city's ongoing commitment to innovation in this sector has positioned it as a model for other cities seeking to adopt similar solutions.

2.3 Berlin, Germany

The improvement of water management in the City of Berlin happened as a part of the political agenda on digitalization, adopting the term "digital water" similarly to other smart cities [19]. Key pressures on the urban water cycle have been identified, including: 1) drinking water production, 2) discharges of stormwater and treated wastewater, 3) combined sewer overflows, and 4) recreational purposes. Based on these challenges, the following objectives have been formulated: enhancing the performance of wastewater and drinking water infrastructure; and encouraging public engagement in urban water management. In Fig. 3 wastewater pump station at the plant in Berlin is presented [20].

Experts are focused on digital water, which illustrates a commitment to integrating technological advances to optimize urban water systems and promote participatory management approaches. Activities related to digital water in Berlin involve the several important solutions which will be explained [19].



Figure 3 Wastewater pump station at the plant in Berlin [20]

Innovative technical systems for water management in Berlin include a number of leading solutions designed to improve efficiency, sustainability, and transparency in water-related processes. One such system involves the deployment of IoT-enabled sensors in water distribution and wastewater infrastructure. These sensors monitor water flow, pressure levels, and detect leaks in real-time, enabling quick intervention and maintenance, which reduces water losses. Another innovative solution is the use of digital monitoring systems for tracking unauthorized water connections. This involves advanced surveillance and data analysis technologies that help utility companies detect illegal connections, ensuring the integrity of the water supply network.

In Berlin are also applied next-generation sensors for realtime bacterial measurement in the Spree River and combined sewer overflow systems. These sensors provide immediate data on water quality, allowing

authorities to take prompt action to prevent public health risks and maintain safe water conditions for recreational activities. In addition, augmented reality (AR) technology is applied to support water infrastructure projects and promote tap water consumption. AR visualizations are used to educate the public about water system upgrades and investments, thereby fostering community engagement and acceptance of necessary infrastructure developments.

To further optimize water usage, smart irrigation systems have been installed in public parks and green spaces. These systems rely on soil moisture sensors and weather data to determine the optimal watering schedule, thereby conserving water resources. The electronic devices crucial for these innovative solutions include IoT sensors for water quality and flow monitoring, AR headsets for visualization in public engagement initiatives, smart meters for accurate consumption tracking, and cloud-based platforms for data aggregation and analysis.

An emphasis on data-driven water management has also led to the development of a centralized digital platform for visualizing operations at drinking water wells. This platform integrates data from multiple sources and provides decisionmakers with valuable insights for optimizing water production and distribution.

By integrating these advanced technologies, Berlin is positioned as a leader in digital water management. This demonstrated the potential for smart solutions to solve complex urban water challenges, while simultaneously promoting sustainability and citizen participation.

2.4 Paris, France

The broader Paris region, home to 7.2 million residents, has implemented integrated smart water management within its sewer system. The establishment of this system dates back forty years, when the primary goal was to improve the deteriorating water quality of the Seine and Marne rivers. The construction of numerous wastewater treatment plants and transport sewer networks, along with the installation of real-time monitoring sensors, has brought the region close to meeting the stringent requirements of the EU Water Framework Directive. Since 2008, the MAGES real-time control system [21] has been in operation, integrating data from 2000 sensors into a hydraulic model that simulates flow under various scenarios. This enables optimized management of multiple treatment plants under different weather conditions. The smart system allows the rerouting of sewage from one facility to another, enhancing system reliability during planned maintenance or unexpected incidents, such as system component failures. In Fig. 4 schematic of data and MAGES output processing operations is shown.

In addition to MAGES, there are several other innovative technical systems that improve water

management. One such solution is the deployment of IoT-enabled water quality sensors across the Seine and Marne rivers. These sensors provide realtime data on parameters such as turbidity, pH, and pollutant levels, helping authorities promptly identify and mitigate water quality issues.

Smart stormwater management is another critical innovation. Automated detention basins equipped with flow regulation devices control the release of stormwater into the sewer network, preventing flooding and reducing the load on wastewater treatment plants during heavy rainfall. Advanced data analytics and AI-based predictive models are integrated into the MAGES system to forecast potential hydraulic issues and optimize operational decisions. This technology allows operators to anticipate system bottlenecks and pre-emptively reroute sewage flows to maintain the system stability. Smart meters have been introduced for accurate monitoring of water consumption in residential, commercial, and industrial sectors. These meters provide consumers and water utilities with detailed insights into usage patterns, enabling more efficient water resource management. Electronic devices crucial for these solutions include flow sensors, water quality probes, communication modules for real-time data transmission, and programmable logic controllers (PLCs) for automated system operation. Data from these devices is aggregated and visualized through cloud-based platforms, enabling centralized monitoring and control. Also, drone technology is utilized for the inspection of large sewer tunnels, reducing the need for hazardous manual entry and enhancing maintenance efficiency. Thermal imaging cameras on these drones help detect structural weaknesses or leaks within the infrastructure.

innovation and compliance with strict environmental regulations.

2.5 Stockholm, Sweden

Digital Demo Stockholm is an innovation partnership between the public sector, academia and private industry that leverages digital solutions to facilitate and improve the quality of life for the citizens of Stockholm. According to this initiative, the management aims to make the city the "smartest city" in the world by 2040 [22]. The water observation network project encompasses a connected real-time water quality monitoring system across the entire city. It was developed to address issues related to water, the environment, and climate through ICT, utilizing an extensive IoT sensor system integrated throughout Stockholm's water supply network. The network monitors key water quality parameters, including conductivity, pH, temperature, and dissolved oxygen. Additionally, big data analytics are combined with the development of water modelling algorithms capable of filtering sensor data to provide a broader understanding of water quality changes. Such changes could alert the city and water utilities to events like algal blooms or the discharge of polluted industrial wastewater while providing detailed information on where and when they occur. This allows the city to take early mitigation measures, allocate resources efficiently, minimize operational costs, and enhance overall process efficiency [22].

In addition to real-time water quality monitoring systems, smart water measurement and leak detection technologies are also used in Stockholm. The smart water meters, equipped with IoT sensors, provide

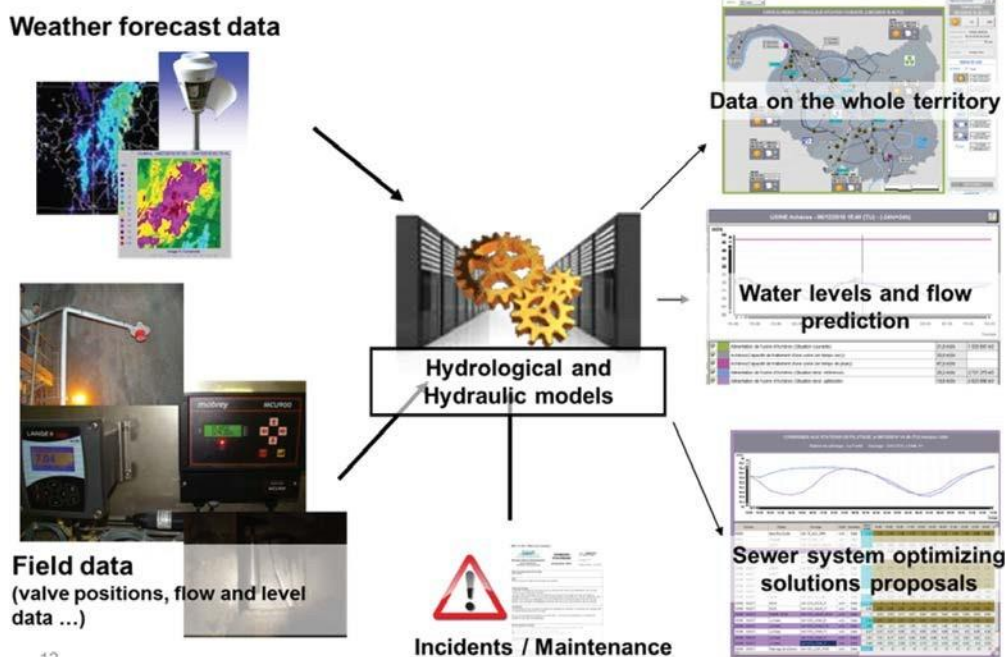


Figure 4 Schematic of data and MAGES output processing operations for Paris [21]

Through these technological advances, Paris is at the forefront of smart water management, demonstrating a commitment to sustainability,

accurate and real-time data on water consumption, allowing for better resource management, reduced waste, and more effective pricing models for

consumers. The meters send data directly to a centralized system, which provides detailed consumption insights and allows for the identification of abnormal usage patterns, such as leaks or unauthorized water use.

Furthermore, advanced wastewater treatment systems are integrated, including membrane bioreactors, which significantly improve the efficiency of the water treatment process. These systems use a combination of biological treatment and filtration to produce cleaner, safer water. Data from these systems are constantly monitored and analysed to optimize performance and ensure that treated water meets environmental standards.

Also, predictive analytics, powered by machine learning algorithms, to forecast potential water demand and supply fluctuations are applied. This helps utilities proactively manage water resources, ensuring a consistent supply even during peak demand or periods of drought.

Electronic devices used in these solutions include smart water meters, IoT sensors for monitoring water quality and pressure, communication modules for transmitting data to central platforms, and advanced data processing devices that analyse sensor data in real-time. Additionally, the city employs automated control systems, such as programmable logic controllers, to regulate water flow and optimize wastewater treatment processes based on real-time data inputs.

With the continued integration of digital technologies, it is possible to achieve water management systems that are more efficient, sustainable and resilient to environmental challenges. Fig. 5 illustrates contents of electrical room in facilities for drinking water treatment [23].

solutions in many areas, but most promising solutions for water management are applied in Rome. Smart water management strategies have been actively implemented to enhance the efficiency and sustainability of its water resources. A significant initiative is the development of the "Vaidi" application by Ace, the primary water utility from Rome [25].

Remote monitoring is applied by using smart water sensors placed throughout the distribution network in order to monitor water quality and to detect changes in flow and pressure in realtime. IoT-connected devices send continuous data to centralized systems for faster decision-making. Similar to Milton Keynes, smart water meters equipped with wireless communication modules are used in Rome. These devices provide both consumers and water utilities with real-time information on water consumption, helping detect leaks and promoting efficient water use.

Supervisory Control and Data Acquisition (SCADA) systems are widely employed for monitoring and controlling water distribution systems in real time. The SCADA systems gather data from sensors and remote devices across the city and present it through a centralized control interface. Water utility integrates sophisticated acoustic sensors to identify underground water leaks. These sensors help pinpoint leaks without the need for extensive excavation.

Satellite imagery - remote sensing, is used to identify anomalies in soil moisture patterns that may indicate hidden leaks in the water distribution system. Automated flow control valves are the electronically controlled valves which regulate the water flow based on demand patterns and emergency situations. They reduce wastage and maintain system pressure. Also very useful are energy-efficient smart pumps, equipped with sensors and variable speed drives, which optimize

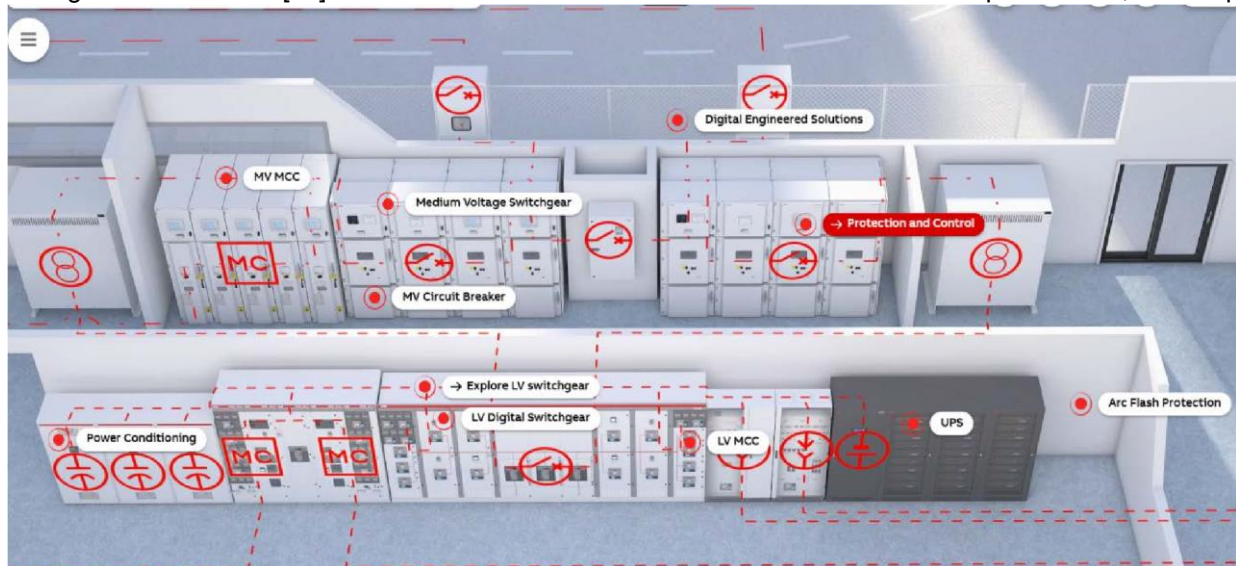


Figure 5 Electrical room in the drinking water treatment facility [23]

2.6 Rome, Italy

In Italy, the fragmented and inefficient management of water resources results in an average of 42% water volume being lost within the network each year [24]. This is additional reason for innovative

water pressure and minimize energy consumption during peak and low demand periods.

In addition, advanced data analytics and AI-driven predictive models to forecast water demand, optimize resource allocation, and improve maintenance

schedules are applied. Besides, water supply includes advanced UV disinfection systems that ensure safe drinking water by effectively inactivating harmful microorganisms.

All applied innovative systems and new technologies can additionally contribute to the improvement of water resources management and make this management more efficient.

3 SMART WATER MANAGEMENT IN SELECTED CITIES IN EUROPE

The elements of smart urban water management in the six cities in Europe shown in this paper are summarized in Table 1. These elements correspond to the scheme illustrated in Fig. 1. Areas of analyses water management are presented with followings acronyms: (DC) Data collection, analysis and modelling, (GW) Greywater recycling, (PE) Public engagement and education, (US) UV system planning - water supply, (FR) Flood risk management systems, (IR) Smart irrigation systems, (AD) Advanced leak detection technologies, (SW) Smart water meters.

Table 1 The elements of water management addressed in the analysed cities

Smart city								
	DC	GW	PE	US	FR	IR	AD	SW
Milton Keynes								
Barcelona								
Berlin								
Paris								
Stockholm								
Rome								

Urban water smart management
element

DC GW PE US

The analysed cities have gone through similar process, well summarized in the evidence-based Roadmap: 6 steps towards Water Smart Cities [26]:

1. Identify challenges and opportunities
2. Define Water Smart City vision
3. Explore co-creation opportunities
4. Co-design solutions
5. Define Business case
6. Implement & evaluate (Continuous).

As water management is a critical aspect of urban sustainability and resilience, innovative technologies in various areas are increasingly adopted in many cities of Europe. In addition to the analysed cities, it should certainly be noted that some aspects of innovative

technologies in the field of water management were applied in many other cities as well.

Therefore, for example, in Amsterdam (Netherlands), advanced solutions for water purification, storage and flood prevention have been developed. Also, phosphate recovery systems ensure efficient recovery of valuable nutrients from wastewater, contributing to the circular economy. The use of smart rainwater storage systems achieves temporary storage of rainwater to mitigate urban flooding. Aquifer Thermal Energy Storage (ATES) that integrates water storage with energyefficient heating and cooling systems for buildings is applied [27].

It is known that Copenhagen (Denmark) is a leader in climate adaptation strategies and smart water management. Cloudburst tunnels are underground systems designed to channel and store stormwater during heavy rainfall. Smart water meters are real-time monitoring devices that optimize water use and reduce water loss. Green-blue infrastructure enables improvement of water absorption and reduction of runoff. This is achieved by using permeable surfaces and green roofs [28].

Rotterdam (Netherlands) was among the first to start implementing flood prevention and urban water storage solutions. Alternative water storage basins have been implemented to collect and store rainwater in order to prevent flooding. Applied smart urban drainage systems are sensorbased systems that improve drainage efficiency. A famous Water Plaza (Bentemplein water square) is multifunctional public spaces designed for temporary storage of rainwater [29].

Advanced water reuse and smart irrigation technologies are implemented in Lisbon (Portugal). The application of smart irrigation systems optimizes the use of water in parks and agricultural areas by using real-time data. AI-based distribution network management enables leaks to be detected and pressure to be managed to improve efficiency [30].

Water management in Vienna (Austria) is focused on groundwater protection and biofiltration technology. The use of automated groundwater monitoring stations enables the collection of data on water quality and levels in real time. Biofiltration systems naturally purify water for reuse in urban areas. Dual purpose water networks effectively separate potable and non-potable water streams [31].

It should be noted that in Helsinki (Finland) data-based approaches and advanced wastewater treatment technologies are also applied. IoT-based water management systems enable the monitoring and optimization of the efficiency of water networks. Membrane bioreactors (MBRs), which are applied, are advanced systems for the treatment of wastewater. Smart water sensors detect leaks and measure consumption in real time, what is of high importance [32].

Certainly, the experiences of these cities should be analyzed and the possibilities of adaptation and

application in the conditions of our region should be considered. An insight and a systematic review of the used devices and new technologies applied to solve water management challenges can be of considerable interest.

4 CONCLUSION

Innovative approaches to water management in cities, characterized by the application of advanced technical and electronic systems to optimize water usage and ensure compliance with water quality standards, are particularly emphasized in the development of smart cities. Solutions presented in selected cities of Europe indicate two possible strategies for achieving smart city objectives in the domain of water management potentially applicable in different areas of Serbia, as well as Bosnia and Herzegovina: a comprehensive or partial approach, based on innovate technology elements and devices.

The comprehensive approach, demonstrated by the examples of Milton Keynes and Barcelona, is facilitated by the systematic collection of thematic data enabled through the widespread deployment of information and communication technologies. The partial approach is exemplified by Berlin, Paris, Stockholm, and Rome highlighting the feasibility of gradual implementation. In addition, there is a possibility of applying innovative approaches in certain elements only, which was initially done in several cities.

Beyond technological advancements and the digitization of water management processes, the transition towards sustainable urban water management in smart cities necessitates the incremental development of services through active collaboration between stakeholders, including local communities, municipalities, enterprises, and civil society actors, alongside developers. This cooperative framework leads to the creation of customized solutions that align with the specific needs and expectations of stakeholders, thereby fostering adaptive and resilient water management systems.

It is imperative to underscore the critical role of institutional support in the development of smart cities. Such support often originates from multiple levels of governance, including national institutions, international organizations, academic institutions, and associations representing relevant industrial sectors. The strategic integration of these participants' efforts in the process and efforts of etengineers in various areas, for applications of novel technologies, ensures the establishment of a robust and adaptive framework for water resource management, enhancing the sustainability and resilience of urban environments.

Acknowledgements

The results are realized throw the project supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia [grant number 451-03-65/202403/200095].

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IMPLEMENTATION OF SMART SOLUTIONS IN SERBIAN CITIES: ARE WE CLOSE TO SMART CITIES?

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Abstract

In this paper, the aim of the research refers to the analysis of the views of the citizens of seven cities in Republic of Serbia on the concept of smart cities. The concept of smart cities is being adopted worldwide, with the exponential growth of smart technologies. In the empirical part of the paper, research was conducted by the author of the paper in connection with the subject of the research. The research instrument used in this paper is a survey that was created online and then distributed to survey students. The sample of respondents consisted of 294 respondents, from whom it was planned to get opinions on the concept of smart cities, to what extent it positively or negatively affects everyday life. The research results indicate the level of respondents' ignorance of the concept of smart cities. Also, there is the uneven implementation of smart solutions in rural and urban areas in Republic of Serbia. The recommendation is to enable the even development of all cities and educate the population about the concept of smart cities, in the sense that there are no significant threats to security and privacy, and that resources such as time and costs are highly, their savings, closely connected with the concept of smart cities.

Keywords: Artificial Intelligence, Republic of Serbia, Smart Cities, Smart Solutions, Survey.

Introduction

The Internet of Things (IoT) is closely related to the concept of smart cities. The number of inhabitants at the world level is constantly increasing, cities are becoming bigger and bigger. Along with this growth of the urban way of life, there is also a continuous development of technologies, which can greatly help citizens in their daily lives: smart payment systems, smart transport options and signaling, management of waste, water, electricity, e-services, are just a few of options. The concept of smart cities is constantly developing, but uneven implementation of the concept is carried out due to technological, economic and administrative barriers and challenges.

The purpose of this paper is to gain insight into the characteristics (constructions) of the concept of smart cities and their application in seven cities in Republic of Serbia (from different parts of the country), first through theoretical foundations, and then with the author's research/survey results. The paper pointed out the aspects of real implementation - how far we have come with shaping cities in Republic of Serbia into smart cities. The paper gives special attention to the identification of opportunities and challenges for the

realization of the concept of smart cities in Republic of Serbia.

Literature review

The concept of connecting everyday objects over existing networks has become very relevant with the advent of smart devices and their recent advancements. The Internet of Things (IoT) is the result of the evolution of conventional networks that connect millions of connected devices. IoT connects to applications in smart homes, cities, distribution & storage within supply chains (in real time), distance learning, etc. Carrying out city operations with the help of ICT has made cities efficient in various aspects, where smart city is an application of IoT. IoT provides the basic components for building smart cities, ie. data generation, data management and application handling. [7, 8, 12] Figure 1 shows the main pillars of smart cities.

A smart city connects physical, social, business and ICT infrastructure. Smart city is defined as an advanced modern city that uses ICT and other technologies to improve the quality of life, competitiveness, operational efficiency of urban services, while ensuring the availability of resources for current and future generations in terms of social life, economic and

environmental aspects. Adapting to the demands of quality of life, modern smart cities are particularly focusing on sustainable and efficient solutions for energy management, transportation, healthcare, governance etc.

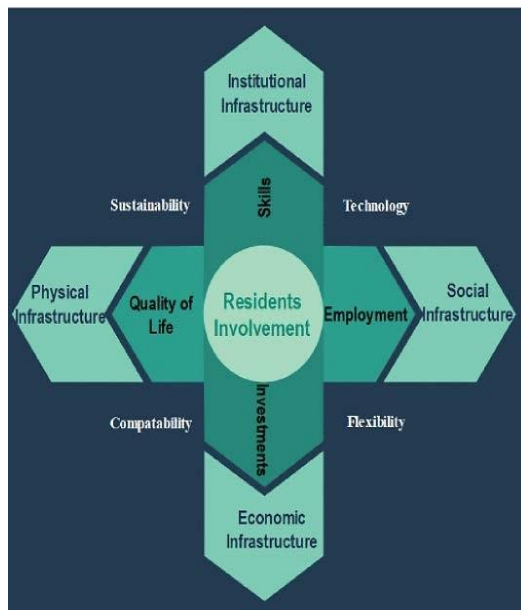


Figure 1. Main pillars of smart cities [13]

Smart city is the ideal solution for solving the challenges arising from drastic urbanization, population growth, deterioration of energy sources, environmental pollution, etc. Therefore, we can argue that adherence to smart city standards offers countless advantages in the implementation and management of smart cities, while facilitating real-time performance monitoring. But, smart cities must ensure individual privacy and security to ensure the participation of their citizens.

Current examples of cities incorporating smart city principles include cities around the world, like New York, Toronto, Copenhagen etc. Privacy protection for city users is of utmost importance for the success of a smart city. If citizens are reluctant to participate, the key benefits of a smart city will disappear. [2] Areas of further research include security monitoring tools, access controls and security buffers such as firewalls, micro firewalls and smart cards. [2]

Recent debates on sustainable urban development are intrinsically linked to smart cities [1]. In fact, it is currently difficult to imagine a smart city without linking it to aspects of sustainability and vice versa. Technology-related approaches, in short, aim to improve the efficiency of services and infrastructure. On the other hand, governance-related approaches focus on governance and interactions between different stakeholders in the city, connecting and developing socioeconomic and productive interactions among

networks of urban actors. Technology provides the means to improve and connect actors and services in order to achieve sustainable urban development, improve the socioeconomic, ecological, logistical, managerial and competitive performance of the city and the quality of life of its population, thus ensuring that the needs of current and future generations are met. [3]

Methodology

Statistical data processing and analysis were done using the software IBM SPSS (Statistical Package of Social Science) version 25. In this paper were used descriptive statistics to describe the sample and an independent t test to examine differences in relation to gender and school of students. A level of 0.05 was used for the threshold value of significance. **Results and Discussion**

294 respondents participated in the research, of which 132 were male and 162 were female (Table 1). Most respondents were aged 18 to 30 (46.9%), followed by respondents aged 31 to 40 (32%) (Table 1). Most respondents have completed basic studies (37.4%), while the smallest number of respondents have

Age of the respondents	18-30 years	138	46.9
	31-40 years	94	32.0
	41-50 years	42	14.3
	years	20	6.8
Level of education	High school	100	34.0
	Bachelor	110	37.4
	Master studies	80	27.2
	Doctoral studies	4	1.4
How long have you been employed?	up to 2 years	24	23.5
	from 2-5 years	39	38.2
	from 5-1 years	21	20.6

completed doctoral studies (1.4%) (Table 1). Respondents are relatively evenly distributed according to the cities included in this research (Table 1). The vast majority of respondents are citizens of their city (62.6%) (Table 1). The cities included in the research are: Novi Sad, Beograd, Čuprija, Zaječar, Čačak, Niš and Prokuplje.

¹ 0 years

18 17.6

		f	%
Gender	Male	132	44.9
	Female	162	55.1
City	Novi Sad	35	7.8
	Čačak	23	21.1
	Beograd	62	15.0

Table 1. Sociodemographic characteristics of respondents

>

	Prokuplje	44	
	Niš	55	18.7
	Zaječar	35	11.9
	Čuprija	42	14.3
Status of respondents in the city	Citizen	184	62.6

Public sector	49	16.7
Private sector	61	20.7

* f- frequency

Based on the results shown in Table 2, it can be concluded that the vast majority of respondents have heard of the term smart cities (77.9%), have heard of smart payment (92.2%) and are concerned about privacy due to the increased use of smart technology (74.5).

Table 2. Familiarity with the terms smart cities and technologies

		f	%
Have you heard of the term smart cities?	Yes	229	77.9
	No	64	21.8
Have you heard about smart payment, smart meters, etc.?	Yes	271	92.2
	No	23	7.8
Do you have privacy concerns due to the increasing use of smart technology?	Yes	219	74.5
	No	75	25.5

Based on the results shown in Table 3, it can be concluded that the degree of agreement of respondents is the highest for the statements that the city has cultural and historical significance ($M=4.35$, $SD=0.61$), the city has good mobile signal coverage ($M=4.29$, $SD=0.56$) and the majority of individual households/buildings have access to the Internet ($M=4.24$, $SD=0.51$), while the lowest degree of agreement for statements that finding a job in the city is easy and the labor market meets the needs of residents ($M=2.04$, $SD=0.97$) and the city uses smart waste disposal in the city ($M=2.52$, $SD=0.97$).

Table 3. The degree of agreement of respondents with the statements related to the environment

	M	SD
The city I live in is well planned and the city management manages it well.	2.65	0.95
There are parts of the city that are not included in the plans.	3.91	0.74

The city is successfully solving all existing problems in the city.	2.55	0.93
Roads are in good condition.	2.92	1.16
Street lighting (LED or other) is modern and functional.	3.47	0.97
Pedestrian crossings are well marked.	3.27	1.11
There is a separate section for pedestrians.	3.35	1.08
The city pays great attention to the maintenance of green areas, as well as their expansion (planting trees etc.).	2.79	1.05
Residents are regularly informed about the plans of the city/ development.	2.66	0.86
The population is high in my city (construction that is concentrated).	3.84	0.97
The city has cultural and historical significance.	4.35	0.61
Most individual households/buildings are equipped with smart remote electricity meters.	3.68	0.90
The electricity supply is stable - without interruptions.	4.00	0.68
Most individual households/buildings have internet access.	4.24	0.51
The city has good mobile signal coverage.	4.29	0.56
The city provides online services through eadministration: identity cards, passports etc.	3.75	1.02
Smart traffic signs have been installed in the city.	3.20	1.20
There are real-time traffic systems in the city.	2.94	1.20
There is good public transportation in the city that works well.	3.46	1.08

The water network works well.	3.47	1.02
The city has provided a smart reading of water consumption.	3.01	0.90
The water distributed from the city's water supply is safe to drink and is constantly monitored.	3.04	1.17
When there is a fault in the water network, there are some smart solutions for quick detection of the fault, which are then quickly repaired.	3.00	0.89
The water goes through new treatment cycles.	3.09	0.82
The city uses smart waste management during disposal.	2.52	0.97
Recycling of various types of waste is supported in the city.	2.93	1.18
The city attaches great importance to raising awareness about air, water and land pollution, as well as prevention.	2.86	1.04
Health services are easily available through eservices.	3.45	0.99
Schools have distance or e-learning options.	3.72	0.79
There are business incubators in the city.	2.99	1.20
There are career development centers in the city.	3.24	1.16
There is a surveillance system in certain places in the city.	3.67	0.91
The city has developed an alarm system in case of natural disasters.	3.54	0.87
Citizens are expected to be involved in the development of the city.	2.80	0.88
Information about the city budget is available and transparent to citizens.	2.55	0.79
I am familiar with the city's plans and strategies regarding the improvement of infrastructure and other important sectors in the city in terms of smart equipment and solutions.	2.61	0.77
The response of the police, firefighters or hospital staff to the call is quick.	3.75	0.78
Finding employment in my city is easy and the labor market meets the needs of the residents. Investing in smart systems and solutions can contribute to economic growth, saving costs and time, improving services and the safety of citizens.	2.04	0.97
Lack of funds, capacity, adequate human resources, infrastructure and accompanying legal legislation can be potential barriers for cities in adopting smart solutions (IoT).	4.16	0.75
	4.16	0.76

*M - mean; SD - standard deviation

The reliability of the smart cities scale was tested using the Cronbach alpha coefficient. Based on the value of the Cronbach alpha coefficient, it can be concluded that the reliability is excellent (Table 4).

Table 4. Reliability scale

	Number of items	Cronbach alpha coefficient
Smart cities	40	0.942

The research examined whether there is a significant difference in the degree of agreement of the respondents with the statements made regarding smart cities in relation to the gender of the respondents. The t test of independent samples was used to examine differences in relation to gender.

Based on the results of the t test shown in Table 5, it can be concluded that there is no significant difference in the degree of agreement for the stated statements in relation to the gender of the respondents.

Table 5. Differences in the degree of agreement for the statements

made in relation to the gender of the respondents

	Middle value	t	p
Male (N=131)	3.35 ± 0.54	-1.022	0.307
Female (N=162)	3.41 ± 0.53		

*N - number of respondents; t test - data sets follow a normal distribution; p - statistical significance at the level of 0.05

The research examined whether there is a difference in the degree of agreement of respondents with the statements made regarding smart cities in relation to the age of the respondents. One-factor analysis of variance (ANOVA) was used to examine differences in relation to age.

Based on the results of the ANOVA test shown in Table 6, it can be concluded that there is a significant difference in the degree of agreement for the statements made in relation to the age of the respondents. The post hoc test found that there is a significant difference between respondents over 50 years old and respondents aged 18 to 30 ($p=0.009$) and respondents aged 31 to 40 ($p=0.025$), where older respondents are significantly less satisfied with the current state of affairs in city.

Table 6. Differences in the degree of agreement for the statements

made in relation to the age of the respondents

	Middle value	F	p
18-30 years (N=138)	3.44 ± 0.48		
31-40 years (N=93)	3.41 ± 0.56	3.841	0.010*
41-50 years (N=42)	3.30 ± 0.63		
51 > years (N=20)	3.04 ± 0.47		

*Statistical significance at the level of 0.05

The research examined whether there is a difference in the degree of agreement of the respondents with the statements made regarding smart cities in relation to the level of education of the respondents. One-factor analysis of variance (ANOVA) was used to examine differences in relation to the level of education.

Based on the results of the ANOVA test shown in Table 7, it can be concluded that there is a significant difference in the degree of agreement for the stated statements in relation to the level of education of the respondents. The post hoc test determined that there is a significant difference between respondents with completed high school and respondents with completed basic studies ($p=0.004$) and respondents with completed master studies ($p<0.0005$), where the more educated respondents are more satisfied with the current situation in the city.

Table 7. Differences in the degree of agreement for the statements made

in relation to the level of education of the respondents

	Middle value	F	p
High school (N=100)	3.18 ± 0.60		
Bachelor (N=110)	3.43 ± 0.42	9.745	<0.0005*
Master studies (N=79)	3.59 ± 0.52		
Doctoral studies (N=4)	3.08 ± 0.57		

*Statistical significance at the level of 0.05

The research examined whether there is a difference in the degree of agreement of respondents with the statements made regarding smart cities in relation to the respondent's city. One-factor analysis of variance (ANOVA) was used to examine differences in relation to the city.

Based on the results of the ANOVA test shown in Table 7, it can be concluded that there is a significant difference in the degree of agreement for the stated statements in relation to the level of education of the respondents. The post hoc test determined that there is a significant difference between respondents from Prokuplje and respondents from Novi Sad ($p<0.0005$), Čačak ($p<0.0005$), Beograd ($p<0.0005$), Niš ($p<0.0005$), Zaječar ($p<0.0005$) and Čuprija ($p<0.0005$), where respondents from Prokuplje are the least satisfied with the current situation in the city. The post hoc test found that there is

a significant difference between respondents from Čuprija and respondents from Novi Sad ($p < 0.0005$), Čačak ($p = 0.001$), Beograd ($p < 0.0005$), Niš ($p < 0.0005$), Zaječar ($p < 0.0005$), where respondents from Čuprija are the least satisfied with the current situation in the city.

Table 8. Differences in the degree of agreement for the statements made in relation to the respondent's city

	Middle value	F	p
Novi Sad (N=33)	3.66 ± 0.32		
Čačak (N=23)	3.49 ± 0.15		
Beograd (N=62)	3.75 ± 0.58		
Prokuplje (N=44)	2.66 ± 0.35		
Niš (N=55)	3.47 ± 0.46	41.658	<0.0005*
Zaječar (N=35)	3.57 ± 0.17		
Čuprija (N=41)	3.05 ± 0.27		

*Statistical significance at the level of 0.05

The research examined whether there is a difference in the degree of agreement of the respondents with the statements made regarding smart cities in relation to the characteristics of the respondents. One-factor analysis of variance (ANOVA) was used to examine the differences in relation to the property.

Based on the results of the ANOVA test shown in Table 9, it can be concluded that there is no significant difference in the degree of agreement for the statements made in relation to the characteristics of the respondents.

Table 9. Differences in the degree of agreement for the statements

made in relation to the characteristics of the respondents

	Middle value	F	p
Citizen (N=183)	3.33 ± 0.52		
Public sector (N=49)	3.50 ± 0.53	2.524	0.082
Private sector (N=61)	3.45 ± 0.59		

*Statistical significance at the level of 0.05

The research investigated whether there is a significant difference in the degree of agreement of

respondents with the statements made regarding smart cities in relation to their knowledge of the concept of smart cities. To examine the differences in relation to the knowledge of the concept of smart cities, the t test of independent samples was applied.

Based on the results of the t test shown in Table 10, it can be concluded that there is a significant difference in the degree of agreement for the stated statements in relation to the knowledge of the concept of smart cities, where respondents who know the concept of smart cities are more satisfied with the current state of the city.

Table 10. Differences in the degree of agreement for the statements

made in relation to the knowledge of the concept of smart cities

	Middle value	t	p
Yes (N=228)	3.51 ± 0.48	8.552	<0.0005*
No (N=64)	2.92 ± 0.47		

*Statistical significance at the level of 0.05

The research investigated whether there is a significant difference in the degree of agreement of respondents with the statements made regarding smart cities in relation to the knowledge of the concept of smart payment. To examine the differences in relation to the knowledge of the concept of smart payment, the t test of independent samples was applied.

Based on the results of the t test shown in Table 11, it can be concluded that there is a significant difference in the degree of agreement for the statements made in relation to the knowledge of the concept of smart payment, where respondents who know the concept of smart payment are more satisfied with the current situation in the city.

Table 11. Differences in the degree of agreement for the statements

made in relation to the knowledge of the concept of smart payment

	Middle value	t	p
Yes (N=270)	3.44 ± 0.51	9.875	<0.0005*
No (N=23)	2.66 ± 0.34		

*Statistical significance at the level of 0.05

The research examined whether there is a significant difference in the degree of agreement of respondents with the statements made regarding smart cities in relation to concerns regarding privacy. An independent samples t test was used to examine differences in privacy concerns.

Based on the results of the t test shown in Table 12, it can be concluded that there is a significant difference in the degree of agreement for the statements made in relation to privacy concerns, where respondents who are not concerned about their privacy due to the increasing use of smart technology have a significantly lower degree of satisfaction the current situation in the city.

Table 12. Differences in the degree of agreement for the statements made in relation to privacy concerns

	Middle value	t	p
Yes (N=218)	3.44 ± 0.53	3.317	0.001*
No (N=75)	3.21 ± 0.51		

In accordance with the literature review and research results in this paper, we can agree with the findings of other conducted research that dealt with the concept of smart cities, that smart cities are the paradigm of the future, with multiple benefits for citizens. [9, 11, 15] However, we can conclude that in the context of the implementation of smart technologies in Republic of Serbia, the implementation was either not carried out in the right way or there is aversion or resistance of citizens towards these technologies. This is especially pronounced in smaller cities than Beograd or Novi Sad. Additional efforts are needed in order to improve the necessary infrastructure for smart technologies, as well as to inform residents about the features of the concept. With proper information, citizens would have reliable information, and the level of concern regarding security and privacy would be reduced. [10] And the author Hussain (2024), agrees and states that in the future it is necessary to strengthen aspects of cyber security related to the concept of smart cities, in order to counter potential cyber threats and violations within the infrastructure of smart cities and IoT networks. In addition, interoperability issues between different IoT devices and systems also pose a significant challenge, requiring standardization efforts and innovative solutions for seamless integration. [5] Syed et. al. (2021), also focus on security and privacy issues of IoT in smart cities, such as encryption, authentication protocols, data anonymization techniques and other methods to prevent unauthorized access to the IoT network and propose a solution in the form of blockchain technology. They also point to the potential of AI. [14] Author Janssen et. al. (2019), claims that security and privacy, business models, data quality, scalability, complexity and governance have strong driving power and also could be key challenges in smart cities. [6] However, economic growth and savings are the most important benefits that motivate smart city activities, and

budget and internal capacity constraints are the most important barriers. [4]

Conclusion

Our presentation of the opinions of respondents from seven cities in Republic of Serbia represents a stable basis for understanding the importance and application of the concept of smart cities in Republic of Serbia, and what could be explored in some subsequent research. The intention was to point out the difference or similarities in the opinions of respondents in rural and urban areas in Republic of Serbia, regarding smart solutions within the concept of smart cities. The main limitation in this research could be related to insufficient familiarity of the respondents (general population in our research) with the concept of smart cities, considering that in Republic of Serbia, a more comprehensive implementation of smart solutions is necessary in order to create smart cities, which already exist in the world, and which would could be explored in future research. Technology is constantly developing, and it is inevitable that city administrations in Republic of Serbia should strive for the most efficient application of smart solutions.

Finally, it is necessary to eliminate the aversion of city dwellers to new technologies, primarily in terms of security and privacy of citizens. The results of our research indicate a tendency to raise environmental awareness among citizens, which is assessed by concern regarding the method of waste removal, but also the water supply system. These are two areas that need to be given more attention in the future, as well as for even development to take place in all cities in Republic of Serbia, with regard to the concept of smart cities, because the concept of smart cities can contribute to fast services and cost reduction in all sectors.

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Project Management in Smart City Development: Challenges and Best Practices

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Abstract: Successful project management represents the basis of effective smart city development, demanding a systematic approach that integrates technology, infrastructure, and urban requirements. However, the proper management of smart city projects encounters different challenges, such as managing budgets, coordinating employees, defining deadlines, and ensuring stakeholder collaboration. Effective project management is essential for overcoming these difficulties and ensuring successful project completion. That is why this study will focus on project management as a means for effective smart city development, and it will also explore challenges and best practices in that context. The goal is to provide a thorough framework for project managers, offering insights into balancing innovation with practical execution in the context of smart city development.

Keywords: Best Practices, Challenges, Development, Project Management, Smart City.

1 INTRODUCTION

With the urban population growing every year and technology rapidly advancing, smart cities have become a strategic solution for communities all over the world to rise to the challenges of urbanization. A smart city optimizes urban infrastructure and operations, uses advanced technology along with unique ideas to enhance urban infrastructure management, manages the operation, offers efficient public services, provides high living standards, and ensures sustainability [1]. However, developing smart cities is a difficult endeavor since it involves a complex set of methods for effectively integrating a diverse range of technological, social, economic, and environmental aspects [2].

Project management plays a pivotal role in the development of smart cities, as these initiatives frequently involve large-scale, multidisciplinary projects that require coordination among a diverse range of stakeholders, including government agencies, private sector partners, technology providers, citizens, [3, 4] etc. Proper management of such projects is necessary to overcome inherent challenges that come with budgetary limitations, regulatory barriers, technological compatibility issues, and continuous innovation demands [5]. Smart city projects are very complex due to their interdisciplinary nature, as they combine urban planning, infrastructure development, data analytics, business intelligence, artificial intelligence, Internet of Things (IoT) systems, environmental considerations, governance, [6, 7] etc. Furthermore, these projects typically span several years

and require long-term strategic planning and foresight. Therefore, project managers need to handle different uncertainties, dynamically changing technologies, and evolving citizen expectations and also balance short-term and long-term goals [8]. With the help of advanced project management tools and the utilization of best practices, complex smart city projects can be facilitated and simplified.

This paper seeks to explore and discuss the key challenges in project management in the development of smart cities, identify best practices, and proffer solutions for such challenges. By reviewing the literature, the goal is to uncover key insights that will help future smart city projects be more effectively planned, executed, and evaluated. In the end, the paper aims to give practical and relevant recommendations that could guide project managers, policymakers, and industry leaders in creating smart cities that would be more efficient, sustainable, and citizen-centered.

The paper is structured in a way that, following the introduction, the next section provides an overview of the key concepts related to smart cities and project management. Section 3 gives examples of successful and failed smart city projects, analyzing the key factors that influenced their outcomes. Section 4 presents challenges in project management for smart city development. To address those challenges, Section 5 offers best practices in project management for smart city development. Section 6 discusses key performance indicators for smart city success, focusing on the metrics that determine the effectiveness and sustainability of smart city initiatives. The final section summarizes the key points of the paper and offers conclusions, along with recommendations for future research.

2 UNDERSTANDING SMART CITY AND PROJECT MANAGEMENT CONCEPTS

1.1 Smart cities

Smart cities can be defined as urban areas that rely on the use of modern technologies in addition to data to enhance the quality of life of their residents, optimize the efficiency of metropolis services, reduce resource usage, and ensure sustainability [9]. Smart cities leverage information and communication technologies to optimize the management of resources, including energy, traffic, and solid waste [10, 11]. Different types of sensors and the IoT are used in smart cities to enable real-time data collection. By analyzing this data, important insights can be gained and

then used to help improve services and infrastructure. The goal is to enhance urban life by making cities more efficient, sustainable, and responsive to citizens' needs. A smart city also seeks to make the world a more sustainable, less polluted place with more advanced systems of public transportation. Additionally, these cities aim to improve safety by using technology like surveillance cameras with facial recognition and data analysis. Smart cities in most cases use renewable energy sources, which aids in conserving the environment [12]. With digital platforms, citizens can access information and services that are easily accessible, which makes the city relatively more inclusive. Smart cities provide numerous services to their citizens, but they suffer from many challenges in privacy protection, data protection, and maintaining equal and fair access to technology for all their citizens. Such smart cities, however, thrive on the proper design and execution that takes into consideration these aforementioned humanitarian challenges in fairness and functionality. There is strong potential for smart cities to increase growth in standards of living while also decreasing our environmental impact [13].

Overall, smart cities represent a vision of the future, where innovation and technology collaborate to develop more sustainable and efficient urban environments.

1.2 Project management

Project management represents the process of applying information, knowledge, abilities, tools, methods, and procedures to project tasks in order to achieve project goals and requirements [14]. Using appropriate software for project management greatly simplifies the process. It centralizes project-related data and communications and increases visibility throughout the project. Some of the most well-known project management tools are Asana, ClickUp, Microsoft Project, Miro, Wrike, [15] etc.

There are five phases of the project management process

[16]:

1. Project initiation,
2. Project planning,
3. Project execution,
4. Project monitoring and control,

5. Project closure.

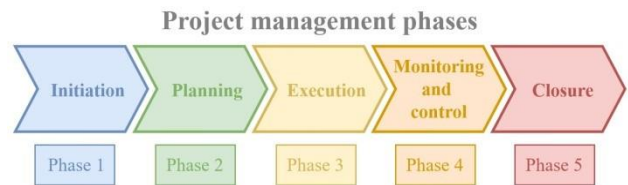


Figure 1 Project management phases

The initiation phase of project management involves transforming ideas into goals and developing a business strategy. This phase entails defining the project (aims, scope, requirements, resources, etc.) and creating a project charter. The planning phase implies developing an outline for completing a project,

which involves creating a thorough project schedule. Proper planning can help to avoid many of the leading causes of project failure, such as a lack of vision, inadequate objectives, incorrect schedule projections, poor resource allocation, etc. The execution phase begins with the implementation of the project plan. In this phase, the project manager coordinates numerous tasks and collaborates with the team to generate and finalize outputs. The project monitoring and controlling phase operates concurrently with the project execution phase. During this phase, the project's progress is monitored and reviewed, quality assurance procedures are established, effort and expenses are tracked, etc. Tracking project performance is essential for ensuring its completion remains within the plan, in the budget, and on schedule. The project closing phase represents the final stage of a project management cycle. This phase entails submitting a final deliverable, creating a project closing report, assessing achievements and failures, etc.

Following the key phases in project management is essential for completing a project successfully, as it helps guide the process and ensures that goals are met effectively.

3 EXAMPLES OF SUCCESSFUL AND FAILED SMART CITY PROJECTS

While smart city projects have immense promise, their realization depends on effective project management and strategic planning. Observing real cases can provide insights into challenges and best practices in managing smart city projects. Comparing successful and unsuccessful projects can identify key factors influencing their success. All this information can help make better decisions and provide higher opportunities for long-term sustainability of smart cities.

One successful example is Barcelona, which has implemented various smart city solutions, such as smart traffic lights, IoT-based waste management, smart parking, an extensive public Wi-Fi network [17], etc. This city has managed to achieve all of this thanks to the integration of advanced technologies into public

transportation and infrastructure, resource management, sustainable planning, risk management, and active citizen engagement. Project managers played a crucial role in ensuring seamless implementation, effective data management, and regulatory compliance.

Conversely, the smart city project of Sidewalk Labs in Toronto represents a notable failure [18]. The project, aiming to create a high-tech urban center, was faced with gigantic challenges related to privacy concerns, financial sustainability, stakeholder conflicts, and regulatory issues. The deficit of transparency and loss of public trust finally led to the project cancellation in 2020. The necessity for effective governance mechanisms, public involvement, and adherence to privacy legislation can be best understood through this example of a smart city project.

These comparisons demonstrate how integrating technology innovation with transparency, regulation, and community involvement is essential to the success of smart city initiatives. A well-defined strategy and strong governance are essential to guide the project toward its goals. Without clear planning and active community engagement, a project can face significant obstacles that may prevent it from reaching its full potential.

4 CHALLENGES IN PROJECT MANAGEMENT FOR SMART CITY DEVELOPMENT

Smart city development projects are inherently complex since they combine innovative technology, urban planning, and a wide range of stakeholders. Effective project management is essential for overcoming the many challenges that emerge during the preparation, execution, and upkeep stages.

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The most important challenges in project management for smart city development are [19, 20]:

- Coordination of various stakeholders,
- Funding and budgetary control,
- Advance technology integration, • Data privacy and security, • Risk management.

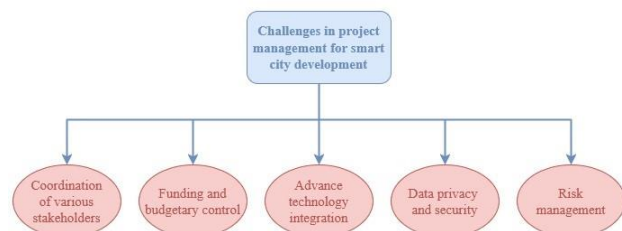


Figure 2 Challenges in project management for smart city development

Projects related to smart cities involve many different stakeholders, ranging from government agencies and private sector businesses to technology corporations and residents. Ensuring effective coordination among all of these stakeholders with varying objectives and priorities can be very difficult and demanding. These projects frequently demand substantial funding, and obtaining reliable financing can be challenging. Furthermore, variable pricing and technology advancements might result in unexpected charges, thereby endangering budgets and deadlines. The

smart city relies mainly on different sophisticated technologies, integrating IoT, artificial intelligence, big data, automated processes [21], etc. Ensuring all these technologies work together and flawlessly is a difficult job that requires serious planning and organization. Considering the amount of data generated in smart cities, providing privacy and data security represents important challenges that are not easy to address. Regulations such as the General Data Protection Regulation (GDPR) in the European Union and the California Consumer Privacy Act (CCPA) in the United States set strict guidelines for data collection, storage, and user consent [22]. Collection and processing of data in the context of smart city initiatives often raise ethical concerns, requiring thorough examination of various issues related to mass surveillance and misuse of personal information, as well as potential biases in Aldriven decision-making. Project managers must therefore not only apply privacy-by-design guidelines and carry out ethical effect analyses but also involve stakeholders in data governance discussions. Public confidence is also provided through transparency in data collection and utilization policies. Because smart city projects pose significant technological and operational hazards, appropriate risk management solutions are required [23]. This involves predicting difficulties such as system breakdowns, bugs, cyberattacks, or unanticipated consequences for municipal people.

To solve these problems, effective project management is crucial as it assures smooth coordination, efficient resource allocation, and the capacity to adapt to emerging technologies and

stakeholder demands throughout the development process [24].

5 BEST PRACTICES IN PROJECT MANAGEMENT FOR SMART CITY DEVELOPMENT

To efficiently manage smart city projects, a proactive strategy that prioritizes cooperation, sustainability, and flexibility is necessary. Throughout the development process, best practices in project management assist in minimizing risks, optimizing resources, and guaranteeing that social, technological, and environmental objectives are achieved.

Best practices in project management for smart city development include [25, 26]:

- Involvement and collaboration of stakeholders,
- Adoption of the agile project management approach,
- Implementation of data-driven decision-making,
- Integration of sustainability planning,
- Promotion of transparent communication,
- Application of risk management and contingency planning,

- Leveraging technology for project monitoring and tracking.



Figure 3 Best practices in project management for smart city development

To guarantee a shared vision and goals that are in line throughout the project, it is crucial that all pertinent stakeholders be included from the outset [27]. Potential conflicts are reduced, and varied viewpoints are taken into account with the support of regular communication and active engagement from residents, IT businesses, community organizations, private sector partners, and government institutions. This collaborative approach fosters a sense of ownership and support, which is critical to the long-term sustainability of the project. Additionally, using an agile project management approach can offer greater flexibility to adapt to the changing demands and difficulties that arise during smart city development [28]. Project managers may guarantee that new problems are promptly resolved and that the project stays on track by segmenting the project into smaller, more manageable phases with regular conduct of reviews and modifications. Given the rapid pace of technological advancement, this iterative method guarantees ongoing adaptation and development [29]. Smart city projects produce massive volumes of data and store them in databases via a database management system [30]; therefore, effectively utilizing this data is critical to making informed decisions. Using analytics, project managers may analyze progress, detect obstacles and delays, and predict risks in real-time. Data-driven techniques can allow for better resource optimization, process improvement, and the efficient and effective achievement of project objectives [31, 32]. Furthermore, long-term sustainability must be a top priority in the design and

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implementation of smart city projects. This includes not just integrating green technologies and infrastructure but also ensuring that the municipality's systems are adaptable to future problems like climate change and population increase. Sustainability and resilience are inextricably linked since developing systems that are both ecologically responsible and flexible to future needs will help future-proof the project and lower long-term operational expenses [33]. Also, establishing confidence among stakeholders and the general public requires open, honest, and transparent communication. Keeping everyone updated on the objectives, status, difficulties, and results of the project

ensures alignment among all parties and minimizes opposition or misconceptions. Gaining public support and guaranteeing the project's success requires frequent updates, public discussions, and an open decision-making process that fosters an impression of accountability and inclusiveness [34]. It is important to mention that there are hazards associated with any project, particularly those involving large-scale smart city initiatives. Early risk identification and thorough contingency planning can minimize adverse effects on the project's scope, funds, and timeline [35]. Proactive risk management, with the help of sophisticated project management tools, comprises regularly assessing risks, having backup plans, and adjusting techniques to avoid disruptions from unexpected occurrences. Sophisticated technology and project management software are essential in an attempt to coordinate and track the progress of smart city projects [36, 37]. The use of various technologies and their associated features enables project managers to examine schedules, expenditures, and milestones in real time and make informed decisions earlier. Teams may increase productivity, lower human error, and guarantee that the project doesn't experience major setbacks by employing project management software and other technology [38]. Also, the integration of digital twins and AI-based planning enhances project monitoring and decision-making by creating virtual models that simulate real-world urban environments [39]. These technologies allow project managers to predict potential challenges, optimize infrastructure planning, and improve resource allocation, ensuring more efficient and data-driven smart city development.

Project managers can apply these best practices to facilitate the successful, sustainable, and efficient development of smart cities. Through this, they will be in a position to create sustainable city solutions that yield long-term returns. Their efforts remain at the forefront of shaping future cities, designing smart, connected, and adaptive urban environments.

6 KEY PERFORMANCE INDICATORS FOR SMART CITY SUCCESS

For the effective measurement of the impact of smart city projects, project managers must set clear-cut Key Performance Indicators (KPIs) that incorporate

economic, social, and environmental outcomes. Long-term sustainability and success of smart city projects are attributed to ongoing monitoring and updating of strategy from collected data.

Some essential KPIs include [40]:

- Energy efficiency,
- Public engagement,
- Cost savings,
- Traffic management,
- Environmental impact.

Energy efficiency refers to the reduction in electricity consumption and the integration of renewable energy sources. Public engagement measures the level of citizen participation in digital platforms and urban decision-making. Cost savings reflect the reduction in operational costs due to smart infrastructure. Traffic management monitors public transport efficiency gains and congestion decreases. Environmental impact deals with the lowering of carbon emissions and improvement of air quality.

By tracking these metrics, project managers can assess

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whether smart city initiatives are achieving their intended goals and make necessary adjustments to optimize performance [41].

7 CONCLUSION

The development of smart cities is a complex and demanding process that comes with many challenges, such as integrating innovative technologies, guaranteeing data security and privacy, coordinating effectively across different groups of stakeholders, etc. However, these challenges are not insurmountable, as shown in the research conducted in this paper. Project managers can, therefore, navigate such complexity by embracing best practices of continuous stakeholder involvement, engaging and adapting to agile methodology while keeping flexibility in the scheme, and utilizing data analytics to make the right strategic decisions. Sustainability and resilience must be maintained during the project planning and completion stages to ensure long-term success. This makes the role of project management even more crucial for the completion of a smart city to successfully bring benefits both to the environment and to the community over a long period. To ensure sustainable and inclusive growth as cities evolve, the adoption of a strategic and adaptive approach to project management is essential in determining the future of urban development.

Future studies could investigate the use of novel methods combined with modern tools and technologies in project management for smart city development, with an emphasis on their influence on efficiency and sustainability. Additionally, future research could explore the impact of stakeholder collaboration and governance frameworks in overcoming challenges encountered during smart city initiatives.

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UDK:711.45:004.78 502.171(292.464)



Alfa BK Univerzitet

DOI:
10.46793/ALFATECHproc25.048T
Original scientific paper

IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN SMART WATER PROJECTS IN THE BALKANS

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Abstract: Smart cities represent a key concept in modern urban planning, where smart water resource management plays a central role. This paper analyzes current Smart Water projects in Serbia, Bosnia and Herzegovina, Croatia, and Montenegro, with a special focus on the implementation of artificial intelligence (AI) and machine learning (ML). The emphasis is placed on practical examples such as water consumption prediction, leakage detection, and water quality monitoring. Through an analysis of projects like the Green AI initiative, the SMART-Water system, and innovations by the Kolektor Sisteh company, the paper examines the technologies and algorithms utilized. The main findings demonstrate the significant efficiency of AI/ML models in improving the sustainability of water resources and optimizing costs. However, challenges such as technical implementation and the lack of local expertise remain open issues. In conclusion, the paper provides a comprehensive overview of the current state and proposes future steps toward advancing AI/ML technologies within Smart Water projects in the Balkans.

Keywords: Smart Water, Artificial Intelligence (AI), Machine Learning (ML), Water Management, Sustainability, Balkans;

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INTRODUCTION

"Smart Cities" is a novel concept of innovative city development: the application of new technologies linked with the Internet of Things, Artificial Intelligence, and Machine Learning for the more effective functioning of the city in all aspects of life for the purpose of enhancing the standard of life of its citizens. Successful natural resources management is one of the most significant tasks in smart water resources management, which is extremely relevant in the Balkans, with scarce resources and infrastructure that remains quite challenging, as Batty et al. point out.

Balkan-related concerns are pertaining to the availability and quality of water sources that have caused losses in the water supply systems due to pollution and lack of monitoring. The start of the current decade has unveiled that the application and implementation of AI and ML technologies hold the promise of better management of such issues by using automation and predictive models derived from big data analytics.

In this article, an effort will be made to give a general overview of practical application of AI and ML technologies in smart water systems in Croatia, Bosnia, and Serbia. First projects, which give an overview of the case and benefits, are SMART-Water from Croatia (Institute Ruđer Bošković—

technologies, loss detection, water quality monitoring, and water consumption prediction applications are addressed.

The emphasis shall be their technical implementation, what algorithms have been utilized in these projects, and the advantages and challenges of performing the research and implementation. The conclusion shall give recommendations on how to improve the existing initiatives and suggestions for future research in this path.

2 OVERVIEW OF SMART WATER PROJECTS IN THE BALKANS

Smart water systems in the Balkans represent a crucial area for improving water resource management. Through the application of Artificial Intelligence (AI) and Machine Learning (ML), these projects offer innovative solutions to challenges such as water leakage detection, quality monitoring, and consumption prediction. Below is an overview of some of the most significant projects in the region.

Green AI Initiative (Serbia)

Led by the Serbian Institute for Artificial Intelligence, the Green AI project focuses on utilizing advanced AI techniques to preserve natural resources, including water. The project employs deep learning to analyze real-time data from sensor networks, enabling timely

detection of anomalies in water supply systems (Serbian Institute for Artificial Intelligence [SIAI], 2023). A key aspect of this initiative is water loss detection within networks using predictive algorithms based on historical data. These models help local utilities reduce operational costs and

improve system efficiency. Furthermore, ML is applied to analyze water quality in urban areas, contributing to enhanced pollution control.

SMART-Water Project (Croatia)

The SMART-Water project, managed by the Ruđer Bošković Institute, is a multisensor system designed for monitoring the quality of standing inland waters (Ruđer Bošković Institute [IRB], 2023). By combining IoT technologies, AI algorithms, and ML models, the system enables:

- Continuous monitoring of oxygen levels, pH, and water temperature.
- Automated generation of reports based on data analysis.

ML models are trained to identify patterns indicating potential contamination. This project is particularly significant for protected areas in Croatia, such as Plitvice Lakes, where ecosystem preservation is of utmost importance (Pavlič et al., 2018).

Kolektor Sisteh (Slovenia and the Region) Although Kolektor Sisteh is primarily based in Slovenia, its AI technologies have been successfully implemented in Serbia, Bosnia and Herzegovina, and Montenegro (Kolektor Sisteh, 2023). Their AI tools focus on water loss detection using advanced algorithms to analyze pressure and flow within networks. A notable example is the use of neural networks for micro-leak detection, which facilitates early problem identification and reduces the risk of significant failures. These systems are particularly beneficial in older urban areas with aging infrastructure.

Water quality Monitoring in Bosnia and Herzegovina In collaboration with universities in Sarajevo and Banja Luka, pilot projects have been developed to monitor water quality in the Bosna and Vrbas rivers. ML algorithms analyze pollution data and identify key causes. These projects include sensorbased data collection and pollutant classification using advanced algorithms (European Environment Agency [EEA], 2021).

Smart infrastructure in Montenegro

In Montenegro, the implementation of smart water systems is part of regional initiatives focusing on loss detection and consumption prediction. A notable project in Podgorica utilizes regression models to analyze seasonal consumption patterns and plan infrastructure maintenance (Pavlič et al., 2018).

These projects demonstrate significant progress in leveraging AI and ML technologies to enhance water infrastructure in the Balkans. Key outcomes include reduced water losses, improved quality analysis, and increased system efficiency. However, challenges

such as insufficient local expertise and high implementation costs remain obstacles that need to be addressed in the coming years.

3 TECHNOLOGICAL ASPECTS OF AI AND ML IMPLEMENTATION IN SMART WATER PROJECTS

The application of Artificial Intelligence (AI) and Machine Learning (ML) in Smart Water projects relies on advanced algorithms, sensor infrastructure, and modern data processing methods. In the Balkans, where water resources are under pressure due to climate change and outdated infrastructure, these technologies offer efficient solutions for optimizing management and preventing problems.

Water leakage is one of the major issues in Balkan water supply networks, where AI models can help in early detection and loss reduction (Romano & Kapelan, 2014).

- Artificial Neural Networks (ANNs) – Used for time-series analysis of pressure and water flow data (Nguyen et al., 2018). Kolektor Sisteh employs ANN models to predict unexpected pressure fluctuations and detect leaks with an accuracy of over 90%.
- Support Vector Machines (SVMs) – This algorithm is used for classifying anomalies in water flow based on historical data (Chen et al., 2020). It has been implemented in the Green AI project.
- Autoregressive Integrated Moving Average (ARIMA) – This model is used for forecasting expected flow values and detecting deviations in systems such as SMART-Water (ElShafie & Noureldin, 2011).

These models allow for leak detection before they become critical failures, thereby reducing operational costs and water losses.

Water quality is crucial for public health, and AI models enable automated sensor data analysis and pollution detection (Chen et al., 2020).

- Regression Models (Linear and Logistic Regression) – Used for predicting pH levels, dissolved oxygen, and nitrate concentrations in water. SMART-Water utilizes regression models for analyzing seasonal changes in water quality (Nguyen et al., 2018).
- Convolutional Neural Networks (CNNs) – These networks analyze satellite and drone images to identify polluted zones in rivers and lakes (Romano & Kapelan, 2014). Implemented in the Green AI initiative.
- K-means Clustering – Used in pilot projects in Bosnia and Herzegovina to classify pollution levels in river basins. This algorithm enables grouping water samples based on pollution severity (Lemberger & Goldsmith, 2021).

These models enable rapid identification of environmental incidents, reducing analysis costs and improving pollution response times.

AI algorithms enable smart distribution planning and minimization of losses in the network.

- Reinforcement Learning (Deep Q-Networks, Qlearning) – Used for adaptive real-time water distribution optimization (Nguyen et al., 2018). Green AI employs these models for dynamic supply management.

- Random Forest and XGBoost Ensemble Models –

These algorithms predict seasonal consumption fluctuations and optimize reservoir capacities (El-Shafie & Noureldin, 2011).

Used in projects in Montenegro.

- Hidden Markov Models (HMMs) – This model enables analyzing unpredictable consumption changes, preventing network overloads (Chen et al., 2020). Implemented in Kolektor Sisteh technology.

These models help in more precise resource planning, reducing the risk of shortages and minimizing losses.

The implementation of the Internet of Things (IoT) is crucial for collecting data required to train AI and ML models. IoT-connected sensors capture:

- Real-time pressure and flow data.
- Water quality parameters (temperature, pH, nitrate concentration).
- Environmental factors (e.g., rainfall and air temperature).

These data are processed in the cloud using ML algorithms, enabling real-time decision-making. For instance, the SMARTWater project uses IoT networks for monitoring water quality in

Croatia (Ruđer Bošković Institute [IRB], 2023).

Integrating AI and ML technologies into existing, often outdated, infrastructures in the Balkans requires specific adaptations:

- Analytical software platforms:
Tools such as TensorFlow and Scikit-learn enable customization of algorithms to local conditions.

- Hybrid models: Combine traditional methods and modern ML solutions to gradually improve system performance.

- Predictive maintenance: AI tools help identify potential failures before they occur, reducing repair costs and operational disruptions.

Although the use of artificial intelligence (AI) and machine learning (ML) offers significant improvements in water resource management efficiency, their implementation in smart water systems faces numerous challenges. The key barriers include financial constraints, lack of local expertise, technical obstacles, and regulatory hurdles. These factors can significantly slow down the adoption of AI/ML technologies in the water management sector across Balkan countries.

One of the main challenges in implementing AI/ML technologies in smart water systems is the high initial cost of acquiring sensor infrastructure, computing resources, and software solutions (Nguyen et al., 2018). In Balkan countries, where local water utility budgets often depend on public funding, investments in IoT and AI systems are limited (Lemberger & Goldsmith, 2021).

Example: In Serbia and Bosnia and Herzegovina, many municipalities use outdated water supply networks that require complete modernization before AI tools can be effectively applied. This further increases the overall costs (European Environment Agency, 2021). Possible Solutions:

- Utilizing EU funds (Horizon Europe, Green Deal) to finance AI pilot projects.
- Public-private investments in water infrastructure.
- Phased implementation through gradual AI system integration into existing networks.

The implementation of AI requires a high level of technical knowledge, particularly in data analysis, machine learning, and IoT integration (Romano & Kapelan, 2014). In the Balkans, there is a limited number of AI specialists focused on water resource management, which slows down the development and application of these technologies (El-Shafie & Noureldin, 2011). Example: In Croatia and Montenegro, water system operators often hire external consultants for AI projects, which increases costs and reduces the long-term sustainability of solutions. Possible Solutions:

- Collaboration between universities and industry on AI research and training programs.
- Development of specialized courses on AI applications in ecology and water management.
- Organizing AI workshops for engineers and policymakers in the public sector.

Most water supply networks in Balkan countries were designed decades ago and are not compatible with modern IoT sensors and AI systems (Chen et al.,

2020). Additionally, unstable internet networks in rural areas can significantly limit the operation of smart sensors and AI analytics (Nguyen et al., 2018).

Example: In Montenegro and Bosnia and Herzegovina, old water pipelines do not support automatic data reading, meaning that full AI implementation would require expensive network reconstruction.

Possible Solutions:

- Development of hybrid systems that combine traditional methods with AI analytics.
- Use of Edge AI solutions, enabling local data processing without requiring a constant internet connection.
- Gradual integration of LoRaWAN and NB-IoT networks for better data transmission.

The legal framework for digitalization and AI adoption in water management is not clearly defined in most Balkan countries (Lemberger & Goldsmith, 2021). Regulations on ownership and data protection from IoT sensors are often unclear, which can hinder information sharing between the public and private sectors.

Example: In Serbia and Croatia, legal issues surrounding water consumption data sharing may limit the operation of AI systems that rely on open data.

Possible Solutions:

- Introducing clear legal frameworks for digitalization and AI data sharing.
- Development of national AI strategies for water resource management.
- Standardization of data formats to enable interoperability between different AI systems.

While AI/ML technologies offer significant advancements in smart water systems, overcoming financial, technical, and regulatory barriers is crucial for their successful implementation. Through strategic investments, specialized training, and policy reforms, Balkan countries can accelerate the adoption of AI-driven water management solutions.

4 DISCUSSION

The implementation of Artificial Intelligence (AI) and Machine Learning (ML) in water resource management in the Balkans shows significant potential but also faces a number of challenges. Below is an overview of key results and limitations based on existing projects and research.

Smart water systems in the Balkans have already achieved notable results, particularly in leak detection, water consumption prediction, and quality monitoring:

- Reduction of water losses: Projects such as Kolektor Sisteh in Serbia and Bosnia and Herzegovina have successfully reduced water supply losses by up to 30% through the use of neural networks and classification algorithms (Kolektor Sisteh, 2023). This reduction has significant economic and environmental benefits, especially in regions with limited water resources.
- Improvement of water quality: The SMART-Water project in Croatia has enabled the automatic detection of pollutants and the prediction of ecosystem changes, ensuring the protection of sensitive areas such as Plitvice Lakes (Ruđer Bošković Institute [IRB], 2023).
- Optimization of operations: AI tools used in the Green AI initiative in Serbia have allowed utility companies to optimize water distribution and maintenance, resulting in reduced operational costs.

Despite positive results, several challenges hinder the broader implementation of AI and ML technologies in water resource management:

- Financial constraints: Installing IoT sensors and training AI/ML models requires significant investment, often exceeding the budgets of local municipalities (EEA, 2021).
- Lack of local expertise: The shortage of AI specialists in the region slows down the development and integration of advanced systems (Pavlič et al., 2018).
- Outdated infrastructure: Many water networks in the Balkans are decades old, making it difficult to install modern IoT systems. Additionally, the lack of stable internet connections in rural areas further complicates implementation.
- Lack of regulations and strategies: Clearly defined policies and strategies for integrating smart technologies into water resource management are still underdeveloped, complicating long-term planning.

Comparison with global standards

When comparing smart water systems in the Balkans with similar projects in developed countries, several similarities and differences can be identified:

- Similarities: ○ The same AI/ML algorithms are used, such as SVM, ANNs, and regression

models. ○ The focus on leak detection and **5 CONCLUSION**

water quality monitoring aligns with global trends.

- Differences: ○ Scope of

Implementation: In developed countries,

integrated national systems are common, while in the Balkans, projects are mainly limited to pilot initiatives and local implementations.

- Investments: Investments in smart water

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technologies in the Balkans significantly lag behind developed markets, where funding is more readily available through publicprivate partnerships and EU grants.

Opportunities for the future

Despite the challenges, the Balkans hold significant potential for the further development of Smart Water technologies:

- Access to EU funds: A well-defined strategic approach would allow countries in the region to attract funding for improving infrastructure and technology.
- Development of local expertise: Collaboration between universities and industries, as seen in CEFAH and Green AI initiatives, could foster education and research in this field.
- Improved regulatory framework: Clearly defined standards and policies would accelerate the integration of AI/ML technologies.
- Regional collaboration: Knowledge and resource sharing among Balkan countries could significantly reduce costs and improve implementation efficiency.

Although the challenges are significant, the results of implementing AI and ML technologies in water resource management in the Balkans highlight the enormous potential for improving efficiency and sustainability. By combining modern technologies, regional cooperation, and strategic investments, the Balkans can position themselves as leaders in the application of smart water systems in this part of Europe.

Smart water systems are a key component of sustainable resource management, especially in regions with infrastructural challenges such as the Balkans. This paper analyzed the application of artificial intelligence (AI) and machine learning (ML) in smart water management projects in Serbia, Bosnia and Herzegovina, Croatia, and Montenegro.

The analysis demonstrated that AI/ML algorithms, including artificial neural networks (ANNs), support vector machines (SVMs), convolutional neural networks (CNNs), and ensemble models like XGBoost, can significantly enhance leak detection, consumption optimization, and

water quality control (Nguyen et al., 2018). Established systems, such as the Green AI initiative in Serbia and the SMART-Water project in Croatia, have shown that AI can reduce operational costs and improve water network efficiency (Romano & Kapelan, 2014).

However, despite technological advancements, the implementation of AI in smart water systems faces numerous challenges. The key issues include high initial costs, a lack of AI experts in the water sector, outdated infrastructure, and an inadequate legal framework (Lemberger & Goldsmith, 2021).

Without addressing these barriers, the broader adoption of AI in the water sector remains limited (Chen et al., 2020).

To enable further integration of AI into water resource management, it is essential to develop strategic guidelines focusing on sensor network improvements, workforce education, and data regulation.

Based on the identified challenges and emerging trends in AI/ML applications in water management, we propose the following research and development directions:

- Future studies should explore how hybrid AI models (a combination of traditional statistical methods and neural networks) can improve failure prediction in aging water networks (El-Shafie & Nouredin, 2011).
- Implementing Edge AI solutions, where data analysis is performed directly on sensors instead of in a cloud environment, could significantly reduce costs and accelerate anomaly detection (Nguyen et al., 2018).
- Development of LoRaWAN and NB-IoT sensors for improved data collection in rural areas, where stable internet connectivity is often unavailable (Chen et al., 2020).
- Integration of multi-sensor systems that combine physicalchemical water parameter analysis with

external data, such as weather conditions and industrial emissions (SMART-Water, 2023).

- Developing specialized university programs to train AI experts in ecology and water resource management (Romano & Kapelan, 2014). As previously researched (Tepić, 2023), education and the inclusion of young people in the development processes of smart technologies are crucial for their successful implementation. Investing in specialized AI training programs and engaging young experts in water management innovations will accelerate the adoption of smart solutions and enhance long-term sustainability.
- Establishing pilot projects in cooperation with local water utility companies to test AI models in real-world conditions before widespread implementation (Nguyen et al., 2018).

Artificial intelligence and machine learning offer significant opportunities for optimizing water resource management, reducing operational costs, and increasing environmental sustainability. However, for AI to be fully integrated into water management, it is crucial to address technical, economic, and regulatory challenges.

This paper makes a significant contribution to understanding the application of artificial intelligence in water resource management and can serve as a foundation for further research and real-world implementations.

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UDK:004.8:351.817
711.45:004.78

DOI:
10.46793/ALFATECHproc25.05
4L Original scientific paper

Cybersecurity aspects of critical infrastructure in scenario of smart city

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Abstract: People organize their lives and work in a space for which it is important to have adequate infrastructure. Critical infrastructure is the most important part of the infrastructure that has a great impact on the security of the state, its economy and society as a whole. These are interconnected systems, which are part of a larger system, where their functioning relies heavily on the ability of another subsystem to provide the necessary service. The cyber security of such systems is particularly important because such vulnerabilities are singled out and can cause a chain effect that extends from the subsystem to the state. With the development of sensor technologies, the Internet of Things, cloud computing, big data, and artificial intelligence, a range of solutions can benefit business operations. Critical infrastructure companies are not immune to global changes, embodied in the vision of smart cities, which should bring improvement to humanity. On the other hand, introducing "things" into critical infrastructure opens up a whole set of problems that were previously unknown. This paper deals with those aspects.

Keywords: cybersecurity, critical infrastructure, smart city

1 Introduction

From the earliest days, man has adapted the environment to himself with the aim of using natural potentials and resources. In this way, society is created, and the existence of man and community is tied to a certain space. From the spatial aspect, infrastructure implies different spatial, technical and traffic systems as the basis for the functioning of all users of the space and the development of all basic activities in it (Žegarac, 1998, p. 12). In geospace, two groups of networks of infrastructure systems are dominant: social and technical infrastructures (Đurđević, 2009, p. 11). Social infrastructure consists of standard facilities in the domain of: health, education, social care, culture, administration, etc. Technical and economic infrastructure consists of networks and facilities: traffic, water management, energy, communications, etc. Each infrastructural branch, or subsystem, with its facilities, network and devices, on the one hand, and organization and functioning, on the other hand, is part of a wider infrastructure system. These are systems of clear and clean connections, where all sub-systems are visible, down to the end elements and pronounced vertical connections (Lukić, 2005, p. 5). It is a complex system composed of a large number of other subsystems, which are systems in themselves. That is why it acts as a system of systems, where the business processes of one system rely on the services that the other system offers by executing its business processes. In this context, the role of cooperation between systems is very important, and this includes those services that a subsystem requires from others and those services that one subsystem offers to other subsystems.

Problems in such complex systems can cause negative effects in the economic, social and security fields. Therefore, the previously mentioned connection

between them can be a vulnerability that various individuals and specialized groups are ready to exploit and thereby implement their intentions. It is common for each country to provide its own observation and definition of critical infrastructure. Thus, NIST defines US critical infrastructure as system and assets, whether physical or virtual, so vital to the U.S. that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters (NIST, 2022). Therefore, critical infrastructure is the most important part of a state's infrastructure, which the state must build, maintain and provide with special care because its failure to function creates a whole set of problems and far-reaching consequences.

Global trends affect the drop in sensor prices and the appearance of a large number of cheap electronic devices, sensors, and microchips that can be installed in some infrastructure elements and provide data on the observed phenomenon. These devices, popularly called "things", use the largest global network - the Internet, to be able to exchange data on the phenomena they observe, and in some cases even act on these phenomena as actuators. They are installed in objects of critical infrastructure and in this way enable the solution of problems that existed in these complex systems, which could not

be solved until that moment with ICT solutions available at that time.

Since the Internet is unsafe, the "things" themselves are under the attack of many malicious users and specialized organizations who want to act on critical infrastructure and therefore on the country whose infrastructure it is. Since smart cities rely on the operation of "things" to make city services more efficient, they are under constant threat from such attacks.

The first chapter is introductory. In the following segment, we will discuss the concept of critical infrastructure. The third part is about smart cities. In the following section, we describe the critical infrastructure elements that are part of smart cities. The fifth unit covers cyber security aspects of critical infrastructure where we cover practical cases. After that comes the conclusion.

2 Critical Infrastructure

Critical infrastructure is the most important part of the total infrastructure and as such requires special attention, relationship and management, because if it is temporarily or permanently damaged, it can produce unfathomable consequences for the state, its security, economy and society as a whole. It is a system of systems, where each subsystem is a whole by itself, but at the same time is a part of the overall system. In this way, a large number of interconnections are realized in one system of systems. Some authors highlight interoperability as a very important characteristic of these large systems (Vesić & Bjelajac, 2023). A connection is established between subsystems by one subsystem requesting certain services from another subsystem, and at the same time the second subsystem provides the requested services to the first. Considering the critical infrastructure as a system of systems and looking at it as a model of interconnected components that are part of a larger whole, allows us to analyze which are the most important services within the critical infrastructure.

As an example, we can look at a scenario where the sewage system uses electricity to transport sewage waste from citizens to treatment plants. Due to the fact that the sewage system, which is a subsystem of critical infrastructure, uses pumping stations in which pumps work, by interrupting the flow of electricity provided by the electrical subsystem, sewage waste cannot be transported to the treatment plant. This can further cause many problems in the health subsystem, as the failure of the sewage subsystem can lead to large scale diseases and epidemics. This further puts pressure on the economic system of a country, which must ensure adequate quality of health services, especially in a

situation where it is necessary to preserve a healthy population as long as possible, due to reduced or even negative natural growth, such as in Serbia.

Due to its importance, and the need for a comprehensive approach, it is common for a country to define its critical infrastructure. Therefore, the mentioned term is not easy to define and for now there is no universal generally accepted definition (Trbojević, 2018, p. 3). Some countries, such as the United Kingdom, define critical national infrastructure as "facilities, systems, sites, information, people, networks and processes, necessary for a country to function and upon which daily life depends. It also includes some functions, sites and organisations which are not critical to the maintenance of essential services, but which need protection due to the potential danger to the public (civil nuclear and chemical sites for example)". In the Republic of Serbia, critical infrastructure is defined by law and consists of those systems, networks, facilities or their parts, the interruption of functioning or the interruption of the delivery of goods or services can have serious consequences on national security, health and lives of people, property, the environment, and the safety of citizens, economic stability, i.e. endanger the functioning of the Republic of Serbia ("Zakon o kritičnoj infrastrukturi," 2018). At the same time, states regulate the criteria by which critical infrastructure is identified ("Uredba o kriterijumima za identifikaciju kritične infrastrukture i načinu izveštavanja o kritičnoj infrastrukturi Republike Srbije," 2022). All of this speaks in favour of the fact that countries treat critical infrastructure with great care.

According to the authors, critical infrastructure has two important aspects (Milosavljević & Vučinić, 2021, pp. 43–44):

- dependency between subsystems - where one subsystem is critical for another if it is necessary for the other to continue working
- critical information infrastructure is a part of critical infrastructure - where, if there is an interruption in the functioning of critical information infrastructure, serious disruptions can occur, even a disaster of critical infrastructure, but the failure of critical infrastructure can also occur for other reasons, while the failure of critical information infrastructure is most often a product cyber attacks (García Zaballos & Jeun, 2016, p. 3)

Bearing in mind that an increasing number of critical infrastructure systems in the modern world rely on the use of information and communication technologies, there is a need to consider them as an inseparable part of critical infrastructure. The authors of this paper also have the above-mentioned point of view.

3 Smart Cities

The concept of a smart city does not have a unique name (Cocchia, 2014) or definition (Hollands, 2008) because it has changed over time and has been studied from several aspects and dimensions (Albino et al.,

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2015), and most generally it refers to a vision in which the city engages its inhabitants and connects the infrastructure electronically (Musa, 2016). It is also described as having the ability to integrate many different technological solutions and manage a wide variety of city assets, which include: local government information systems, schools, libraries, transportation systems, hospitals, power plants, law enforcement and other services in that community. The primary goal of building smart cities is to improve the quality of life of its citizens by using technology that increases the efficiency of services and meets their needs (Musa, 2016). Therefore, the concept of a smart city is inseparable from infrastructure, because they aim to improve the quality of life of its citizens, through effective and efficient infrastructure management.

Achieving the vision of a smart city presupposes the use of the Internet of Things, abbreviated IoT, which is also called the Internet of intelligent devices and represents a radical evolution of the current Internet into a network of interconnected objects that not only retrieve information from the environment but also interact with the physical world through actuation, but use existing Internet standards to provide services for information transfer, analytics, applications and communications (Gubbi et al., 2013). Therefore, smart cities represent one of the main realizations of the Internet of Things technology and that is why their importance is great.

Some authors (Atzori et al., 2010) point out that the basic idea of IoT is the comprehensive presence of various "things" or objects, which includes: RFID tags, sensors, actuators, mobile phones, etc., while others (Borgia, 2014) add virtual/digital entities, which move in time and space, while some (Simić et al., 2016) group everything into intelligent devices: sensors, actuators, microcontrollers and microcomputers. What distinguishes "things" is that they can interact with other "things" and act synergistically to achieve a common goal. The technological and marketing trends that are driving the development of IoT are (Rose et al., 2015):

- ubiquitous connectivity
- widespread adoption of IP-based networking
- computational economics
- miniaturization

- advances in data analytics
- the rise of cloud computing

IoT devices need to send data via the Internet to a server that would process them or, as is more common today, to the cloud. According to NIST: "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared

pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models." (Mell & Grance, 2011). From an economic point of view, cloud computing is often described as turning capital costs into running costs, while some authors believe that the phrase "Pay as You Go" is more appropriate (Armbrust et al., 2010). Cloud computing provides enough resources needed to accept and process the potentially large amount of data that "things" can generate in a relatively short period of time and create analysis and conclusions based on that data with machine learning and artificial intelligence algorithms.

Big data is a term that encompasses the use of techniques for accepting, processing, analyzing and visual presentation of potentially large data sets in a reasonable time frame that is not available with standard IT technologies (NESSI, 2012). Although there is still a vagueness surrounding the concept of big data, these technologies are quite often described in terms of their aspects, which are popularly called V's. Some of them are (Papadokostaki et al., 2017):

- volume - refers to the constant growth of the volume of data generated from different sources and which traditional databases cannot process
- variety - refers to various data collected through sensors, smartphones and social networks
- velocity - it refers to the speed of data acquisition and additionally to the speed with which the data needs to be processed and analyzed
- value - refers to extracting knowledge or patterns from raw data
- veracity - refers to possible unreliability and noise that may be hidden in the data

These three technologies: IoT, cloud computing and big data work together to enable intelligent processing based on certain smart algorithms. On the basis of intelligent processing, it is possible to perform certain business operations that were not possible until that moment using traditional information and communication technologies. In this way, it is possible

to support new or improved business models. One important segment is how to integrate this set of technologies with the existing traditional ones, which is supported through the hybrid cloud scenario.

4 Smart Cities and Elements of Critical Infrastructure

In practice, it is increasingly common that certain business scenarios regarding critical infrastructure rely on intelligent solutions from the domain of smart cities. These solutions aim to provide efficient management of critical infrastructure, because most often traditional technologies cannot do it or cannot do it cost-effectively, i.e. there is no economic justification. In the example of city water supply systems, SCADA systems are used in the processes of water intake, then later distribution of potable water to consumers. Considering that these traditional systems use expensive sensors, which in some configurations have to be powered by electricity, it is not economically profitable to use them in anomaly detection, because they need to be installed in large numbers.

We mentioned earlier that critical infrastructure systems are interconnected and that elements of one system can use the services of another system. In this way, they depend on the services provided by some other system. One example can be a remote water reading system. IoT modules are installed on devices for reading water consumption, where the data is transferred to the cloud infrastructure in a certain time interval, stored in the database, and later integrated with the traditional information system that deals with the collection of bills for water used. In this context, IoT modules take over the functionality of water meter readings, which reduces the need to engage people who until now performed the mentioned processes manually, most often with the use of PDA devices. In this way, all reading errors that occur as a result of manual data entry are eliminated. After the data is downloaded from the IoT module and ends up in the smart solution database, it can later be transferred to the inhouse application or ERP that deals with water invoicing, and in this way through integration, the realization of an important business process of the water company is realized. If, for any reason, the described system fails, then the waterworks will be left without the possibility to generate income based on the water delivered to consumers, which will create a disruption in its operations and thereby endanger all those who use its services, citizens, the economy and the entire state.

As another example, let's assume that there is a smart solution that monitors the amount of atmospheric precipitation, and depending on that amount of

precipitation and the speed with which the sewage drains are filled, flooding of traffic roads may occur. A smart solution based on sensors and the amount of water that exists in the sewer drains is needed to start the business process of notifying the reliable that it is necessary to empty the sewer drains according to a certain priority. When major weather disasters occur, it is an extensive job that needs to be done in a relatively short period of time. If such a smart system fails, then another element of the critical infrastructure is threatened, i.e. its functionality is reduced. In this particular case, traffic roads are less passable and their safety for citizens, emergency services, etc. is reduced.

In the research in Dublin, an intelligent solution was presented that uses several data sources on which it performs analysis: a crowdsensing approach in the analysis of data from social networks, data from the SCATS system and GPS data from city buses (Panagiotou et al., 2016). Based on different algorithms that are applied in real time on a large amount of data, anomaly detection is carried out on traffic roads, where it is possible to build a recommendation system based on the mentioned analysis, where there is a crowd and recommend another route from destination to destination. If emergency services, such as ambulances, firefighters and police, rely on such a system, if it stops working, then serious problems can arise with major consequences for citizens and society as a whole.

Based on the presented scenarios from practice, it can be concluded that intelligent systems implemented in smart cities somehow inherit the characteristics of critical infrastructure systems, because they are used in their business processes. If such intelligent systems stop working or their efficiency is reduced, they threaten the operation of other subsystems of the critical infrastructure, regardless of whether they are intelligent or not. Therefore, it is necessary to work on their resilience or provide a backup alternative that can partially or fully take over the function of the required service. That is why the question of the security of such systems is very important, from the level of the individual to the community and all the way to the state.

5 Cybersecurity of Critical Infrastructure Elements in Smart Cities

IoT smart solutions bring efficiency to a company's business processes and the same goes for critical infrastructure. By presenting "things" on the one hand, opportunities for new and better business models open up. On the other hand, a whole new set of problems emerges as IoT devices use the Internet, which is insecure. Therefore, the topic of cybersecurity of IoT

devices is very important, especially in the protection of critical infrastructure.

Malicious users exploit vulnerabilities in known communication protocols and the devices that use them and have the ability to conduct attacks that can disable or greatly render inaccurate numerous devices that are embedded in critical infrastructure. The consequences for infrastructure and people, the long time required for system recovery and the large scale of damage that can be caused by cyber attacks on critical infrastructure are of concern to countries and organizations that manage them. The history of cyber attacks is characterized by financial losses, the ability to damage physical equipment and the potential to cause human casualties (Alladi et al., 2020, p. 1). Below we will describe some examples of cyberattacks on critical infrastructure from practice that involve the use of IoT technologies in smart city scenarios.

In the Netherlands, a group of ethical hackers discovered 6 key zero-day vulnerabilities in Enphase IQ Gateway home solar energy conversion devices (*DIVD-2024-00011 - Six vulnerabilities in Enphase IQ Gateway*

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devices, 2024; Candan, 2024). The vulnerabilities exist from version 4 to version 8. These vulnerabilities allow hackers to gain complete access and control over a device if the devices connect to the public Internet. The problem is very serious because it is estimated that over 4 million such systems exist in 150 countries and they can be controlled. If the attack is successful, huge losses of electricity and money can occur and therefore pose a significant threat to national security.

In the smart city of Olsztyn, Poland, a cyber attack took place on June 24 and 25, 2023, in which the smart systems that regulated traffic were disabled (Rieß-Marchive, 2023). The attack had its effect on Sprint SA's intelligent transportation system, which adjusts various parameters so that traffic in the city can adapt to changes dynamically and that public transport vehicles have priority. This system includes many elements, such as a traffic management, center traffic intersection monitoring with violation detection, Wi-Fi access points in trams and a weather information system. The attack covered the city center with 96 intersections, including traffic lights whose work was disrupted, as well as other elements of the traffic system. The consequences of the attack are multiple, from traffic jams and congestion on the roads, through the unavailability of ticketing systems in public transport to other dedicated information systems at the service of citizens..

It has been noted that smart homes are a good target for potential attacks and exploitation of their vulnerabilities, as they are constantly connected to the Internet (Das & Gündüz, 2019, p. 125). A DDOS attack can turn off heating and hot water in smart buildings by

overloading the building's main control system with traffic.

These are just a few examples of cyberattacks on critical infrastructure elements in smart city scenarios. In practice, there are many more of them and their form changes, as malicious users constantly try to find new ways to implement their intentions. There are a large number of vulnerabilities that IoT "things" bring when they are placed in critical infrastructure, and therefore it is necessary to adequately protect these devices. As the exploitation of vulnerabilities by malicious users is constantly changing, it is necessary to improve protection measures or find adequate alternatives in response to threats coming from the cyber world.

6 Conclusion

Critical infrastructure is the most important part of the total infrastructure. It is characterized by the interconnectedness of systems and is usually defined at the level of one country. At the same time, it refers to

the intensive use of information and communication technologies. Smart cities are a vision of a modern society where intensive data exchange and human interaction with technology are realized in order to improve the quality of life. In such an environment, the role of "things" is very significant and they form an important part of the infrastructure elements. Given that "things" use the public Internet, the potential threats coming from the cyber world are very large with numerous related problems if the vulnerabilities of these systems are exploited. Since critical infrastructure subsystems rely on each other, well-designed cyber attacks can disable not only the targeted critical infrastructure subsystem but also those that rely on its services. This can produce cascading effects in which the security of the state is significantly threatened.

On the other hand, critical infrastructure systems largely use operational technology in their operations and at the same time have their own information technologies. Every day, these two technologies are increasingly integrated with each other, and in this way, the surface on which it is possible to carry out a cyber attack is becoming larger and more heterogeneous. As an increasing number of IoT devices are embedded in critical infrastructure, comprehensive measures need to be implemented to protect it in the long term, and where this is not possible, wellthought-out recovery scenarios.

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Global location coding (Universal Geographical Indicator System)

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Abstract: In today's globalised society, where more and more of the goods and services are being routed automatically, there is a growing necessity to use a global location coding system. The longitude and the latitude are global indicators of dimensionless points on the sphere, but, in reality, most locations of practical interest could be considered as areas covering a definite surface. It may be argued that a point within that surface may be used as a location indicator, but this indicator is not unique. The other issue with the geographical coordinates is that to the coordinate of any particular point of interest a tolerance interval need be included. Thus, location indication through area codes is natural and more useful. In this work, the authors propose a global system for indicating geographic areas through limited sequences of decimal digits. Each such sequence of a certain length indicate in a unique manner a definite geographic area. Sequences of increasing lengths indicate the smaller areas, i.e. with a narrower tolerance. This method for location coding is achieved by dividing recursively the surface of the Earth in sections, and then recursively into smaller and smaller subsections, with each new division encoded by a single digit. E.g. a twelve digit sequence indicates an area of about 50 m in diameter. Using such global coding system for geographic locations may substantially simplify the delivery of goods and services, direct and focus a remedial effort in emergencies, or be used advantageously for planning and improvement of city management.

Keywords: location coding, geographic information system, smart city area numbers, smart city, mail delivery routing, goods and services delivery, land monitoring

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1 INTRODUCTION

1.1 Geographical coordinate system

In the globalised world of today, it may be of some profit to be able to determine the location of an object in an unambiguous manner. In addition, it would be convenient if this unambiguous determining expression for the location of an object be universally understandable and easy to interpret.

The universal rational interpretation of the planet Earth is spherical, thus, it is the spherical coordinate system that is most naturally being used to denote location on it. For this, two angles are used, the longitude, λ_{LON} , which determines the coordinates in East - West direction, and the latitude, λ_{LAT} , which determines the coordinates in North - South direction. Whilst this is indeed the most natural interpretation of coordinates on a sphere, there are several issues with

Contact information:

how these coordinates are used. Firstly, these coordinates, as they are currently used, are expressed in angular degrees, minutes, and seconds, with one angular degree having 60 angular minutes, and one angular minute having 60 angular seconds. That is, the hexagesimal number system is being used for expressing fractions of one angular degree, which may be quite inconvenient for performing computations with angles. More recently, the angles λ_{LON} and λ_{LAT} are being expressed in angular degrees written as decimal fractional numbers, which somewhat resolves this issue. Secondly, the angles λ_{LON} and λ_{LAT} can have positive and negative values :

$$-180^{\text{mm}} < \lambda_{\text{LON}} < +180^{\text{mm}} , \quad -90^{\text{mm}} < \lambda_{\text{LAT}} < +90^{\text{mm}}$$

Here, again, the need to pay attention to the mathematical signs of the coordinate numbers is mathematically perfectly correct, but may present difficulties to general public with little inclination towards numerical notations. In addition to this, the longitude and the latitude angles are expressed in angular degrees, which is a widely accepted unit of measurement, but it is not an SI standard unit for angles. On the other hand, expressing the angles in radians, which is an SI unit, is an option, but its use would involve computations using π , which is a transcendental number. The use of radians would probably introduce more problems into expressing geographical coordinates than it would solve.

1.2 Geographical locators not based on coordinates

An important problem with mathematically based coordinate systems for geographical locations is that the coordinate systems determine a point, which is a dimensionless object. In reality, a location is always indicating the position of an object, occupying a non-zero area on the ground, and subsequently, on the map. That means, that geographic coordinates ought be expressed as pairs of intervals, and not merely pairs of numbers. This, of course, may be achieved by adjoining tolerance values to conventional geographic coordinates. This, however, induces more of the problems of the same nature as those mentioned before.

As an early attempt to circumvent some of the problems with geographic coordinates in practical everyday situations, postal codes have been invented. Postal codes have been used to denote geographical locations or routes without using mathematical notation. Usually, postal codes are short strings of numbers or combined numbers and letters. They indicate geographic areas, such as towns or city suburbs, sometimes

streets, sometimes post-office facilities, and sometimes mail delivery paths. Some postal codes are even allocated to vehicles, vessels, or to mobile entities, e.g. to military or rescue units. Some jurisdictions use no postal codes, and amongst those that do use them, there is a great variety of forms and usages. In addition, postal codes are allocated nearly exclusively to inhabited places. There have been attempts to employ complex alphanumeric strings to indicate intended locations with great precision. These systems usually require access to a data-base mapping the strings into locations and vice versa. In today's interconnected world, a round-the-clock access to such a data-base is possible, but the throughput capacity of the communication interface can almost certainly be a serious limiting factor. Finally, postal codes are nearly universally decreed by legislative or executive powers that be. Nearly universally, because, nowadays a large part of mail and parcel delivery, especially those destined for rapid delivery, is effectuated by private courier enterprises. Thus, sometimes, private, proprietary delivery codes are being used, which are not widely known or described to the wide public. Taking all this into account, postal codes cannot be seen as global nor universal locators, firstly due to the variety of forms and usages, and also due to the limits of their application.

Thus, at this moment, there is no system for global determination of geographic locations that could be accepted and used by everyone. In this interconnected global world, in which most banal activities rely on information and communication technologies, in a world that purports to be "smart", there is a great need for a universal, accurate, yet simple system for coding geographic locations.

2 UNIVERSAL LOCATION INDICATORS

2.1 Maidenhead square system and USNG

A very worthy idea for resolving the issues mentioned above is to use so called locator grids. The world is thus divided into rectangular areas, where each area is coded by an alphanumeric string.

Maidenhead square system has been derived from an older grid locator system, the QRA. It has been intended for denoting locations of radio transmitters for VHF communication, and has been and still is in use, mainly by amateur radio operators. This grid locator system divides the world into a grid of 18 by 18 fields, each of which is divided into 10 by 10 squares, with each square further being divided into 24 by 24 sub-squares. Thus, the coding string for the Maidenhead squares is composed from 2 latin letters, from A to R, then 2 digits, from 0 to 9, then another 2 latin letters, from A to X. An example of the Maidenhead code (MHC) for the premises of Alfa University has been presented here, together with its geographic coordinates :

$$\lambda\lambda_{\text{LON}}(\text{ALFA}) = +20^{\text{mm}}24'54'' = +20.415^{\text{mm}}$$

$$\lambda\lambda_{\text{LAT}}(\text{ALFA}) = +44^{\text{mm}}18'40'' = +44.311^{\text{mm}}$$

$$\text{MHC}(\text{ALFA}) = \text{KN04ET}$$

The Maidenhead square system in its original form has limited precision, but an extension has been proposed. Thus, the sub-squares may be divided even more, with each division adding two more digits, and then two more letters to the locator code, and so interleaved on. All in all, there is a lot of merit in the Maidenhead square grid locator system.

Another well developed grid location system is the American grid locator system, the USNG (United States National Grid). On the top level, it is very similar to the Maidenhead squares, but it differs significantly as to the subdivisions of the top level grid fields. USNG system is intended for civilian use, whereas the American military uses an almost identical system, the MGRS (Military Grid Reference System). Both of these American grid encoding systems divide the world map into 60 by 22 squares, with polar areas subdivided separately. These top level squares are then being recursively subdivided into smaller squares up to final resolution of about 1 m. The location is encoded by an ASCII alphanumeric string, i.e. by Latin letters and digits, whose length depends on the required precision. The maximum precision is thus encoded by a string of 15 characters. There are, in fact, two slightly different versions of codes, NAD 83 and NAD 27. This is due to the different reference points used for determining exact geographic coordinates. Thus, the USNG code for the Alfa University is (in both versions) :

$$(\text{NAD } 83) \text{ 34TDQ5334306594}$$

$$(\text{NAD } 27) \text{ 34TDQ5334206378}$$

The resolution of these codes is about 1 m. Shorter codes, comprising nine characters, locate the University premises within a square the length of a side is about 100 m : 34TDQ5334. Here the locator code is the same for both reference points.

Both the Maidenhead squares and USNG are global in extend, and can indicate the location of any object or region on the globe. Similar grid coordinate systems exist, and nearly every country has defined one, for military, surveying, or other purposes. Still, they are mostly mutually incompatible, and cannot be used globally.

2.2 Universal geographical indicator system

In this work, the authors propose a new, universal geographical, truly global, indicator system for a grid based geographic coordinates. It has been inspired mainly by the Maidenhead squares, but there are significant differences.

In this Universal Geographical Indicator system, the locations are coded as strings comprising only digits from 1 to 9. Thus the reading of the code is not

so much culturally biased as is the case for the previous two systems, which use also Latin letters.

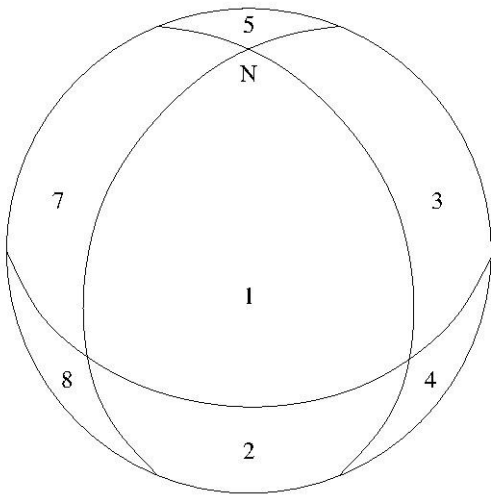


Figure 1 The numbering of the globe octants

This new geographic locator system has been conceived to be extremely simple to interpret and to use.

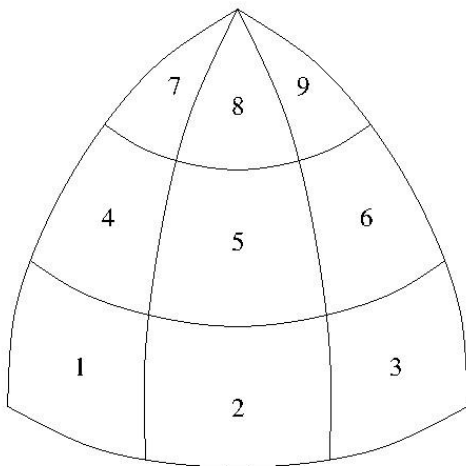


Figure 2 The numbering of sub-divisions of one octant

The globe has been divided into eight octants, encoded by digits from 1 to 8 (Figure 1). This is the first symbol of the proposed geographic locator code. On a world map (in cylindrical projection) the octants appear as squares or rectangles (Figure 7).

Table 1 The limiting square dimensions at number of locator code digits

Number of Angular North - East - West East - West code digits size South length at length at				
	[mm]	length	$\lambda\lambda_{LAT} = 0^{mm}$	$\lambda\lambda_{LAT} = \pm 60^{mm}$
1	90	10010 km	10010 km	5005 km
2	30	3337 km	3337 km	1668 km
3	10	1112 km	1112 km	556 km
4	3.33333	371 km	371 km	185 km

5	1.11111	123 km	123 km	65 km
6	0.37037	41.2 km	41.2 km	20.6 km
7	0.12346	13.7 km	13.7 km	6.76 km
8	0.041152	4.57 km	4.57 km	2.29 km
9	0.013717	1.53 km	1.53 km	763 m
10	0.004573	508 m	508 m	254 m
11	0.001524	169 m	169 m	84.8 m
12	0.00051	56.5 m	56.5 m	28.3 m
13	0.00017	18.8 m	18.8 m	9.42 m
14	0.000056	6.28 m	6.28 m	3.14 m
15	0.000019	2.09 m	2.09 m	1.05 m

Each octant has been further divided into nine fields of equal angular dimensions i.e. 30^{mm} (Figure 2). These nine fields are being coded by digits from 1 to 9. This is the second symbol in the proposed locator code. Again, on a map in cylindrical projection, the fields obtained by sub-division may be seen as squares (Figure 8).

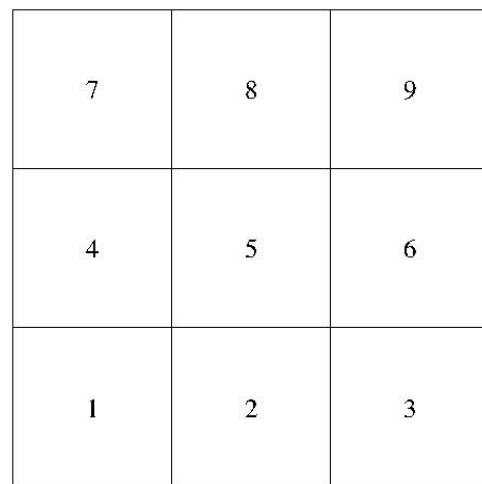


Figure 3 The numbering of sub-divisions of one locator square

Of course, on each level of sub-divisions the actual form of the locator square is not a true planar square but rather a trapeze on the surface on a sphere (Figure 5). As the recursive sub-divisions progress, the curvature of the sphere is of diminishing importance, and the form of the locator area approaches a planar square, or a rectangle. The dimensions, both angular and linear, of a sub-division square are presented in Table 1. It should be noted that, as a consequence of the sphere geometry, whilst the angular dimension of a locator square is the same for both dimensions on one level, the longitudinal linear dimension becomes shorter as the position of the square becomes closer to the poles.

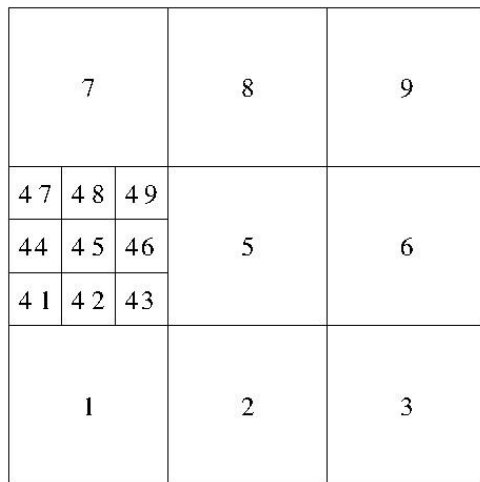


Figure 4 An example of numbering of two levels of sub-divisions of a locator square

Each such locator "square" is being divided into nine divisions of equal angular size. The nine sub-divisions are, again, denoted by digits from 1 to 9 (Figure 3). This is the third digit in the locator code. These sub-divisions are continued recursively, until the size of the locator square of a required size has been reached. The same pattern of allocating digits to subsquares is applied on each level sub-divisions (Figure 4).

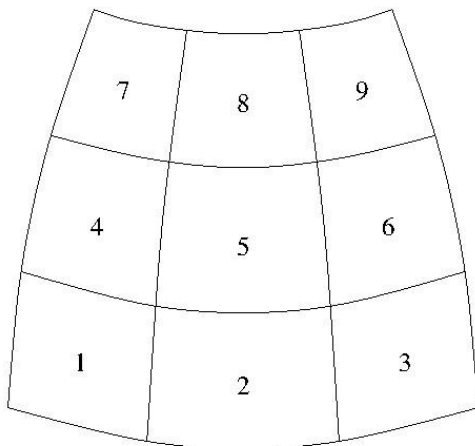


Figure 5 The numbering of a primary, curvilinear, locator square

Another particular issue of the geometry of the divisions is that the locator "squares" that are nearest to the poles in reality of triangular shape, even if approximately flat (Figure 6). Still, the same scheme for allocating digits to sub-divisions remains in use.

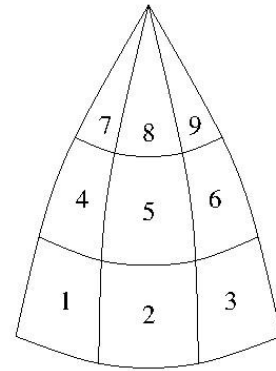


Figure 6 The numbering of a locator triangle, with its apex at the geographic pole

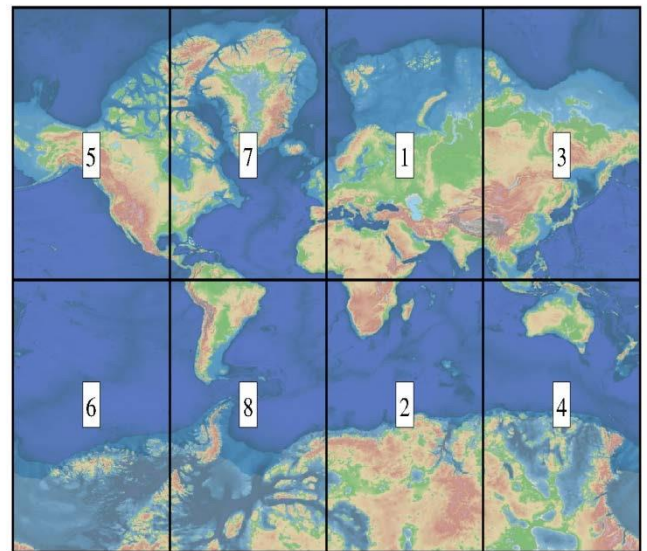


Figure 7 The world map divided into octants

In summary, advantages and disadvantages of the Universal Global Locator Indicator system have been listed:

There are several significant advantages :

The Universal Global Locator Indicator covers the whole surface of the earth.

The location is encoded using only digits from 1 to 8 at the first place, and then digits from 1 to 9.

The production and the interpretation of the code is simple and straight forward, and does not require complicated computations nor extensive use of data bases.

It is adaptable, whereby longer codes are used for greater precision of location determination.

The code may be adapted for other purposes, e.g. digit 9 at the first place may be used to indicate locations mobile units.

The length of location codes may be significantly shortened if used regionally, for which purpose the prefix digits may be completely omitted.

There are, however, some disadvantages:

The tolerances of location indication is non uniform, the East - West tolerances are reduced for locations closer to the poles.

There may be some difficulties of interpreting locations of objects which straddle the grid lines.

However, these and other disadvantages may be overcome with some modifications. In particular, digit 0 is so far unused, and some interpretations of the location codes may be made different for codes containing digit 0.



Figure 8 The numbering of the first and second level subdivisions of the first octant shown on the world map

3 UNIVERSAL GEOGRAPHICAL LOCATION INDICATOR FOR ALFA UNIVERSITY PREMISES

In this section, the Universal Geographical Location Indicator code has been derived for the Alfa University premises. The global location indicator code has been determined to the length of 12 digits. The code is

$$UGI(ALFA) = 146-445-124-168$$

The maximal width of the containing square i.e. rectangle determined by this code is about 56 m. This length is in the direction North - South, whereas the length in direction East - West is about 39 m. The reasons for this have been explained in the previous section. That means, that the maximal tolerance of location is about 28 meters, which is deemed to be sufficient for the establishing a correct location of a building of this size.

Table 2 Twelve digit numerical global location code for Alfa University premises

Digit	Numerical code	Location tolerance
1	1	5005 km
2	4	1668 km
3	6	556 km

4	4	185 km
5	4	62 km
6	5	20.6 km
7	1	6.7 km
8	2	2.3 km
9	4	763 m
10	1	254 m
11	6	84.8 m
12	8	28.3 m

The digits of the Universal Geographical Indicator code with the maximal tolerances of location of the corresponding code length are presented in Table 2.

In the rest of this section, several images have been presented, which show the location of the Alfa University on the world map, and the extent of the encompassing rectangles containing this location.

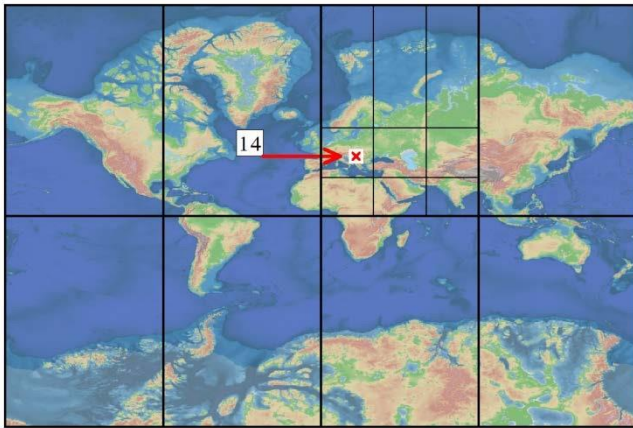


Figure 9 Determination of the locator of ALFA University, digits 1



and 2 **Figure 10** Determination of the locator of ALFA University,

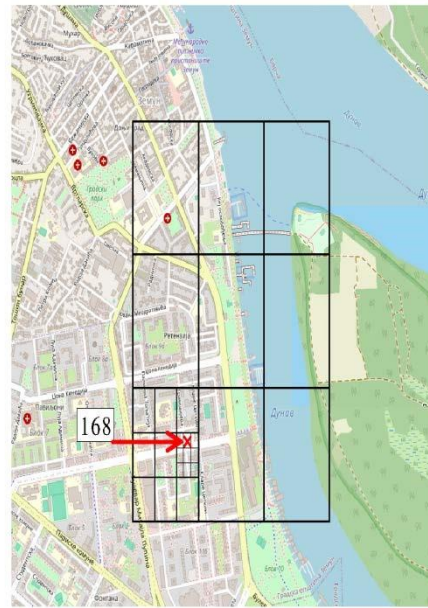


Figure 11 Determination of the locator of ALFA University, digits 10, 11, 12

4 CONCLUSIONS

In this work, a new version of a grid-based system of geographic coordinates has been presented. The principal idea is that the top level division of the surface of the globe is in 8 octants, and all subsequent sub-divisions are performed uniformly and recursively. The indicator code comprises only digits, the first digit being one from 1 to 8, and all subsequent digits being from 1 to 9. The system has some significant advantages over some similar existing grid coordinate systems. The Universal Geographical Location Indicator is truly global, it covers the surface of the whole earth. The length of the universal global indicator code depends on the required tolerance of location determination, and is freely adaptable according to the required precision. Also, the code is purely numerical, and as such it may be considered to be appropriate and understandable globally. The spectrum of uses of this geographic locator codes is wide, from their being used as postal codes, over the use in emergency and rescue operations, to surveillance of territories and water bodies. It is unambiguous, universal, simple to interpret, and as such may be integrated into various information technology systems pertaining to smart cities, and to smart land and water management.

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Robotization and artificial intelligence in the function of Industry 4.0

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Abstract: This research paper will present how advances in robotics and artificial intelligence affect economic and social transformation. Based on the review of the latest literature and research conducted in practice, the relationship between artificial intelligence (AI) and robots will be evolved due to rapid technological development and the increasing application of methods, techniques and tools of artificial intelligence in various spheres of life and work. Starting with a clear definition and tracing the evolution of artificial intelligence in robotics, the paper will highlight its role, importance and application in various fields. Studies show that artificial intelligence and robotics offer great opportunities for improving life and work, improving efficiency and precision, reducing costs, errors, etc. In this context, this research study presents a critical assessment of the application of the phenomenon of artificial intelligence and robots, based on successive studies of relevant literature, evaluating artificial intelligence and robots, their development, characteristic forms and application in everyday life. Due to their capabilities, robots with elements of artificial intelligence have successfully replaced humans in performing many difficult and physically demanding and dangerous jobs, as well as in mentally simple and repetitive activities, which certainly justifies their humane application. Practice indicates that the process of implementing artificial intelligence and robots requires an adequate ICT infrastructure, followed by specialized training of key users, as well as compliance with all ethical rules of use. Research results indicate that robotics and artificial intelligence have become key players in the transformation of the world, opening the door to new ways of working and optimizing existing business processes. In this sense, the application of artificial intelligence and robots opens the door to new technological innovations and potential opportunities for the improvement of the product and service sectors. Considering the topicality of the topic, there are still insufficient studies dealing with the application of artificial intelligence (AI) in robotics by researching the integration, progress and implications of intelligent robotic systems based on artificial intelligence. Practice shows that in addition to all the benefits, one should be extremely careful and not ignore the criticism of experts in this field about the exponential development of robotics and artificial intelligence and the present fear that robots will one day become a threat to human society.

Keywords: Digitization, Industry 4.0, Robots, Artificial Intelligence.

1 INTRODUCTION (Introductory remarks)

It is known that artificial intelligence (AI) and robotics are digital technologies that will have an increasingly significant impact on the development of humanity in the near future. Many experts emphasize that one of the main drivers of humanity's progress is industry 4.0, and robotics based on artificial intelligence is the main driver of the current industrial revolution (Denić N 2024). The results of research in practice indicate that robots have become an irreplaceable factor in modern industrial production, and that many countries have based their economic progress on their development and application. The situation is similar in our environment, where the continuation of digitization and the development of robotics and artificial intelligence are among the five priority goals in the Republic of Serbia (Stojanović J.. 2024). Some authors emphasize that artificial intelligence is the ability of a computer or a computer-controlled robot to perform tasks that are usually associated with intelligent beings, i.e. artificial intelligence is defined as the use of computers and related equipment to control a machine in the way humans would (Richards & Smart , 2013). Many countries in their programs list the development of

artificial intelligence and robotics as one of the priorities in the development of modern technologies (Stojanović K 2024). The literature states that a robot is essentially a actuator with two or more programmable axes and some degree of autonomy that can move in its environment to perform predetermined tasks. The branch of technology that deals with the design, construction, operation, and application of robots, as well as computer systems for their control, processing of sensory feedback, and general information processing is called robotics. In this regard, many countries apply, develop and implement artificial intelligence in robotics, which will contribute to economic growth, employment and a better quality of life for all citizens. It is known that the basics of artificial intelligence are machine learning, deep learning and neural networks, which lay the foundation for understanding how artificial intelligence improves robotic capabilities by integrating sensors and advanced algorithms for decision-making needs. In this context, fundamental questions are raised about what we should do with these new sophisticated technologies, what specifically the robotic systems based on artificial intelligence should do, what risks they involve and how we can control them. Another aspect that we find in the review of literature and research in practice indicates that investments in the application of AI in robotics significantly increase the

consumption of renewable energy. Research also indicates that the use of industrial robots has a detrimental effect on the consumption of electricity obtained from renewable sources. Below are some of the different types of robots powered by artificial intelligence, such as industrial robots, service robots, autonomous vehicles, and drones, to showcase the versatility of the technology. Also, in such studies, one must talk about challenges and ethical considerations, that is, critical analysis, dealing with bias, and concern for the fairness and safety of the use of AI and robots.

2 DEVELOPMENT OF ROBOTS AND CHARACTERISTICS OF ROBOTS

The relevant literature states that robotics includes the design, construction and programming of physical robots, with the partial participation of artificial intelligence. Robotics and AI can therefore be seen as covering two overlapping sets of systems: AI-only systems, robotics-only systems, and systems that are both. It is of interest to the research to take into account all three factors, in this sense, not only the intersection is important for consideration, but also the union of both of these sets, which is presented in the following figure 1. (Balajee, 2020).

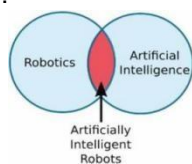


Figure 1 Venn diagram of robotics and AI (Izvor Darapuredu... 2021)

It is known that robotics entered the big door when the industrial revolution brought many significant changes for people, considering that with its appearance, the efficiency and effectiveness of production increases significantly. In this context in industry, in robotics, one part of artificial intelligence is used to automate processes that are physically demanding and repetitive, where practice shows that machines can do it with greater precision and give better results. Studies show that artificial intelligence is created when a human is replaced by a system in the performance of complex tasks, which will continue to work and communicate with others, without anyone noticing that the human has been replaced by a robot. Based on the literature and experience in practice, it is concluded that in addition to the application of robots in industry today, they are applied in all areas of human activity, based on the principle that the simpler the task, the faster we will train the robot to perform it. They help man to build faster, when putting out fires or transporting the wounded in war. The development of artificial intelligence and its integration into robot control systems expands our possibilities of their application, including areas where robots have not been applied so far. Based on the above facts, it is necessary for states to take these statements into account and invite

investors to invest in the development of artificial intelligence models and robots in order to reduce their negative impact on the environment and sustainable development.

2.1 Robot evolution

In the literature, it is stated that the word robot comes from the Slavic word "robota", which means work, worker. The term robotics appears for the first time in the short science fiction story "The Liar" by Isaac Asimov. In this context, it is said that the word robot was first used by the Czech writer Karel Čapek in the play R.U.R. – Rossum's Universal Robots in 1920, in the context of the characters in the play who were mass-produced workers, incapable of creative thinking (Daley, 2022). The action of this drama begins in a factory that produces artificial humans - robots, similar to today's idea of androids. Some authors point out that in the end, whatever they look like, all robots have three key elements that define them (Zuhlke, 2022): sensors, control systems and a program. From an evolutionary point of view, robots have become smaller and more useful over time, so that today they are almost irreplaceable in many areas and critical situations in business and industry. According to the mentioned author, we can say that the robot performs certain tasks autonomously (Zuhlke, 2022). Authors like Sam Daley (2022) emphasize that, despite the extraordinary expansion and development of robotics, robots still have some general universal characteristics in common, namely that they are all more or less composed of some mechanical parts. The facts show that it was the industrial revolution and the invention of electricity that enabled the use of more complex mechanical parts and thus significantly accelerated the development of robotics as a science. Some authors emphasize that it is very important to emphasize that from the very beginning of designing robots, their creators face the challenge of how the robots should behave. In this sense, solutions should be provided to the questions of how to train robots to perform complex tasks, and at the same time enable intelligent interaction with the environment in which they function. Wellknown authors state that in this regard there are two most commonly used strategies with completely opposite approaches (Bakker & Kuniyoshi, 1996):

1. Program the robot down to the smallest detail so that it knows what to do.

2. Provide the robot with a simple learning strategy and allow it to find on its own through interactions how it should react to the environment.

Chronologically observed in the literature, the first invention or innovation that had and still has a great influence on the development of robots is attributed to Leonardo da Vinci. Leonardo's mechanical knight is the first documented humanoid automaton, designed by him in 1495. In this regard, the sketches found in Leonardo's notebook are extremely significant, together with the sketches of mechanical birds and insects that the author designed in an attempt to imitate nature. As usual, this invention did not go beyond the

sketches, however, later others realized his designs to prove that the design really works. It was this famous scientist and versatile artist who in 1478 invented the first powered cart, shown in the following picture 2. (Tech Target Contributor, 2021).



Figure 2Leonard's stroller

Reviewing the available literature, it is not entirely clear whether Leonardo managed to complete his robot-knight project, but recent reconstructions have shown that the robot was completed and functional according to the blueprint. Regarding the laws of robotics themselves, the following three laws of robotics are generally used (Kaminka, Spokoini, Amir, & Agmon, 2017):

1. The first law of robotics: A robot must not injure a human being or, through its inactivity, allow a human being to be injured.

2. The Second Law of Robotics: A robot must obey the orders of human beings, unless those orders conflict with the First Law.

3. The Third Law of Robotics: A robot must protect its own existence, unless it conflicts with the First and Second Laws

It is known that the first industrial robot in the world is Unimate, which was installed on the assembly line in the General Motors factory in 1961. In our country, Professor Rajko Tomović developed the first prosthetic hand with five fingers in the world in 1963 at the Mihajlo Pupin Institute, the hand had touch sensors, and its grasping capabilities were comparable to today's. As for the classification of robots itself, the World Federation of Robotics (IFR) classifies

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professional/commercial service robots in twelve categories based on the definitions of various terms in ISO standards, but it is noticeable that there is no clearer definition of "professional" and "commercial". One of the characteristic classifications of robots is presented below. (Source Darapuredu... 2021)

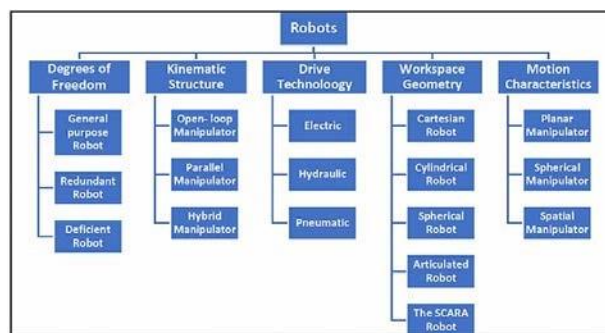


Figure 3. Classification of robots (Izvor Darapuredu... 2021)

It is also noticeable that lately there is more and more talk about the introduction of robotics and artificial intelligence into the education process through learning tools. In many cases, robots in schools can also be assistants that help teachers in the teaching process (EUBusinessSchool, 2022). One of the first divisions of robots is related to the environment in which they function. A representation of the different types of robots according to this criterion can be seen in Figure 4. (Ben-Ari & Mondada, 2018)

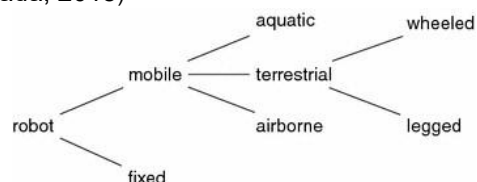


Figure 4 Types of robots according to the environment in which they work

Source: (Ben-Ari & Mondada, 2018)

According to these authors, if we divide robots according to the environment in which they work, we can first divide them into mobile and fixed robots. The literature states that the two biggest challenges in robotics are costs and development complexity. It is also pointed out that robots can be divided according to the intended area of application and the tasks they perform. This division is shown in the following figure 5.

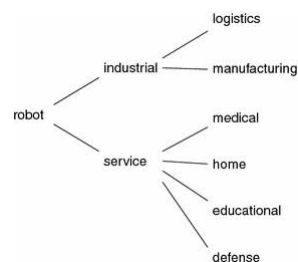


Figure 5 Tipovi robota prema njihovoj funkciji

Izvor: (Ben-Ari & Mondada, 2018)

3. APPLICATION OF ROBOTS IN PRACTICE

One of the situations that significantly affected the use of robots was the pandemic caused by the COVID 19 virus, when in 2020 robots, since they were not sensitive to viral infections, were able to take on a task that was potentially too dangerous for humans to perform. (Hearn, 2020). Well-known authors indicate that it was then that robots became part of a multi-layered response to the crisis and after the pandemic remained as a widespread and even everyday infrastructure (Dempsey, 2022). Other authors also emphasize that when planning the path of the robot, it takes into account the presence of people and their intentions if they are near it, which ensures that the robot maintains a safe distance from all people, as well as moves in a way that allows it to be in the field of view. people and not to surprise them when he approaches them (Shneier & Bostelman, 2015). Research shows that today robots enable further and more flexible automation of processes, and that in this sense jobs that require more intelligence, knowledge and creativity remain for humans, so it can be said that in this sense, robotic systems contribute simultaneously to increasing productivity and humanizing work. Another need for robots led to the development of robots of a different form, known as mobile robots. These robots replace humans in performing tasks in difficult conditions and dangerous areas. In terms of the actuality of robotics itself, the fact that the size of the global professional service robots market is estimated at USD 33.44 billion in 2023 and is projected to grow at a compound annual growth rate (CAGR) of 11.3% from 2024 to 2030. The following figure 6 presents the global professional service robots market value prediction.

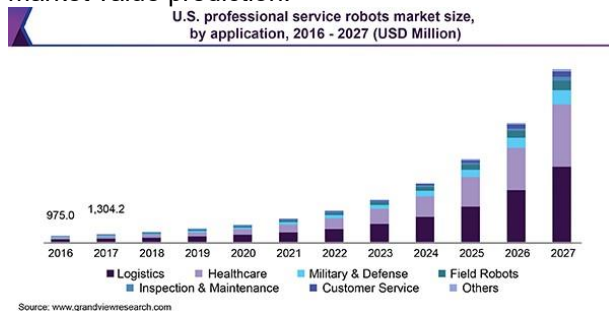


Figure 6 The global professional service robots market value prediction
(Source: Coherent Market Insights)

In this context, according to a report published by the International Federation of Robotics (IFR), sales of service robots for professional applications will increase by 48% in 2022, reaching 158,000 units, with agriculture, hospitality, professional cleaning and logistics showing a steady increase in demand for these solutions. For example, in the transport and logistics segment, robot sales increased by 44%, with more robots designed to transport cargo and goods. Here in the Republic of Serbia, artificial intelligence is most developed in the field of industry and agriculture. Worldwide, in the agricultural sector, sales reached

around 8,000 units, which is an 18% increase compared to the previous year. Of these, around 75% of robots were used in agricultural tasks such as cleaning agricultural buildings and milking cows, sheep, etc., highlighting the growing preference of agricultural and farm owners to optimize their productivity while minimizing labor costs and mitigating the environmental impact of modern agricultural practices. . Research also shows that by applying intelligent data processing in agriculture, different estimates can be obtained, from what the yield will be to how to increase it. In addition to the mentioned examples of application in agriculture, some authors emphasize that robots can defuse bombs, collect data on the edge of volcanic craters, transfer hazardous materials, explore the ocean floor and perform various research or maintenance tasks in space (Hagis, 2003). The following figure 7 presents the Global robotics market

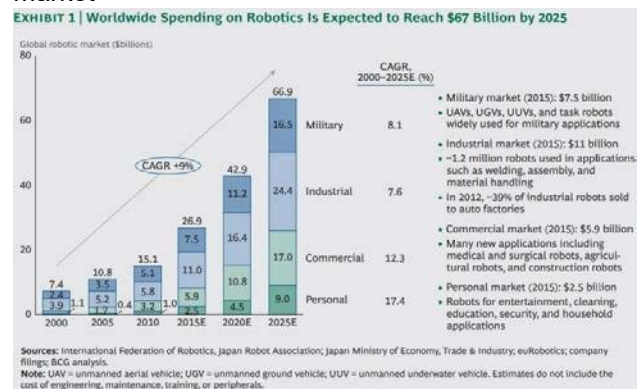


Figure 7 Global robotics market (Source: International Federation of Robotics;
Japan Ministry of Economy; Trade & Industry; euRobotics; company filings;
BCG analysis)

The pandemic situation provided an opportunity to explore the possibilities of robotic and autonomous systems that can provide cities with the resources to deal with unexpected situations such as emergencies, weather disasters, pandemics, heat waves and blizzards and ultimately to transform and strengthen urban flows, which it leads to new ways of organizing and planning life in the city that arise as a result of the emergence of constellations of man and robot. The crisis accelerated the ongoing transformation of non-human-robot relations and made visible all its tensions and potentials. The research results indicate that the cognitive abilities of urban artificial intelligence cannot be found exclusively in computer bits and human neurons, but arise from encounters and contexts, with institutions, policies, practices, and even the materiality of the city itself, which are key to the emergence of urban AI. In the strategy of the government of the Republic of Serbia, the underdeveloped startup ecosystem, a small number of researchers in the field of AI, weak support for the private sector in the development of artificial intelligence, as well as insufficient cooperation between science and business,

and above all cooperation, are highlighted as key problems for the use of AI in Serbia technical faculties with economy.

4 RESEARCH METHODOLOGY

Among other things, this work uses the study of literature as a method. In this sense, the descriptive method is used in the part of the work on artificial intelligence and robots. The connection of these areas with human lives and their development until today was investigated, with the help of reading electronic sources and summarizing them, using the chronological method, then the compilation method, the descriptive method, and finally the synthetic method.

5. CHALLENGES AND PARADIGMS OF ROBOT APPLICATION

Some authors emphasize that it is great that robots will do all the bad, difficult, dirty and dangerous jobs instead of us, but the question arises, do the people who do those jobs want that too (Ceurstemont, 2019). In this sense, well-known authors emphasize that urban robots, as well as other urban systems that rely on networked computing, are subject to failures, as well as forms of vandalism, disruption and criminal exploitation that risk making urban infrastructure insecure and fragile (Kitchin and Dodge, 2019). This is followed by OSHA (US Agency for Occupational Safety and Health) identifying 7 possible hazards within robot work zones (Hogg, 2011): 1. Human errors 2. Control system errors 3. Unauthorized access 4. Mechanical failure 5. External factors 6. System power and 7. Improper installation. New generations of smart robots, or smart technical systems in general, are turning to new

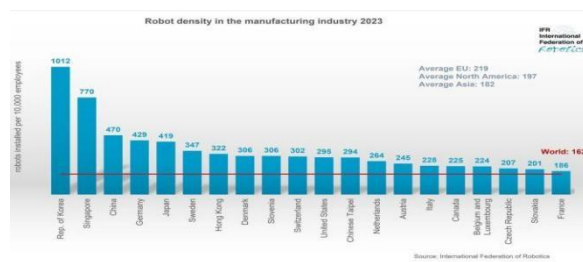


Figure 8 Robot density in manufacturing industry, 2023. (Source: World Robotics 2024)

It is known that AI can be entirely software, while robots are physical machines that move. In this regard, robots are susceptible to physical impact, usually via "sensors", and exert physical force on the world, usually via "activators", such as a gripper or a turning wheel. Accordingly, we can say that autonomous cars or airplanes are robots, while only a small part of robots is "humanoid". It is important to emphasize that in the future, autonomous and mobile robots will be able to help elderly and immobile people, help with household chores, act as caregivers and perform repetitive, boring or dangerous tasks in nursing homes, hospitals, military environments, disaster sites and schools, among other things. Practice shows that some robots use AI and some do not: Typical industrial robots blindly follow fully defined scripts with minimal sensory input and no learning or reasoning (around 500,000 such new industrial robots are installed every year (IFR 2019 [OIR])). It's probably fair to say that while robotic systems are of more concern to the general public, artificial intelligence systems of intelligence and their

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applications, especially in service activities, medicine and home use, although there are certain limitations in this process. In this context, some authors emphasize that robots have the potential to stimulate innovation, improve access and provide data for improved decision-making, but there is also a risk that they will reproduce and automate inequality or result in a more fragmented and unclear urban governance (Guenat et al., 2022). Also notable are opinions that the impact of robots was often limited in scope and reliability when pushed to their limits in crisis scenarios (Wang et al., 2021). Well-known authors emphasize that although people have been dreaming about robotic assistants for decades, the robotic vacuum cleaner is one of the first to be developed to the extent that we can use it in practice (Hendriks, Meerbeek, Boes, Pauws, & Sonneveld, 2010). The following figure8 shows the application of robots in industry.

application to robotics are more likely to have a greater impact on humanity. Also, AI or robotic systems for a narrow set of tasks are less likely to cause new problems than systems that are more flexible and autonomous. As noted by Lin (2022), the pandemic caused by the COVID-19 virus has accelerated the exploration of a new form of advanced technologies with the potential to achieve more resilient but also less inclusive urban flows. Forbes states that precisely by using the power of advanced technologies and artificial intelligence, countries such as Serbia, Greece, the United Arab Emirates and Israel have managed to establish an optimized and efficient framework for the distribution of vaccines. Although robots possessed only narrow intelligence based on repetition and separation, they benefited from their ability to connect data and coordinate action, as well as from a logic based on adapting to real-time changes in urban flows that can usefully be described as smart (Kitchin and Dodge 2019) or cybernetic. As one of the examples of the use of artificial intelligence in the suppression of the corona virus pandemic, the reports of world organizations mention decoding the structure of the virus and understanding how it attacks cells in the

body, discovering drugs to alleviate or treat the disease, predicting the locations of the next hotspots,
CONCLUSION

In this paper, we take an optimistic view of the transformative potential of the application of artificial intelligence in robotics, emphasizing the need for an ethical approach to application while respecting the standards of environmental protection and sustainable development. Studies show that artificial intelligence facilitates and improves people's lives in various fields. However, robots combined with artificial intelligence can make life easier in many situations. The results of the research indicate that robots have played an important role in society, business and production and that they have changed the production economy during the last ten years. The robot must be controlled by a system that we want to be as efficient and independent as possible, which is why artificial intelligence would be the perfect control center for a robot. Research in practice indicates that systems with artificial intelligence are developing more and more every year. In addition, robots, thanks to the continuous development and advancement of technology, are becoming capable of imitating humans in some situations, which is why we are increasingly including them in our daily lives to help us. In the process of development and application of AI, not only in robotics, there are numerous pitfalls that should be avoided already in the development phase and that we must pay attention to, because the consequences of some of these problems could be catastrophic. It is obvious that a studious analysis of the future trends and development of artificial intelligence and robots represents the application of innovative methods of technologies and approaches, through the prospects for progress and the expected impact on industry and society. Research results indicate that it is recommended that systems based on artificial intelligence or robots be thoroughly tested in safe environments before being used in practice, where we can react even if something goes wrong. Based on the research conducted, it is obvious that humanoid robots with artificial intelligence will be a part of everyday life in the future. It is recommended that future research should be conducted from the point of view of both ethics and business on the points that should be taken into account when introducing robots with elements of artificial intelligence in business. The results also point to some negative connotations of the application of AI in robotics, such as the fact that the use of robots can lead to reduced contact between people and possible restrictions on personal freedoms. Finally, this research lays a critical foundation for future research and thus the paper can be considered to have fulfilled a certain role.

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ELECTRIC CARS AND THEIR INTEGRATION INTO MODERN POWER NETWORKS

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Abstract: Electric vehicles are becoming more widespread in modern times; however, with this green technology comes a new challenge of supporting charging requirements and integrating said requirements into our current power networks. In this paper, we will explore the modern technologies and concepts that are being considered for the enhancement of various power networks around the world, as well as the challenges of integrating a growing number of electric vehicles into the networks. We will also review the immense rise of electric vehicle sales in modern times to showcase why a seamless integration into the power networks is required and how big the industry has become. We will also highlight various guidelines being put in place by the three main markets to ease this complex process.

Keywords: Electric cars; Power networks; Challenges; Integration

1 INTRODUCTION

Global energy demand is increasing each year. Still, the primary source of energy supply comes from dirty fossil fuels. Burning and utilising these fossil fuels greatly impacts our environment and global climate change. This constant pollution will lead to unsustainable conditions; therefore, a shift to more renewable energy sources is needed.

Nowadays, the automotive industry is turning to greener solutions for most vehicles. One of those solutions is electricity. More regions, such as the European Union and the United States, are creating regulations limiting greenhouse gas emissions from automobile manufacturers [1][2], so the electric vehicle industry is developing technologies at an ever-increasing pace.

Earlier versions of various electric vehicles were not perfect. In many ways, a conventional combustion engine would still outperform them daily. However, with larger batteries being developed, leading to more significant ranges, and newer electric motors delivering more power, the vehicle industry began to change.

These vehicles have fewer moving parts, reducing their maintenance cost and rate of failure compared to conventional combustion engines. When we also consider the many electric vehicle incentives governments worldwide offer [3], an increasing number of drivers nowadays choose electricity over conventional combustion engines.

With this massive shift in the industry, many cities face the challenge of integrating a new network of stations capable of drawing enough power to charge various electric vehicles. Reducing emissions and

creating a greener future is only possible if the infrastructure required for battery charging is created.

The number of electric vehicles is increasing year after year [4], and there is a real possibility of overloading numerous city power networks. Effective grid management will prove vital for integrating these vehicles. **1.1 The rise of electric vehicles**

Electric vehicles (EVs) are steadily increasing, especially in Asian countries like China. Current trends suggest that the rise in numbers will not stop soon. Only about 17000 electric vehicles were being driven in 2010. However, that number rose to over 40 million cars in 2023, shown in Figure 1.

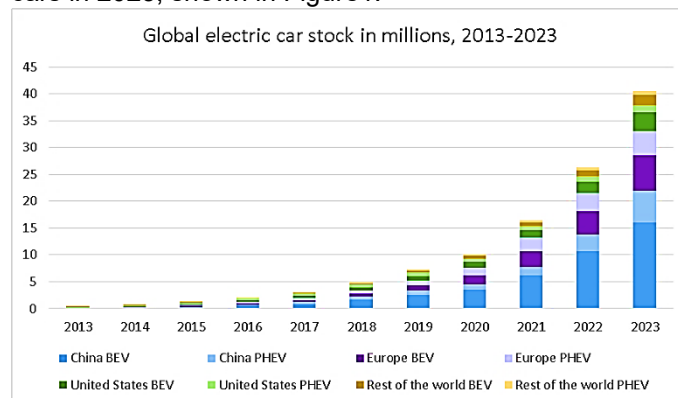


Figure 1: Number of electric vehicles around the world from 2010 to 2023 showcased in millions [4].

The chart showcases the number of BEVs (battery electric vehicles) and PHEVs (plug-in hybrid vehicles) on the road in the last 13 years and includes passenger cars only. It shows the meteoric rise of electric vehicles, especially between 2015 and 2019, where the number of battery vehicles went from 720000 in 2015 to 4.8

million in 2019. As we can see from the chart, China is the biggest battery and hybrid electric vehicle market, with the country having around 16 million battery cars and almost 6 million hybrid vehicles in 2023. Europe comes second with 6.7 million battery cars and 4.5 million hybrid cars in 2023. The United States had the lowest number of electric vehicles in the three big markets, with 3.5 million battery and 1.3 million hybrid cars registered in 2023. In the rest of the world, around 2 million battery and 700000 hybrid cars will be driven in 2023 – totalling around 28 million battery vehicles and 12 million hybrid cars on the road worldwide in 2023.

The chart clearly shows that the current trends in the electric vehicle industry are exceptional.

The three main markets, especially China, exhibit stable growth with no signs of stopping anytime soon. Those markets are the main driving force in yearly sales; however, they are not the only ones having a meteoric rise in the last few years. Many Southeast Asia and Latin American countries show significant yearly growth in electric vehicle sales. Vietnam had only 100 electric vehicles on the roads in 2021; however, by 2022, that number skyrocketed to 7000 vehicles and, in 2023, to 30000 cars.

Countries like Malaysia and Thailand are also tripling and quadrupling their year-on-year sales. The constant growth can also be seen in Brazil, Mexico, Colombia, and many European countries [5]. The increasing number of electric vehicles can also be seen in 2024, with the first quarter of 2024 showcasing more sales than the first quarter of 2023. This growth can be seen in the following chart, which shows the quarterly sales of electric vehicles between 2021 and 2024.

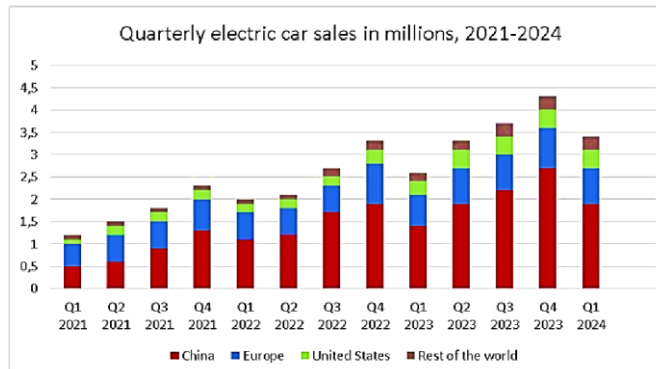


Figure 2 Number of electric cars sold quarterly from 2021 to 2024 showcased in millions [6]

As we can see from Figure 2, quarterly sales kept increasing steadily in the last 3 years. Sales increased from just above 1 million electric cars sold in the first quarter of 2021 to over 4 million in the previous quarter of 2023. China is the market that has the most sales in every quarter after the first two quarters of 2021, in which Europe and China were tied on the numbers of electric vehicles sold. Europe is currently the second largest market, with the region selling 800000 cars in the first quarter of 2024. The United States comes third in quarterly sales, with the region selling 400000 vehicles in the first quarter of 2024. The rest of the world covers countries like Malaysia, Thailand, Mexico and Colombia. Those countries are exhibiting an increase in quarterly sales as well. However, the number is still smaller, with the sales in the first quarter of 2024 reaching 300000 vehicles.

The number of electric vehicles on the road and quarterly sales in the last few years shows that electric car sales are increasing year after year. Because of this, various power networks must prepare for a realistic scenario in which electric vehicles overtake classic fossil-fueled cars.

Networks will need to find a way to seamlessly support hundreds of thousands of new vehicles registered worldwide each year. In the next section of the paper, we will examine the evolution of power grid technologies and various guidelines being developed to prepare for the integration process in multiple world regions.

2 RESEARCH OF POWER NETWORKS AND THE INTEGRATION OF ELECTRIC VEHICLES

As seen in the previous section, the number of electric vehicles keeps increasing worldwide. This growing fleet of cars will impact the current power networks with their growing demand for electric power. As more people own these vehicles, they need to charge them naturally. Networks must handle this additional load without overloading or creating potential power outages. Because of this, careful planning and preparation are required so the inevitable rise of EVs does not impede electricity delivery from producers to consumers. Many areas, like China and various European countries, face this reality. We will look at the positive and negative impacts of EVs, multiple challenges of integration and how different regions are reacting to the growing number of electric vehicles.

Introducing electric vehicles to the grid will be a big test for power suppliers. Vehicles will impact the grid positively and negatively [7]; however, the integration can be successful with careful planning. At the end of the process, the positive impacts can be better power management, improved power quality, frequency regulation and integration support for renewable energy. The negative consequences are the inevitable increase in load demand, the possibility of overloading and overall reduction of stability, phase and voltage unbalance, and an increase in power loss and current harmonics. Although these problems might occur with the widespread integration of electric vehicles, they can be solved using different power strategies. One of those strategies is making use of synchronous loading. This strategy would make a charging schedule for electric vehicles. It would lower the chance of instability and overloading at the cost of restrictive charging at certain times of the day. For instance, the cars would be charged between 10 pm and 7 am, which is the time when consumers use the power grid less. For this strategy to be effective, incentives need to be created that motivate users to charge their vehicles during off-peak hours.

Furthermore, coordinating scheduled off-peak charging on the household level is much more complicated. The impact of expected charging hours on household power bills is relatively small, while grid operators and charging stations have much stronger incentives to charge during off-peak hours. This scenario poses significant challenges, as an entire street or neighbourhood may experience many electric vehicles charging simultaneously. Uncoordinated charging could

cause many power grids to suffer overloading issues or blackouts.

Wireless power transfer is a ground-breaking solution for charging vehicles without physical contact. With this technology, vehicles could be charged by inductive coupling, using a magnetic field to transfer power between coils of wire [8]. Wireless power transfer is creating quite a stir in the charging of devices from home appliances to vehicles to public transport.

Several advanced technologies are shaping the future of power grids. One of those is implementing high-voltage direct current (HVDC) power lines that could replace the much more common alternating current (AC) transmission system. This technology offers efficient electricity transmission over long distances with lower losses than traditional AC systems. It also stabilises the grid and makes it more economical due to the ability to exchange power between previously incompatible networks.

High-voltage direct current powerlines are usually used for long-distance transmission, costing less per kilometre than traditional AC lines. They are partly used because HVDC cables are usually smaller than AC cables, as they have less heat loss, so less material is needed.

The most significant benefit of HVDC systems is the ability to interconnect asynchronous grids and integrate

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more renewable energy sources [9]. Another benefit is the ability for these cables to be installed underwater, connecting locations separated by seas. With this transmission system already being used on many overseas lines worldwide and many new lines being constructed [10], the system's power could alleviate the stress of integrating many electric vehicles into the power networks.

With the rise of innovative technologies, power grids that use sensors and special software to cover the demand for electricity in real time can be created. Modernising and digitalising current power networks can vastly improve their capabilities while minimising costs and maintaining stability and reliability. Smart grids can more efficiently control power usage by reducing the functions of non-critical devices during peak power usage and returning them during non-peak hours. It will optimise the time for EV charging during off-peak hours, balance loads on a grid, and mitigate overload due to risk during charging. EVs can act as distributed energy resources supplying back power to the grid, enhancing resiliency and rewarding owners economically.

An electric vehicle (EV) charging system will be optimised for off-peak hours, balancing power loads and reducing the risk of grid overload. Electric cars can also act as distributed electric energy resources supplying power back to the grid, thus enhancing resiliency and providing an economic incentive to owners.

With smart meters, electricity suppliers could get valuable data about electricity consumption and voltage levels in real time. Data might be used to monitor the

stability of the network and warn the supplier about any issues that could lead to system disruption and blackouts. Consumers would also benefit from using smart meters. The rise of electric vehicles will lead to more accurate energy billing and better demand management. Users can also use these precise readings to monitor their power usage more carefully and lower the energy consumed, leading to lower power bills and less strain on the network. Smart power grids also tend to use more renewable energy sources, decreasing the number of fossil-fueled power plants and replacing them with clean solar, wind and hydro energy.

Improving battery storage capabilities is necessary for backup at peak load conditions and stabilising the grid. Microgrids are self-sufficient energy systems that can operate independently and will further heighten reliability, especially for remote regions. These microgrids allow local energy management, thus helping reduce outage hazards while increasing efficiency. These strategies will strengthen our energy infrastructure and futureproof it for electric vehicles.

As one of the biggest markets for electric vehicles, China needs to integrate millions of cars being bought every year. In January 2024, China's National Development and Reform Commission (NDRC), with the help of the National Energy Administration (NEA), the Ministry of Industry and Information Technology (MIIT)

and the State Administration for Market Regulation (SAMR), released guidelines meant to smooth out the integration of electric vehicles into their current power grids [11]. These guidelines aim to enhance core systems used in the EV industry.

One of the guidelines calls for advancements in core vehicle-to-grid (V2G) technologies. Battery technology is still imperfect, with current batteries withstanding a limited number of bidirectional charging and discharging cycles before their battery capacity degrades. The policy calls for battery technology enhancements to achieve 3000 charge cycles. A robust V2G system architecture and an efficient bidirectional charging system must be feasible.

The policy also calls for better standardisation of these systems, focusing on interfaces, communication protocols, power regulation, and charging technology.

Another essential guideline proposed in the policy calls for optimising electric vehicle charging fees. Plans are underway to unveil differentiated pricing models for residential and household charging to effectively manage the ever-increasing demand posed by electric vehicles on the grid and to advance its sustainability goals. These charging tariffs would encourage EV owners to charge their cars during off-peak hours, for instance, late at night, when electricity demand is at its lowest.

Multiple efficient electric vehicle integration models are also proposed in different scenarios and locations, such as residential areas or industrial parks. The government will prioritise bidirectional charging technology for multiple public sector vehicles, primarily

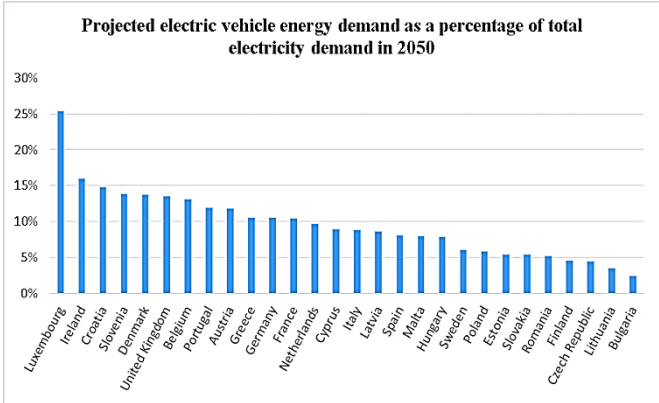
rental and public vehicles. Enhancements of charging facilities are also one of the policy's key guidelines. It calls for creating intelligent charging facilities and upgrading existing charging facilities. A management system for residential area charging will also be established, and the policy will define responsibilities and rights for users and power grid companies.

Finally, the policy calls for reinforcing support and assurance for power grid companies. Grid operators will be supported in integrating vehicle-to-grid management with brand-new load systems. Existing systems such as metering and grid connections will also be improved, while grid clearing will be optimised.

Some of these guidelines can already be seen in 2024, with the Chinese economic planning agency setting up multiple nationwide vehicle-to-grid system trials in which many electric vehicles feed power into the grid during peak hours [12]. These trials can show if cars can be used to smooth out rough peaks in electricity supply and demand. The prosecution also set up different pricing for charging in residential properties and daily charging, as called for in the policy set out a few months ago.

Europe also faces the formidable challenge of integrating many electric vehicles. According to data from the European Environment Agency (EEA), the projected share of electric cars by 2050 will reach 80%[6]. Additional energy will be required for this projected scenario.

Although power grids are not expected to have significant challenges in supplying the electricity required for charging these vehicles until 2030, by 2050, the percentage of electricity used by various European countries to charge the predicted stock of electric cars will vary from 3% to 25%. This demand in power supply needs to be fulfilled. With the rising integration of green energy sources such as solar, hydro or wind energy, many countries will look at these solutions to meet the demand for the proposed vehicles. These solutions will vary depending on the country's climate, with many sunny countries such as Greece or Spain harvesting solar power to smooth out the peak hours of charging during the day. Other countries with multiple extensive wind farm integrations, such as Germany or the United Kingdom, might choose this type of energy.



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Figure 3 percentage of total electricity demand in 2050 (assuming the predicted 80% share of electric vehicles in 2050) [13]

As seen from the chart, by 2050, in 12 European countries, charging electric vehicles will take away more than 10% of distributed power. This chart assumes the 2050 electric vehicle share prediction is correct, with the prediction being calculated from current trends of electric vehicle stock around the world. Further implementation of green energy solutions is also required, as even though the CO2 emissions will lower because of the rise of electric vehicles, the current power network infrastructures worldwide still use a lot of fossil fuels for power generation. Even though vehicle emissions still outweigh the emissions created in the power industry, further creation of solar, wind and hydro energy farms would generate more energy while lowering pollution.

As the third largest market, the United States is also planning better integration in the coming years to facilitate more than five million electric vehicles driven on the road in the region, growing steadily.

Because of these numbers, the U.S. Department of Energy (DOE) published a document covering the future of vehicle grid integration as part of its EV Grid assists initiative. This initiative aims to assist stakeholders in making progress towards their electrification goals by using data, tools, and real-world cases.

The department's document demonstrates technologies that can solve everyday challenges and create stronger stakeholder coordination. Good integration can lead to cheaper electricity rates and cost-effective charging with clean energy resources, and the document highlights the main points to achieve this through five objectives [14].

The first objective covers required investments in infrastructure to facilitate electric vehicle charging and enhance grid stability.

The second objective focuses on lowering the pollution of the power grids while also increasing the utilisation of charging assets to limit peak load impacts that are created.

The third objective suggests better standardisation of electric vehicle chargers and a more explicit statement of power grid requirements to allow easier innovation of technologies and integration into a more stable, compatible environment.

With the fourth objective, the document calls for more customer-centred options, such as multiple products or services to fulfil their charging needs and offering compensation for any services given to the grid.

The final objective highlights the need for well-built cyber and physical systems that handle the connections between the vehicle, charger, and power grid without severe manufactured or natural disruptions, making the system more robust.

With automakers Mercedes-Benz, Stellantis, Honda, Hyundai, Kia, BMW, and General Motors also uniting to

create modern high-powered charging networks across the continent, the future of integration seems bright. Users will be more incentivised to choose electric over fossil-fueled cars [15].

3 CONCLUSION

In this paper, we analysed the rise of electric vehicles, modern technologies being applied to the current power grids, and various guidelines to ease the future integration of cars. The vehicle industry is changing drastically. Electric vehicles transformed from a concept for the future to a reality in just a couple of decades. Although the rising number of electric vehicles creates a challenging test for the stability of current power networks worldwide, many countries are investing in modernising various power grid systems. This process benefits users and distributors as it will lead to more significant implementation of green energy sources into the grid. With the evolution of innovative technologies happening rapidly, ordinary power networks could be transformed into smart ones, decreasing the energy price for consumers while making the networks more stable using multiple sensors and innovative technologies. Countries like China have proven that they can transform their vehicle fleet from fossil-based to electric without overloading their power networks. With the government gaining millions of electric vehicles per year, they are investing in more robust and modern power systems to prepare for the inevitable future of electric vehicles.

Although China and many richer European countries are upgrading their power grids, many countries still do not have sufficient systems to integrate these vehicles

without issues. Without proper investment from these countries, travelling the continent can become problematic for electric vehicle users. Some countries have excellent infrastructure and plenty of charging stations, while their neighbours will have barely enough to support one city. Because of this, in many countries, the future of electric vehicles will be determined by their infrastructure and the prices of electricity that distributors set. One thing is certain: electric cars are rising in numbers in many countries, and if the trend doesn't waver, countries will have to accommodate the charging requirements that come with them.

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UDK:351.777.6:004.8

DOI:
10.46793/ALFATECHproc25.07
8K Original scientific paper

Optimization of AI Methods for Air Pollution Prediction

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Abstract: One of the biggest problems of large urban areas is air pollution, and in this regard, artificial intelligence (AI) methods can predict the level of pollution using a wide range of parameters. The use of artificial neural networks (ANN) based on Levenberg-Marquardt algorithm with Bayesian regularization (LMBR) is considered in this paper. It is shown that this algorithm achieves very high prediction accuracy, competitive with radial basis neural networks, which are commonly used for regression tasks. It is also shown that by choosing the optimal sample size, in addition to tuned ANN parameters, a balance can be achieved between the desired accuracy of the method and the deviation between simulated and real data. Relative error was used as a measure of that deviation. At the same time, it has been shown that sample size is not always a decisive factor affecting the efficiency of the AI method itself, but that a complete picture can be obtained by taking into account the entire structure of the input data.

Keywords: Air pollution; Artificial neural networks; Bayesian regularization; Levenberg - Marquardt algorithm.

1 INTRODUCTION

In order to solve the problem of air pollution, modern technologies include the application of AI methods to predict pollution levels. There is a wide range of applied AI methods, which can generally be classified into five categories: Fuzzy Logic [1], Hidden Markov Models [2], Ensemble Models [3], Artificial Neural Networks [4] and Deep Learning [5]. From the point of view of our work, the category of ANNs is the most interesting and these methods are quite robust against all types of relations (monotonic, non-monotonic, etc.) in input data. However, despite this, these and other AI methods are dependent on the structure of the input data set and in this sense, there exist just recommendations based on the results of individual

studies. The situation was alleviated by preprocessing the data that includes input variable selection techniques (IVS). These techniques can be classified into three categories [6].

The first category consists of input variable filtering methods, which are mainly based on the application of statistical analysis methods [7]. Methods in this category are characterized by being independent of the type of ML method applied and being relatively simple to implement. An example of a method in this category is the mrMR algorithm (mr-minimum redundancy, MR-maximum relevance) [8]. More recently, two statistical tests have been applied to select input variables based on their relevance to the output variable.

The second category includes the so-called wrapper methods [9]. These methods

include:exhaustive feature selection, sequential forward and backward selection and recursive feature elimination. The methods of exhaustive feature selection and recursive feature elimination are computationally demanding and they cover more of the parameter space than other methods. Sequential forward selection consists of sequentially adding variables to an initial empty set (SFS method), while in the core of sequential backward selection is eliminating variables from the complete initial set (SBS method). The selection of variables is carried out by following the values of the loss function or some other metrics of the effectiveness of the AI method. The SFS method is less computationally demanding than the SBS method, which is otherwise very impractical when there is a large number of input variables. These methods are characterized by the fact that for each specific set of input variables, it is necessary to determine the accuracy of a given AI method. This means that these methods are more demanding in terms of computing time and complexity compared to filtration methods.

Finally, methods within the third category, known as embedded methods, are the most complex for practical implementation [10]. The denominator of these methods is that the selection of input variables is done during the training of the AI method. This is the reason for their complexity and they are especially complex when applied to artificial neural networks (ANN), since their structure also depends on the number of input variables. Typical examples of these methods are the applications of the CART and ID3 algorithms in decision trees, where at each stage the set of attributes that has the best discrimination property between the categories of the target variable [11].

By applying IVS techniques, in principle, an optimal set of predictors can be obtained, which achieves the same or higher degree of efficiency as with full sets of predictors. This simultaneously saves computing time and memory resources. However, the optimal set of predictors does not have to be (which is most often the case) optimal for all types of AI methods. This means that these methods are still dependent on the structure of the input data.

Therefore, the term optimization has a much broader meaning in AI methods. This does not mean that every data set can be solved by tuning the parameters of an ANNs in its hyperspace. A comprehensive approach also requires taking into account the relationships between the input variables, in order to assess which method is most effective. Such a detailed approach cannot be the subject of a single paper, but it is still possible to examine the impact of individual parameters of the data set. Probably the most important and influential parameter is the sample size, and this is what this paper is dedicated to.

For air pollution prediction, our choice was the LMBR algorithm, which is well described in the literature and there is no need to repeat it in detail here [12]. We will only list the basic settings of this algorithm. The essence of this algorithm is to minimize the loss function F :

$FF = \alpha\alpha EE_{WW} + \beta\beta EE_{DD}$ (1) where E_w represents the sum of the squares of the neural weights $w_{ij(k)}$ (index k refers to a specific neural layer) across all neural layers, while E_d is the classical loss function (or random mean square error). After arbitrary initialization of the parameters α , β , neural weights $w_{ij(k)}$ and biases parameters $b_{(k)}$, the input vectors in the form of matrix $XX(aa \times x \times mm)$ (n -number of samples, m -number of attributes) are propagated forward through the neural network. In the next step, the Hessian matrix of the second derivatives $HH \cong 2\beta\beta\beta\beta^{TT}\beta\beta + 2\alpha\alpha II_{pp}$ and the loss function F are determined and finally the corrections of the neural weights $W_{(k)}$ (in matrix form) are made:

$$WW_{aarree(pp)} = WW_{mmaarr(pp)} - \mu\mu HH - 1\beta\beta rr \quad (2)$$

In the above formula, μ is the Levenberg's damping factor, J is the Jacobian, and e represents the loss function summed over all samples. With the calculated neural weights according to Eq. (2) and E_w, E_d , the parameters α , β are calculated again which corresponds to minimizing the loss function F . The entire cycle of calculating the parameters $W_{(k)}$, α , β , E_w , E_d continues until the condition of convergence is met.

Since air pollution prediction with ANN is a regression task, it is necessary to set the maximum deviation between simulated and real data, or simply put, the tolerance. In this sense, we introduced the relative error r_i as a measure and it is given by the formula:

$$rr_{aa} = \frac{|yy_{aa} - yy_{aatt}|}{yy_{aatt}} \quad (3)$$

where y_i , y_{it} represent the simulated and real values of the target variable ($i=1,2,...,n$). In addition, the value of $\Delta_{ggr} = 0,04$ (or 4%) is the selected limit value of the relative error: $rr_{aa} \leq \Delta_{ggr}$. To establish a relationship between the relative error and the random mean square error of the ANN, it can be very easily shown that the following formula holds:

$$NN$$

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2 Methodology

$$EE_{DD} = 1 \quad {}^2 \leq MM\Delta_{ggr}{}^2 \quad (4)$$

$$(yy_{aa} - yy_{aatt})$$

$$NN$$

$$aa=1$$

where is $MM = \max(yy_{aatt})$, $aatt = 1,2 \dots NN$, so that at $MM = 1$ it turns out that $EE_{DD} \leq 10^{-4}$ (in dimensionless form).

The structure of the ANN was as follows: the input layer had 12 neurons, the hidden layer had 10, and the output layer had one neuron. The optimization procedure is shown below.

Pseudo-algorithm of optimization
procedure INPUT: $\alpha\alpha, \beta\beta, WW, bb, \Delta_{aa}(\%)$ ($aa = 1,2,3,4$); $X(n \times m)$; *structure of ANN*; *tuning ANN*; $accuracy = cell(1,4)$;
for $i=1:4$ $out=[]$;
 for $j=1:500:n$
 $out=[out; ANN(1:j, \Delta_{aa})]$;
 end
 $accuracy\{i\}=out$;
end
OUTPUT: $accuracy$

As can be seen from the above pseudo-algorithm, the air pollution prediction simulation is performed for several different values of the threshold $\Delta_{aa} \in \{1\%, 2\%,$

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$3\%4\%\}$. For each of these values, the sample size was continuously increased in steps of 500 and a simulation with ANN was performed on each of these samples and the accuracy was determined. In this way, four different curves of the dependence of the ANN accuracy on the sample size were determined, at a fixed threshold. As a result of the optimization, a curve was selected where the accuracy was $>95\%$ and where there no major oscillations in the accuracy with the change in the sample size.

Finally, a database of 9358 samples obtained by averaging the measured air pollution components per hour, was used [13]. The data were measured in a significantly polluted area in an Italian city between March 2004 and February 2005. The output or targeted variable was Benzene (C_6H_6) concentration (mg/m_3) and the input features or predictors were: hourly averaged concentration CO (mg/m_3), PT08.S1 (tin oxide) hourly averaged sensor response (nominally CO targeted), true hourly averaged overall NMHC (Nonmethane hydrocarbons) concentration (mg/m_3), PT08.S2 (titanium dioxide) hourly averaged sensor response (nominally NMHC targeted), true hourly averaged NOx concentration (ppb), PT08.S3 (tungsten oxide) hourly averaged sensor response (nominally NOx targeted), true hourly averaged NO₂ concentration ($\mu g/m_3$), PT08.S4 (tungsten oxide) hourly averaged sensor response (nominally NO₂ targeted), PT08.S5

(indium oxide) hourly averaged sensor response (nominally O₃ targeted), $T(^{\circ}C)$ and relative humidity RH(%) and absolute air humidity AH.

In preparation for numerical simulations using the LMBR algorithm, the data were traditionally first manually filtered to remove incomplete data. Extreme points were removed by graphical display of the data and visual inspection. Then, the data were converted to the interval $[0,1]$, according to the formula, which is a necessary and standard step in preparation for working with artificial neural networks.

2.1 Data preprocessing

In preparation for numerical simulations using the LMBR algorithm, the input data are filtered in a traditional way by removing incomplete data. Since the data are in the form of a matrix $XX(aa \times x \times mm)$, if any row of data is incomplete, then the entire row is removed: $XX(aa, :) = []$. By visual inspection of the graphical representation of the input data, outliers are also removed. Then, the data were converted to the interval

$[ss, bb]$ according to the formula:

$$xx'_{aaii} = ss + \frac{XX_{aaii} - XX_{mmaaaa}}{XX_{mmssxx} - XX_{mmaaaa}} (bb - ss) \quad (5)$$

where is $ss = 0, bb = 1$ and xx_{mmssxx}, xx_{mmaaaa} are the maximum and minimum values of the input data for $aa = 1,2, \dots aa; ii = 1,2 \dots mm$. This is necessary and standard step in preparation for working with artificial neural networks. Beside that, the interval $[-1,1]$ is also often used. After numerical simulations with artificial neural networks, the data were then restored back to the original interval.

3 Results and Discussion

The results of the optimization procedure are shown in Figure 1 below and the x,y-axes indicate the sample size N and accuracy ACC(%) of the LMBR algorithm.

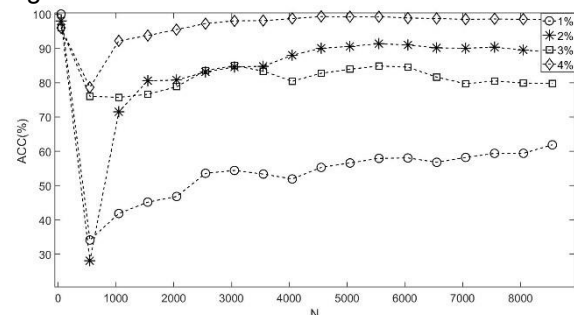


Figure 1 Accuracy ACC(%) vs. sample size N

In Fig.1 can be seen that the accuracy of the LMBR algorithm is highest at a threshold of $\Delta = 4\%$, for almost

all sample size values. Two characteristic areas are clearly distinguished. The limiting value of the sample size between these areas is $N=3000$. In the first area, where $N<3000$, the value of the $ACC(\%)$ parameter does not exceed 95% except in the case, $\Delta=4\%$. On the other hand, at $N>3000$, the accuracy of the LMBR algorithm, at a relative error threshold of 4% exceed 95%, while at other values of relative error the accuracy does not exceed 90%.

Also, in the above figure, an interesting property can be observed for sample size $N<1000$. Namely, contrary to our expectation, the accuracy first decreases with increasing sample size and a global minimum can be observed for all values of the relative error threshold. Then the values of the $ACC(\%)$ parameter start to increase, so that after $N>1000$ we have a relatively stable increase in accuracy, for all values of the sample size, at all values of Δ . This unusual property of AI methods in that their accuracy decreases with sample size has also been observed by other authors. For example, researchers have investigated the application of machine learning methods to classify autistic and non-autistic individuals [14]. They have shown that even with a small sample size, high accuracy of machine learning (ML) methods can be achieved by combining various methods of their validation. By dividing the input data set into training and validation sets and using nested crossvalidation, they achieved the best results in the sense that the efficiency of the ML methods was independent of the sample size.

Another interesting result can be seen in Fig. 1. The curve of the values of $ACC(\%)$ at a higher value of the relative error threshold is not always above the value at a lower threshold, for $N>3000$. Thus, the values of $ACC(\%)$ at $\Delta=2\%$, are higher than the values at $\Delta=3\%$, contrary to our expectation. It can also be seen from the figure that all accuracy curves above the value of sample size $N>3000$ enter saturation. As previously pointed out, this sample size limit is also the limit above which the desired level of accuracy is achieved at a given relative error threshold. Note that above this value, there are also smaller accuracy oscillations, which are practically negligible for

$\Delta \geq 4\%$.

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Based on these results, it can be concluded that the optimal region for simulating real air pollution data with the LMBR algorithm is determined by the parameters: $NN \geq 3000$, $\Delta \geq 4\%$. We confirmed these results by radial neural networks, where we achieved accuracy nearly of approximately 100% on the entire dataset. These ANNs has also been used in other research for air pollution prediction [15]. The key question that arises at this point is: can this result be generalized to other algorithms and other databases? There is no exact answer to this question, since there is no parameter space of the input data in which their properties could be exactly related to the properties of AI methods. There are only recommendations based on the results of other research.

All these results point to the need to define a parameter space of input data in which their properties could be more closely related to the properties of AI methods. There is not much research on this topic, and we would like to highlight one comprehensive study that examined the accuracy of AI methods depending on the sample size effect according to Cohen's scale and quality of input data [16].

4 CONCLUSION

In this paper, we have examined the possibility of predicting air pollution using the LMBR algorithm and shown that it can be a shortlist of candidates, in addition to radial neural networks. It should be emphasized that other AI methods can also be considered. This is because AI methods are still dependent on the structure of the input data, which, as we have seen, greatly affects the generalization property of ANNs. In addition, we have shown that the size of the selected relative error greatly affects the efficiency of the LMBR algorithm. The question that naturally arises here is whether the application of other ANN algorithms would lead to the same result. These and other questions such as: whether some other metric instead of the relative error would lead to better results and whether the parameter space of the input data could be defined, are left for future work.

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Implications of the application of artificial intelligence and Industry 4.0 on society

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Abstract: In this research paper, based on a systematic research of recent relevant literature, the possibilities of developing artificial intelligence and industry 4.0 will be presented with the aim of improving business processes and life and love in the continent. Companies and business systems are increasingly using advanced technological solutions to improve their operations. In the paper, the evolved problems accompanying the development of the artificial intelligence implementation process will be identified and the key success factors of the implementation process will be identified. The paper will examine in detail the possibility and feasibility of integrating artificial intelligence within the framework of Industry 4.0. Artificial intelligence undoubtedly brings numerous advantages and simplification of the operations of companies and organizations. The technological revolution, digital transformation and innovations have led to significant changes in all spheres of human activity, in this sense, the definition and determination of artificial intelligence plays a key role in achieving a balance between technological innovations and the protection of social norms and standards. The work will define the nature of cooperation and engagement of experts from different authorities for the optimal implementation of the integration of artificial intelligence within the framework of Industry 4.0. However, researches in practice indicate numerous problems and prejudices and the necessity of defining the security and risks involved in the implementation projects of artificial intelligence and Industry 4.0, to which experts dealing with the management of implementation and implementation projects must pay particular attention to the use of a reliable and responsible artificial intelligence system.

Keywords: Digitization, Digital transformation, Artificial intelligence.

1 INTRODUCTION

Artificial intelligence technologies are an integral part of Industry 4.0, and it is logical that they are the main subject of research. Research on the impact of the Industry 4.0 concept on society with a special emphasis on the use of modern

technologies such as artificial intelligence, blockchain, big data and cloud computing is becoming more and more relevant every day. Artificial intelligence research in the era of Industry 4.0. indicate that small and medium-sized enterprises use cloud computing and IoT technologies to monitor industrial processes, but there is little real use in business. Artificial intelligence is a concept that was initially popularized, especially in movies, which suggested that intelligent robots and machines would take over the world. Artificial intelligence refers to any computer system that imitates natural intelligence in order to perform a specific task. In the literature, it is stated that artificial intelligence is the ability of a machine to perform functions that are related to people's minds (Staff, 2023). Research on the application of artificial intelligence technology in Industry 4.0 shows that a very small percentage of companies use artificial intelligence technologies, as well as that intelligent production is the key to Industry 4.0. In this context, the development of artificial intelligence significantly contributes to the advancement of technology that enables devices to

better simulate human behavior. Due to the steady progress, the limits of artificial intelligence are being tested, and its definition is also being adapted accordingly (Petersson, 2021). Some authors state that in some cases, the process of artificial intelligence is supervised by humans, reinforcing good decisions and discouraging bad ones, or there are artificial intelligence systems that are designed to learn without human supervision (Glover, 2024). Today, artificial intelligence is increasingly present in the real world. Artificial intelligence is used in all industries and serves as the basis of machine learning. In this context, machine learning is important for, for example, smart production, which also represents the link between artificial intelligence and

Industry 4.0, which will additionally strengthen the concept of smart production with its algorithms. Artificial intelligence can be useful in making decisions based on data and performing repetitive or computer-driven tasks (Glover, 2024). One of the key things is how artificial intelligence and Industry 4.0 will affect work processes, services, security, as well as regulation. legislative aspect. Many companies and organizations are transforming their business models by integrating artificial intelligence into the business model, in addition to the digitization and computerization of operations. In addition to the above applications, artificial intelligence helps protect people by piloting online fraud detection systems and robots for dangerous jobs (Glover, 2024). Looking at the history of development, machine learning technology

as the "engine" of artificial intelligence was not initially recognized as very widely applicable. It is known that Industry 4.0 is not based on a single technology, but on a combination of different technologies, such as communication networks, data analysis and other technologies that make up the entire technological ecosystem (Mourtzis et al. ., 2022, p. 292-293) . There is a small number of scientific papers in the literature that touched on all the ways in which the use of Industry 4.0 technology affects the development of the company. The research results indicate that the implementation of Industry 4.0 is necessary for companies and business systems to competitively survive the new technological revolution by achieving maximum production capacity with maximum material consumption, minimum production costs, minimum losses and greater customer satisfaction. In this sense, it can be said that, among other things, new sophisticated technologies are becoming drivers of change in higher authorities and in the marketing environment, whereby the next era of customer interaction is expected to be based on digitalization and the use of communication platforms (Crittenden, 2019).

3 DEVELOPMENT OF ARTIFICIAL INTELLIGENCE AND INDUSTRY 4.0

Artificial intelligence is increasingly becoming a part of our everyday life and is present in many areas of life and love. In the literature, it is stated that artificial intelligence is a method that enables a computer, computer-controlled robot or software to think intelligently like humans. It is achieved by studying the patterns of the human brain and analyzing the cognitive process (Duggal, 2024). The facts mentioned above indicate the topicality of research and the need for systemic research of the challenge and power that artificial intelligence brings to society, in the context of the introduction of Industry 4.0 technology. With recent technical advances in the power of artificial intelligence, supplemented by hardware and so on. and with deep learning, it is possible to establish the most intelligent systems in companies that are able to predict and consequently prevent unwanted events based on shared historical data within the framework of the deep learning artificial intelligence system. Some authors emphasize that by applying new technologies and digital tools, companies can improve their business processes, reduce costs and increase efficiency (Berman & Najt, 2024, p. 23). Well-known researchers describe the fourth industrial revolution as a transition from traditional production to a new era in which physical and digital processes are intertwined (Hofmann & Rusch, 2017, p. 23). model and the increase of intersectoral relations, which in turn can lead to significant effects on the economy (Denić 2024). In the literature, it is stated that, in general, artificial intelligence focuses on three main cognitive abilities: learning, reasoning and self-correction. (Burns, Laskowski, & Tucci, 2022). Given that artificial intelligence is developing day by day and that it is divided into different types that can tell us how far artificial intelligence has come, where it is going and what the future holds (Betz, 2024). Viewed chronologically, the term Industry 4.0 was mentioned for the first time in 2011 at the Hannover fair by the German government, universities and private companies. In the literature, the definition of Industry 4.0 is often used as a strategic program for the development of advanced production systems with the aim of increasing the productivity and efficiency of the national industry (Xu et al., 2021, p. 530).

4 TYPES OF ARTIFICIAL INTELLIGENCE

In the relevant literature, artificial intelligence is mainly divided into narrow or weak and broad or strong. Examples of narrow artificial intelligence (Labbe & Wigmore, 2021): Image and face recognition systems; Chatbots and virtual assistants; Self-driving vehicles; i Models for maintenance planning.

Well-known authors emphasize that broad or strong artificial intelligence or systems are not intended to completely simulate artificial intelligence, but are designed to automate certain human tasks using machine learning, deep learning and natural language recognition (Labbe & Wigmore, 2021). This is followed by opinions that broad artificial intelligence should

therefore have cognitive abilities that can completely imitate humans. When a new task is presented to her, she can solve it independently using logic and knowledge from other domains. Broad artificial intelligence can also successfully pass Turing's test (Burns, Laskowski, & Tucci, 2022). Many advantages of applying artificial intelligence are cited in the literature. In this sense, Haleem (2022) as an advantage of using artificial intelligence, for example in marketing, states that neural networks develop dynamic tools for service providers that enable the processing of large volumes of data and provide more meaningful insights for better creation and understanding of perfect customer segments, marketing automation, content creation and предвиђаје продаје. Some authors highlight Industry 4.0 as a framework, that is, Industry 4.0, which is characterized by the integration of the physical and digital worlds, represents a new model of production that uses advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), robotics and large quantities Big Data. In the review of the literature on industry 4.0, some digital technologies are common: cloud computing, IoT, industrial LoT, big data processing, blockchain technology, cyber-physical systems, digital twin, artificial intelligence. New sophisticated technologies enable the creation of "smart" factories and business systems that are capable of independently optimizing their processes and adapting to changes in the environment (Schwab, 2016, p. 67). One of the characteristic definitions of Industry 4.0 was given by Carvalho & Cazarini (2020, p. 6), who define Industry 4.0 as an advanced production model that includes a set of technologies that are not necessarily new or are complexly integrated with each other. The most important thing is that Industry 4.0 combines the use of intelligent sensors, artificial intelligence and data analysis to optimize business and production processes in real time. Some authors dealt with the application of Industry 4.0, stressing that in the context of banking, Industry 4.0 enables the rapid adoption of new technologies that improve the user experience, increase the security and efficiency of financial transactions, and at the same time create new challenges, such as the need for greater data protection and adaptation to new regulatory requirements (Berman & Najt, 2024, p. 92). Experiences from practice indicate that the introduction of artificial intelligence, similar to the digitization and automation of business, brings with it the need to reorganize workplaces. Artificial intelligence can be used in the areas of cost reduction, product quality improvement, production process planning and many other areas. In the literature, it is stated that the digitalization process also creates new challenges, such as the security of cyber attacks and the regulation of new technologies within the framework of existing legislative and ethical frameworks (Brown & Jones, 2020, p. 56; Lee & Kim, 2020, p. 77) . The application

of artificial intelligence not only enabled the continuity of the message, but also created new message capabilities in the field of financial services, such as digital currencies and cryptocurrency (Gupta & Patel, 2020, p. 14). Digitization and Industry 4.0 represent transformative processes that shape the modern world. Industry 4.0 includes fundamental changes in the technological infrastructure that we already use today (Mubarak & Petraite, 2020, p. 1). In the literature, it is stated that the theoretical background covers different aspects, including information technology, internet creation, artificial intelligence, data processing and machine learning (Atwell, et al., 2022, p. 112). Research results in practice indicate that IoT can be well connected with other elements of Industry 4.0, such as Cloud production, cyberphysical systems, use of big data and artificial intelligence (Stojanović K 2024). Artificial intelligence can be divided into four different groups: - interactive artificial intelligence, - systems with limited memory, - theory of mind, - self-awareness. The following figure 1 shows 4 types of artificial intelligence.

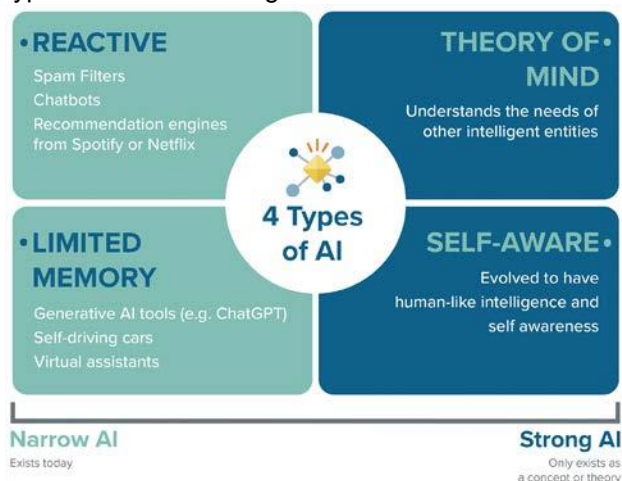


Figure 1 4 Type Artificial intelligences
Source Petersson 2021

The first two categories belong to narrow artificial intelligence, while the last two belong to powerful artificial intelligence, which has not yet been developed (Petersson, 2021). A device based on interactive artificial intelligence is not capable of storing data or relying on its previous experiences to make a decision in real time (Buitin, 2022). Reactive AI cannot build on prior knowledge or perform more complex tasks. Examples of this reactive machine artificial intelligence are IBM Deep BLUE, Netflix Recommendation Engine (Betz, 2024). Systems with limited memory due to their abilities represent more complex forms of artificial intelligence than interactive intelligence (Buitin, 2022). Examples of this artificial intelligence are chatbots and virtual assistants, as well as self-driving cars (Betz, 2024). In these systems, the basis for artificial intelligence is preserved data collected in the past (Petersson, 2021). Artificial intelligence certainly represents a new era in the development of information and communication technologies, as it brings numerous innovations and opens up possibilities for

the realization of previously unfeasible ideas. Since 2017, more and more studies have focused on artificial intelligence.

If the theory of mind were applied to artificial intelligence, it would mean that the system has social intelligence and can understand people's emotions. Emotional signs are so nuanced that machines with artificial intelligence would need a lot of time to fully read the emotions of others, which would lead to errors in the learning phase (Betz, 2024). Such artificial intelligence would have the ability to understand people's intentions and predict people's behavior, which is a key ability for AI systems to become integral members of people's teams (Burns, Laskowski, & Tucci, 2022). Примена теорије ума у образовању mentors use artificial intelligence with theory of mind to adapt to the individual needs of students, thus providing personalized learning experiences and emotional support (John, 2023). Artificial intelligence reaching the level of theory of mind would overcome current limitations (Petersson, 2021). Artificial intelligence theory of mind can improve the patient-physician interaction by understanding and responding to the patient's emotional states and needs. It can also support mental health monitoring and therapy (John, 2023). In fact, systems should be able to understand and process the concept of mind, changes in emotion during decision-making and other psychological concepts in real time, which could enable a two-way relationship between humans and artificial intelligence (Buitin, 2022). Chatbots and virtual assistants using AI theory of mind can better understand and respond to customer problems, leading to greater customer satisfaction (John, 2023). There is no doubt that artificial intelligence is one of the powers that has been intensively developing in recent years for the needs of both individuals and organizations. Drones and self-driving cars that have built-in theory of mind artificial intelligence can navigate complex traffic routes more safely and predict the intentions of other vehicles and pedestrians in traffic (John, 2023). Robots that have built-in theory of mind and artificial intelligence can help care for the elderly, people with special needs or children by understanding their emotions and providing appropriate assistance (John, 2023). Self-awareness - Such devices are at the level of popular intelligence, which they can even surpass (Burns, Laskowski, & Tucci, 2022). This type is one of the ultimate goals of artificial intelligence, because they believe that when artificial intelligence with self-awareness is achieved, AI machines will be out of control because they will have a sense of self (Betz, 2024). Self-aware artificial intelligence relies on how researchers understand consciousness and how to imitate and implement it in machines (Buitin, 2022). The closest progress that exists involves artificial intelligence that is able to learn from interactions and improve over time, or true self-awareness is the goal to be achieved (senek, 2024). We currently know too little about the functioning of the human brain to be able to create a system that

would be so intelligent (Petersson, 2021). In the future, self-aware artificial intelligence will transform industries such as health care, environmental management, and personal assistance through innovation: medical diagnostic systems, environmental bots, and personalized learning assistants. On the other hand, we must be aware that the development of artificial intelligence, similar to the development of ICT technology, opens up many new professions and jobs that did not exist in the past. The literature mentions machine learning, natural language processing and deep learning for artificial intelligence automation as key techniques that transform business. In this context, each technique plays a key role in improving decision-making, optimizing performance and driving innovation (Franklin, 2024). Machine learning has been identified as one of the main factors of the transition from traditional industry to Industry 4.0. The research results indicate that the integration of AI into business systems and companies can be studied at the level of the entire organization, it can also be studied at the level of individual functions or departments present in organizations. Industry 4.0 refers to the integration of information and communication technologies in the production process, which enables the creation of memory factories and systems (Thaduri, Aljumaili & Kour, 2019, p. 86). Artificial intelligence with technologies such as industrial IoT, big data analysis, cloud computing and cyberphysical systems help businesses by making business operations more efficient in terms of using business resources, faster and in a more efficient manner. This is followed by the views of the author who emphasize that Industry 4.0, marked by revolutionary technologies such as the Internet of Things, artificial intelligence, blockchain technology and big data, brings significant changes to all sectors, especially the financial sector (Schwab, 2016, p. 32). Essentially, the idea of cyber-physical systems, where virtual and physical worlds intertwine and create, is the basis of these concepts. AI develops and learns through experiences that are stored and based on experiences from which a spontaneous reaction is later established in the same situations. When it comes to fixed or repetitive processes and tasks, artificial intelligence can be very efficient and can replace humans. In this respect, it can be said that the key elements of these processes include artificial intelligence that enables machines to learn and adapt, internet devices that connect devices and systems, and cloud technologies that enable access to data from anywhere in the world (Atwell, et al., 2022, p. 134). Research results indicate that artificial intelligence systems can drive several types of business automation, such as enterprise automation and process automation, which help reduce human error and release human labor at a higher level (Goodvin & Quiroz Vazquez, 2024). The consequences of the integration of artificial intelligence in companies and business systems can already be seen, but it will be even more visible in the future, when many

organizations will integrate artificial intelligence into their workplaces, which will replace many employees and robots with integrated artificial intelligence, which will be increasingly present. However, practice shows that with advanced technology comes challenges such as data privacy, information security and ethical issues related to the application of artificial intelligence. For this reason, some authors state that it is important to follow the latest trends in this field and to develop an appropriate strategy for managing the process (Taalbi, 2019, p. 47). Artificial intelligence has various advantages that require the integration of technology and human labor, thereby improving operational efficiency and driving business value (Goodvin & Quiroz Vazquez, 2024). All in all, the theoretical background of artificial intelligence, digitalization and Industry 4.0 covers a wide range of concepts and technologies that have the potential to change the way different industries and business companies function. What is the character of these technologies and the ICT sector in society is best expressed by the estimate that today in Serbia more than 115,000 people with an average income of more than 2,000 euros work in the ICT sector. Research in practice shows that the processes of processing increasingly large amounts of business data and the application of information technology have gradually spread through almost all sectors and all aspects of business are aimed at automation and greater efficiency. The results show that Serbia's current export of the ICT sector is close to 4 billion euros. The most important thing for this progressive evolution of business is continuous technological development. Some authors state that artificial intelligence tools also enable marketing segmentation and strategies for adapting marketing campaigns to customers based on their interests (Goodvin & Quiroz Vazquez, 2024). While others emphasize that Industry 4.0 will especially affect production because a large number of new technological innovations can be applied to production, storage, operations, manipulation, etc. (Vendrell – Herrero, et al., 2024, p. 88). In this sense, this revolution also improved the functioning of financial markets, accelerated the development of media and transport, and facilitated global integration through globalization (Carvalho & Cazarini, 2020, pp. 6-7). Interview tools such as IBM Watson Assistant help chatbots to overcome some of the problems of the previous problems that could not answer many questions of customers (Goodvin & Quiroz Vazquez, 2024). Based on the review of the literature and research in practice, it is noticeable that artificial intelligence, Industry 4.0 have been hot topics in recent years, but they certainly do not represent a new concept. Some authors state that the process of creating content using artificial intelligence is still largely unregulated, so employees must monitor the use of artificial intelligence in content creation in order to prevent copyright infringement, publication of false information and other unethical business practices

(Goodvin & Kuroz Vazquez, 2024). Viewed chronologically, the process of technological transformation can be traced differently through the history of mankind. For example, 40 hours ago, the Internet was invented or 570 hours ago, Johannes Gutenberg invented the stamp. Although this invention was invented in China long ago, Gutenberg's invention is still more acceptable to the western world (Atwell, et al., 2022, p. 123). Regarding the use of the position, the authors emphasize that the increased use of technology in the workplace represents a greater potential for security solutions. Organizations must be proactive in detecting irregularities in order to prevent threats and protect organizational and user data (Goodvin & Kuroz Vazquez, 2024). In this sense, Industry 4.0 represents a new, disruptive model, as it affects changes in the competitive environment, business models and existing processes. Forecasts are that the development of artificial intelligence in Serbia by 2030 will have an impact of more than 15 percent on the global growth of the gross domestic product. In the literature, it is stated that industry 4.0 logically follows the previous three industrial revolutions and means a rapid digital transformation of the process in the frame of processing and manufacturing industries (Atwell, et al., 2022, p. 130). When talking about the future of artificial intelligence, it is obvious that it will dictate new technologies and innovations. In this context, companies must understand the adaptation of artificial intelligence, as this is the key to maintaining a competitive advantage (Goodvin & Kuroz Vazquez, 2024). It is known that the transformation of business is based on the intelligent networking of machines using advanced information and communication technologies, with the aim of enabling autonomous communication between devices, analysis and purchase of large amounts of data, autonomous delivery of decisions, requests for status in real time, as well as the creation of additional risks (Gartner, 2021, p. 85). Companies today are faced with huge amounts of business data, however, companies cannot take advantage of this huge amount of stored data without the help of artificial intelligence. For example, large data sets are processed by deep learning to identify subtle patterns and correlations that can provide companies with a competitive advantage (Tucci, 2024). The director of the organization Data Science Conference, Aleksandar Linc Đorđević, states that Belgrade ranks third in Europe in the development of artificial intelligence, just behind London and Vienna. As noted by Ghosh et al (2019), the use of AI in larger organizations has increased by more than 70% in recent years, but according to research, as many as 80% of large organizations are already actively incorporating the use of AI. their operations (Ghosh et al., 2019) The current projection that the value of the artificial intelligence market is almost 500 billion dollars and the use of this technology in the next few years could increase the world GDP up to 4,400 billion dollars of new value speaks volumes for the importance of this

authority. , of which 1,000 billion can be created only in banking. In this context, according to the report of the European Commission: artificial intelligence will significantly contribute to the automation of 14% of jobs, while another 32% of interest will experience major transformations. Projects and procedures for the introduction and implementation of artificial intelligence in business have their own specificities and key success factors. When introducing artificial intelligence in the company, it is very important to adhere to appropriate implementation methodologies, choose the right tool, prepare your team for the efficient use of artificial intelligence and plan the implementation strategy. It is also necessary to ensure that the integration of artificial intelligence corresponds to the specific company or organization. Here are some steps for implementing artificial intelligence (Demkovič, 2024)



Figure 1 4 Type Artificial intelligences
(Demkovych,2024)

3 RESEARCH METHODOLOGY

For the purposes of research, the relevant literature, published scientific articles, conducted studies and other sources relevant to artificial intelligence and Industry 4.0, or the research problem of our work, will first be reviewed. This information was then analyzed, using a descriptive method with the aim of summarizing the key results that were reached by reviewing the literature. In this sense, with the intention of summarizing the views of the author, the method of compilation was used, which means that different opinions and views of the author are combined and summarized. In addition, a comparison of relevant research studies of artificial intelligence and Industry 4.0 was made, which enables the application of the comparison method in this work. This made it possible to identify potential similarities, differences, and trends between different studies, thus providing a more comprehensive picture of the research problem. In the empirical work, the methods of surveying and summarizing data using statistical methods are used, with the result being explained in a meaningful way and connected with each other.

5 NEW TRENDS IN ARTIFICIAL INTELLIGENCE AND INDUSTRY 4.0

Research results in practice indicate that as companies and organizations began to accept Industry 4.0, the fifth industrial revolution also appeared (Xu, et al., 2021, p. 530). In the context of Industry 4.0, the goal is the transition to intelligent or smart production. The very term Industry 5.0 was introduced by the research authorities that are considered the next industrial revolution. The integration of artificial intelligence in the organization is most often achieved through the use of various tools, applications and intelligence systems that have integrated artificial intelligence, which ensures the optimal functioning of such tools, systems and applications, which ensure the improvement of the entire company. According to some authors, this is a systemic transformation that includes an impact on civil society, management and structures, and popular identities, in addition to purely economic and production consequences (Vaidia et al., 2018, p. 238). In addition to the above with artificial intelligence, machines will be able to learn, think and act in the same way as humans, which will contribute to greater automation and problem-solving abilities (Glover, 2024). One of the basics of business improvement is the integration of new technologies with operational activities, which leads to increased effectiveness and efficiency of business and stronger organization of production. In this respect, modern society is largely looking to federal and business regulations on artificial intelligence to help guide the future of technology (Glover, 2024). Many internal and external factors, such as legal regulations, financial pressures, changes in consumer habits, social and cultural aspects, etc., exert direct pressure on business operations and business decision-making processes. In this respect, the application of artificial intelligence is very useful. In this context, the well-known author Greval (2021) states that the main positive aspect of the use of artificial intelligence in marketing is the adaptation of offers for buyers, which increases the value for sellers and reduces search costs, facilitating the creation of customized offers at the right moment and at the right stage of the purchase process in the B2C environment. where there is a large number of buyers, that ensures the extraction of consumer surplus and reduced search costs for customers. However, despite the fact that AI is becoming more and more powerful and is now able to perform many tasks that only humans could do in the past, especially due to the advanced learning and programming capabilities of AI, the fact is that the "real" human contact will continue to be which will be needed in many places and will continue to be the key to success. The transformation of business models as part of Industry 4.0 results in improvements that lead to increased profits, reduced costs, improved user experience, innovation, etc. (Gartner, 2021, p. 90). In today's era, it is almost impossible to find an organization that does not use information and communication technology in its operations. Many

organizations have digitized their operations and fully supported them using ICT technology. According to some authors, the difference compared to the previous industrial revolution was not found in the invention of a new technological product that changed the world, but rather in the upgrading of existing systems that fundamentally changed the functioning systems of primary production, but also other related businesses (Taalbi, 2019, p. 45). The results in practice indicate that the use of artificial intelligence for the enterprise also brings large amounts of revenue, and it is also important to note that the demand for skills such as data science, natural language processing, computer science and deep learning techniques is extremely high, while the supply of talented печенняка у тим областима контакти. It is interesting to note that Serbia is the world leader in the number of women involved in artificial intelligence and computer science, with a figure of around 40%, while the next country in the world is Finland with only 24%. In our environment, in professional circles, there is a prevailing opinion that in the fourth industrial, that is, digital revolution, we have a chance to catch up and catch up with the developed world. In this direction, Serbia will invest 100 million euros in the development of artificial intelligence in the two years ending in 2026. In view of the extremely dynamic development of information technologies, companies and organizations are forced to focus their business processes on the integration of digital tools that enable better efficiency, faster and cheaper performance of everyday activities, as well as personalized services (Berman & Najt, 2024, p. 82). . For the successful and efficient integration of artificial intelligence as well as technology in general, as well as for the successful digital transformation of organizations, it is naturally necessary that technology be presented to employees as a tool for easier and more successful work, but not as a substitute for it. As for investing in new technologies in our environment by 2026, Serbia is planning to invest 30 million euros in another supercomputer, which will be free for researchers and startups, 20 million euros in software for the public sector, primarily in healthcare, energy and transport, as well as 30 million euros for incentives for the development of artificial intelligence. AI is already very powerful today and can perform individual tasks that would otherwise be performed equally by employees, but it can perform certain tasks significantly faster and more accurately (Stojanović J

2024). The Government of the Republic of Serbia is financing 35 projects in this area for a total of less than 2.5 million euros in the function of the development of the artificial intelligence project. Also, as far as education in this field is concerned, 7 master study programs in the field of artificial intelligence are accredited at 6 faculties. In parallel with the intensive development of ICT technology and advanced technological solutions, as well as the digital transformation of organizations and the economy, AI is also developing intensively. In the world framework, there is currently a current initiative by SAD, which announced that three leading companies will invest significant funds in the infrastructure for artificial intelligence. OpenAI, SoftBank and Oracle will form a joint venture called Stargate, with an investment plan of 500 billion dollars. In all cases, AI technologies are unrelated to other emerging technologies. As with any new introduction, there were many challenges in implementing artificial intelligence technologies. The most common are: technical problems, confirmation of the effectiveness of the artificial intelligence system, data security and others.

CONCLUSION

The intensive development of information and communication technology has also brought with it the development of artificial intelligence. As part of the Industry 4.0 initiative, artificial intelligence is embedded in production systems to support planning, management, and execution processes and take initiative and responsibility for real-time decision-making. Although a generally accepted definition of artificial intelligence (hereafter AI) does not (exist) yet, artificial intelligence could be defined as the ability of a non-human factor (e.g. machine, robot, etc.) to exhibit characteristics that are otherwise characteristic only of humans (such as thinking, learning, planning, creativity, innovation, etc.). By introducing advanced technologies such as Internet of Things (IoT), artificial intelligence (AI), Big Data, cloud computing and blockchain, banks are able to radically transform their business model, improve their operational processes and create new features for your users. With the help of artificial intelligence, technical systems and other devices become capable of sensing events in the environment, analyzing them and solving problems that arise. The idea is that artificial intelligence can solve more demanding tasks, using machine learning to analyze and monitor changes in the environment and at the same time adapt to new circumstances and environments. Based on the research, it can be concluded that companies have not implemented artificial intelligence due to a lack of experts and do not see a clear benefit from implementation. Systems supported by AI integration are able to analyze their previous actions and their effects and adjust their future behavior based on the analysis. However, it is

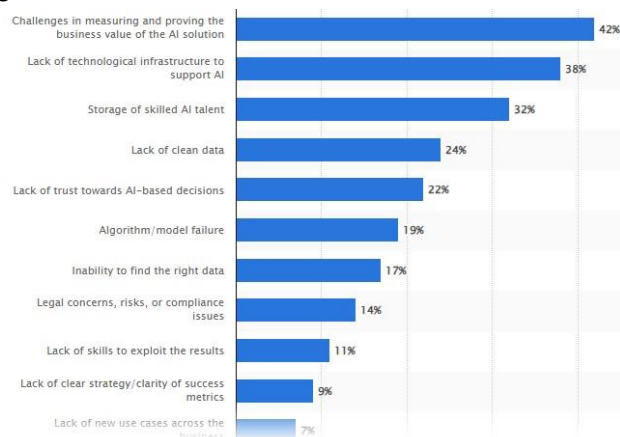


Figure 3 Leading challenges in implementing artificial intelligence (AI) initiatives in businesses in 2023 Artificial intelligences
<https://cdn.statcdn.com/Statistic/1445000/1447886-blank-754.png>

difficulty in generating new ideas and concepts that bring important to be aware that artificial intelligence lacks creativity and innovation and will have competitive advantage to the company.

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Malware attacks on public data of smart cities

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Abstract: Public data in smart cities is frequently targeted by malware. Protecting such data represents a serious threat, as basic security services, individuals, and the functionality of the system itself are at risk. Malware attacks are a growing threat due to the complex technologies used. Open data is utilized to improve the management of urban systems and increase efficiency. With the help of advanced technologies such as artificial intelligence, encryption, blockchain, and security measures, smart cities can enhance system protection and reduce the risk of attacks. This paper analyzes public data in smart cities, the types of attacks on public data, and how malware attacks affect it.

Keywords: malicious software, open/public data, attacks, smart cities

1. The role of Open Data in Smart Cities

Public or open data is inevitable in the development of smart cities, enabling transparency, improved services, and better interaction between citizens and authorities. Here are some aspects of their role from [1]:

Increasing transparency and accountability: Open data provides citizens with access to information about city governance, thereby increasing the accountability of local authorities. Citizens can monitor decisions related to public spending, projects, infrastructure, and other aspects of life in the city.

Data on energy consumption, transport, pollution, waste and other elements enable city authorities to better manage resources and use them more efficiently.

Open data provides an opportunity for innovation, enabling private companies, start-ups and researchers to develop new applications, services and products that improve the quality of life of citizens. These include applications for monitoring public transport, energy management or optimizing resource consumption.

Data usage for analysis and decision making could lead to better living conditions. For example, air quality data can help predict pollution and implement preventive measures.

Open data on energy, water resources, and pollution can be used to guide environmental initiatives, reduce carbon footprint, optimize consumption, help to understand the warnings and the nature of the appearance and implement sustainable practices in the daily lives of cities.

Open data can improve the interaction between citizens and authorities, allowing citizens to contribute to decisionmaking. Citizens can use the data to make proposals, report problems (e.g., accidents, infrastructure failures) and actively participate in policy making.

Connectivity and integration of different systems: Public/open data enables the connection and integration of different city systems (e.g., transport, utilities, health, education) into a single ecosystem, which helps better coordination and efficiency in the functioning of the city.

1.1 Example of successful implementation of a smart city

Copenhagen is known for its focus on sustainability and smart city initiatives. It can be read in the paper [2] that the city has implemented smart traffic management systems to reduce congestion and improve air quality. Copenhagen also uses a smart grid to optimize energy consumption and support renewable energy sources.

2. Types of malwares targeting smart cities

Malware that targets open data has a specific goal – to steal, damage, or manipulate that data. These attacks can have a wide range of negative effects on individuals, organizations, and society as a whole. Below I will describe a few types of malwares. We will focus only on a few of them, so as not to expand the focus of research on them too much or possibly reduce the emphasis from smart cities.

2.1 Data manipulation malwares

In smart cities, data manipulation malware can be a serious security risk. These cities rely on internet connected (IoT) technologies and big data to manage infrastructure and services. It follows that protection

against such threats is crucial to ensure the security and efficiency of city systems.

The goal of such malware can be to alter or falsify data in order to create confusion or to sabotage various operations. As an example, we can cite a disruption in the functioning of infrastructure, a change in traffic data [3] to cause a traffic jam or divert the flow of vehicles.

2.2 Malwares for information stealing

Malware of this type is designed to gain

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unauthorized access, collect, and steal sensitive data from centralized databases, such as citizen or infrastructure data.

Depending on the type of malware, we can talk about a trojan that is copied everywhere in the system later to exploit the vulnerabilities of the attacked systems, or they can have the general purpose of copying events from the system, perhaps stealing data from the population that can be useful for attackers, as well as to collect confidential data/information. In some cases, they take control of the infrastructure and demand large ransoms. We can also include rootkits, which can camouflage their existence and thus serve as a point of transmission of all types of data.

2.3 Data-deleting malwares

This type of malware deletes data from your computer or network. This can cause serious damage, especially if this will no longer give you the ability to recover your data.

As a goal of such data manipulation, we can emphasize the threat to the functioning of a (critical) system/city services. If it deletes key configurations, any type of system could be in malfunctioned state because of it. They spread in many ways, through emails, web pages, USB drives, SD cards, and so on, as the authors of the paper [7] described.

2.4 Malwares spreading disinformation

They have been successfully used to spread misinformation and manipulate public opinion, create false reports or statistics. This type of attack may be becoming more and more popular. The list [6] can serve as a good source of information about the attacks. IoT devices, mentioned in articles [1][4], are very prevalent in smart cities, so they can even control traffic, but they have a multitude of purposes.

Various statistics [8] show that as technologies advance, both attacks and types of attacks are becoming more and more frequent and that it is necessary to use and prepare for the same with existing solutions that include artificial intelligence capabilities.

3. Impact of the attacks on smart cities

Attacks has always been, and always will be. The implicit aspects are, at the very least, the functionality or safety of urban systems. Smart cities use various

technologies such as the Internet of Things (IoT), automation, sensors, and other digital tools to improve the quality of life of their citizens and optimize city services. However, these systems can be vulnerable to malware attacks.

Impacts occur in various forms, such as disruptions in the functioning of services. Changes to weather conditions may affect airports or public transport. Eventually, if it comes to reading temperature data, they can affect the choice of citizens' wardrobe.

Such unrealistic data can lead to a loss of trust in the public data. I'm sure you've all been disappointed at times because of weather forecasts that are inaccurate for some reason. If the data is unreliable or subject to manipulation, citizens can lose trust in the city's smart solutions.

There are also financial losses. The stock market data is also public. What would happen if we got the wrong information about the stock market in a certain time range? There are too many changes happening from second to second, this can obscure the true state of affairs and misguide brokers in the next steps. Compromised data can lead to direct financial losses through ransomware or indirect costs due to service downtime.

In addition to all of the above, it may happen that some data is open but should not or leak due to some attack. Inadequate data protection can lead to legal consequences for the city administration, various companies that have guaranteed the security of the same.

4. Attack methods

The types of attacks are most distinguishable from the types of malwares [9]. There are many types identified separately today, and so the ways in which different systems are infected.

A 2023 survey provides the following taxonomy [10] of attack patterns:

Polymorphic and metamorphic attack, ransomware attack, fileless software attack, advanced persistence threat (APT), zero-day attack. This is just one in a series of categorizations of the same, we will stick to this distribution in the continuation of the work.

4.1 Polymorphic and metamorphic attack

A polymorphic attack, as the name implies, occurs in a variety of forms. The strategy of the software itself is to constantly change shape and can take the form of trojans, viruses, worms, bots, or keyloggers. For the same reason, it's hard to catch. In this way, the goal of execution remains the same, which is to avoid detection programs [14].

In a metamorphic attack, the malware is more complex, completely altering its code each time it executes and making replicas of itself.

The attack consists of 5 steps, the initial access is made using an email, a malicious link, or compromised

4.3 Fileless software attack

This attack does not use traditional files that could be detected and analyzed by antivirus programs. It uses existing tools, processes, and resources within the infected system to perform its malicious actions. They often rely on legal tools and already present processes in the system.

This is a sophisticated form of malware that allows attackers to gain access to systems and remain undetected an extended period of time.

The attack consists of 5 steps, the initial access is made using an email, a malicious link, or compromised

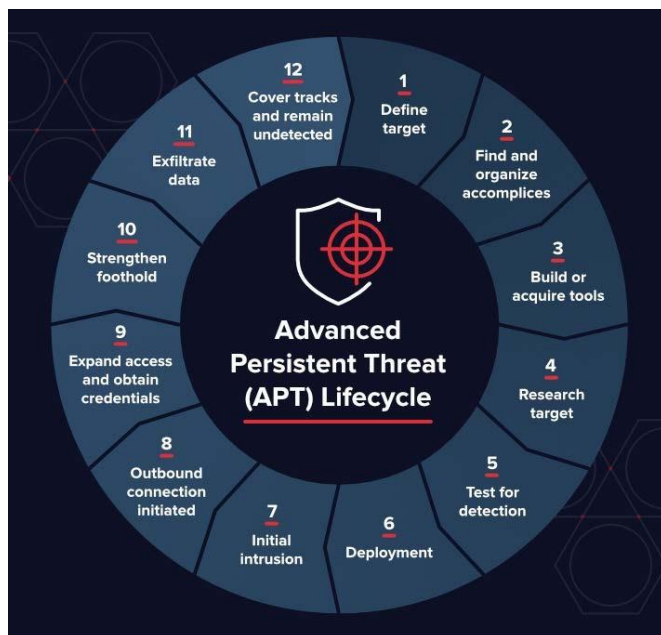


Figure 2: The life cycle of an advanced persistence threat [12]

Given that internal applications or tools within the operating system are used, they are very well camouflaged and difficult to detect.

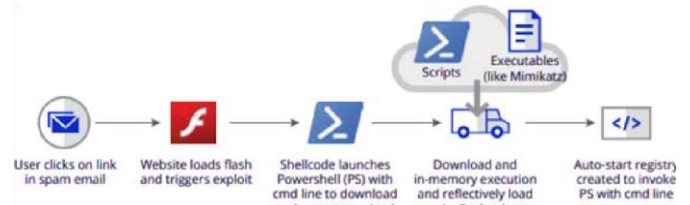
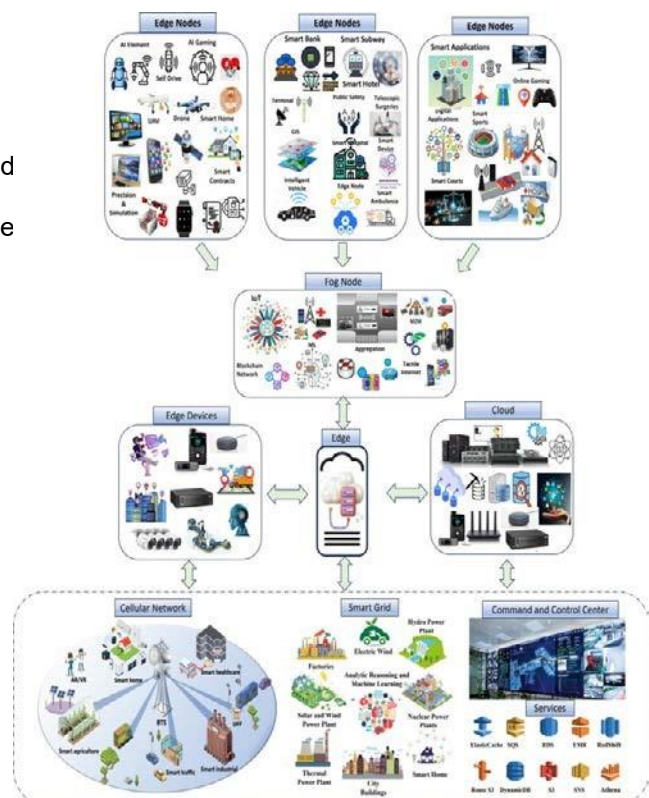


Figure 3 Security requirements of computing in smart cities



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Their potential targets are intellectual property, confidential data, personal information, infrastructure data, access credentials, sensitive or incriminating communications, and to remain in someone's system for as long as possible.

The most well-known attacks of this kind are Stuxnet, Flame, Duqu, and Project Sauron.

4.5 0day attack

Zero-day attacks have an element of surprise because they were previously undetected; [16] An attacker embeds a zeroday exploit into their planned list of vulnerabilities that they carefully scoured through lines of code for hours, weeks, or even months to discover these flaws. Once they are found, they integrate the zero-day exploit into their planned vulnerability list. After creating a penetration and planned spectra of the program, they launch their attack, catching their targets off guard.

Cyber attackers use a variety of techniques to carry out zero-day attacks, such as social engineering phishing, spamming and phishing, various messages alluding to unpaid or unsuccessful payments to various services, the technique of embedding exploitation tools in advertisements and malicious websites, and infecting computers, networks, or servers.

5. Protection strategy

In the daily pace of growth and the emergence of new technologies, technological advances, there is no universal form of protection of any system.

5.1 Tehničke mere

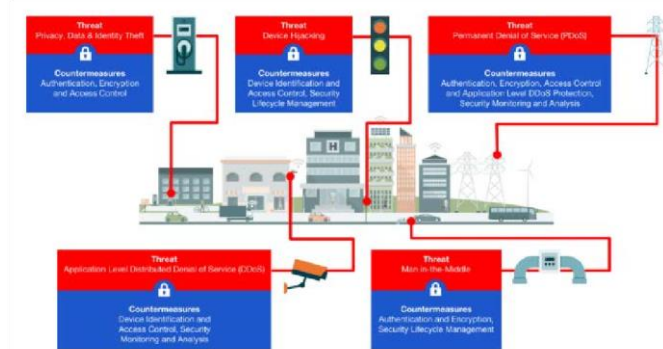


Figure 4: Smart cities and countermeasures [17]

5.1.1 Encryption of the data

The privacy and security of data is ensured by encrypting it when it is sent over the network. Encryption is the process of converting data into an unreadable format that can only be restored to its original form using a specific key. Without this kind of encryption, any third party could easily get access to sensitive information. The goal of this technique is to ensure that only those who need access to the content have access. We could extend this topic to different types of encryptions, to encryption algorithms, to the use of data encryption, and so on. These topics are present everywhere in everyday communication. **5.1.2 Network segmentation**

By using the exact same network, we can make it easier to attack the internal network. By segmenting the network, we isolate parts of the system and thus increase security. Open data systems should be kept separate from critical parts of the system. This approach reduces the risk of the attack spreading to the entire system, as attackers who compromise one network segmentation will not automatically have access to other segments.

5.1.3 Regular software updates

We are talking about updates that address known vulnerabilities. If there is a known problem/vulnerability in a system, each new update can resolve the vulnerabilities. Delaying it can expose devices to attacks that use the previously mentioned vulnerabilities.

5.1.4 Malware detection tools

Use advanced tools to identify and remove the malwares. In order to successfully examine or catch a threat, it is necessary to use behavioral analysis techniques, heuristic scanning, and so on. Often, the tools are also integrated into other systems, such as attack protection or network monitoring, to ensure a quick response to potential threats.

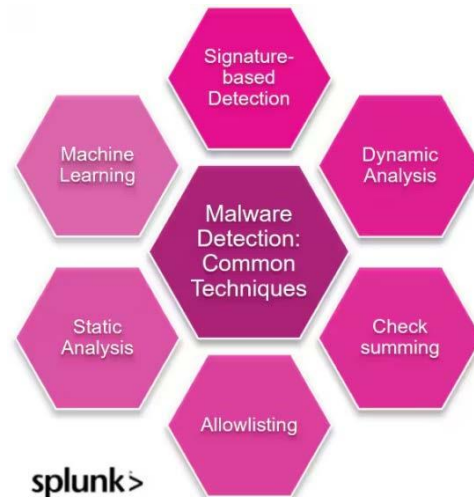


Figure 5: Smart cities and countermeasures [18]

There are many solutions, including VirusTotal, Malwarebytes, Windows Defender (Microsoft Defender), antivirus products such as Kaspersky, Sophos Intercept, Eset Nod32, RougeKiller and many others. They are all powerful tools, and it's hard to choose which one would be the most useful. There are also comparisons on the internet of these tools. That might make it a little easier for us to choose. There is no need to underestimate the importance of products that are based on AI or blockchain technology. More and more of them can be found on the market, and with the help of various agents, various automations of the same can be defined.

5.2 Forensic analysis

It's a form of computer analysis. It consists of a process of investigation, identifying the mode of attack, the impact of it, and analyzing the evidence. It should be carried out when a security incident has occurred or when there is a suspicion that data has been compromised.

Access Tracking: Collect all requests for access to data to detect suspicious activity and identify threats. Access controls are also checked here, and if there are forensic leads. Some of the well-known tools for the same are Splunk or Ossec.

Attack Reconstruction: Digital forensics can help identify the source of an attack and the data affected. It needs to be fully clarified how and where the attack began, how it developed, and of course what consequences it caused. Tools for the same are EnCase, FTK, Wireshark, and others. It leaves the reader's curiosity at all times to explore or become interested with any of the tools not mentioned in the work.

Expert/General Understanding Training: Developing the capacity to respond quickly to attacks. There is no single way to do it, but the internet has become a good place to find material. Various organizations and individuals offer retraining/upskilling in the cybersecurity field in general. Increasingly,

companies or organizations are hiring in-house people to cover security.

5.3 Legal and procedural approaches

Data Management Policies: Clearly defined policies on the collection, processing, and sharing of data. There are different types of regulations such as GDPR, CCNA, and all of them are very defined and

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control a specific territory. Nowadays, there is a lot of emphasis on them and it is necessary to take into account the rules set out in the regulations. More on this in the paper under [20].

Public Education: Informing citizens and organizations about the importance of cyber security. Depending on the form of the company and the way of working, internal trainings can also be organized. In this way, people can be prepared for some cybersecurity challenges.

6. Case studies

Attack on San Francisco's public transportation system (2016): Hackers attacked the San Francisco City Transportation Agency. The ransomware attack has disabled access to timetable data. During the attack, more than 2,000 computers were locked and 100 bitcoins were demanded for ransom. It was worth about \$73,086. The transport company did not make a statement as to whether it ultimately paid the ransom or simply allowed their data to be lost [19].

To minimize the impact of the attack, the company has given everyone a free ride.

A surveillance camera system was infected in China (2021): They found a database that was exposed to the entire internet, and no password or any additional authentication was required to access it. The same database contains gigabytes of facial recognition data from hundreds of people and the rest of the important information from a couple of months of camera research. It has triggered a negative wave of opinion in general about the use of facial recognition systems.

Tampa Bay Irrigation System Attack (2021): Hackers tried to play around with the levels of chemicals in the water. In this case, the attack was quickly detected and they were able to prevent great trouble caused by the presence of various chemicals in drinking and technical water.

Many other examples can be found in the article [21] and in articles on the Internet in general. Probably all possible cases have not yet been identified.

7. Conclusion

Malware attacks on smart city open data are a serious threat that requires an integrated approach to protection. Newly developed solutions using an artificial intelligence model, or a blockchain solution with a high

level of security, should not be underestimated. In addition to technological solutions, it is crucial to improve legal frameworks, citizen education and cooperation between the private and public sectors in order to effectively respond to these challenges.

Even the slightest flaw can create an opportunity for attackers to get their hands on important data, or worse, to manipulate a population of people.

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UDK:

37.091.313-057.875
711.45:004.78

DOI: 10.46793/ALFATECHproc25.096D
Original scientific paper

Project-Based Learning in Smart House Development: Artificial Intelligence and IoT Technologies for Efficient Living

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Abstract: This paper examines the application of project-based learning in the development of smart houses, emphasizing the integration of artificial intelligence (AI) and Internet of Things (IoT) technologies to enhance efficiency and comfort in daily life. Through project-based activities, students acquired technical skills such as programming, working with sensors, and implementing machine learning algorithms, alongside soft skills like teamwork and problem-solving. The evaluation of the results revealed significant improvements in students' understanding of STEM (science, technology, engineering, and mathematics) concepts, as well as increased motivation and engagement throughout all stages of the project. The use of the Multi-Role Project (MRP) model facilitated the combination of practical engineering tasks

with reflective learning processes. The findings indicate that such projects not only enhance students' competencies in STEM fields but also prepare them to contribute to the advancement of smart cities and sustainable technologies.

Keywords: Project-based learning; smart house; artificial intelligence; IoT; STEM education; sustainable development; smart cities;

1 INTRODUCTION

Smart cities represent a vision of the future where technology is used to improve the quality of life, increase energy efficiency, and reduce the negative impact on the environment. They integrate advanced technologies such as the Internet of Things (IoT), machine learning, and sustainable urban practices, creating an environment that is not only technologically advanced but also environmentally sustainable. A key challenge lies in educating new generations to acquire the competencies needed to contribute to the development of such communities.

In this context, project-based learning stands out as an innovative and effective educational approach, enabling students to integrate theoretical knowledge with practical skills by working on real-world problems. Through this method, students not only solve technical tasks but also develop critical thinking, collaborative skills, and creativity — all key attributes needed for the future.

As research shows [1], [2], project-based learning contributes to increasing student motivation and developing multidisciplinary skills. Its application in STEM education allows students to confront real challenges, using technology and innovation to develop solutions [3]. Additionally, integrating the concept of smart cities into educational projects, as analysed in [4], further highlights the potential of this approach in the context of sustainable development.

This paper explores the potential of project-based learning through the analysis of the "Smart House" project, conducted in collaboration with students. The aim is to demonstrate how this approach not only fosters individual and team competencies but also prepares students for active participation in creating sustainable and technologically advanced urban communities.

2 THEORETICAL FRAMEWORKS

2.1 Fundamentals of Project-Based Learning

Project-based learning is based on the principles of learning through real-world projects, where students actively explore, ask questions, and solve problems. This approach enables the integration of theoretical and practical knowledge, developing critical thinking and collaboration skills [1]. Dewey emphasized that education should be centered on the child, fostering experiences that are connected to their interests, needs, and real-world applications. This perspective forms the foundation for experiential and project-based learning, where students engage actively in solving practical problems [5]. The benefits of project-based learning include increased student

motivation, better understanding of complex topics, and the development of 21st-century skills such as communication and creativity [2].

2.2 Project-Based Learning and STEM Education

Integrating project-based learning into STEM education provides students with the opportunity to apply knowledge from multiple fields through interdisciplinary projects. According to [3], this approach allows students to understand the connection between science and technology and everyday life while simultaneously developing practical skills.

The MRP model, developed by [2], offers an additional framework for implementing project-based learning in STEM education. This model relies on the concept of learning through real projects and includes two parallel processes: an engineering project, where students create tangible products, and learning through the project, which encompasses reflection and the development of professional skills. The MRP method has proven particularly effective in developing teamwork, communication, and technical competencies, as well as in preparing students for real challenges they will encounter in professional environments. **2.3 Smart Cities as an Educational Context**

Smart cities use technologies such as the Internet of Things (IoT) and machine learning to enhance infrastructure and sustainable development [4]. The integration of machine learning allows for the optimization of urban resources, such as energy grids, transportation systems, and waste management. These technologies not only improve efficiency but also contribute to reducing the carbon footprint, making them key elements in sustainable development.

In education, projects related to smart cities provide students with the opportunity to apply knowledge in creating innovative solutions to urban challenges. For instance, the "Smart House" project involves designing systems for household automation, which not only develops technical skills but also raises awareness about the importance of energy efficiency and sustainability. By applying methods such as project-based learning and interdisciplinary education, students acquire competencies that are crucial for contributing to the development of such cities in the future.

It has been emphasized that the use of machine learning in smart cities not only enhances infrastructure but also enables students to explore the potential of new technologies through practical applications in real situations [4]. Such projects allow young people to understand how theoretical knowledge can be used to address global challenges, such as urbanization and climate change.

3 METHODOLOGIES

3.1 Educational Context

The "Smart House" project was implemented within the course *Applied Information Technologies* at the Technical School in Čačak. The project involved fourth-year students from the *Information Technology Electrotechnician* program. The course covers topics such as programming, web programming, an introduction to artificial intelligence, databases, and technical documentation. The project was carried out as a collaborative effort, with multiple teachers contributing based on their areas of expertise, ensuring students received comprehensive guidance across various disciplines.

When selecting the project topic, care was taken to cover as many of these topics as possible, allowing students to integrate theoretical knowledge with practical skills.

The project encompassed the following areas:

- Programming: Developing technical solutions using Arduino microcontrollers, sensors, and programming tools,
- Web Programming: Creating applications for remote control of smart house functions,

- Artificial Intelligence: Applying AI algorithms for license plate recognition and security control,
- Databases: Managing and storing data collected through sensors,
- Technical Documentation: Documenting all project phases, including planning, implementation, and evaluation.

Through project implementation, students acquired various skills, including:

- Technical skills: Development of hardware and software solutions, working with tools like the Arduino platform and MIT App Inventor,
- Communication skills: Presentation of results and team coordination during different project phases,
- Problem-solving: Addressing technical challenges through an iterative process of testing and evaluation.

3.2 Project Plan: "Smart House"

The theme "Smart House" was chosen due to its relevance to the concept of smart cities, which are essential for the sustainable development of urban environments. According to [4], smart cities integrate technologies such as machine learning and the Internet of Things (IoT) to optimize resources and increase efficiency. The "Smart House" project provides students with an opportunity to explore and apply these concepts in everyday life, thereby developing technical and analytical skills.

The research question was:

"How can we design and implement a smart House system using artificial intelligence and IoT technologies to enhance functionality, safety, and user comfort, in line with the principles of sustainable development?"

The project plan and implementation were structured into multiple phases, integrating various topics from the course *Applied Information Technologies*. The phases included:

- Initial Design: Students explored available technologies, such as light and temperature sensors, considered technical feasibility and costs, and created initial sketches and ideas,
- Prototype Development: Using the Arduino platform and sensors, basic modules for light and temperature control were developed,
- AI System Integration: Algorithms for facial recognition and security features were implemented, along with integration with cameras for enhanced safety,
- Mobile Application Development: Using MIT App Inventor, students created an application for remote control of smart house functions, including lighting and temperature,

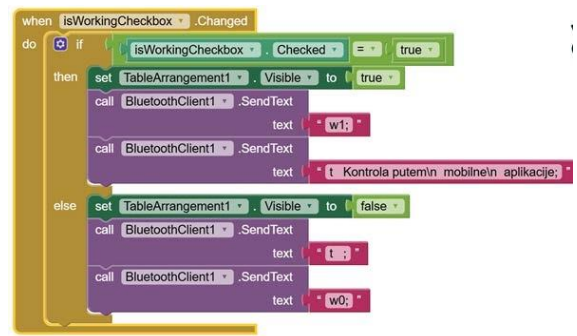


Figure 2 A section of the code for Bluetooth connection

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Figure 1 The webcam recognizes the license plate and opens the garage door

4.4 Mobile Application Development

Students designed a mobile application to interact with the smart systems using MIT App Inventor, as shown in Figure 2. They created an interface that allows users to manage smart house functions, such as lighting, temperature, and energy consumption. The application also enabled Bluetooth connectivity with the Arduino Mega board, providing remote control. Added functionalities included real-time alerts, such as motion detected by sensors or temperature changes. Management begins with selecting a room, as demonstrated in Figure 3.

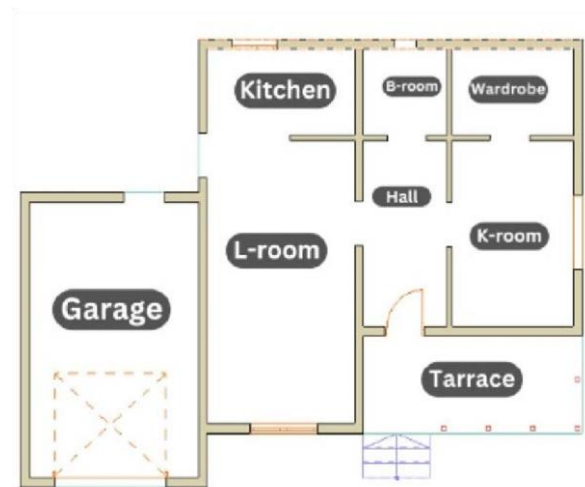


Figure 3 The initial screen of the application

4.5 Testing and Iteration

Throughout the project, testing and improvement occurred through a cyclical process involving continuous evaluation and enhancement of the system. Students faced technical challenges, such as sensor malfunctions, incorrect calibration, and programming errors. Through an iterative approach, errors were identified and corrected, while system functionalities were progressively improved.

In the testing and iteration phase, students followed a cyclic process of evaluating and improving their prototype. This aligns with the methodology described in [6], where students used MATLAB as a tool to simulate and optimize bioprocess systems.

The iterative nature of the "Smart House" project aligns with the principles discussed in [7], where project-based learning emphasizes continuous evaluation and refinement. Similar to the challenges faced in interdisciplinary projects like CAD/CAM in mechatronics [7], students in this project engaged in iterative testing to identify and resolve issues related to

sensor calibration, hardware integration, and software functionality. This process not only improved the reliability of the prototype but also reinforced the importance of applying theoretical knowledge in practical settings.

Active participation from team members and feedback from teachers played a crucial role in this process. Their suggestions and recommendations allowed for prototype enhancements and increased system efficiency. This phase provided students with valuable experience in solving engineering problems and highlighted the importance of re-evaluating results for the success of complex projects.

4.6 Presentation and Demonstration

At the end of the project, students presented their results through detailed PowerPoint presentations and practical demonstrations of the prototype's operation. Presentations covered key aspects of the project, including descriptions of technical solutions, challenges encountered during development, and strategies implemented to overcome these challenges. The focus was on explaining the design and

implementation process, as well as learning through problemsolving.

Practical demonstrations showcased the prototype's functionalities, including automatic light regulation, temperature control, and soil moisture monitoring, as well as advanced security measures such as license plate recognition for access control and fire protection using fire sensors. These demonstrations allowed the audience to understand the technical complexity of the project and the innovative solutions students devised and implemented.

4.7 Evaluation

Feedback from teachers and other students regarding the presentations was essential for evaluating the project's success. Teachers emphasized the technical aspects and professionalism of students during the presentations, while students shared their experiences and suggestions for improving future projects, as shown in Table 2. This exchange of opinions helped identify the project's strengths and weaknesses, further enhancing the learning process.

Table 2Feedback on Key Aspects of the Smart House Project

Category	Teacher Comments	Student Comments
Prototype Design	"Well-designed functionalities, but sensor connectivity could be more stable."	"It was our first time working with sensors, and it was challenging, but we learned a lot."
Programming	"The code is functional, but there is room for optimization and better documentation."	"Working on Bluetooth connectivity was interesting, although it was difficult at first."
AI Technology	"Ambitious AI system integration; more examples could be added in the future."	"It was great working on image recognition, but optimizing accuracy was tough."
Mobile Application	"The app interface is intuitive, but additional functionalities could be implemented."	"We're proud we managed to connect the app with all house functions."
Teamwork	"Teams collaborated well and showed a high level of responsibility."	"Teamwork was key, and we all contributed our knowledge."
Presentation of Results	"Presentations were clear and professional, but demonstrations could have been more detailed."	"It was exciting to showcase our results to the audience."

5 CONCLUSIONS

These The "Smart House" project demonstrated how project- competencies are vital for success in the modern world, based learning can be a powerful tool for enhancing the especially in the context of the development of smart cities and educational process, particularly in STEM fields. Through this future technologies. Students in the "Smart House" project project, students not only acquired technical skills and practical

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reported heightened motivation and a deeper understanding of concepts such as IoT, AI integration, and system optimization.

The application of models like the MRP further enriched the teaching process, enabling students to combine engineering work with reflection on their own learning.

Smart cities, as a concept, offer broad opportunities for integrating technology and sustainability into educational projects. Education plays a central role in preparing young people for global challenges such as urbanization and climate change.

The outcomes of the "Smart House" project underscore the benefits of project-based learning in

knowledge but also developed essential soft skills such as teamwork, communication, and critical thinking.

developing interdisciplinary skills. PBL fosters teamwork, problem-solving, and the ability to integrate knowledge from multiple fields, such as electronics, programming, and hardware design. Similarly, students in this project demonstrated improved collaboration and technical expertise while working on complex, real-world challenges. These findings support the conclusion that PBL is an effective pedagogical strategy for preparing students to meet the demands of modern technology-driven industries.

The "Smart House" project serves as an example of how educational initiatives can contribute to the development of critical skills and competencies essential for the future. The integration of theoretical

knowledge and practical application through this project demonstrated that project-based learning is not only useful but also a necessary approach in modern education.

Acknowledgements

This study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, and these results are parts of the Grant No. 451-03-66 / 2024-03 / 200132 with University of Kragujevac - Faculty of Technical Sciences Čačak.

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THE INFLUENCE OF KNOWLEDGE MANAGEMENT ON STUDENTS' FUTURE EMPLOYMENT DETERMINATION

Ana-Marija VUKIĆ¹, Dragana SAJFERT², Ana BAŠIĆ³

Abstract: The aim of this research was to examine the impact of knowledge management on students' future job choices. A questionnaire consisting of 11 questions was used as an instrument. A google table was created for statistical data processing, which was filled with data from the survey completed by students and provided the basis of the questionnaire for further statistical data processing. 80 students responded to the questionnaire, of which 65 filled out valid questionnaires. The results of the research were as follows: 32.3% of the students responded that they wanted to work in a foreign company. When asked what they expect from work, 50.8% of students said a high salary. When asked what is most important for motivation in your future work, the answers are: good working atmosphere 32.8%. This study examined the relationship between four components: vocation choice, job expectations, personal development, motivation for future work - academic satisfaction.

Keywords: job expectations; knowledge management; motivation for future work; personal development; vocation choice.

1. INTRODUCTION

How do students determine the right career path? When we are children, we usually have ready answers - a doctor, a university professor, an academic, an astronaut, a model, or maybe the next Novak Djokovic, Steven Jobs... It is not difficult to imagine the circumstances in which we will live, the great places we will travel to, the extraordinary car that we will drive. Unfortunately, life passes quickly and as the day of entering the labor market approaches, the beginning of real life, everything we wanted mostly no longer holds, our interests are different, and we look at life more seriously. We try to choose a profession that moves in relation to our desires and real employment opportunities. Finding a job that will be an intermediate solution between the desire and the reality of life is very complex, but not impossible. That's why it's best, if you can, to review your wishes and interests before enrolling in studies, and at the end of your studies, before you get into the situation of looking for a job, try to match your wishes and real conditions. The majority of students are not sure what they really like to do and what suits them, and this is mainly because they are either not aware of their potential or are not familiar with the possibilities. Some people again have "big" ideas, which, as they think, could easily launch them into the world of the successful, famous and rich. But is it reality or just a dream?

In any case, the choice of occupation, a choice so important, so fateful, is often pressed and made difficult by the feeling of a great burden of responsibility. But why not turn the whole thing at least 90 degrees to the left or right, why can't occupation and work be fun and pleasure. There is a lot of evidence that points to the fact that some people experience great satisfaction at work while working, and that their productivity is significantly higher than the performance of those who perceive work as a burden and drudgery (workaholics).

Today's employers have a different mindset about work than young job seekers. It is very important that young people understand that they should look for a job, not wait for a job. Young people born in the early 2000s are changing the rules and attitude towards work. Older people call them Generation Y, Millennials, or the Internet generation. The generation of young people is with sophisticated technologies, computers and mobile phones. The life of young people is unimaginable without the Internet, they want to have information immediately and now. Young people want to achieve their careers as soon as possible, hoping for independence and success in business. The youth generation wants to achieve a balance between personal life goals and business goals. Future students do not base their approach to life on living to work, but want to work to enjoy life. The young generation tends to do what they love. In the nomenclature of occupations, new occupations appear that are fully

adapted to their thinking and the needs of the economy. These new occupations allow for mobility, creativity and flexible working hours. More and more practical knowledge is appearing at the faculties. Employers are trying to adapt their requirements and the way of employment to the new age and the new generation. At faculties, there are competitions in solving case studies, in this way the economy suggests indicators of what kind of knowledge is needed and what is expected from schooling. Employers expect young people to bring usable knowledge of the profession, language, computers and possess

an adequate business culture to their first job. Students are aware of this fact, so they dedicate themselves to personal development and the development of skills that will be useful to them at work.

2. LITERATURE REVIEW

The authors state in their research that the career commitment of individuals to their career; in the field of vocational psychology, career commitment is considered a vital factor in promoting a sustainable career [1]. The authors documented in their study that career exploration was significantly related to CDSE [2]. A person looking for a job should take the initiative, that doesn't mean being a curmudgeon, being unpleasant and aggressive. This means taking responsibility for starting the event. This is called "solution selling" and is a key paradigm for business success. According the authors, people generally wait for something to happen, or for someone to take care of them [3]. But people who get good jobs are pro-active - they are the solution to problems, not the problem themselves. The author states in her research that to date, no research has been done that examines individuals who work and go to school, and aims to examine the effects of this on their academic performance [4]. Little literature is available that examines the effects these dual roles can have on an organization. The authors state that students are a valuable human resource as future employees [5]. The authors state in their research that student employment is a vital aspect of development for many students during their careers [6]. The authors showed in their research that part-time student employees perform vital roles for the university while also gaining valuable work experience that leads to future employment opportunities [7].

The authors state that students registered in an undergraduate program study 12 courses for specialization and easier employment [8]. The authors found that some students work an average of 25 hours a week and have better success than students who do not work [9]. The authors in their study sought to develop and validate an instrument for measuring work will, defined as the perceived ability to choose an occupation in addition to limitations among students [10]. The authors conducted a study that examined the relationship between four components of career adaptability – concern, control, curiosity, and self-confidence [11]. The authors state in their research that career decision-making is a critical task for high school students, but little is known about how career interventions affect their decision-making skills [12]. The authors examined the moderating role of traditionalism beliefs in the indirect relationships between parental support, career decisionmaking, and career adaptability among college students [13]. The authors report in their study the results of an investigation of the reliability and validity of the short

form of the Career Decision Scale (CDSES-SF) in high school students [14]. The authors report a study of the effect of proactive personality and career decision-making on career adaptability under employment pressure among graduate students [15]. The authors conducted a study that examined the relationship between willingness to work and career decision-making (CDSE) and students' academic satisfaction [16]. The authors report in a study that examined the mediating effect of graduate students' career decisions [17]. The authors state in their research that staying satisfied and healthy in a complex and uncertain professional world is a priority for individuals when choosing a career [18]. The authors state that the transition from school to studies is one of the most critical steps in the career of graduates, as it can determine professional results and future career success [19]. The authors states that slow economic growth and cost cutting have caused an increase in job insecurity [20]. The authors state that school engagement plays a prominent role in promoting academic achievement [21].

3. METHODOLOGY

Hypothesis

H1: Students have a positive attitude towards working in a foreign company

H2: Students have a positive attitude towards salary

H3: Students have a positive attitude towards working on the working atmosphere

Sample

The research that dealt with students' future career choices was conducted during the 2021/2022 and 2022/2023 and 2023/2024 school years. The research that included the analysis included 65 students from different study programs. Data collection was carried out by surveying respondents, as well as personal interviews. The respondents filled out a methodologically creative questionnaire in advance, the answers to which formed the necessary database, the further processing of which led to the necessary conclusions and future directions in this research

3.1. Research Instrument

A questionnaire was used to measure future job choice on a 5point Likert (1932) scale ranging from 1 - Strongly disagree to 5 - Strongly agree. The items are based on the questionnaire and the obtained results of the students' future determination for work.

3.2. Research goals

The aim of this study is to examine the impact of students' future determination for their career. On the basis of the research of students' future commitment to work, conclusions can be reached that will reveal their

desires and the possibility of employment. It could even be said that future employment can mediate between the wishes of students and the needs of the economy. The goal of the research is to discover the approach and effects and needs of work that include future employment, and in this way, the needs for employees in the company are solved.

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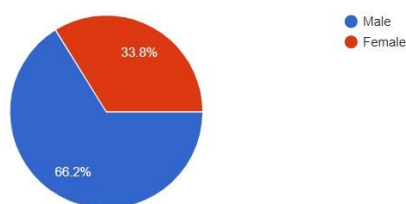
Sample: Students of all four years of study from all study programs. 65 students filled out the questionnaire.

4. RESULTS

The graph 1 shows the gender of respondents from the population of surveyed students. Based on the results of the tests conducted using the Google program, 66% are male students, while 34% are female students.

1. Data about the respondent

65 responses



The graph 2 shows the study average of the surveyed students. There are 1.5% of students with a grade of 6, 15.4% with a grade of 7, 32.3% with a grade of 8, 40% with a grade of 9, and 6.2% of students with a grade of 10

2. Grade average during studies

a) 6
b) 7
c) 8
d) 9
e) 10

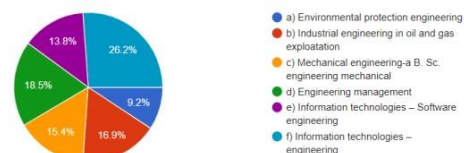
65 responses



The graph 3 shows the responses of students according to study programs: Environmental Engineering 9.2%, Industrial Engineering in Oil and Gas Exploitation 16.9%, Mechanical Engineering - B.Sc. Eng. Mechanical Engineering 15.4%, Engineering Management 18.5%, Information Technology - Software Engineering 13.8% and Information Technology - Engineering 26.2%.

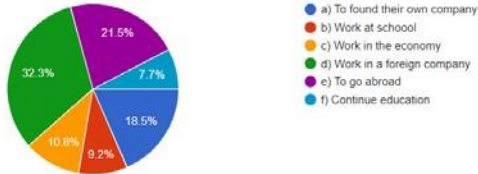
3. Filed study

65 responses



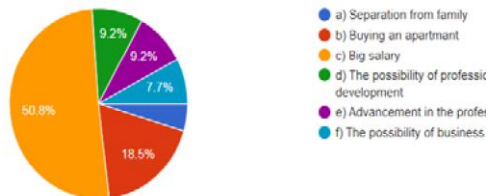
The graph 4 shows the students' answers to the question, after completing my studies, I would like to: start my own company 7.7%, work at school 9.2%, work in the economy 10.8%, work in a foreign company 32.3%, continue my education 21.5%. In this way, Hypothesis 1 was confirmed.

4. After finishing my studies, I would like to
65 responses



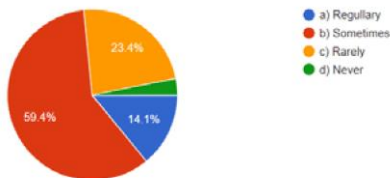
The graph 5 shows the answers to the question of what you expect from work, the students said: separation from family 4.6%, buying an apartment 18.5%, big salary 50.8%, possibility of professional development 9.2%, advancement in the profession 9.2% and the possibility of business travel 7.7%. In this way, hypothesis 2 was confirmed.

5. What do you expect from work?
65 responses



The graph 6 shows students' responses to the question of how much you think about business opportunities, students answered: regularly 14.1%, sometimes 59.4%, rarely 23.4%, never 3%.

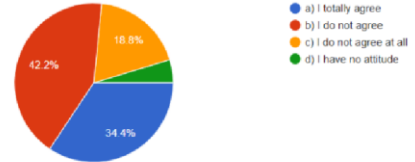
6. How often do you think about business opportunities?
64 responses



The graph 7 shows the students' answers to the question, this job would allow me great professional and personal progress, the students answered: I

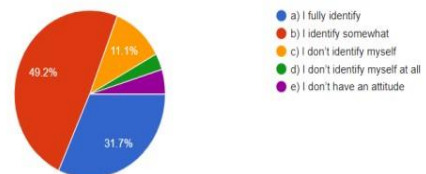
somewhat agree 34.4%, I agree 42.2%, I completely agree 18.8% and we position 4.6%.

7. Select the extent to which you agree with the following attachment: This job would allow me great professional and personal growth.
64 responses



The graph 8 shows students' responses to the question of how much you identify with your future job, goals and values: I identify completely 31.7%, I identify somewhat 49.2%, I do not identify 11.1%, I do not identify at all 3% and I have no opinion on 5%.

8. How much you identify with your future job, the goals and values it represents?
63 responses

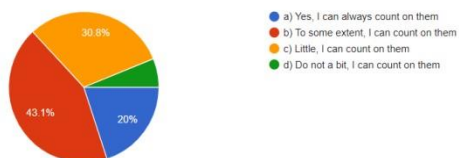


The graph 9 shows the answers to the students' question, do you have full support at the faculty from your colleagues for this research, the answers are: yes I can always count on them 20%, to some extent I can count on them 43.1%, a little, I can count on 30.8 of them and I can't even count on 6% of them.

9. Do you have the full support of your colleagues at the faculty for this research?

Copy

65 responses

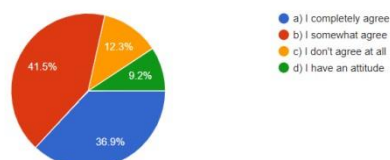


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The graph 10 shows students' answers to the question of what is most important to you for motivation in your future work, the answers are: adequate salary 21.9%, good working atmosphere 32.8%, possibility of advancement 14.1%, professional development 15.6%, and job security 15.6%. In this way, hypothesis 3 was confirmed.

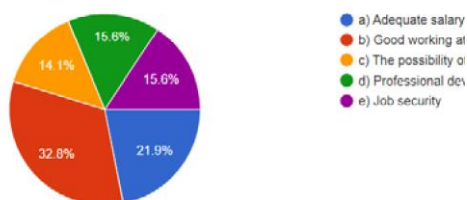
11. Choose to what extent you agree with the following statement: This job will allow me great professional and personal progress in the future.

65 responses



10. What is most important to you for motivation in your future work?

64 responses



On the graph 11, there are answers to the question to the students, this job will allow me great professional and personal progress in the future, the answers are: I completely agree 26.9%, I somewhat agree 41.5%, I do not agree at all 12.3% and we have a position of 9.2%

5. DISCUSSION

By processing the obtained data, graph 1 shows the gender of the respondents, based on the obtained results, 66% were male students, while 34% were female students. There are more male students than female students at the technical faculty, so it is logical that more of them are surveyed. The average grade of students during their studies is at most 40% with an average grade of 9. A comment could be made here, that the best students go to lectures all the time, so they can be surveyed. The majority of surveyed students are from the information technology - engineering study program, 26.2%. It's probably the same reason, more people come to lectures and exercises. In the answers of the students, most of them declared that they wanted to work in a foreign company, 32.3%. Unfortunately, the economic situation today is such that they want to go abroad after completing their studies. We hope that the situation will change by the time this generation graduates so that more of them will stay in Serbia. The students' answers for expectations after completing their studies mostly opted for a higher salary, 50.8%. In rich countries this is usually not the main motive. To the question of how much you think about business opportunities, students answered sometimes 59.4% at most.

When asked if this job would enable me to make great professional and personal progress, the students answered that they mostly disagree, 42.2%. Obviously, students do not prioritize great professional and personal progress. The students' answers to the question how much do you identify with your future job, goals and values, the most decided I identify to some extent 49.2%. To the question of whether you have complete support at the faculty from your male and female colleagues for this research, the most answers, I can somewhat count on them, are 43.1%. When asked what is most important to you for motivation in your future work, 32.8% gave the best working atmosphere. When asked by the students, this job will

enable me to make great professional and personal progress in the future, the highest response was somewhat agree, 41.5%.

6.CONCLUSION

This study investigated students' future job orientation. On the basis of the obtained results, conclusions can be drawn about the significant connection of students' future commitment to work on several study programs in Serbia. Further research is needed in order to understand the obtained results of student commitment.

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UDK:711.45:004.78
DOI:
10.46793/ALFATECHproc25.107P
Original scientific paper

Intelligent Connectivity for Smart City Development

Vladan PANTOVIĆ¹, Dragorad MILOVANOVIĆ², Filip JOVANOVIĆ³

Abstract: The paper presents an overview of the progress of modern information and communication technologies (ICT), which are necessary for the development of smart cities (SC). A focus was given to the explanation of the concept of Intelligent Connectivity (Icon) that includes the convergence of key technological trends: mobile networks of the fifth generation (5G), Internet of Things (IoT), Artificial Intelligence systems (AI) and Cloud Computing (CC). The 5G smart networks are expected to enable the integration of Internet of connected objects (AIoT) by supporting intelligent connectivity Icon and becomes a key prerequisite for an advanced Smart City (SC) infrastructure. The intelligent connectivity for SC development should enable the integration of technologies with sensor networking, information processing and real-time [3296](#) control to efficiently utilize infrastructure.

Keywords: Smart City; Intelligent Connectivity; 5G, IoT; Artificial Intelligence

1 INTRODUCTION

Smart city (SC) is an innovative solution for today's urban areas that utilize advanced digital technologies to provide better infrastructure, modernize government services, improve accessibility, accelerate economic growth, and improve sustainability. Opportunities and challenges depend on many different factors, such as the population, location, climate, environment, and area of the city as well as priorities and primary implementations. Currently, numerous smart city developments are ongoing around the world. SC projects have emerged mainly as a result of highly innovative ICT solutions, and additionally, they have started to use new generation wireless networks taking advantage of the Internet of Things (IoT), Big Data (BD)

and cloud computing (CC) technologies to establish a smart connectivity in Smart City development [1, 2, 3].

The concept of intelligent connectivity (Icon) includes the convergence of key ICT trends: 5G (fifth generation) mobile networks and AI (Artificial Intelligence) systems. Icon is based on the use of advanced technology for improved communication between devices, systems and users. The goal is a seamless and intuitive user experience and support for new applications and services that were previously not possible. The technological trend is the efficient and reliable connection of devices and systems, as well as new applications and services. Icon systems provide improvements in different aspects of operations and

organizations, such as quality of life and infrastructure in the Smart City (SC). SC solutions are developed and implemented in smart environment, smart mobility, smart living and smart people.

Smart environments (SE) are new concepts in developed improved services for the residents of a city, better quality of life for an individual, or more efficient manufacturing for a company [4, 5].

Smart Home (SH) provide a variety of options to interact with others without having to leave the house. The entire home ecosystem, including heating, air conditioning, water, electricity, energy consumption, lighting, entertainment, appliances, household robots, air quality, smoke/gas/leak detection, home access, security, and privacy, can be fully managed and monitored thanks to SH intelligent, connected, automated, and integrated control, computing, and communication system. Although there are many different things and services available today, the markets and solutions are a dispersed. Furthermore,

complete smart and automated home solutions that incorporate all necessary components are still relatively lacking. Additionally, standardization and common norms are insufficient, particularly when it comes to data security and privacy. We are still waiting for a significant advancement in smart homes. For technology companies (mobile network operators, vendors, and service providers), this will create new business opportunities to offer plug-and-play solutions that are complete and personalized. Collaboration between tech companies, constructors, and building owners is necessary.

Smart Factory (SF) combines mainstream information, communication, networking, computing, and control technologies and procedures to improve a factory's intelligence, automation, productivity, quality, flexibility, adaptability, and predictability, is still relatively in its beginning. In the new era of smart manufacturing, where the integration of certain mainstream digital technology becomes commonplace and transforms the whole industrial sector, a smart factory is at the centre of Industry 4.0. Numerous advantages are offered by smart factories, including better process monitoring, management, maintenance, and repair; higher manufacturing efficiency; lower manufacturing costs; better quality products; faster production cycles; more robust processes; improved security; better threat and hazard prevention; and innovative production solutions.

Smart society (SS) refers to a concept that uses a wide range of advanced digital technology to improve society at all levels. A smart society is anticipated to provide a range of advantages for people, communities, and the public and private sectors through the use of various technologies. A higher quality of life in terms of better services for living conditions, healthcare, employment, education, social benefits, free-time activities, and

public safety are among the potential advantages for people. New commercial prospects, more effective manufacturing, testing, and design processes, lower production, operation, and maintenance costs, and reduced impact on the environment are some of the possible advantages for the private sector.

Smart cities SC connect social infrastructure and physical infrastructure. Investing in ICT infrastructure improves economic growth and quality of life. The main objective is to provide residents with services that increase the effectiveness of daily activities. Assuming a variety of different applications and particular requirements, SCs rely on the sharing of information and large volumes of data.

5G connectivity ecosystem comprises a broad set of technologies, users, companies, products and services that evolve together to meet new requirements and create markets. The ecosystem also includes the regulatory direction, standardization organizations, as well as relevant industry associations. Members make contributions that complement and reinforce the contributions of other members, resulting in a complex integrated system. A systemic approach in creating a technological ecosystem implies observing the complete network and components as an integrated and inter-reliant system. The approach ensures that the various elements work seamlessly together to realize the benefits of 5G technology:

- identifying problems or requirements and forming system requirements, as well as the most promising technological options
- research and development of innovative technologies and the formation of a flexible system architecture supports increased data transfer rates, low latency and massive connectivity of intelligent devices
- ensuring compliance with international standards for the interoperability of various suppliers and service providers
- cooperation with device manufacturers for a diverse and interoperable technological ecosystem
- cooperation with regulatory authorities to resolve legal and political challenges associated with the commercial application of 5G technology
- conducting extensive prototype testing and performance demonstrations, concept validation that ensures reliability, performance and adherence to standards
- adoption of a systemic approach, so that all stakeholders in the 5G technological ecosystem can achieve integrated, efficient and secure cooperation that meets the various requirements of both consumers and companies.

To ensure seamless interoperability between ICT devices, the International Telecommunication Union Telecommunication ITU-T is establishing standards that specify the requirements, frameworks, operations, and management systems for ICT technologies, enabling the development of advanced wireless networks [6-12].

The main goal of this research was to raise awareness of the community about the current state of the smart city SC developments revealing its key future trends. The paper is organized as follows. After an introduction, intelligent connectivity ICon enabling technologies are presented with focus on cloud-driven IoT-based big data BD and 6G enabled the New Smart City. In conclusion, we point out that there is a need for a critical reassessment of the ICT sector for smart cities SCs development.

2 ICon enabling technologies

ICon represents the synergy of smart technologies and communication infrastructure with a goal more efficient services, improvements in user-computer interaction, as well as improvements management and data analytics. The convergence of communication, IoT and AI is an obvious logical one progress in the evolution of these technologies. Data collected by IoT devices and sensors can now be effectively analyzed and contextualized using AI method. The two technological concepts absolutely complement each other, are rapidly developing and they have a vital role in the progress of smart cities and society. Artificial intelligence is the real driving force behind the full potential of ICT (Fig.1).

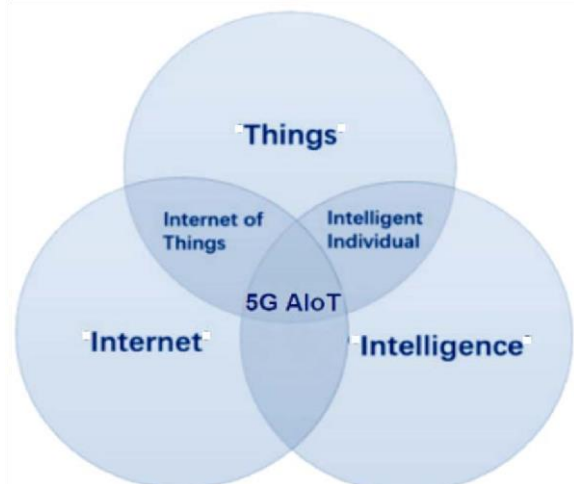


Figure 1 The relationship among 5G, IoT and AI.

Significant features of 5G network connectivity are high data transfer speeds and very low latency. SC systems have been applied in various domains to test the potential of new smart systems while identifying the infrastructure necessary to support future services for a large number of devices. The goal is to develop integrated solutions and new applications for building smart cities and improving the social life of citizens, including economic growth. The IoT is one of the significant ICT technologies to support smart cities SC, along with connectivity, data analytics and artificial intelligence AI. Many countries have launched SC projects of smart cities and large investments in development. Analyzing the advantages and challenges of 5G IoT technology is crucial for the development of future smart cities.

However, in reality there are still many challenges. The ICon concept encompasses various design

principles, industrial standards and development heterogeneous computing platforms and network topologies. A successful smart environments require standardization that includes interoperability, compatibility, and reliability [9, 10, 11].

Connectivity. In order to build smart cities SCs and set the groundwork for more connected future, 5G/6G low latency, and IoT are essential. For systems like energy management, traffic management, and public safety systems to operate seamlessly, high-speed, reliable communication is required. Large volumes of data produced by IoT devices can be efficiently transmit to the faster and more reliable connectivity offered by the 5G and upcoming 6G networks. Because it facilitates rapid actions and real-time decision-making, low latency is especially crucial in SCs. IoT is essential to SCs because it facilitates the deployment of SC systems and provides the data required for data-driven decision-making.

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The following use case classes are defined by the joint initiative 5GPPP of the EU ICT industry: highly populated metropolitan areas, broadband access at any location, connected autonomous vehicles, the future smart office, NB-IoT, tactile Internet, and automation. Key KPI indicators that match the performance requirements (in terms of the service's user experience) that the 5G network can provide are established for each unique scenario. Device density in a particular region, mobility, infrastructure topology, traffic type, user data flow, delay, reliability, availability, and communication category are the criteria used by the PPP initiative to categorize fundamental functionality.

Internet of Things. The entities in the development of SCs include sensors, networked devices, machine-to-machine (M2M) communication, and IoT. Internet of Things serves as the foundation for the interconnection of SCs, including public safety, energy, and traffic control systems. The seamless transfer of data between various systems and devices is made possible via M2M communication, which serves as the basis for SCs' effective operation. Sensors and actuators are examples of networked devices that supply the data required for SCs to make data-driven decisions. In particular, sensing is essential to data gathering and analysis because it offers real-time data on a variety of metrics, including ambient conditions, energy consumption, and traffic movement.

Smart city applications based on IoT infrastructure are categorized based on network type, scalability, coverage, flexibility, heterogeneity, reliability and end-user engagement. Applications can be grouped into personal and residential, communal, mobile and business. Utilities include smart energy grid, smart metering/monitoring, water network management and video surveillance. Similarly, mobile applications include intelligent transportation systems and logistics, and traffic management.

The implementation of 5G IoT supports making cities much smarter. Numerous devices are linked to a mobile network with very high speed. An intelligent and controllable environment is made possible by automation, which is embraced by the Internet of connected objects (IoT). It essentially comes down to data management, formatting, and connectivity. Different IoT protocols, data formats, processing, and interfaces are needed for various use cases. Interoperability and open standards are crucial because the Internet of Things does not yet have a global standard. The challenge is that industry initiatives are fragmented and unfocused, and IoT deployments and use cases are unfocused.

The smart city SC has many criteria for IoT applications. IoT, for instance, is anticipated to provide low cost, low power consumption, high quality of service (QoS), extensive coverage, increased flexibility, high security and privacy, ultra-dense

implementation, and equipment manufacturer compatibility. To create a completely autonomous environment, IoT implementation relies on a variety of network topologies.

Data. The development of SCs requires the use of data analytics, data management, data storage, and data infrastructure. The amount of data generated is enormous and increasing daily due to the growth of the IoT and the increased use of technology in urban areas. These statistics offer important insights into how a city operates, including public safety, energy use, and traffic flow. Cities can use data analytics to make sense of these data and make data-driven decisions to increase their sustainability and efficiency. An SC infrastructure must have enough data management and storage to guarantee that the generated data are secure and easily accessible for analysis. Since it serves as the basis for all data-related operations, SCs also require a robust data infrastructure. This covers the technology, software, and network needed to handle, store, and analyze large volumes of data. Cities can fully benefit from big data BD and data analytics DA with the proper data infrastructure in place, creating a more intelligent and sustainable future.

Artificial Intelligence (AI). Enhancing efficiency, sustainability, and the standard of living for residents, AI have the potential to significantly contribute to the growth of SCs. AI-driven solutions can assist SCs in lowering energy use, streamlining traffic, and enhancing public safety. AI systems, for instance, can monitor building energy consumption to spot inefficiencies and reduce waste, or they can analyze traffic patterns to minimise air pollution and congestion. AI-powered chatbots and virtual assistants can also help SC projects by giving citizens real-time information and assistance, including directions or details on local services. AI can also be used to evaluate data from multiple sources, including social media, to comprehend the needs and preferences of individuals and make data-driven decisions that are advantageous to the society.

Digital services. Technologies such as digital twins DT, blockchain BC, virtual reality VR, metaverse, and simulated environments have the potential to completely transform the creation of SCs. Cities can test and evaluate new systems and technologies in simulated environments before implementing them in the real world. Real-time monitoring and analysis are made possible by digital twins DT, which offer a virtual replica of a physical system. The metaverse is a virtual environment that coexists with the real world and presents new opportunities for creativity and teamwork. Robotics and virtual reality VR present new opportunities for SC automation, simulation, and training. Blockchain BC offers a secure and decentralized platform for data administration and exchange, laying the foundation for the creation of innovative SC systems. There are many opportunities for innovation and advancement in quickly evolving field of developing and implementing these technologies in SCs.

Cloud platforms. The development of SCs depends heavily on city platforms, cloud computing, cloud storage, edge computing, hybrid data storage, infrastructure as a service (IaaS), and platform as a service (PaaS). For the control of SC systems, including public safety, electricity, and traffic management, city platforms offer a unified infrastructure. Scalable and adaptable methods for processing and storing massive volumes of data produced by SC systems are offered by cloud computing and storage. By processing data at the network's edge, edge computing EC reducing latency and improving response times. The advantages of cloud and edge computing are combined in hybrid data storage, which offers a scalable and adaptable approach to data processing and storage. The platform and infrastructure for the creation and implementation of SC systems are offered by IaaS and PaaS, respectively. These technologies provide a foundation for the creation of new and creative SCs, which will result in a more smarter and efficient future.

2.1 Cloud-driven IoT-based Big Data

The expanding volume of data is increasing expectations for smart cities. Thus, the IoT-provided massive volumes of data, or big data BD, form the foundation of city infrastructure. volume, velocity, and different data types define the term BD. A city could gain valuable insights from a large amount of data gathered from many sources based on big data BD technology.

In order to support the development and analysis of smart cities, it is also important to monitor, gather, archive and share open sensor data from IoT devices. A number of researchers have offered diverse formal definitions of a smart city from a variety of viewpoints. Many smart city SC concepts and themes (smart people, smart transportation.) are required as a result of the development of ICT technologies. These should primarily leverage the benefits of data management

technologies IoT, BD, and CC) to create a deep connection between every element and layer of a city.

There are certain benefits to cloud-driven IoT-based big data BD. Data about exponential growth throughout time could be gathered and analyzed logically and effectively to support decision-making. Big data BD produced by IoT devices could enable these scenarios because traditional approaches are not cost-effective when handling large volumes of data and are not appropriate for data processing and storage systems.

Due to the availability of enormous computational storage facilities for processing these data within smart cities SC, the use of big data BD in these settings offers both many benefits and constraints. However, this big data BD technology's dependence on cloud computing CC and IoT services is one of its significant advantages. Intelligent networks with complex connections between components and residents' equipment are required for the majority of big data BD deployments in smart cities SC. Therefore, this intelligent connectivity ICon should be able to transfer responses back to the entities and collect data from the resources in an efficient manner. For real-time big data BD applications in smart cities SC, quality of service (QoS) is therefore crucial.

To process big data BD, cloud computing CC represents a good solution. CC is an standard that gives users in the cloud access to a shared platform of computational resources. For example, when it comes to capital savings and expenditures, CC can offer a number of advantages to both individuals and organizations. The relationship between IoT, BD, and CC is showed in Figure 2 based on the references.

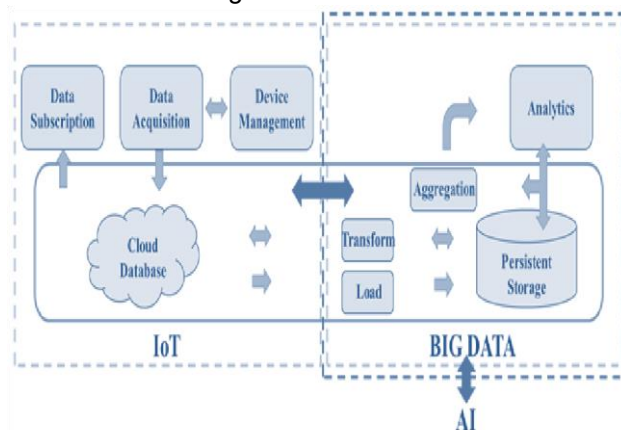


Figure 2 The relationship among IoT, big data BD and cloud computing CC.

CC users benefit from a network-based environment that allows them to share resources and computations from a specific location. NIST defines cloud computing as a framework that facilitates appropriate Internet connectivity and a collective pool of programmable grids, storage systems, software, and servers that could be quickly set free via communication from a provider.

Because data centers in physically accessible locations present a variety of security challenges and risks, CC users are unsure of the exact location of their sensitive data. Furthermore, because threats spread quickly, well-known security techniques like firewalls and host-based antivirus AV software are unable to offer adequate security platforms in virtualized systems. Additionally, CC offers enterprises cost-effective maintenance, limited upfront investment, and instant access to physical resources. CC is also regarded as a powerful enabler that enhances agility and operational activities.

2.2 6G enabling the New Smart City

The sixth-generation (6G) wireless communication is the successor of fifth-generation (5G) communication. Candidate technologies like artificial intelligence (AI), integrated sensing and

communication (ISAC), and non-terrestrial networks (NTN) can be used in development smart city SCs as 6G communication systems evolve. Ubiquitous connectivity, artificial intelligence and communication, and integrated sensing and communication are three emerging use cases (Fig.3) [13].

The main themes of the upcoming 6G are summarized as follows:

- The convergence of sensing, computing, control, localization, and communications: computing, control, localization, and sensing in addition to current wireless communication.
- Smart reflective surfaces and environments: Driven by smart reflective surfaces that serve as walls, roads, doors, and entire buildings, helping to maintain a line of sight and obtain a quality signal with minimal loss.
- Massive availability of small data: Shifting from centralized big data BD to massive distributed small data.
- More resource availability (bits, spectra, and reliability): Higher frequency spectrum (THz), reaching 1 Tb/s.
- Self-sustaining networks: AI to facilitate intelligent wireless networks that are self-sustaining.
- Ubiquitous connectivity that encompasses air, ground, and sea: Integrating the space-air-ground-sea mode to facilitate wireless communications in flying vehicles, XR, brain-computer interface (BCI), and more.

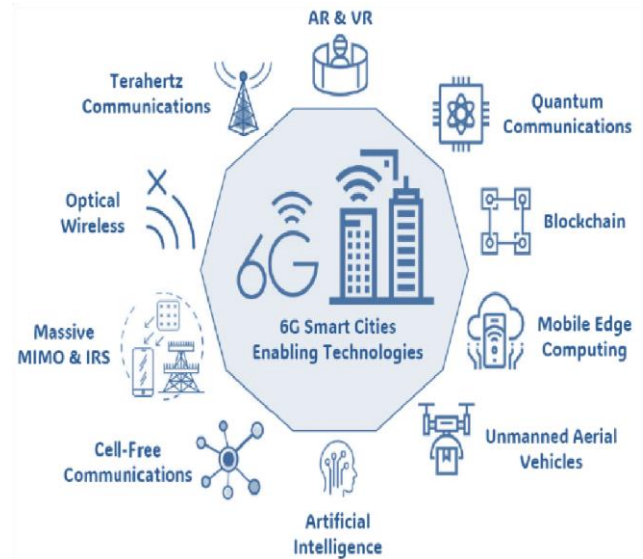


Figure 3 Enabling technologies in 6G for smart cities SC.

From a technical perspective, 6G makes it possible to integrate into a single network with increased throughput and reliability. These features make 6G networks perfect for the widespread implementation of the Internet of Things (IoT) paradigm, particularly given that billions of devices are anticipated to be connected to infrastructure in the near future.

Recently, the draft of the international mobile telecommunications IMT-2030 6G recommendation has been completed and 6 major usage scenarios have been defined [8]. Three of these scenarios, enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultrareliable and low-latency communication (URLLC) are more complex versions of the IMT-2020 5G usage scenarios. That is, immersive communication, massive communication, and hyperreliable and low-latency communication (HURLLC).

The foundation of modern wireless communication networks is radio access technologies (RAT), which allow for high-speed data transmission and reliable connectivity for mobile devices. Radio access technologies are developing to offer even faster speeds, lower latency, and increased network capacity with the upcoming new generation of cellular networks.

IoT-based communication is essential to the creation of smart communities. Reliable wireless networks are crucial for the IoT to continue expanding. The usage of RAN or cloud RAN (CRAN) in the developing 5G cellular system, which integrates cloud computing CC technologies into the radio access network, is one way to address this issue. More scalability, flexibility, and performance are offered by CRAN, which makes it possible for 5G to link a large number of IoT devices, all of which are essential for SCs. The concept of network slicing (NS), which enables service providers to design unique virtual networks for various applications and services, is another crucial component of 5G RATs.

Edge computing (EC) involves processing data and performing other computational tasks closer to the

source of the data, rather than sending them all to a central data center or cloud. Edge devices, which are located closer the network's edge and have real-time data processing capabilities, can be used to do this. 5G and EC edge computing together can offer a powerful platform for developing previously impossible new services and applications. Using edge devices, for instance, real-time video analytics can be carried out at the network's edge. The processed data is then sent over 5G networks. Numerous uses, including remote surveillance and health monitoring, may be made possible by this. The application of edge computing EC and 5G to driverless cars is another example. Autonomous vehicles can make decisions in real time, enhancing efficiency and safety, by processing sensor data and other information at the network's edge. The presence of a cloud in the IoT system of an SC can result in high energy consumption and network delays. Based on a cloud computing CC, edge computing EC has become a solution to this problem by bringing network, storage, and processing resources closer to the data source. However, a crucial problem in edge computing EC while executing tasks produced by IoT systems is the effective use of energy while maintaining delay constraints. In IoT-based SCs, resource allocation using distributed edge computing EC is studied using a multi-criteria optimization approach. To guarantee effective resource computation for delay-sensitive tasks, an actionable approach-based edge resource allocation method is effective solution for three-layer network architecture for IoT-based SCs. In SCs and the IoT, edge computing EC provides a number of advantages, such as reduced latency, improved security, increased scalability, lower costs, and enhanced reliability.

New SCs might benefit from a variety of cutting-edge technologies, such as remote healthcare, smart grids, and driverless cars, with the aid of 6G networks. Furthermore, cutting-edge technologies like virtual reality, augmented reality, and immersive gaming might be supported by 6G networks, opening up new business and residential options in these places. It might take a few years before 6G networks are generally accessible, though, as their development is still in its infancy. Researchers and business professionals are still investigating the possible advantages and applications of 6G networks in the context of recent advancements in SC. Intelligent transportation and logistics, connected robotics and autonomous systems, worldwide ubiquitous connection, and pervasive intelligence are some examples of use cases that have been identified and presented in the context of SCs.

Better monitoring and control of urban resources based on the development of intelligent infrastructure, such as linked sensors and devices, made possible by 6G networks. This covers data-driven intelligent urban planning, water and energy efficiency, and intelligent waste management. Furthermore, by facilitating greater access to services like such as e-healthcare,

online education, and digital governance platforms, 6G-enabled SCs are anticipated to promote inclusivity and enhance people' quality of life.

3 CONCLUSION

As urban environments continue to evolve, the smart sustainable city SC has generated considerable attention. As research and industry studies present, there is a need for a critical reassessment of the entire ICon wireless communication sector for SCs. The development of the SC concept relies heavily on ubiquitous connectivity because the existing communication infrastructure cannot keep pace with the rapid growth and extended operation of SCs.

Smart cities SC are the result of modern ICT development that integrates mobile communications and AI. 5G networks significantly influence the development of SC infrastructure. Along with data analytics and artificial intelligence, the Internet of Things is a crucial ICT technology that facilitates smart networking in urban areas. Smart connectivity solutions have been the focus of several national SC programs. In terms of various degrees of new technologies, practically every city nowadays aims to be SC to some degree. Critical infrastructure integration and monitoring, resource optimization, maintenance activity planning, security monitoring, and maximizing citizen services are all taken into account. An innovative city that uses ICTs primarily to improve the quality of life and efficiency of city operations and services while meeting the needs of present and future generations in terms of the economy, society, environment, and culture is referred to as a smart sustainable city.

The quick advancement of IoT technologies encourages academics to explore new services and application areas. Additionally, by sharing and gathering data inside IoT services, human needs will be taken into account in order to increase awareness of smart city principles. Consequently, sensing, processing, networking, and actuation should all be integrated into the network.

With the development of ICon technologies, we are currently witnessing the ongoing evolution of urban settings. ICTs are helping many cities become smarter these days, increasing the efficiency of infrastructure and traditional services. Both industry and academics are conducting research on sixth generation (6G) technologies in light of the introduction of 5G technologies. One of the best options for enabling SC to support the development of new services and applications is 6G networks.

As technology continues to evolve, the creation of a new generation of wireless technology might be justified for a number of reasons. SCs and 6G are technologies that will transform the way we live and work in the near future. However, combining these technologies leads to a series of challenges that have to be addressed. The challenges for SCs include interoperability, data privacy and security, digital divide, and implementation challenges.

The next generation of SCs is anticipated to be made possible by 6G networks, which offer faster data transfer speeds, lower latency, and increased connectivity. Overall, 6G networks have the potential to transform how cities function by providing faster, more reliable, and more efficient connectivity, supporting a wide range of SC applications.

Actually, 6G requires new infrastructure and technology, which may be difficult to develop and deploy. Like any new technology, 6G may raise security issues that need to be resolved to protect users' privacy and safety. Finally, governments and private industries collaboration are necessary for development and implementation, and regulatory obstacles that need to be overcome. International coordination and collaboration will also be necessary to achieve worldwide connectivity with 6G.

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Testing IoT devices and systems in smart cities: challenges and solutions

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Abstract: Smart cities rely on complex IoT systems to enhance urban services, yet testing these large-scale, heterogeneous, and security-critical deployments poses unique challenges. This paper identifies key issues—scalability, interoperability, security, and resource constraints—and reviews state-of-the-art solutions, including simulation frameworks, standardization efforts, automated testing, and AI-driven approaches, providing actionable insights for robust, reliable IoT testing in smart cities..

Keywords: Interoperability, IoT testing, Scalability, Security, Smart cities

1 INTRODUCTION

Smart cities represent a paradigm shift in urban management, integrating information and communication technologies to enhance efficiency, sustainability, and quality of life for citizens. Across domains such as transportation, energy management, healthcare, and public safety, these initiatives leverage data-driven services powered by IoT devices and complex infrastructures to improve urban living. IoT systems are key enablers of these environments, consisting of interconnected devices, sensors, actuators, and platforms that continuously publish and collect data, acting upon it in various ways. These systems are expected to grow exponentially in the near future, with forecasts predicting more than 75 billion IoT devices will be connected by 2025, and as many as 500 billion by 2030 [1] (Fig. 1).

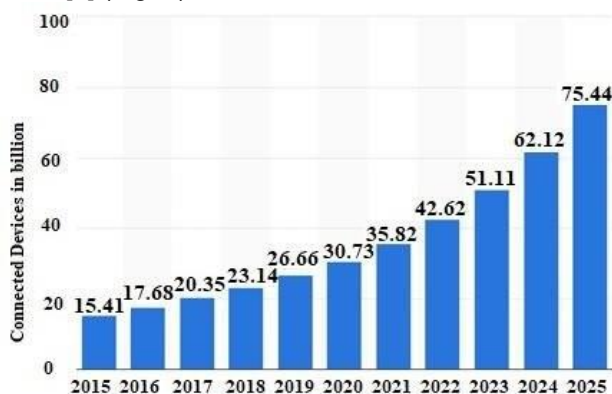


Figure 1 Internet of Things (IoT) connected devices from 2015 to 2025 (in billions)[1]

Compared to other IoT scenarios, smart cities present a unique set of challenges for testing. Cities operate at larger scales, often connecting thousands to millions of devices in a highly distributed environment. These devices must function under fluctuating network conditions and strict resource constraints, while also supporting diverse use cases, including public transport coordination, energy distribution, and emergency services each with specific performance and security requirements. Moreover, the impact of any IoT failure in a city environment can be substantial, potentially affecting essential services and infrastructure, as well as raising privacy and safety concerns. Consequently, ensuring robust testing frameworks that can address real-time responsiveness, multi-vendor interoperability, and continuous data flows becomes imperative in urban IoT deployments.

Unlike traditional software systems, IoT systems span multiple layers from physical sensing devices and communication networks to data processing platforms and application services. This multi-layered architecture enables real-time interaction with the physical world but also introduces significant complexity. The continuous generation of vast, heterogeneous data streams and the need for rapid response highlight the critical importance of rigorous testing to ensure reliability, security, and interoperability of current and future systems [2,3]. However, testing IoT systems under real-world city conditions poses unique challenges, as will be examined in this paper. Traditional software testing methods may not suffice due to the heterogeneous devices, limited resources, and highly distributed nature of IoT deployments. Moreover, vulnerabilities in IoT systems can lead to widespread disruptions,

making security and privacy assurance indispensable [4,5].

2 BACKGROUND AND CONTEXT

The foundation of a smart city lies in a layered ecosystem of technologies that include sensing components, communication networks, data platforms, and application services. At the lowest

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protocols such as Wi-Fi, 5G, LoRaWAN, MQTT, or CoAP, each chosen for its suitability to specific range, bandwidth, and energy constraints [6,7], for a simplified view of such a system refer to Fig. 2. Such vast amount of data coupled with the abundance of different usecases, pose a tough challenge for engineers to solve.

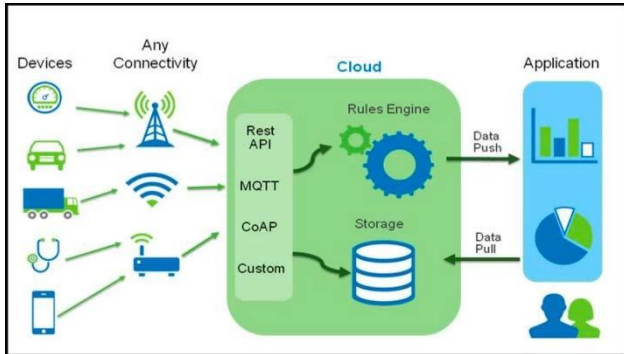


Figure 2 Simplified IoT data flow found in smart cities

Above the communication layer reside data management platforms cloud or edge-based environments responsible for storing, filtering, and processing sensor data. These platforms transform raw data into meaningful insights, applying analytical reasoning, machine learning algorithms, and custom domain specific logic, that help us make sense of what is happening in our cities. On top of these platforms, application services present user-facing functionalities, dashboards, and controls to city operators and citizens. While some reference models propose numerous layers, many IoT systems share four essential ones: a device layer, a network layer, a platform (cloud/edge) layer, and an application layer [6], see Fig. 3. Together, these interconnected layers must work seamlessly, enabling physical devices to interact with the real world and deliver responsive, data-driven services that us citizens can use to improve our quality of life, or for decision-makers to be able to more easily come to conclusions and make the best possible data-driven decisions.

level are sensors and actuators embedded within streetlights, public transportation systems, water management facilities, and buildings collectively known as the “device” or “thing” layer. These devices capture real-time information from the environment, some of the data they collect are temperature, air quality, traffic flow, energy consumption and many others. This data then travels through communication networks, which may rely on a variety of

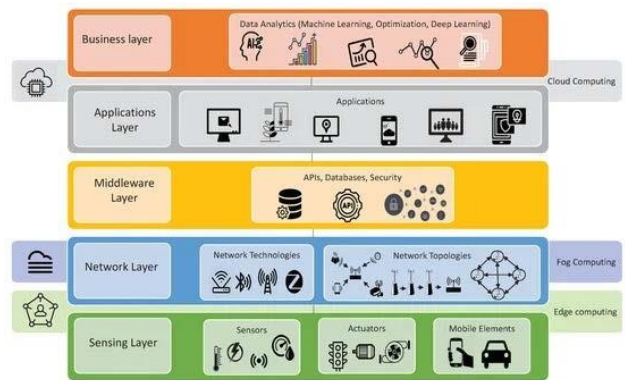


Figure 3 IoT layered architecture [25]

From a software engineering perspective, ensuring quality in such layered, heterogeneous environments demands robust testing. Traditional testing principles such as unit, integration, system, and acceptance testing still apply, but their implementation differs. IoT devices may run on constrained hardware with limited computational resources. Communication links may be intermittent, data formats may be diverse, and system configurations may evolve dynamically. Conventional testing tools and approaches often assume stable, resource-rich environments, making them insufficient for IoT and smart cities. Instead, new testing frameworks must consider the unpredictable nature of networks, the variability in device capabilities, and the integration of various communication protocols. Furthermore, security and privacy testing must be prioritized, as IoT devices often reside in public spaces where breaches can have serious societal impacts. Consequently, the testing of IoT systems requires adaptation, innovation, and the development of specialized techniques and tools that can operate effectively within these complex, distributed environments.

3 CHALLENGES IN TESTING IOT DEVICES AND SYSTEMS IN SMART CITIES

Smart cities often rely on extensive, citywide IoT deployments that integrate tens of thousands of heterogeneous devices from air quality sensors and

smart meters to traffic lights and surveillance cameras. Ensuring that each device interacts seamlessly with the rest of the system poses significant challenges, especially when scaling test efforts to match realworld complexity. Cities like Santander, located in Spain, have experimented with large-scale IoT testbeds, deploying thousands of sensors and services to support applications such as intelligent transportation and environmental monitoring [8]. At this scale, selecting representative devices for testing and ensuring coverage of diverse communication protocols is nontrivial [9,10]. Additionally, some devices operate under strict power constraints and cannot rely on stable energy or network availability, complicating testing strategies that assume continuous connectivity [11].

Interoperability is another key concern. Today's IoT market includes devices from numerous vendors, each with unique interfaces, data formats, and proprietary standards. Without universal protocols, testers must grapple with integrating components that may not readily communicate, leading to fragmented testing scenarios and difficulties in ensuring end-to-end functionality. The absence of widely adopted standards hinders automated testing and complicates the creation of unified test frameworks [12].

Data heterogeneity further compounds these issues. IoT devices continuously stream large volumes of data in varied formats, making it challenging to achieve consistent, highquality data for testing. In addition, there may be a lack of standardized APIs, limiting the ability to efficiently gather and analyze this data. Such complexities can skew test results, introduce delays, and reduce trust in the overall system's reliability [10].

Security and privacy remain among the most pressing concerns. As IoT networks expand, so too do the potential attack surfaces (Fig. 4). Testing for vulnerabilities in open, interconnected urban environments is far more complex than in isolated, well-defined systems. Even minor security gaps can allow malicious actors to disrupt services or compromise sensitive information. The distributed nature of IoT systems and their reliance on various networks makes replicating potential attack scenarios during testing difficult, necessitating specialized security test methodologies [13].

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Real-time constraints heighten these challenges. Many smart city applicationsfrom traffic signal optimization to emergency response systemsrequire near-instantaneous data processing and reaction. Testing must ensure not only logical correctness but also strict timing requirements and fault tolerance under unpredictable conditions [14]. Meanwhile, the resource limitations of many IoT devices such as limited processing power, memory, and battery

capacityrestrict the complexity and duration of tests that can be run directly on the devices themselves.

Finally, the tight coupling between hardware and software in IoT systems complicates both test design and execution. A bug at the hardware level can have cascading effects on software components, and vice versa. These multilayered dependencies make isolating faults more difficult and require broader test coverage across the entire IoT stack. Moreover, environmental conditions and non-repeatable scenarios such as variable wireless signal quality or fluctuating weather conditions can affect device behavior and test outcomes, making it hard to reproduce and diagnose issues [15].

Overall, testing IoT devices and systems in smart cities involves not only addressing technical hurdles such as scale, interoperability, data variety, security, real-time constraints, and resource limitations but also dealing with the inherent unpredictability and complexity of real-world conditions. Developing effective test strategies and tools that can handle these multidimensional challenges is crucial for ensuring that the promises of smart cities are fully realized.

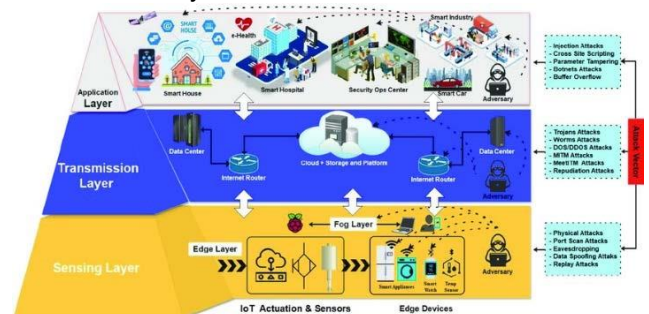


Figure 4 IoT layered architecture [25]

4 STATE-OF-THE-ART SOLUTIONS AND TESTING METHODOLOGIES

Addressing the complex challenges of testing IoT systems in smart cities has prompted the development of various methods and tools. These solutions often combine simulation, automation, interoperability standards, intelligencedriven testing, and robust security validation to ensure that devices and services function reliably in large, heterogeneous urban

environments.

Simulation and Emulation Tools:

Simulating city environments and modeling sensor networks at scale allows testers to evaluate IoT deployments before committing to costly real-world experiments. Digital twins and hybrid simulation-based testing frameworks replicate realworld scenarios, enabling the validation of device behavior,

communication protocols, and data processing pipelines under controlled, yet realistic conditions [15]. For instance, testbeds incorporating fog and cloud layers replicate distributed architectures found in many

smart city applications, allowing developers to fine-tune device configurations and optimize network resource usage before mass deployment [16] (Fig. 5).

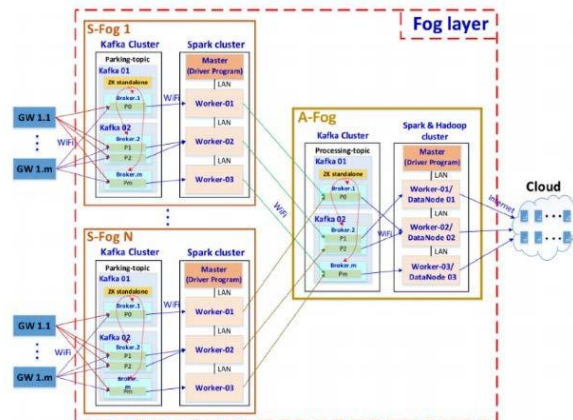


Figure 5 Two-tier fog layer architecture [16]
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Automated Testing Frameworks:

Continuous integration and continuous deployment (CI/CD) pipelines are increasingly used to streamline IoT system testing, integrating automated test suites that run at every code commit or hardware update. By combining unit, integration, and systemlevel tests, developers and testers can quickly identify regressions and validate changes without manual intervention [17]. Automated testing frameworks also enable scalable testing of large device fleets, helping teams maintain quality in fastpaced, iterative development cycles.

Interoperability Testing Solutions:

Ensuring that devices from different vendors and platforms communicate seamlessly is vital. Standardized protocols, such as oneM2M (Fig. 6), promote interoperability and enable test frameworks to verify compliance and compatibility across diverse devices [18]. Platforms like F-Interop have emerged to support online interoperability and performance tests for IoT protocols, allowing stakeholders to confirm that devices and services adhere to agreed-upon specifications before deployment [19]. These initiatives also help prevent vendor lock-in and ensure that smart city solutions remain flexible and future-proof.

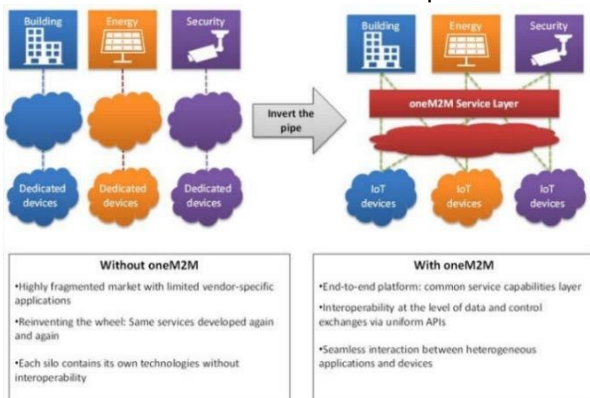


Figure 6 Comparison between oneM2M and non-oneM2M solutions [27]

AI/ML-driven Testing Approaches:

As the volume and complexity of IoT data grow, artificial intelligence (AI) and machine learning (ML) techniques are increasingly employed to detect anomalies, predict failures, and guide adaptive test strategies. For example, ML-based analysis can identify unusual patterns in sensor data and trigger targeted testing scenarios focused on potential faults [20]. Adaptive testing frameworks dynamically adjust test cases, resource allocation, and timing based on insights gleaned from data-driven models, helping to ensure coverage of rare yet critical scenarios.

Security Testing and Penetration Frameworks:

Robust security validation is crucial in interconnected city environments, where a single compromised device can lead to widespread disruption. Specialized testing frameworks employ penetration testing, fuzzing, and runtime verification to identify vulnerabilities in communication protocols, authentication mechanisms, and device firmware [21]. By subjecting IoT solutions to stress tests and adversarial conditions, these tools help ensure that systems can withstand real-world threats, safeguarding both infrastructure and citizens' privacy.

5 CASE STUDIES

Real-world pilot projects and testbeds have played a critical role in understanding the complexities of testing IoT systems for smart cities. For example, the SmartSantander project, conducted in the city of Santander, Spain, deployed thousands of IoT devices ranging from environmental sensors to traffic and parking sensors across an urban landscape to enable data-driven decision-making [8]. Within this

large-scale environment, testers needed to address multiple challenges simultaneously, including hardware variations, network congestion, and the seamless integration of new applications as the city's needs evolved. Lessons learned from this initiative underscored the importance of continuous monitoring, adaptive testing strategies, and open data standards that streamline interoperability among disparate devices and platforms.

Another noteworthy example is the FIESTA-IoT initiative (Fig. 7), a European testbed federation that integrates multiple heterogeneous testbeds into a single, standardized platform [22]. By unifying different testing environments under a common set of semantic models, data formats, and APIs, FIESTA-IoT enabled researchers and developers to run cross-domain experiments quickly and cost-effectively. In practice, this meant that an IoT solution initially trialed in a smart home setting could be easily tested in a smart agriculture context, allowing engineers to identify issues related to scaling, data heterogeneity, and realtime constraints before deploying solutions in production.

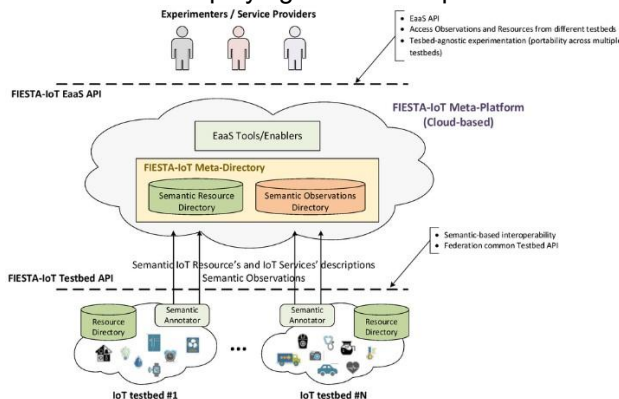


Figure 7 FIESTA-IoT testbed federation concept overview [23]

Lessons from these projects suggest a few best practices. First, establishing early standards for device communication and data modeling helps mitigate interoperability issues. Second, using federated testbeds and shared data models simplifies testing across multiple domains and scales, encouraging broader participation and knowledge exchange. Third, maintaining flexible, automated, and adaptive testing frameworks allows for the rapid iteration and improvement of IoT solutions, even as the city's technology infrastructure and environmental conditions change.

6 CONCLUSION

In the coming years, as smart cities become more interconnected and sophisticated, testing IoT systems will continue to demand innovative, multifaceted approaches. The diversity of devices and protocols, coupled with real-time demands and evolving security threats, requires more than traditional testing

blockchain technology can bolster data integrity and provide tamper-evident audits across large networks, especially when standardization lags or vendor heterogeneity is high. Similarly, AI and ML hold immense promise for dynamically adapting test strategies to detect anomalies, predict failures, and optimize resources in complex, distributed scenarios.

By building on the simulation, automation, and interoperability testing approaches outlined in this paper, researchers and practitioners can create resilient, self-improving test environments. Integrating these solutions with emerging blockchain-based tools and advanced AI/ML algorithms has the potential to enhance both security and efficiency across the entire lifecycle of urban IoT systems from design and deployment through ongoing operation. In this way, smart cities can realize not only the benefits of large-scale, data-driven services but also maintain the trust and reliability that underpin safe and sustainable urban living.

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A Computationally Implemented Method for Assessing Air Pollution in Urban Traffic Based on Traffic Density Analysis

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Abstract: Monitoring and assessing air pollution levels in urban areas represents a key challenge in environmental protection and traffic management. This paper proposes a computationally implemented method for indirect air pollution assessment based on traffic density analysis, eliminating the need for direct sensor-based measurements of pollutant concentrations. The proposed system employs computer vision for real-time vehicle detection and classification, while air pollution levels are estimated using a mathematical model that accounts for the average emission rates per vehicle. The system architecture includes an embedded computer (Raspberry Pi) for video data processing, network infrastructure connectivity, and data transmission to a central server for further analysis and visualization. Experimental results confirm that the proposed approach enables reliable and efficient air pollution assessment under real-world conditions, opening avenues for enhancing environmental monitoring strategies and optimizing traffic flow in urban environments.

Keywords: Air pollution assessment, traffic analysis, IoT, computer vision, mathematical modeling, urban ecosystems

810 1 INTRODUCTION

Air pollution is one of the most serious environmental problems today, with a direct impact on human health and the environment. Increased urbanization and intense traffic in cities significantly contribute to higher concentrations of harmful gases, such as carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter PM_{2.5} and PM₁₀, which negatively affect air quality. Monitoring pollution levels is crucial for implementing effective environmental protection measures and improving the quality of life for citizens.

Numerous studies have highlighted the detrimental effects of air pollution on both human health and the environment. According to Manisalidis et al. (2020), air pollution is a major contributor to respiratory and cardiovascular diseases, reproductive and neurological disorders, and even cancer. Pollutants such as particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO₂), volatile organic compounds (VOCs), and heavy metals have been linked to increased morbidity and mortality rates. The study emphasizes that urbanization and industrial activities significantly contribute to air pollution, exacerbating its harmful effects on public health. Furthermore, climate change, driven in part by air pollution, influences the spread of infectious diseases and intensifies environmental degradation. Addressing this issue requires a multidisciplinary approach, including continuous monitoring, public awareness, and the development of sustainable solutions [1].

Although sensor-based air pollution measurement systems are precise and reliable, they are not available

in every part of the city, making continuous and comprehensive air quality monitoring challenging. The limited availability of these sensors can lead to incomplete or inaccurate data, hindering the implementation of adequate measures to reduce pollution. Therefore, it is necessary to develop alternative methods for assessing pollution levels that do not require direct measurement of pollutant concentrations but still provide a reliable estimation of air quality in urban areas.

This paper proposes a novel approach to indirect air pollution assessment using traffic density analysis. By implementing a system that utilizes computer vision for vehicle detection and classification, it is possible to estimate pollution levels based on the average emissions of individual vehicle types. This method enables continuous real-time pollution monitoring without the need to deploy a large number of sensors. The application of this system can enhance environmental protection strategies, enable more accurate pollution assessments, and contribute to optimizing traffic flow in urban areas.

2 RELATED WORK AND COMPARISON

The issue of assessing air pollution in urban environments caused by traffic is attracting increasing attention from researchers, given the significant impact of traffic infrastructure and density on air pollution and public health. Modern studies utilize various approaches, including machine learning, traffic density analysis, and sensor-based models.

The authors of the study [2] propose a method for predicting urban air pollution caused by traffic using data from web applications (Google Traffic). They applied a machine learning approach by training a decision tree algorithm to predict PM2.5 concentration.

On the other hand, the study by Ranka Godec et al. [3] analyzed the impact of traffic density on pollution levels by measuring PM10 particles, carbon (elemental and organic), and polycyclic aromatic hydrocarbons (PAHs), as well as gas pollutants (SO₂, NO₂, and CO) at various intersections. The results indicated significant differences in PM10 concentrations between locations, with the highest values recorded in areas with the densest traffic. Additionally, it was observed that residential heating during nighttime contributes to PAH emissions, highlighting the need for comprehensive models that account for multiple pollution sources.

Kostadinov et al. [4] used recurrent neural networks (RNN) with LSTM units to forecast PM10 levels in

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Skopje. Their model demonstrated that vehicles are not the primary source of air pollution, emphasizing the need for a holistic approach that considers industrial and climatic factors.

Govea et al. [5] developed a system based on IoT technologies and predictive models, utilizing convolutional neural networks and decision trees for traffic data analysis and PM2.5 and noise mapping. Their model achieved high accuracy (R² = 0.93 for PM2.5 and R² = 0.90 for noise); however, it depends on the availability of IoT sensors, which can be a limiting factor in certain urban environments.

The study [6] presents findings showing that traffic network parameters, such as traffic density and the number of intersections, significantly correlate with PM2.5 concentrations. This research highlights the necessity of detailed spatial analysis of traffic and air pollution, as correlations identified using the GWR model were significantly more precise than those obtained through standard linear regression analyses.

Mapping urban air quality is widely applied in urban planning; therefore, the authors [7] developed the CLADF (Contextually Localized Adaptive Deep Forest) model for precise mapping of NO₂ pollution with a resolution of 100 m and 1 hour, using mobile sensors and traffic flow as key contextual factors.

Compared to previous research, our method offers an innovative and practical approach to air pollution assessment by analyzing traffic density through computer vision. Unlike methods based on IoT sensors [5] or deep neural networks [4], our system enables autonomous data collection using real-time video analysis, eliminating the need for external data sources and predictions.

Additionally, our approach considers the number of vehicles and their average emissions, allowing for more accurate estimations compared to statistical models such as the one proposed in the study by Ranka Godec et al. [3]. While the GWR-based study [6] provides a

detailed analysis of traffic's impact on PM2.5 levels, our method enables direct analysis of real-time traffic conditions and pollution levels, making it more suitable for implementation in urban environments.

3 METHODOLOGY

The proposed method for assessing air pollution in urban areas is based on traffic density analysis using computer vision techniques and a mathematical emission estimation model. This method enables indirect determination of air pollution levels without the need for direct sensors to measure the concentration of harmful gases.

• Setting up the development environment

Figure 1 shows the hardware implementation of the system in multiple steps. The hardware foundation consists of an embedded Raspberry Pi computer Nikola STANIĆ,

connected to a surveillance camera placed in a high-traffic location. The camera continuously captures real-time video footage, while the Raspberry Pi processes the recorded material using computer vision algorithms based on the OpenCV library. • **Vehicle detection and classification**

The video footage is processed in real time, with the system detecting and recognizing vehicles using pre-trained object detection models. A key aspect of this methodology is identifying and counting vehicles that cross a defined observation line, providing data on traffic density within the observed time interval.

• Data transmission to the central server

The system records the number of vehicles every two hours and transmits the data to a central server via the internet. The server performs additional data processing using a mathematical model for estimating pollutant emissions. The model takes into account the average emission values of gases such as SO₂, NO₂, O₃, CO, PM10, and PM2.5 per vehicle, which are then multiplied by the number of detected vehicles to obtain the total air pollution level for SO₂, NO₂, O₃, CO, PM10, and PM2.5 during that time period.

The mathematical model is based on the formula Eq(1).

$$PP_{xxxx} = PP_{xxxx,aa} \times NN_{aa} \quad (1)$$

aa=1

Where:

XX - represents any of the present pollutants, such as SO₂, NO₂, O₃, CO, PM10, or PM2.5.

P_{xx} – estimated emissions of individual pollutants.

P_{xx,i} – average emissions of individual pollutants per vehicle of type i.

N_i – number of vehicles of type i detected during the observed period.
 N – total number of different vehicle types.

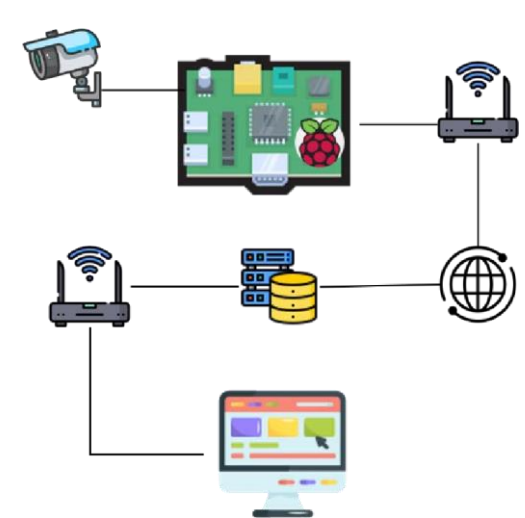


Figure 11 Hardware implementation of the system

The proposed methodology enables an efficient and cost-effective assessment of air pollution levels, contributing to the improvement of environmental monitoring strategies and optimization of traffic in urban areas. Additionally, within this methodology, the potential of existing cameras at intersections is utilized, eliminating the need for additional pollution measurement sensors while simultaneously maximizing the efficiency of existing resources.

4 DATA ANALYSIS AND VISUALIZATION

The collected data is stored in a database on the server and used to analyze pollution trends over different time intervals. The results are presented through a web application, shown in Figure 2, developed in Python (Flask) and JavaScript. This application allows users to interactively view pollution levels in urban areas. The interface is designed to be simple and intuitive, with a dropdown menu where users can select the

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station from which they want to view pollution data, along with the date and time of the measurements. As stated in the methodology, the data is displayed at two-hour intervals.

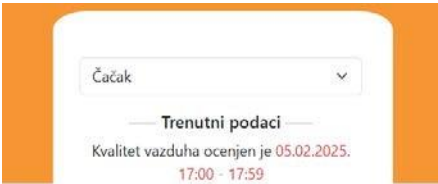
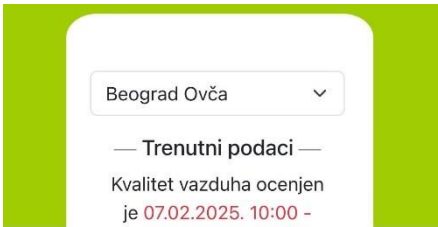


Figure 12 Web Application: Air quality assessment at the Čačak monitoring station



Additionally, Figure 3 presents the measurement results

from another station in different city, where the same Web Application: Air assessment at the Beograd Ovča measurement environment has been implemented.

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Experimental Validation and System Evaluation

The system was tested in real-world conditions in urban environments with varying levels of traffic activity. The obtained results were compared with

environmental organizations with valuable data for making informed decisions on environmental protection.

This study contributes to the existing body of research by introducing a method that does not require sensor deployment in public areas while simultaneously providing highly accurate air pollution assessments based on traffic parameters and computer vision. The implementation of such a system can significantly enhance environmental monitoring strategies and optimize traffic flow management in urban areas.

Future research will focus on improving the vehicle recognition model to include a broader classification of vehicles based on emissions, distinguishing between electric, hybrid, and internal combustion engine vehicles. Additionally, further enhancements may involve integrating meteorological data, such as wind speed and humidity, to achieve more precise calculations of pollutant dispersion.

Moreover, the research will expand to optimize the model for real-time processing on edge devices, such as embedded systems with low power consumption. Furthermore, the development of an adaptive model is planned, which could utilize data from drones and other sources to enable dynamic and comprehensive pollution analysis across different urban zones.

With these advancements, the proposed method could become even more relevant for practical applications in smart cities, supporting the

data collected using traditional sensor-based methods for measuring air quality.

Considering the results of the experimental tests, the deviations between the pollution estimation using the mathematical model and the measurements obtained from sensor systems are negligible, especially in the case of heavy traffic. Based on the pollution calculations using the mathematical formula, the deviations range within $\pm 7\%$, indicating the high precision of this model in comparison to sensor measurements. This deviation coefficient is considered realistic, given the variations that may arise due to specific traffic conditions and local factors in urban environments.

5 CONCLUSION

The objective of this paper is to present the architecture and functionality of the proposed system, analyze its reliability and efficiency through experimental results, and highlight the potential benefits of its implementation in real-world conditions. This approach can significantly contribute to improving air quality monitoring and providing city authorities and Stefan ĆIRKOVIĆ, Nikola STANIĆ, Katarina KARIĆ

development of sustainable strategies for reducing air pollution.

Acknowledgements

This study was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, and these results are parts of the Grant No. 451-03136/2025-03/200132 with University of Kragujevac – Faculty of Technical Sciences Čačak.

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Performing EDA Techniques for Time Series Forecasting in Smart Cities

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Abstract: In the age of smart cities, where interconnected technologies produce substantial data, time series forecasting has become a crucial instrument for efficient urban management. Exploratory Data Analysis (EDA) is an essential initial phase in comprehending and organising data for precise and insightful predictions. This study examines the utilisation of exploratory data analysis approaches for time series data in the framework of smart cities. It emphasises techniques for detecting trends, seasonality, autocorrelations, and correlations in data streams from sources like environmental monitoring systems. The research investigates ways to identify patterns, test hypotheses, and confirm assumptions using visual and quantitative methods. Employing diverse visualisation tools, statistical summaries, and decomposition techniques enhances the comprehension and preprocessing of time series datasets. The objective of the research is to perform and evaluate the efficacy of standard tools such as time plots, autocorrelation and correlation analysis, seasonality decomposition, and identifying trend patterns in conjunction with sophisticated techniques such as seasonal decomposition of time series (STL), correlation heatmaps, and trend detection techniques. The findings emphasise EDA's significance as a fundamental step in empowering researchers and practitioners to make informed decisions, ensuring strong analytical results, and developing resilient time-series forecasting models for contemporary urban issues.

Keywords: EDA techniques; environmental data; preprocessing time series; smart cities; time series forecasting.

1 INTRODUCTION

The concept of smart cities, which use data-driven solutions to improve urban living, has gained popularity due to the rapid growth of urbanisation and improvements in technology. Time series forecasting is important for smart cities because it allows for predictions about infrastructure, resource allocation, and public services. Forecasting accurately can help improve energy management, traffic flow, pollution control, drought management and catastrophe preparedness, which will ultimately lead to a better quality of life for those living in cities.

Exploratory Data Analysis (EDA) is a crucial first step in accomplishing these goals. It helps to analyse time series data, discover trends, and find patterns in data that can affect predictions. EDA approaches assist in transforming raw data into useful insights by visualising trends, seasonality, and correlations within the data. This technique is particularly important for time series data since temporal dependencies and anomalies can have a major effect on the predictive models.

Anestis Kousis [1] conducts a bibliometric study of research on Data Mining (DM) technology used in smart city applications. It seeks to identify the primary data mining approaches and the evolution of the study area throughout time. The research encompasses 197 publications published from 2013 to 2021, using the Scopus database and the Bibliometrix library in R. The results indicate a diverse array of DM technologies used across all levels of a smart city initiative, with several ML algorithms utilised at the instrumentation, middleware, and application layers. DM for smart cities is an expanding scientific domain garnering global attention in study and cooperation.

Chen [2] presents a hybrid method (STL-LSTM) to enhance short-term metro ridership forecasting. It integrates SeasonalTrend decomposition using Loess (STL) with the LSTM neural network to alleviate irregular oscillations. The original series is divided into three sub-series, and the LSTM neural network forecasts each one. The whole production is consolidated. The STL-LSTM model attains superior accuracy compared to the single LSTM, support vector regression, and the EMD-LSTM model.

The Fourth Industrial Revolution's data science is changing cities' technology and operations. Automating and intelligent city systems need actionable city data insights and data-driven models. Sarker [3] studies "Smart City Data Science," which uses sensor, internet-connected device, and other data to improve decision-making and citizen services. Artificial intelligence, especially machine learning analytical modelling, may improve municipal data understanding and computer operations. The report provides academics, industry experts, and policymakers with 10 open research problems for datadriven smart cities.

Martin Strohbach [4] investigates the possibilities of a cohesive Big Data analytical framework for Internet of Things (IoT) and Smart City applications. It offers a summary of Big Data and Internet of Things technologies, showcases a case study in the smart grid sector, and introduces a preliminary version of the framework that tackles the challenges of volume and velocity. The results are derived from comprehensive outcomes of the EU-funded projects BIG and the Germanfunded project PEC. The objective is to decrease development expenses and facilitate new services for residents and urban policymakers.

Green IoT seeks to diminish energy usage by lowering the energy demands of IoT devices. Mohammad Shorfuzzaman [5] seeks to develop

prediction models using sensor data to analyse energy use in an IoT-enabled smart home setting. Two methodologies are employed: a comprehensive energy consumption model using linear and non-linear regression approaches, and a multi-step time-series model applying the autoregressive integrated moving average (ARIMA) methodology. The LSTM regression model surpasses conventional linear and ensemble regression models because of its significant variability. The suggested predictive models will assist customers in reducing energy use and enable energy suppliers to more effectively plan and anticipate future energy demand, hence promoting sustainable urban development.

The rising levels of particulate matter (PM2.5) in air pollution inside smart cities globally present a substantial risk to both the populace and the ecosystem. In Malaysia, traffic congestion significantly contributes to air pollution in urban areas such as Kuala

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Lumpur and Johor Bahru. Machine learning methods have been extensively researched worldwide for air pollution prediction, although their use in Malaysia remains limited. This work intends to use machine learning methods to forecast PM2.5 levels in smart cities using the Malaysia Air Pollution dataset. The Rishanti Murugan [6] study evaluates Multi-Layer Perceptron (MLP) and Random Forest algorithms, concluding that Random Forest exhibits superior accuracy in forecasting PM2.5 air pollution indices in smart cities.

This article explores the use of EDA approaches for forecasting time series in smart cities. It aims to conduct and evaluate the effectiveness of techniques such as time plots, seasonality decomposition of time series using the LOESS method, ACF and PACF functions, and trend pattern identification by using various trend detecting tests. This approach helps build smarter, more efficient, and more sustainable cities by connecting data analysis with predictive modelling.

2 TIME SERIES DATA IN SMART CITIES

Understanding time series data in the context of smart cities is essential for optimising urban management, improving resource efficiency, and elevating inhabitants' quality of life. Smart cities produce enormous volumes of time series data through a variety of IoT devices, sensors, and interconnected systems, which is an essential element of urban operations. Primary sources of such data include transportation and traffic systems, environmental monitoring, smart buildings and infrastructure, healthcare systems, public safety and security, and energy and utilities.

Time series data is a set of observations or measurements gathered at regular, consecutive periods over time. It is utilised to monitor alterations, trends, patterns, or behaviours of a variable across time. Time series generally consists of three (trend, seasonality, and residuals) or four components (trend,

seasonality, cyclical, and residuals) depending on the characteristics of the data and the phenomena being analyzed. If seasonality is clear, residual noise is sufficient, and there is no cyclical behaviour, a time series can be decomposed into three components. However, the presence of cyclical patterns in addition to trend, seasonality, and residuals shows that the time series consists of four components.

The key components of a time series are:

- **Trend:** It represents a long-term direction or changes (linear or otherwise) of the data over an extended period. It can indicate overall increase, decrease, or stability in the data. For example, global warming manifests in temperature data as a long-term increase in the annual average across many regions in the world.
- **Seasonality:** It refers to the regular and repeating patterns in the data that occur at regular periods within a time series. In time series analysis, seasonality appears as periodic fluctuations that repeat over fixed time intervals like days, weeks, months, or years. For example, a high air temperature or higher electricity demand due to air conditioning during the summer months.
- **Cycles:** A cycle represents non-fixed fluctuations usually caused by economic or social factors. Unlike seasonality, cycles may vary in length and do not follow a certain fixed interval. For example, recessions affecting housing markets.
- **Irregularities:** The irregular component, sometimes referred to as the residual or noise, is the remainder after the seasonal and trend components have been estimated and removed. It results from short-term variations in the series which are neither predictable nor systematic.

3 EXPLORATORY DATA ANALYSIS TECHNIQUES

EDA techniques are used for examining the relationships between features and the goal variables. There are many EDA techniques which can be categorized for univariate, bivariate and multivariate data. Techniques related to univariate analysis are descriptive statistics which include mean, median, mode, variance, standard deviation, skewness, kurtosis, visualization techniques which include histogram, boxplots, density plots etc. Techniques related to bivariate analysis include statistical measures such as correlation coefficient (Pearson, Spearman, Kendall) and covariance, and visualization techniques like scatter plots, pair plots, box plots, heatmaps, correlation matrices etc. Multivariate data analysis include techniques such as Principal Component Analysis (PCA), clustering and factor analysis, and visualization techniques such as pair plots, 3D scatter plots, parallel coordinates plots etc.

However, there are certain time series EDA techniques specifically used for time series data like pattern detection techniques which include trend analysis, seasonality analysis, seasonal decomposition, autocorrelation (ACF) and partial autocorrelation (PACF), stationarity testing (Unit root tests), and visualization techniques like line plots, lag plots, seasonal decomposition plots etc.

3.1 Decomposition of time series

Time series can contain a series of patterns combined together, and it is possible to decompose the time series into these components.

Decomposition represents the process of disaggregating a time series into its fundamental components, facilitating the detection of patterns and comprehension of behaviour, hence enhancing the selection of predictive models [7].

It is sometimes essential to execute some adjustments or transformations by removing the source of variance in order to be able to simplify the observed patterns before performing the actual decomposition. There are four categories of adjustments: calendar adjustment, population adjustment, inflation adjustment, and mathematical transformations. Adjustments, such as calendar modifications, are applied to data exhibiting seasonality and variations due to basic calendar effects [8].

After the transformations are performed, the process of decomposition starts with choosing one of the two decomposition models, specifically the additive model or the multiplicative model [9].

The classical or additive decomposition can be written in the form of the sum of the three components, namely the seasonal, trend, and irregular components:

$$yy_{tt} = SS_{tt} + TT_{tt} + EE_{tt} \quad (1) \quad \text{where:}$$

yy_{tt} = data in period tt ,

SS_{tt} = seasonal component in period tt ,

TT_{tt} = trend component in period tt ,

EE_{tt} = irregular component in period tt .

This model is mainly used when the variation of the seasonal component is relatively constant over time. However, if the variations increase over time, it is better to use a multiplicative decomposition model that can be represented as a product of all three components:

$$yy_{tt} = SS_{tt} * TT_{tt} * EE_{tt} \quad (2)$$

A procedure used to decompose time series into its three components is called the STL method. This method was first presented by Robert Cleveland, William Cleveland, Jean McRae, and Irma Terpenning in 1990. STL stands for "Seasonal and Trend decomposition using Loess," where Loess is the method used to estimate non-linear relationships. The decomposed time series components can be presented using plots to visually determine the existence of a trend or seasonality [10].

The STL technique possesses the subsequent characteristics [10]:

- features a simplistic design
- enables rapid computation of extensive time series
- enables the specification of the seasonal and trend component periods
- allows for the decomposition of time series with missing values
- supports only additive decomposition, excluding multiplicative decomposition

3.2 Trend analysis

In addition to visualisation techniques using time series decomposition, the trend can also be determined by statistical tests for trend detection. The primary objective in identifying a trend within a time series is to determine the presence of a trend type, that is, to determine whether the trend is linear, monotonic, or any trend, assuming that the data are uncorrelated.

The statistical tests used for this objective are:

- Classic t-test for assessing the presence of a linear trend
- Mann-Kendall test for evaluating the existence of a monotonic trend
- WAVK test for assessing the presence of any nonmonotonic trend via local regression

The classic t-test tests the presence of a linear trend in the data under the assumption that the time series may be autocorrelated, which is generally the most common case. The hypotheses used for the tests are as follows [11]:

H_0 (null hypothesis): No trend exists in the data.

H_1 (alternative hypothesis): A linear trend exists in the data.

For determining a monotonic trend, the Mann-Kendall Trend test is used. Since the linear trend is also a monotonic trend, similar results can be expected as with the classic t-test [12].

The hypotheses used for this test are as follows:

H_0 (null hypothesis): No trend exists in the data.

H_1 (alternative hypothesis): A monotonic trend exists in the data.

The WAVK test using local regression is used to determine any non-monotonic trend.

The hypotheses used for this test are as follows [11]:

H_0 (null hypothesis): No trend exists in the data.

H_1 (alternative hypothesis): There is a non-monotonic trend in the data.

3.3 Seasonality analysis

Seasonality appears as recurring patterns in a time series linked to particular time periods. These patterns may result from multiple variables, including meteorological conditions, holidays, or consumer behaviour. Recognising seasonality enables data scientists to reveal fundamental trends and enhance forecast accuracy.

Some of the common methods for identifying seasonality include visual methods which include autocorrelation analysis and decomposition of time series. Although these methods may be effective, there are statistical tests such as the KruskalWallis, and Canova-Hansen test which provide a robust statistical approach to confirm the presence of seasonality.

The Kruskal-Wallis test is a non-parametric statistical method used to determine whether statistically significant differences exist among three or more groups within a dataset. It is similar to Wilcoxon's Rank Sum test in that we are comparing the sum of ranks applied to the data. The test statistic is calculated as [13]:

$$KK = \frac{12}{NN*(NN+1)} \sum_{i=1}^k \frac{R_i^2}{n_i} - 3 * (N + 1) \quad (3)$$

where:

KK = calculated value of K statistics,

CC_{aa} = the sum of ranks for the i th group,

NN = data set

Canova and Hansen proposed a test statistic that the seasonal pattern is stable. It introduces Lagrange multiplier tests of the null hypothesis of no unit roots at seasonal frequencies against the alternative of a unit root at either a single seasonal frequency or a set of seasonal frequencies. The tests complement those of Dickey, Hasza, and Fuller and Hylleberg, Engle, Granger, and Yoo that examine the null of seasonal unit roots [15].

Autocorrelation or ACF function is crucial in the identification of time series processes. It represents the correlation between the values of a time series and its lags over a period of time. The autocorrelation function at lag n , indicated by $\rho\rho_{aa}$ is denoted as:

$$\rho\rho_{aa} = \gamma\gamma_{\gamma\gamma_{aa0}} \quad (4)$$

where:

$\rho\rho_{aa}$ = autocorrelation at lag n ,

$\gamma\gamma_{aa}$ = covariance of lag n , $\gamma\gamma_0$

= standard deviation of lag n .

4 RESEARCH METHODOLOGY

This research utilised the R programming language and RStudio IDE (version 2021.09.0 Build 351) as the software tools. R is a statistical programming language extensively utilised in academia for various statistical computations, data analysis, and data visualisation. CRAN, a comprehensive R archive network, works as a

central repository for R software packages, which consist of functions, data, and documentation that enhance the capabilities of the R programming language. CRAN is available through its website (<http://cran.r-project.org>), where users can search for packages, download R, and obtain documentation regarding R and its packages [16].

The raw data were gathered by multiple sensors from the

sensor station situated in Kać, in the municipality of Novi Sad, from January 2014 to December 2020. Upon data collection, they are transferred to the online portal. Subsequently, data collected from various sensors can be stored in Excel format. The sensors are part of a network category known as "Proactive Networks." The sensors collect data hourly, resulting in a total of 288 measurements over a 24-hour period. The sensors can be classified into seven groups. The initial category has six sensors exclusively designed to measure soil moisture (SM1, SM2, SM3, SM4, SM5, SM6). Additional categories include a humidity sensor (AH1), wind speed (WS1), wind direction (WD1), air temperature (AT1), precipitation (PP1), and battery power status (BT1). Only the air temperature time series will be used for applying EDA techniques and data analysis [17]. The dataset consists of four attributes: time, device, ID value, and value. Table 1 [18] provides descriptions of all the features in the dataset.

Table 1 –Structure of the data set

Data are retrieved from the online portal in Excel format and then saved in a data frame. A data frame is a twodimensional, tabular data structure used in R and other computer languages for the management and analysis of data in a structured fashion for statistical and data science applications. The preparation technique initially involves filtering out the parameters that won't be used and then aggregating the values of air temperature using the "mean" function to obtain the average values. Ultimately, the data are saved as a data table and organised in ascending order by months and years. Upon preparation of the data, EDA techniques may be applied [18].

5 RESULTS AND DISCUSSION

The first technique that will be used is the decomposition of time series by using the STL method. The STL method is implemented in the R language using the "stl()" function found in the R package *stats*. This function is used to decompose the air temperature time series into its components using the additive decomposition model, and then, if necessary, those components can be removed. This function contains two main arguments, *s.window* and *t.window*, which control how fast the trend and seasonal component can change. The first argument represents the number of consecutive years used to

evaluate the value in the seasonal component. It has no default value and must be defined, and the value "periodic" is usually set. The second argument is the number of consecutive observations of the time series that are used to estimate the values in the trend component. If this value is not explicitly defined, the default value is taken [8].

Attribute name	Description
Time	date and time of the measured parameter
Device	the device identification number of the measured parameter
ID value	sensor identification number of the measured parameter
Value	the measured parameter value

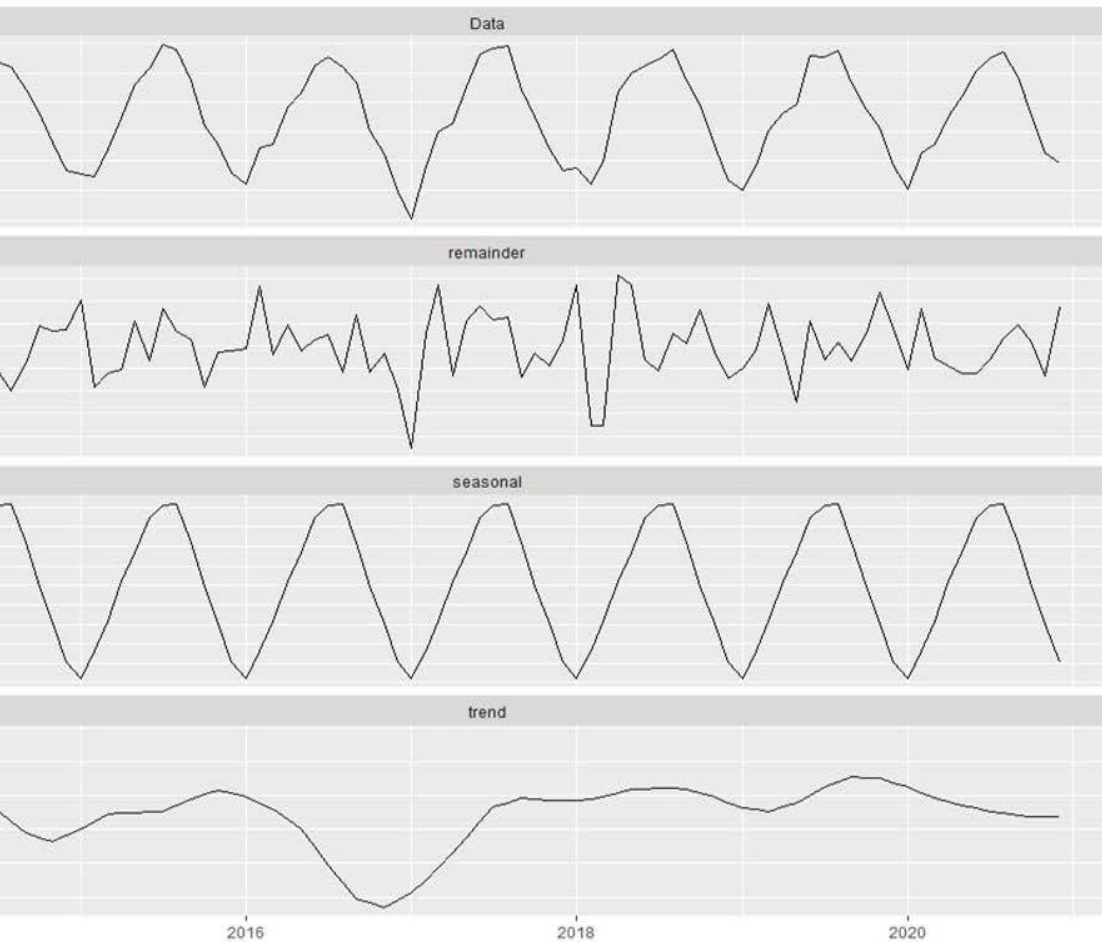


Figure 1. Decomposed air temperature time series with all its components

Figure 1 shows four panels. The bottom three panels show the three components (trend, seasonality, and error) separately. If these three components were added together, the raw data shown in the first panel above could be reconstructed. As can be seen in the figure, the seasonal component shown in the third panel is very obvious, and it changes slowly so that the pattern is quite similar for each year. The remainder component shown in the second panel symbolises the residual left over after subtracting the two remaining components from the data. The last panel shows the trend of the data series, which seems nonlinear.

The classic t-test tests the presence of a linear trend in the data under the assumption that the time series may be autocorrelated, which is generally the most common case. A classical t-test is performed using the

"`notrend_test()`" function from the *funtimes* package which will test the data set of the temperature time series for a significance level of $\alpha = 0.05$. If the p-value of the test is less than the significance level, then the null hypothesis can be rejected, and it can be said that there is statistically significant evidence that a linear trend is present in the data.

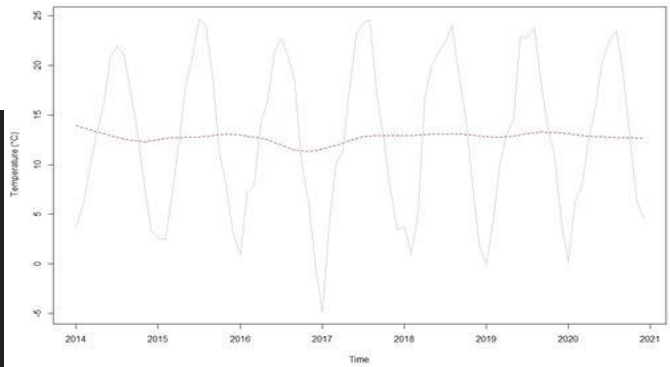
Figure 2 shows the results of the executed classical t-test, where it can be seen that the p-value of 0.914 is

```
Sieve-bootstrap Student's t-test for a linear trend

data: temperatura.TS
Student's t value = 0.35744, p-value = 0.914
alternative hypothesis: linear trend.
sample estimates:
$AR_order
[1] 10

$AR_coefficients
  phi_1    phi_2    phi_3    phi_4    phi_5    phi_6    phi_7    phi_8
0.77476739 -0.10086897 0.11274414 -0.09014890 -0.02198085 -0.04585700 -0.10057103 0.12518475
  phi_9    phi_10
-0.12970698 0.45326079
```

significantly higher than the significance level of 0.05, which indicates that the null hypothesis cannot be rejected. Therefore, the conclusion is that there is no linear trend in the time series.



```
data: temperatura.TS
WAVK test statistic = 7.4696, moving window = 8, p-value = 0.911
alternative hypothesis: (non-)monotonic trend.
sample estimates:
$AR_order
[1] 10

$AR_coefficients
  phi_1    phi_2    phi_3    phi_4    phi_5    phi_6    phi_7    phi_8
0.77476739 -0.10086897 0.11274414 -0.09014890 -0.02198085 -0.04585700 -0.10057103 0.12518475
  phi_9    phi_10
-0.12970698 0.45326079
```

Figure 4. The results of WAVK test for air temperature time series

In Figure 4, you can see the results of the WAVK test, where the p-value of 0.911 is much higher than the significance level of 0.05 and the null hypothesis cannot be rejected. The test suggests that there is no non-monotonic trend in the time series, which can be visualized on the graph by adding a dotted red line showing the trend (Figure 5).

Figure 2. The results of the classical t-test for air temperature time series

To determine a monotonic trend, the Mann-Kendall trend test is used. Since the linear trend is also a monotonic trend, similar results can be expected as with the classic t-test. The "notrend_test()" function performs the Mann-Kendall Trend test, using the value MK as the test parameter.

```
data: temperatura.TS
Mann-Kendall's tau = 0.033276, p-value = 0.888
alternative hypothesis: monotonic trend.
sample estimates:
$AR_order
[1] 10

$AR_coefficients
  phi_1    phi_2    phi_3    phi_4    phi_5    phi_6    phi_7    phi_8    phi_9    phi_10
0.77476739 -0.10086897 0.11274414 -0.09014890 -0.02198085 -0.04585700 -0.10057103 0.12518475 -0.12970698 0.45326079
```

Figure 3. The results of Mann-Kendall Trend test for air temperature time series

Figure 3 shows the execution results of the Mann-Kendall trend test. The test statistic is 0.033276, and the p-value is 0.888. Since this p-value is much higher than 0.05, the null hypothesis of the test cannot be rejected, which leads to the conclusion that even a monotonic trend is not present in the air temperature time series.

A WAVK test using local regression is used to determine any non-monotonic trend. The test is performed using the "notrend_test()" function, where the value "WAVK" is taken as the test parameter.

Figure 5. Display of air temperature time series with trend visualisation

Autocorrelation diagrams, or ACF diagrams, show the correlation between a certain time series and its lags. If there is a correlation between the series and its lags it implies that there are some trends or a seasonal component

in it, and therefore its statistical properties are not constant over time. The "acf()" and "pacf()" functions in R can display the autocorrelation plots separately from each other. If we want to display the combination of the time series together with its autocorrelation and partial

autocorrelation on one graph, we use the "PlotACF()" function from the *DescTools* package. The lag.max parameter indicates the number of lags that will be displayed on the diagrams, and in our case it is 36.

Figure 6 displays a graph of the air temperature time series along with ACF and PACF diagrams. This shows that the time series has seasonality and that the ACF function is slowly decreasing, which means that the data is not stationary. There are important positive and negative autocorrelations with a lot of initial lags that are well outside the 5% significance limits shown by the blue dashed line in the ACF plot. These lags are 1, 5, 6, 7, 11, 12, and 13. The PACF diagram only shows jumps at delays 1, 2, 3, 4, 5, and 6. The other delays are within the acceptable range so this could be due to the carry-over correlation from the initial and earlier delays.

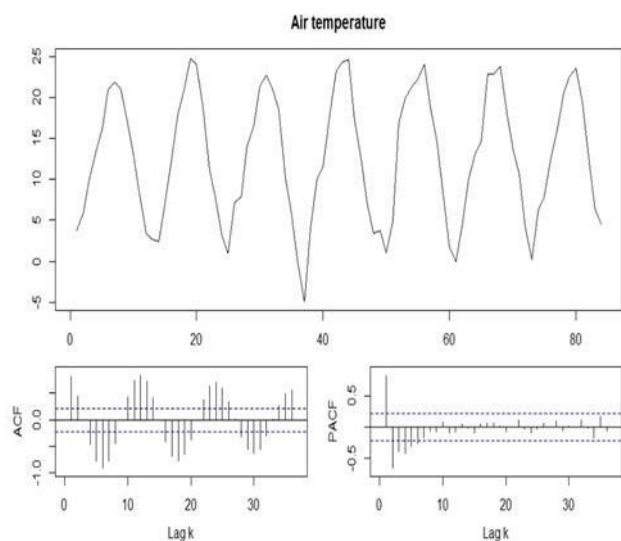


Figure 6. Display of air temperature time series with its ACF and PACF diagrams

Figure 7 shows the results of the Kruskal-Wallis rank sum test for the air temperature time series with two groups: Mesec (engl. Month) and Vrednost (engl. Value). The values are compared across months only. This test suggests that there are no significant differences between the two groups, which means that the average values of air temperature time series do not differ significantly across months because the p-value of 0.4794 is higher than the significance level of 0.05.

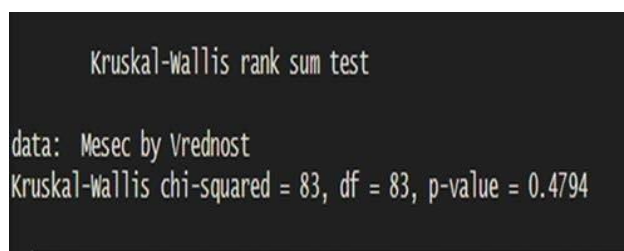


Figure 7. Results of Kruskal-Wallis rank sum test for the air temperature time series

The Canova-Hansen test for seasonal stability is part of the *uroot* package. The test is performed using the "ch.test()" function, where the frequency is 12 since

the data are monthly averages. As you can see in Figure 8, the Canova Hansen test showed that the p-value was 0.356, which is higher than the significance level of 0.05. This means that there is a 95% chance that the null hypothesis is not true. Therefore, this test suggests that there is no unit root in the seasonal component nor strong evidence of a seasonality pattern in the time series.

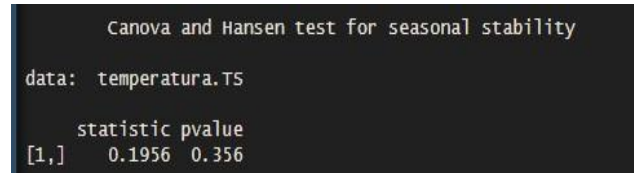


Figure 8. Results of Canova Hansen test for the air temperature time series

5 CONCLUSION

Exploratory data analysis (EDA) is a powerful technique that not only improves forecasting precision but also guarantees the application of suitable modelling techniques—such as ARIMA, LSTMs, or Prophet—according to the inherent patterns in the data. Furthermore, finding time series features like stationarity and detecting trend and seasonality patterns during exploratory data analysis guarantees data integrity, which is crucial for making accurate and reliable predictions.

EDA techniques were performed on air temperature time series for detecting trend and seasonality patterns. Since no seasonality was found by the Canova-Hansen test, alternative seasonality tests and visual methods were also taken into account when searching for seasonality. Visual inspections using STL decomposition and ACF and PACF functions indicated strong seasonality repeating patterns included in the air temperature time series. According to the seasonality and trend tests performed, the conclusion was that the data is nonstationary, and there were no significant differences between tested Month and Value groups. Also, a strong seasonality pattern was detected in the time series which both the STL decomposition and ACF function confirmed. On the other side, trend tests indicated that there was no trend in the time series - no linear, monotonic or any trend.

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Application of blockchain technologies as a function of progress

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Abstract: In this paper, based on a studious, comprehensive review of the latest literature, the possibilities of applying blockchain technologies from the perspective of entrepreneurship, tourism, production, supply chain, media companies, and environmental protection and sustainable development are explored. In this context, the impact of blockchain technology on business, the evolved advantages and disadvantages of application, safety and security issues, future application trends and presented examples of good practice will be explored. It will be shown how the technology works, what changes it brings to the existing data storage infrastructure, and at the same time shed light on the possibilities of using the technology in other areas. In the theoretical consideration, the most promising sectors for the use of blockchain technology will be identified from the aspect of optimizing existing business processes. The latest research indicates that the widespread application of blockchain technologies will cause many changes in electronic business. Blockchain allows banks to simplify and automate many processes, further reducing operating costs. The results of research in practice indicate that the key disadvantage of Blockchain technology is that it is not 'green' enough, because the operation of the computers that generate the codes that make up the Blockchain requires a large amount of electricity. Research also indicates that currently the possibilities of using blockchain technology are unlimited, which will certainly initiate a technological revolution in many areas of business, because its time is yet to come.

Keywords: Digitization, Electronic business, blockchain technology.

1 INTRODUCTION

Block chain technology (Blockchain technology) is gaining more and more importance today because it is starting to be applied in almost all areas of business. In this context, blockchain technology represents one of the most prominent innovations in the world of computing today. Although products using this technology are still in the early stages of development, they seem to have great potential to improve people's lives in various fields. The beginnings of this sophisticated technology date back to 1976. William F. Ehrsam, Carl H. W. Meyer, John L. Smith and Walter L. Tuchmano published a paper entitled "Message verification and transmission error detection by block chaining", in which they presented the idea of secure exchange encrypted messages. In the period from its creation until today, blockchain technology has been significantly improved and perfected, so that the algorithms that are applied have been modified and adapted to the modern business environment. The literature states that blockchain technology emerged as a response to the economic and social crisis caused by the 2008 financial collapse. In this regard, their application as a completely anonymous and decentralized payment system is particularly intriguing and characteristic. It was the loss of trust in the financial system at that time that quickly created interest in the emergence of the bitcoin cryptocurrency, with which the first transactions were made in 2010. After that, until 2017, about 720 cryptocurrencies were

developed, while in February 2021, their number reaches about 8413 different payment systems. Today, it is predicted that there are somewhere around 30000 cryptocurrencies. Forecasts are that today in the world there are more than 12,500 developers dealing with blockchain, of that number, around 520 are in Serbia. Blockchain technology is a young technology that is just being developed in the world, in this sense there is a respectable number of developers in Serbia, which indicates that in this environment there really is an intellectual capacity for the application of this sophisticated technology. In this sense, it is extremely important that we investigate the background of blockchain technology because, due to the rush of enthusiasm for it, people neglected to examine it in detail and started spreading misinformation or limiting it to cryptocurrencies instead of looking at the bigger picture. In the literature, it is emphasized that the real Blockchain technology was first mentioned a little more than 15 years ago, more precisely until 2008, when the first block of data was created by Satoshi Nakamoto, that is, the time of the creation of the Blockchain technology is parallel to the time of the emergence of the idea of the Bitcoin cryptocurrency (Denic, 2024). In a study of the Bitcoin network, Nakamoto explains that although the current system works in principle, the creation of transactions between two people is based on trust in third parties or financial institutions, such as banks, which in the past have not proven to be the most reliable and have often been the main cause various financial crises and currency hyperinflation. However, new technology promises to change the world in all areas of our life, and it is also becoming more and more interesting for entrepreneurial practice (Denic, 2024).

Blockchain technology has rapidly evolved into a large number of applications, such as government, tourism, banking, financial markets, agriculture, accounting, manufacturing, supply chains, environmental protection, voting systems and government services, etc. From the Association for Electronic Communications and Information Society in the Serbian Chamber of Commerce (PKS). They state that there are currently more than 20 companies in Serbia that specialize in blockchain technology development. In this sense, the most well-known use of blockchain to the general public is in the financial sector, especially in transactions with so-called cryptocurrencies, but blockchain technology can have a much wider range of applications. One of the applications of blockchain technology is the application in business, which represents the implementation of the concept of smart contracts (smart contracts), that is, contracts that, once agreed, execute their clauses by themselves, without the need for mediation.

Blockchain technology brings enormous potential for optimizing business processes and increasing the efficiency of business processes in modern business. Another possibility of application of blockchain technology is for electronic voting, where every vote is transparently recorded and the monitoring and counting are publicly available. There are two terms in the name of blockchain technology: "block" and "chain". A block is a data structure that stores data. In the case of the Bitcoin network, this is data about transactions related to the Bitcoin cryptocurrency, but in general, any data can be written into a block, such as various files, GPS coordinates, data about the status of Internet of Things devices, and so on. The term chaining refers to how blocks are linked together. With blockchain technology, blocks of data are structured in such a way that they are resistant to attackers who could change the information written in the block. The block header contains a field to store the identification code of the previous block in the chain (Tripathi, Ahad, & Casalino, 2023). In the following figure 1, one of the characteristic architectures of blockchain technology is presented.

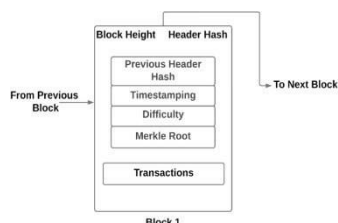


Figure1: Blockchain Technology Architecture Source (Tripathi, Ahad, & Casalino, 2023).

Blockchain technology consists of several built-in security features, such as cryptography, software-mediated contracts, and identity control (Groopman, 2022). Blockchain technology is an advanced data management mechanism that enables transparent information sharing within business networks. Blockchain technology enables so-called digital

transaction records, which can be programmed to record not only financial transactions, but almost anything of value. Blockchain technology enables new ways of organizing business and has the potential to transform several economic sectors, especially the business of small and medium enterprises (Denić 2024). Many companies are researching and studying the possibilities of using this technology, and the versatile usefulness of the technology is shown by the fact that it is already being used in various industries (Stojanović J 2024). One of the applications is in the healthcare sector, for keeping patient records. There are already many promising use cases, although the research is still in its infancy. However, although early research does not specifically mention blockchain technology or name it as such, it is generally accepted in the literature that the Bitcoin network is the first practical application of this blockchain technology. In this context, on the other hand, there is still a significant lack of theoretical knowledge, which is why companies, despite the implementation of technology, still do not achieve the value they expected. Blockchain implementation is complex and requires large capital investments and adaptation of organizational processes, as it fundamentally transforms and automates business processes. The following Figure 2 presents a SWOT analysis of the application of blockchain technology in public administration in the Republic of Serbia.



Figure2: SWOT analysis of the application of blockchain technology

Source (Study on the feasibility of using blockchain in the work of public administration in the Republic of Serbia). <https://mduls.gov.rs/wp-content/uploads/Blockchain-studija-NIA.pdf>

Businesses today are increasingly inclined to use systems based on blockchain technology. The benefits of using it include multiple factors: time and cost efficiency, saving time spent on contacts with intermediaries, privacy, security, fraud reduction, record keeping and decentralization. Research indicates that this technology also brings greater transparency in relation to data to companies in various industries, however, practice shows that such innovations in the world by their nature have both advantages and disadvantages. In this context, although blockchain technology is designed to be secure, individual nodes and computers connected to the network can be potential targets for hacker attacks. Therefore, it is necessary to develop additional security

mechanisms to protect data and transactions. Another challenge is the acceptance and understanding of the technology by the general public (Tripathi, Ahad, & Casalino, 2023). The transaction verification process, which is based on work algorithms, requires a lot of processing power, and therefore electricity. In this sense, Blockchain technology is a very large consumer of electricity, which has a negative impact on air pollution, given that Bitcoin transactions are mostly a speculative business (80%-90%), spending energy on this business is a pure waste of resources. However, some authors state that blockchain technology is one that has the potential to mitigate or even solve environmental impacts. Applications developed on the basis of blockchain technology can also help the environment. For example, a startup in Seattle uses a platform to combat climate change and aims to reduce or remove carbon from our environment (Levi et al., 2018).

Blockchain technologies in entrepreneurship

Nakamoto created a system in which the exchange of personal financial assets does not depend on trusting a third party, but on network participants ensuring that the data in the network is accurate, with Nakamoto paying particular attention to the protection of personal data and privacy, thus creating the possibility of applying this technology in business. As blockchain technology and its use cases continue to develop and improve, the aforementioned technology enables companies to achieve greater transparency, traceability and operational efficiency for many blockchain technology business transactions and contracts. The rise of the Internet led to the decline of brick-and-mortar stores and traditional media companies, but it also spawned the largest technology companies we know today (Denić, 2024). The application of these technologies in education, for the storage of diplomas and certificates, would significantly reduce the possibility of misuse and falsification of diplomas. The pricing models companies choose to implement blockchain technology are also critical. Different approaches, such as transactional payment or subscriptions to access services, can affect the general acceptance and availability of this technology for smaller businesses (Di Stefano, Khizhniak & Turol, 2023). More than 90 banks around the world are also starting to think about useful technology solutions and actively engage, according to Deloitte (2020), more than 50% of executives in different countries around the world said that they are. they have used blockchain technology rank blockchain among the top five priorities in the companies where they do business. Investments in blockchain technology are expected to reach \$3.1 trillion by 2030. Blockchain technology has brought significant changes to banking, simplifying banking transactions, reducing costs and increasing security. According to the obtained data, which is presented in Figure 2, it was determined that about 19% of small and medium-sized enterprises use blockchain technology. About 24% of

companies plan to use it in the next two years, 25% are evaluating the possibilities of using it, and 32% of companies are not thinking about using it. Gartner (2021) and Grand View Research estimated that the business value created by blockchain technology will increase to \$176 billion by 2025 and \$3.1 trillion by 2030. According to the Global Startup Ecosystem Report (2021), companies based on blockchain technology represent 10% of startups worldwide.

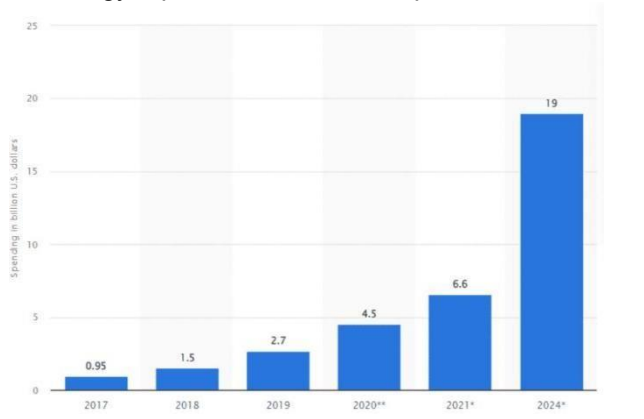


Figure2:The use of blockchain technologies in small and medium-sized enterprises Source: Top Technology Trends Survey (2019).

The smart contract segment dominated blockchain technology in the financial sector in 2018 and is expected to generate the most revenue through 2026. The growth of this segment is primarily driven by the increased need for selfexecuting contracts between banks, but also between banks and clients. Using blockchain technology, transactions are conducted directly between parties in a decentralized network, significantly reducing the need for intermediaries (Hayes, 2024) Table 1 Blockchain in banking

Source: (Hayes, 2024)

Lastnost	Banke	Bitcoin
Opening hours	9:00 a.m. to 5:00 p.m. on weekdays; limited hours on weekends; closed on bank holidays.	24/7, 365 days a year.
Transaction costs	• Card payments: Commissions are paid by stores. • Checks: 1\$–30\$. • ACH transfers: up to 3\$. • Transfers: Domestic up to \$25, International up to 45\$.	Variable fees \$0–\$50 determined by miners and users.
Transaction speed	• Card payments 24–48 hours • Checks: 24–72 hours • ACH: 24–48 hours • Transfers: up to 24 hours	From 15 minutes to over an hour, depending on network traffic.

KYC rules	Requires KYC procedures; legal customer registration.	No identification required; anyone can participate.
Ease of transfer	Requires identification, bank account, and mobile phone.	Request
Privacy	Data stored on the bank's private servers; depending on the security of the bank and the user.	Traceable, but anonymous ownership is possible.
Security	Depends on the security of the bank's servers and the user's security measures.	A larger network means greater security; cold storage recommended.
Approved transactions	Banks can reject or freeze accounts.	The Bitcoin network does not restrict usage, local guidelines must be followed.
Account seizure	Government authorities can easily track and seize bank accounts.	Anonymously used Bitcoin is difficult to track and seize.

Blockchain technology in tourism can play a key role in removing these barriers and streamlining the process. Tourism is an industry that is under great pressure from information and communication technologies. Research in practice indicates that the tourism sector needs to combine technology, knowledge and money in order to create new products that will satisfy the needs of customers. Blockchain technology has attracted the attention of many researchers in the mentioned sector. This creates an opportunity to develop smart objections or a single digital identification document to support many business activities (Cutts, 2019). Kvok and Koh (2019) believe that the applicability of blockchain technology in the tourism sector is suitable for exchanging information, ensuring better business processes, reducing costs and improving user experience. Based on the research, it is expected that blockchain technology will have a great impact on the tourism sector. **Blockchain technology in logistics**

Predictions are that the logistics industry is likely to benefit the most from the adoption of blockchain technology. In this context, it is currently difficult to track the edge in the international freight environment due to the long weather cycle and opaque information. It enables faster and more reliable logistics operations and enables better supply chain optimization by providing accurate and up-to-date data on delivery status (Cai et al., 2023). Complex trade networks can be carefully traced from origin to user endpoints. This, in turn, provides a higher level of security, increases object confidence and quality control. As a result, we can say that blockchain technology offers promising solutions to supply chain monitoring challenges, but careful consideration of costs, privacy, pricing models and investment decisions is required before deciding to apply it (Di Stefano, Khizhniak & Turol, 2023). . The Swiss postal agency "SwissPost" and the state telecom "Swisscom" published a joint statement on December 6, 2018. They jointly developed a friendly blockchain to build a simple, secure and sustainable infrastructure. According to a recent prediction, digital technologies will play a key role in repairing the disrupted global

supply chain in the next three to five years (Denić 2024). Blockchain technology is used to track cargo in real time, enabling greater transparency and reliability in tracking the movement of goods. This improves the efficiency of logistics operations and reduces the chances of errors or fraud (Baltruschat et al., 2023). When managing the supply chain, we must pay attention to three important flows: informational, financial and, on the spot, material. Blockchain data chaining technology can be used in all the above-mentioned flows, both in the logistics market and in proactive management (Lesueur et al., 2021). In the literature, it is emphasized that supply chain technology should help in tracking the path of the product from the supplier of raw materials. consumer. In May 2019, the Korea Customs Service put the world's first blockchain-based logistics service for export customs clearance to trial. It signed an appeal with 48 institutions and companies, including public institutions, shipping companies and insurance companies, to promote blockchain-based export logistics and export customs clearance services.

The computer company IBM and one of the largest logistics companies, TectitMaersk, have joined forces and developed a platform for digitized shipment tracking called TradeLens[1] based on blockchain technology. The leverage platform uses a distributed blockchain network to collect data from many different entities and allows all network participants to see this data in real time. The platform is still in the development phase and time will tell how useful it is and what the rate of adoption is among logistics companies and their clients. It is predicted that blockchain technology in the supply chain should also enable accurate demand forecasting, effective disruption management and

reduced inventory management costs due to its ability to create and share records of activities throughout the supply chain. For the successful implementation of blockchain technology in the transport sector, clear standards and guidelines must be developed and education and training provided for all involved parties (Tahora et al., 2023). Blockchain technology can also contribute to social responsibility in supply chains by providing information on the origin of goods, as a company's control over the origin of goods is often limited.

Blockchain technology in the media offers a fair deal for all actors in the media industry, while at the same time enabling a large amount of innovation and new business models. The wellknown author Kahn MTE 2021 highlights the application of blockchain technology in the industry in power: design and management of the energy sector. However, data shows that blockchain technology is estimated to be worth USD 166.6 million in the media and entertainment industry alone in 2020, growing at an annual growth rate of 71.4 percent in the period to 2026. Research shows that new technologies are profoundly changing the global media and entertainment industry, especially in the areas of program production and distribution, with blockchain technology having the most prominent technological impact (Stojanović K 2024). According to Accenture, 55% of media and platform leaders consider blockchain technology one of their companies' top five priorities. Likewise, 83% of executives plan to increase investment in blockchain technology over the next three years. It is expected that the development of advanced technologies and digital transformation will drive the growth of technology implementation in the media industry. In this regard, some authors emphasize that the media industry is plagued by many intermediaries, unequal distribution of profits and numerous inefficiencies that could be solved using blockchain technology. In this sense, smart objections play an important role here, because they would contain a set of rules based on which a predetermined process would be launched. **Blockchain technology and the environment.**

One of the main challenges that blockchain technology is currently facing is its impact on the environment. It is noticeable in the literature that in the last few years, governments and organizations around the world have focused on the use of various technological tools to mitigate climate change and the challenge of biodiversity loss. The impact of blockchain technology on the environment is extremely obvious. In this context, Johnson (2021) points out that Bitcoin mining is quite expensive and generates significant amounts of waste. It produces about 0.13% of global carbon emissions, which is 37.2 billion tons per year. Tim Berners-Lee (2022), known as the inventor of the World Wide Web, called Bitcoin mining one of the most pointless ways to consume energy. In this sense, the well-known author Trubi (2018) claims that the amount

of electricity consumed by blockchain technology poses a serious threat to the global commitment to reducing greenhouse gas emissions. Blockchain technology, combined with smart objections, promises transparent and secure platforms capable of providing creative and ecologically responsible business solutions (Polas et al., 2022). Despite the potential advantages, the huge energy consumption is one of the main obstacles that must be overcome. Many actors in the economic sector are naturally looking for ways to solve the problem (Polas et al., 2022). The well-known author Lu (2020) explains that modern companies have realized that the social aspect of sustainable development is also very important for economic development. Currently, blockchain technology related to cryptocurrencies is heavily criticized for its environmental impact, or the social aspect of sustainable development is completely different.

Blockchain technology in SMEs Blockchain and product lifecycle management (PLM) can work together in several ways - one option is to use blockchain technology to secure and store data as part of the product management process. Blockchain technology can serve as a reliable log that records all changes that occur in the process, which could help companies reduce the risks associated with product data changes and ensure that product data is accurate. Companies are exploring the possibilities of implementing blockchain technology into their daily processes, but they are also incorporating it into them. At the same time, there are a large number of startups and smaller companies experimenting with blockchain technology and providing various enterprise use cases. Blockchain technology has proven to be extremely useful in modern business, offering opportunities to improve business efficiency, increase transparency and reduce the risk of fraud. In practice, there are fears that blockchain technology could be used for money laundering and the creation of illicit value. The authors Tapskot et al. (2021) state that blockchain technology in the financial sector could reduce processing costs, reduce fees, make payments safer and more reliable. The rapid growth and popularity of this technology is evident from the event in 2010 when Laszlo Hanyecz bought two Papa John's pizzas for about \$30 with 10,000 bitcoins, which were valued at over \$80 million in 2018, highlighting the exponential growth of the technology and cryptocurrency (Tripathi, Ahad and Casalino, 2023). However, the attitudes and potential disadvantages of using blockchain technology for small and medium-sized enterprises. The technology is still relatively new and inexperienced, so there are concerns about scalability, security and regulatory compliance. Moreover, implementation costs may be too high for them, especially for those who do not have technical expertise or development resources (Denić 2020). In this context, Bulsara and Vaghela (2020) emphasize that blockchain technology offers solutions to stores through the Internet, primarily in the areas of

cyber and financial security. The same authors explain that smaller businesses could use blockchain technology to facilitate inventory management and payment processing. Important features that blockchain technology brings to online stores include cost savings, easier and faster transactions, improved business processes, transparency, improved supply chain management and greater access to global consumers, especially for smaller businesses (Bulsara and Vaghela, 2020). Although blockchain technology offers numerous advantages, it also presents certain limitations and challenges. Scalability is one such challenge, as the size of the blockchain grows with each added block, potentially leading to increased storage and processing requirements (Alshahrani et al., 2023). It is concluded that blockchain technology can reduce transaction costs and speed up money transfer processes in transactions between companies. It is predicted that the use of blockchain technology in the financial sector could reduce the operating costs of international transactions from 26 to 15 dollars and reduce the annual operating costs of companies. According to Darlington et al. (2022), decentralization means that there is no single point of control in the system. Transactions and data are distributed through a network of nodes, making the system more resistant to attacks. This improves the security and reliability of the system, which is especially important for companies that need secure and reliable systems. Well-known authors Marten and Kai 2017 emphasize the importance of security and privacy in ways: improving security, data ownership, access control and privacy protection. Blockchain technology consists of somewhat embedded security features such as cryptography, software-mediated objections, and identity control (Groopman, 2022). In traditional systems, this data is collected centrally, but rewards are awarded based on previous purchases. The transition to a blockchain-based system enables the calculation and issuance of reward points when they are earned (Marr, 2022). In some cases, the use of blockchain technology may conflict with legal regulations. For example, in some countries, some forms of cryptocurrencies and ICOs (initial coin offerings) are illegal, which can cause legal problems for companies using this technology (Sommerhalder, 2023). In the future, we can expect blockchain technology to play a key role in creating new business models and improving existing processes (Tripathi, Ahad, & Casalino, 2023). In order to realize the full potential of the blockchain, it is useful for users participating in multiple interconnected chains to be connected via a single protocol. This reduces friction between users as they can access different decentralized applications without changing networks (Sommerhalder, 2023). Since the blockchain is an immutable ledger, the data on this platform can be secured, which prevents manipulation or falsification. We have mentioned immutability as one of the important advantages of blockchain technology,

sometimes the immutability of data can also pose a danger, and that for some data it may be more appropriate not to be recorded permanently.

CONCLUSION

By implementing a platform based on blockchain technology, numerous advantages can be achieved in a real business environment. However, it is important to emphasize that the implementation process itself requires professional and trained human resources, i.e. a high level of knowledge and technical skills for the implementation and maintenance of these technologies. Blockchain enables the transparent sharing of information within a business network, which increases trust between participants and reduces the need for central intermediaries. Blockchain technology represents the basis for the transition from the Internet of information to the Internet of digital values. Also, every transaction using blockchain requires a significantly higher consumption of electricity, which is certainly significant in terms of environmental protection and sustainable development. The implementation of blockchain technology in business processes also requires a

complementary digital infrastructure, which is not always easy for small and medium-sized enterprises to access. Research has shown that blockchain technology can significantly improve the efficiency of operations by reducing transaction execution time and increasing their transparency. However, the problem that arises in the application of this technology is that there are a large number of different blockchain platforms with different protocols and standards, and when exchanging data, there may be a problem of system interoperability. In agriculture, which accounts for 11% of the GDP of Serbia, it is proposed to introduce blockchain technology into the agricultural distribution system so that production and deliveries can be managed more efficiently. The adoption of blockchain technology is growing quite rapidly in various sectors around the world. Logistics processes, like other aspects of life, can be defined and evaluated using data to which blockchain technology gives added value. Companies are exploring the possibilities of implementation in their daily processes, but startups are experimenting with blockchain technology to provide different use cases. It is proposed to introduce a land management system that uses blockchain technology to improve the land management system in Serbia, but where public trust is currently lacking. Blockchain enables the automation of many business processes through smart objections, which reduces operational costs and increases the speed of transactions, confirming our first hypothesis "Blockchain technology can improve operational efficiency by reducing transaction execution time and increasing their transparency in companies." "Blockchain technology was developed primarily for the cryptocurrency system, but it could also play an important role in solving the challenges

facing global economies today. Many developing countries lack the robust banking, internet or electronic systems necessary to take advantage of the global digital transformation. The adoption of blockchain technology and cryptocurrency could be instrumental in helping these countries. By studying these authorities, we found that blockchain technology not only improves efficiency and security, but also drives innovation and new business models. By enabling decentralization and greater autonomy, it opens the door to new possibilities and solutions that can positively affect more aspects of the social infrastructure, or even the society itself, as a disruptive technology, can lead to equal and decentralized network management using a distributed ledger. Our research has shown that companies that adopt this technology can significantly improve their business. This, in turn, leads to greater customer satisfaction and long-term business growth. It is clear that blockchain technology represents a significant turning point in the digital transformation of companies. The versatility of blockchain technology is evident in its wide range of uses, as it can facilitate and improve various processes, from storage to delivery and, on the spot, not least, payments. Its use itself increases the transparency and efficiency of the supply chain and generally improves the performance of all logistics processes. Data accuracy and transparency enable organizations to proactively manage processes, which increases the speed of logistics processes and reduces costs. It is important to emphasize that the complete security of Blockchain technology has not yet been fully proven and sufficiently researched, and that more and more scientific papers dealing with this topic are appearing in the literature. After the system evaluation and familiarization with all the possibilities offered by blockchain technology, it is to be expected that sooner or later the regular practice of business: production, sales, logistics, education, healthcare, banking, environmental protection and sustainable development and life in general will undergo a complete transformation. with the help of blockchain technology.

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Smart Home Data Preprocessing Using Python

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Abstract: Smart home systems generate large volumes of data from various sensors, such as temperature, humidity, motion, and energy consumption. Effective preprocessing is essential to enhance data quality, reduce noise, and enable accurate analysis. This paper examines Python-based data preprocessing techniques for smart home environments. The preprocessing workflow includes data cleaning, handling missing values, normalization, feature selection, and data transformation. Data cleaning addresses duplicate records, outliers, and inconsistencies, while missing values are imputed using statistical and machine learning approaches. Normalization techniques standardize sensor readings to ensure consistency across data points. Feature engineering and dimensionality reduction refine the dataset for improved predictive modeling. By enhancing data quality, preprocessing contributes to smarter home automation, efficient anomaly detection, and optimized energy management. This study underscores the critical role of preprocessing in smart home analytics, facilitating reliable and meaningful insights for decision-making. The proposed techniques enhance the integration of smart home data into machine learning models, driving advancements in intelligent home automation systems.

Keywords: data preprocessing; Python programming language; smart homes.

1 INTRODUCTION

This paper provides a comprehensive overview of data preprocessing techniques employed in smart home applications, focusing specifically on the utilization of the Python programming language. Additionally, it demonstrates these techniques through a use case on a selected smart home dataset.

Smart homes generate vast quantities of heterogeneous data from various sensors and devices (Alrefaei, 2024; Rizki, 2020). This raw data, however, is often noisy, incomplete, and inconsistent making direct analysis and modeling challenging (Bilal, 2022). Effective data preprocessing is therefore a crucial step in transforming raw sensor readings into structured, high-quality datasets suitable for machine learning, data mining or other analytical tasks (Tayeb, 2020).

In recent years, there has been a significant expansion of AutoML tools capable of automating all or some steps of data preprocessing. Notable examples include H2O-AutoML, Autosklearn, AutoWEKA, TPOT, AutoGluon, and DataRobot. However, no AutoML technique is yet mature enough to completely handle data preprocessing with complete accuracy (Bilal, 2022; Salehin, 2024). To maintain flexibility, enable advanced customization, and retain full control over data transformations, we opted for manual data preprocessing using Python programming language.

Python was chosen for this study due to its widespread use in data exploration and analysis. As a versatile, general-purpose, interpreted, and open-source language with dynamic semantics, Python supports rapid application development and is widely employed in data science applications, including data

manipulation, automation, business analytics, and big data research (Lasser, 2021; Raschka, 2020).

In this paper, we will examine common preprocessing steps, relevant Python libraries like numpy, pandas, matplotlib and seaborn, and best practices for handling specific data challenges encountered in smart home environments.

The increasing complexity of smart home systems, with their interconnected devices and diverse data streams, necessitates a robust and adaptable preprocessing pipeline to ensure the accuracy and reliability of subsequent analyses (Essafi, 2024).

By providing a structured approach to preprocessing smart home data, this paper aims to serve as a valuable resource for researchers, engineers, and developers working in this domain. Through practical insights and real-world applications, we emphasize the importance of high-quality data preparation in unlocking the full potential of smart home analytics.

2 DATA ACQUISITION

Smart homes leverage a diverse array of sensors to capture a rich tapestry of data reflecting the activities and conditions within the home environment. These sensors encompass a wide range of modalities, including motion sensors detecting movement within specific areas (Nef, 2015; Babangida, 2022), temperature sensors monitoring ambient conditions (Kaur, 2024; Pirzada, 2018), light sensors measuring illumination levels (Pirzada, 2018), door/window sensors tracking entry and exit points (Babangida, 2022), and smart appliance usage data recording energy consumption and operational status (Maguluri, 2024; Mpawenimana, 2020; Umamageswari, 2024).



The heterogeneity of these sensor types contributes to the complexity of smart home data, demanding tailored preprocessing strategies for each data modality.

The methods of data acquisition vary considerably depending on the specific sensor and its intended application. Some systems employ continuous data streams, constantly monitoring and recording sensor readings (Pirzada, 2018). This approach provides a detailed picture of the home's dynamic state but results in large volumes of data that require efficient processing and storage. Other systems may utilize event-based logging, only recording data when a significant event occurs, such as a door opening or a motion detection (Tax, 2019). This method reduces data volume but may miss subtle changes or patterns. The choice between continuous and event-based data acquisition involves a trade-off between data richness and computational efficiency.

The data collected in smart homes encompasses a wide spectrum of information relevant to various applications. Energy consumption data, typically measured by smart meters, is crucial for energy management and forecasting (Maguluri, 2024; Mpawenimana, 2020; Umamageswari, 2024). This data reveals patterns of energy use, enabling optimization strategies to reduce costs and improve efficiency. Activity patterns, inferred from sensor data, provide insights into residents' daily routines and habits (Babangida, 2022), (Tax, 2019; Mishra, 2020). This information is valuable for applications such as personalized healthcare recommendations, activity-based lighting control, and security systems. Moreover, smart home data can even serve as a proxy for health indicators (Hunter, 2020; Mishra, 2020), providing unobtrusive monitoring of an individual's wellbeing. For instance, changes in activity patterns or bathroom usage might signal a decline in health status. The versatility of smart home data makes it a powerful resource for a wide array of applications, but this diversity also necessitates sophisticated preprocessing techniques to extract meaningful insights from the raw data.

3 DATA PREPROCESSING

The raw data collected from smart homes is rarely suitable for direct analysis. It often suffers from various imperfections that necessitate careful preprocessing to ensure accurate and reliable results. This section delves into the common preprocessing techniques employed to address these issues.

3.1 Data Cleaning

Missing values and outliers are common occurrences in smart home data (Mpawenimana, 2020; Naware, 2024). Missing values arise from various

sources, including sensor malfunctions, communication errors, or simply the absence of specific events. Outliers represent data points that significantly deviate from the expected pattern, often due to noise, errors, or unusual events. The presence of missing values and outliers can significantly distort the results of data analysis and lead to inaccurate conclusions.

Several methods exist for handling missing values. Simple imputation techniques include mean imputation, where missing values are replaced with the mean of the available data, and median imputation, where missing values are replaced with the median. However, these methods can distort the data distribution if a substantial portion of the data is missing. More sophisticated methods include k-nearest neighbors imputation, which uses the values of similar data points to estimate missing values, and model-based imputation, which uses a statistical model to predict missing values (Mpawenimana, 2020). The choice of imputation method depends on the characteristics of the data and the amount of missing data.

Outliers can be identified using various statistical methods. Box plots provide a visual representation of data distribution, highlighting data points that fall outside the interquartile range. The z-score, which measures the number of standard deviations a data point is from the mean, can also be used to identify outliers. Once identified, outliers can be handled through removal, transformation (e.g., using logarithmic transformation to reduce the impact of extreme values), or imputation (Naware, 2024). The decision on how to handle outliers depends on the context and the potential impact of the outliers on the analysis. Removing outliers might lead to loss of information, while retaining them could bias the results. Careful consideration is necessary to choose the most appropriate approach.

3.2 Data Transformation

Data transformation is essential for ensuring that features are on a comparable scale. Features with different scales can disproportionately influence machine learning models, leading to inaccurate results. Two commonly used transformation techniques are normalization and standardization (Baydomu, 2021).

Normalization scales features to a specific range, typically between 0 and 1. This is achieved by subtracting the minimum value of the feature and dividing by the range (maximum minus minimum). Normalization is particularly useful when the features have different ranges and the scale is important for the model's interpretation.

Standardization, also known as z-score normalization, transforms features by subtracting the mean and dividing by the standard deviation. This



results in features with a mean of 0 and a standard deviation of 1. Standardization is preferred when the data is not uniformly distributed or when the range of the features is not meaningful. It is especially useful for machine learning algorithms sensitive to feature scaling, such as support vector machines (SVMs) (Chang, 2022; Mittelsdorf, 2018; Nef, 2015) and neural networks (Mpawenimana, 2020; Yuan, 2024; Umamageswari, 2024).

The choice between normalization and standardization depends on the specific dataset and the machine learning algorithm used. In some cases, both techniques may be applied to different features or at different stages of the preprocessing pipeline.

3.3 Feature Engineering and Selection

Feature engineering and selection are essential steps in preparing smart home data for analysis. Feature engineering involves generating new features from existing ones to enhance model performance (Yuan, 2024). This process may include combining sensor data to represent higher-level concepts, creating temporal features such as moving averages or time lags (Naware, 2024), and encoding categorical variables into numerical representations. For example, aggregating motion sensor data from multiple locations can produce a feature representing overall activity levels in the home. Likewise, calculating the moving average of energy consumption over a specific time window can help identify trends that may not be evident in the raw data.

Feature selection aims to identify the most relevant features for a given task, reducing dimensionality and enhancing model efficiency (Madhukar, 2024). High-dimensional data can lead to overfitting, where the model performs well on training data but poorly on unseen data. Feature selection techniques help mitigate this issue by selecting a subset of the most informative features for the prediction task.

Common feature selection methods include filter methods (e.g., correlation analysis, information gain), wrapper methods (e.g., recursive feature elimination), and embedded methods (e.g., L1 regularization). Additionally, principal component analysis (PCA) (Madhukar, 2024) is a widely used dimensionality reduction technique that transforms original features into a smaller set of uncorrelated principal components, capturing the most significant variance in the data.

The choice of feature engineering and selection techniques depends on the specific application and the characteristics of the dataset. It is essential to carefully balance model complexity and performance to achieve optimal results.

3.4 Data Smoothing and Noise Reduction

Smart home sensor data is often affected by noise, which can obscure underlying patterns and degrade the performance of machine learning models (Wei, 2025). Noise may arise from various sources, such as sensor inaccuracies, environmental interference, or communication errors. To address this, data smoothing techniques are employed to reduce noise while preserving essential features of the data.

Moving averages, where each data point is replaced by the average of its neighboring points, are a simple and effective smoothing technique (Yoon, 2024). The window size of the moving average determines the degree of smoothing. Larger window sizes result in smoother data but may also obscure finegrained details. Median filters, which replace each data point with the median of its neighboring points, are more robust to outliers than moving averages. They are effective in reducing impulsive noise, which is characterized by sudden, sharp spikes in the data.

More advanced techniques, such as wavelet transforms and Kalman filtering, can be used for more sophisticated noise reduction (Wei, 2025). Wavelet transforms decompose the signal into different frequency components, allowing for selective removal of noise in specific frequency bands. Kalman filtering is a recursive algorithm that estimates the state of a dynamic system by combining noisy measurements with a model of the system's dynamics. The choice of smoothing and noise reduction technique depends on the characteristics of the noise and the desired level of smoothing.

4 USE CASE

4.1 The dataset

To demonstrate the data preparation process, we utilized the publicly available smart home dataset provided by Taranveer (2020), which includes weather information.

The dataset is available in CSV format and contains 32 columns with smart meter readings for home appliances in kW, recorded at one-minute intervals over a span of 350 days, along with weather information specific to that location. Original column names in the dataset are described in Table 1.

Table 1 Table Descriptions of column names from the dataset

The name of column	Description
time	Time
use [kW]	Total energy consumption
gen [kW]	Total energy generated by means of solar or other power generation resources
House overall [kW]	Overall house energy consumption
Dishwasher [kW]	Energy consumed by specific appliance
Furnace 1 [kW]	Energy consumed by specific appliance
Furnace 2 [kW]	Energy consumed by specific appliance



Home office [kW]	Energy consumed by specific appliance
Fridge [kW]	Energy consumed by specific appliance
Wine cellar [kW]	Energy consumed by specific appliance
Garage door [kW]	Energy consumed by specific appliance
Kitchen 12 [kW]	Energy consumption in kitchen 1
Kitchen 14 [kW]	Energy consumption in kitchen 2
Kitchen 38 [kW]	Energy consumption in kitchen 3
Barn [kW]	Energy consumed by specific appliance
Well [kW]	Energy consumed by specific appliance
Microwave [kW]	Energy consumed by specific appliance
Living room [kW]	Energy consumption in Living room
Solar [kW]	Solar power generation
temperature	Temperature
icon	Overall weather condition (clear-night:39%; clear-day:36%; Other:25%)
humidity	Humidity
visibility	Visibility
summary	Summarise weather (Clear:75%; Partly Cloudy:12%; Other:13%)
apparentTemperature	Apparent temperature
pressure	Pressure
windspeed	Wind speed
cloudCover	Cloud cover (0 :14%; 0.31 :10%; Other :77%)
windBearing	Wind bearing
precipIntensity	Precipitation Intensity
dewpoint	Dew point
precipProbability	Precipitation probability

4.2 Data cleaning and feature selection

For preliminary results, we conducted data cleaning and feature selection. A program was written to load the dataset, display its shape, show the first five rows, print the columns and their respective data types, check for entries with null values, drop rows containing missing values and checks the unique values.

We used the following Python libraries to clean the obtained dataset: NumPy, Pandas, Matplotlib, Seaborn, and Time.



We checked the data types and resolved any inconsistencies. Although 'cloudCover' is one of the unique entries, it appears that it should be a float. The 'cloudCover' entry appears in the first 57 minutes of the first hour, which seems to be an error. These values have been replaced with the first valid entry, assuming

dataset includes columns related to energy generation, energy consumption per room/appliance, weather data, and a 'time' column.

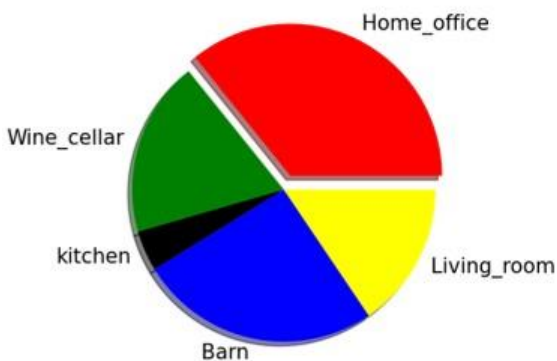
From the correlation matrix of the dataset, it is evident that three pairs of variables are highly correlated: 'use [kW]' and 'House overall [kW]', 'gen [kW]' and 'Solar [kW]', and 'Temperature' and 'apparentTemperature'. To facilitate analysis, the variables 'House overall [kW]', 'Solar [kW]', and 'apparentTemperature' were dropped. Since the 'time' column is now the index of the data frame, it has also been removed. The object columns 'icon' and 'summary' were deemed irrelevant for further analysis and were discarded. Additionally, two variables related to the 'Furnace' and three variables related to the 'kitchen' were combined by summing the corresponding variables into new columns, and the individual columns were dropped. Finally, the column names were renamed to remove spaces and the '[kW]' unit.

The final results of data cleaning are presented in Table 2.

Table 2 The dataset information of prepared data

Column	Non-Null	Count	dtype
use	466308	not-null	float64
gen	466308	not-null	float64
Dishwasher	466308	not-null	float64
Furnace	466308	not-null	float64
Home_office	466308	not-null	float64
Fridge	466308	not-null	float64

ENERGY CONSUMPTION FOR ROOM



ENERGY CONSUMPTION FOR DEVICES

ENERGY CONSUMPTION FOR DEVICES

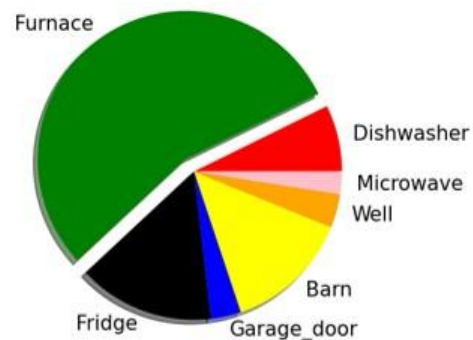


Figure 1

that cloud cover does not change dramatically in the first hour. Additionally, we observed that the A line graph illustrating the dependency of various energy consumption per month throughout the year is presented in Figure 2, with months on x axis, and a numerical variable Electricity Consumption [kW] on y axis.

4.3 Discussion

Considering only the variables related to energy consumption in different rooms, it can be concluded that energy consumption is highest in the home office and lowest in the kitchen for the given dataset. Approximately the same energy consumption is

Column	Non-Null	Count	dtype
Wine_cellar	466308	not-null	float64
Garage_door	466308	not-null	float64
Kitchen	466308	not-null	float64
Barn	466308	not-null	float64
Well	466308	not-null	float64
Microwave	466308	not-null	float64
Living_room	466308	not-null	float64
temperature	466308	not-null	float64
humidity	466308	not-null	float64
visibility	466308	not-null	float64
pressure	466308	not-null	float64
windspeed	466308	not-null	float64
cloudCover	466308	not-null	float64
windBearing	466308	not-null	float64
precipIntensity	466308	not-null	float64
dewpoint	466308	not-null	float64
precipProbability	466308	not-null	float64

4.3 Data visualisation

To effectively present the data, data visualization is both essential and highly beneficial. A program was developed to generate a pie chart illustrating the data in columns containing variables related to energy consumption within the premises and for specific devices, as shown in Figure 1.

recorded in the wine cellar and the living room.

Similarly, when analyzing the variables related to energy consumption for specific devices, it is evident that the furnace consumes the most energy, while the microwave and garage door consume the least. The fridge and barn exhibit approximately the same energy consumption. The high energy consumption of the



furnace is expected, as it generates heat using electric resistance coils, which is then distributed throughout the house. This heating system is known for operating safely, cleanly, and without producing hazardous byproducts.

Regarding monthly energy consumption, the results indicate that the highest values are recorded in February, July, and November. These findings align with expectations, given the increased energy usage during winter months for heating and during summer months for cooling. Additionally, solar panel energy

generated smart home data. The variability in sensor readings, missing or inconsistent values, and privacy concerns further complicate the preprocessing pipeline. Addressing these challenges requires a strategic approach that balances computational efficiency with data integrity.

Future research should initially focus on evaluating the obtained results and completing a comprehensive preprocessing workflow to ensure high-quality data preparation. Additionally, further efforts should be directed toward developing more sophisticated,

door, no significant variations in energy consumption are observed throughout the year.

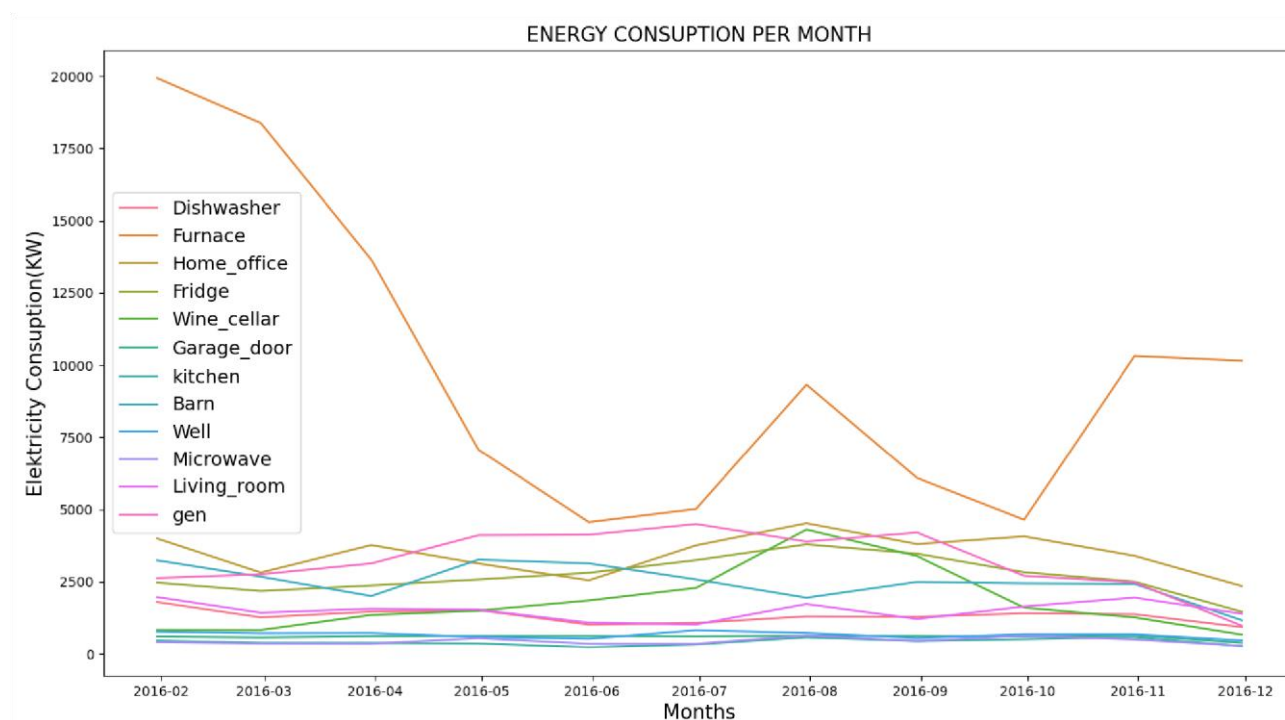


Figure 2 Energy consumption per month throughout the year production is significantly reduced during the winter months. For devices such as the microwave, fridge, and garage **5 CONCLUSION**

Data preprocessing is a crucial step in smart home data analysis, as it directly impacts the accuracy, reliability, and overall quality of insights derived from the data. The techniques employed must be carefully selected and rigorously evaluated to ensure that smart home data is properly cleaned, transformed, and structured for meaningful analysis. The choice of preprocessing methods depends on various factors, including the specific application, the nature of the data, and privacy considerations. Given the diverse and complex nature of smart home data, preprocessing remains a challenging yet indispensable task.

Despite advancements in data preprocessing techniques, several challenges persist, particularly in handling highdimensional, heterogeneous, and rapidly

efficient, and privacy-preserving preprocessing techniques. These advancements will not only enhance data quality but also improve the effectiveness of machine learning models and analytical frameworks used in smart home applications.

Moreover, the establishment of standardized preprocessing pipelines and evaluation frameworks would significantly advance the field. Standardization would promote reproducibility, facilitate comparability across studies, and support the broader adoption of best practices in smart home data analysis. Ultimately, by refining data preprocessing methods and addressing existing challenges, researchers and developers can unlock the full potential of smart home technologies, leading to smarter, more efficient, and privacyaware intelligent home automation systems.

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how people exchange ideas. Computers of all kinds connected by the World Wide Web are used for human communication. Ideas and data are effortlessly reproduced and exchanged today. The information technology revolution opens the door to fantastic possibilities for human cooperation, and of course, for the development of science. [10][11][12]

The concept of "smart" cities is a way of creating a better, more sustainable city in which people's quality of life is improved, the environment is improved, and their economic prosperity is increased, all with the help of modern technologies.[1] Also, the safe city concept is based on the use of modern technologies, including artificial intelligence and analytical tools, in order to increase safety and enable better management of urban environments. Safe cities use the integration of technologies for surveillance, data analysis and rapid response to reduce threats such as crime, traffic accidents and other security problems. One of the key challenges is managing large gatherings of people, such as public events, protests or rallies, where are accurate crowd counting and tracking of people of a

UDK:351.778.5:711.4]:004.9

DOI: 10.46793/ALFATECHproc25.143G
Original scientific paper

INTEGRATION OF DRONES FOR INTELLIGENT CROWD COUNTING IN THE SAFE CITY CONCEPT

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Abstract: Rapid urbanization and increasing population density in urban areas pose a significant challenge to maintaining security and effective crowd management during mass gatherings, such as public events, protests and emergencies. The "safe city" concept relies on modern technologies, including drones and artificial intelligence, to improve security, optimize resource allocation and reduce the risks associated with mass gatherings. This paper explores the use of drones, equipped with advanced cameras and object detection algorithms like YOLO and Fast R-CNN, to count people in crowds and analyze their movements in real time. By combining multi-criteria analysis, the algorithms were evaluated according to key criteria, including accuracy, processing speed, robustness to noise, segmentation efficiency and energy efficiency. The results show that the YOLO algorithm is superior in applications that require fast real-time processing, while Fast R-CNN provides higher accuracy in complex scenarios. Integrating drones with these algorithms enables accurate crowd counting and tracking, which contributes to better security and management in modern urban environments.

Key words: safe city, drones, artificial intelligence, YOLO, Fast R-CNN, crowd counting, multi-criteria analysis

INTRODUCTION

Urbanization is a global trend, with an increasing number of people living in cities. Today, more than 56% of the world's population, or 4.4 billion people, live in urban areas, and that number is expected to grow to nearly 70% by 2050. [9] This urbanization trend brings numerous challenges, including managing large numbers of people, their safety, and effective emergency response. Science is mostly a collective activity. We can only prosper "standing on the shoulders of giants". It is a story about how to build new knowledge from the work of others, and that is why the exchange of ideas is its fundamental aspect. In recent decades, we have experienced a revolution in the way

crucial importance.

The need for drones in mass management

Drones have proven to be a powerful tool for real-time surveillance and analysis, especially in situations involving mass gatherings. Their use in the concept of a safe city can significantly contribute to the efficient management of large gatherings of people. The concept of smart cities, IoT, Blockchain, drones and techniques based on artificial intelligence are still evolving and will offer more opportunities in the future.[2] Here are some of the key advantages we have today:

• Wide view from the air:



Drones make it possible to monitor large areas from above, providing a complete picture of crowds in gathering places such as squares, stadiums or streets. This is particularly useful for identifying areas of greatest concentration of people and potential security risks.

• **Quick reaction in emergency situations:**

In the event of a crowd that can turn into a dangerous situation, drones enable the timely collection of information and forwarding it to the competent services for a faster response.

• **Accurate people counting:**

By combining high quality cameras and object detection algorithms such as YOLO and Fast R-CNN, drones can accurately identify and count individuals even in dense crowds. This is crucial for analyzing attendance at public events or rallies, assessing risk and planning further measures as well as providing real-time intelligence.[3]

• **Monitoring mass dynamics:**

Behavioral analysis algorithms can detect crowd movement, identify unusual patterns, and warn of potential dangers, such as panics, stampedes or clashes.

• **Flexibility and mobility:**

Unlike stationary cameras, drones can easily change position and adjust the height and angle of the footage, making them ideal for dynamic situations like protests or sport events.

With the continued growth of urban environments, technologies such as drones are becoming a key part of the infrastructure of safe cities. Their use enables effective monitoring and management of large gatherings of people, increasing the safety of citizens and reducing the risk of incidents during mass gatherings. The combination of drones and mobile computers further increases efficiency, enabling rapid on-site data analysis. Mobile computers built into drones enable real-time data processing, reducing the need to send large amounts of information to remote servers, saving time and resources. The integration of drones with analytical tools not only improves security, but also provides key data for better planning and decision-making in the cities of the future. The integration of drones and GIS is expected to bring revolutionary benefits in the fields of precision agriculture, urban planning, emergency health response, disaster management, smart city development, food delivery, etc.

YOLO and Fast R-CNN for crowd detection

YOLO (*You Only Look Once*) and Fast R-CNN are two leading object detection algorithms widely used in

applications such as crowd counting. Both algorithms rely on deep learning and computer vision, but approach the problem in different ways. YOLO is known for its speed and efficiency, while Fast R-CNN provides high accuracy in complex scenes. These object detection algorithms have emerged as key advances, providing revolutionary solutions in various sectors.[5]

YOLO (You Only Look Once)

YOLO works by dividing the input image into a grid of cells and each cell predicts whether it contains an object. Its key advantage is speed as it processes the entire image in one pass. The process includes the following steps:

• **Share the image on the network:**

This algorithm divides the input image into a grid of $S \times S$ cells, with each cell predicting B bounding boxes and class probabilities.[6]

• **Loss function:**

YOLO uses a loss function that combines coordinate, frame size and classification errors: [6]

$$\mathcal{L} = \lambda_{\text{coord}} \sum_{i=0}^{S^2} \sum_{j=0}^B 1_{ij}^{\text{obj}} ((x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2) + \lambda_{\text{noobj}} \sum_{i=0}^{S^2} \sum_{j=0}^B 1_{ij}^{\text{noobj}} (c_i - \hat{c}_i)^2$$

• **Non-Maximum Suppression (NMS):**

It is used to eliminate overlapping frames, relying on Intersection over Union (IoU).

Fast R-CNN

Fast R-CNN uses a Region Proposal Network (RPN) to generate potential regions of interest (RoI), which are then analyzed using CNN for classification and frame boundary regression. [8]

Its key steps are:

• **Feature extraction:**

The input image is passed through convolutional layers to generate a feature map:

$$ff = CCNNNN(I)$$

• **Region Proposal Network (RPN):**

Generate regions of interest using predefined anchor boxes. The object probability is calculated as:

$$PP(mmbbiirrccctt | x, y, w, h) = \sigma(Wcls \cdot f + Bcls)$$

• **ROI pooling:**



Each proposed region is transformed into a fixed size for further classification.

- **Loss function:**

It combines loss of classification and boundary regression:

$$\mathcal{L}(p, u, t, v) = \mathcal{L}_{\text{cls}}(p, u) + \lambda[u \geq 1]\mathcal{L}_{\text{reg}}(t, v)$$

Multicriteria analysis

Weighted Sum Model (WSM) is one of the oldest and simplest methods of multi-criteria decision-making.[7] This model is often used when there is a need to make decisions based on several criteria that have different importance, i.e. weight. The method is intuitive, easy to implement and widely applicable in various fields, such as engineering, economics, project management and technology. This model works by giving each alternative a score based on its performance against each criterion and the associated criteria weights, which reflect their relative importance in making a decision. The total score of the alternative is calculated as the sum of the product of the normalized weights and the evaluated values of the alternatives according to the criteria Steps in the methodology:

- **Defining criteria:**

Criteria are key factors used to evaluate algorithms in the context of crowd counting.

- **Assigning weights to the criteria:**

The weights of the criteria represent their relative importance in the overall evaluation of the algorithms.

- **Algorithm performance according to criteria:**

Performance is rated on a scale of 0 to 1 based on available information about the algorithms.

- **Score calculation (multi-criteria analysis):**

For each algorithm, the total score is calculated as the sum of the product of the algorithm's performance and the criteria's weight.

- **Comparing the results:**

After the calculation, the total results are

compared Criteria for evaluating algorithms:

- **Detection accuracy:**

The ability of an algorithm to correctly recognize people in a crowd.

- **Processing speed:**

How fast the algorithm can process data from the drone's camera.

- **Robustness to noise:**

The algorithm's resistance to visual disturbances, such as shadows or poor lighting.

- **Segmentation efficiency:**

The ability of an algorithm to accurately single out people in a crowd.

- **Energy efficiency:**

How many resources the algorithm consumes during operation.

Difficulty of criteria

The difficulty of the criteria reflects their relative importance for the application of drones:

- Detection accuracy: 0.30 (most important)
- Processing speed: 0.25
- Robustness to noise: 0.20
- Segmentation efficiency: 0.15
- Energy efficiency: 0.10

The difficulties are normalized so that their sum is 1.

Here is a detailed explanation, a table with the analysis results, and a comparison of the advantages and disadvantages of the YOLO and Fast R-CNN algorithms in the context of their use for crowd counting using drones. **Algorithm performance results**

Algorithm performance according to each criterion (rated from 0 to 1):

Criterion	YOLO	Fast R-CNN
Detection precision	0.85	0.95
Processing speed	0.95	0.70
Robustness to noise	0.70	0.85
Segmentation efficiency	0.80	0.90
Energy efficiency	0.90	0.60

Normalized weights and total scores

Calculating the total score for each

algorithm: Total score = $\sum_{aa=0}^{aa}$

(Performance × Difficulty)

Criterion	YOLO (Score)	Fast R-CNN (Score)
Detection precision	$0.85 \times 0.30 = 0.255$	$0.95 \times 0.30 = 0.285$
Processing speed	$0.95 \times 0.25 = 0.2375$	$0.70 \times 0.25 = 0.175$
Robustness to noise	$0.70 \times 0.20 = 0.14$	$0.85 \times 0.20 = 0.17$
Segmentation efficiency	$0.80 \times 0.15 = 0.12$	$0.90 \times 0.15 = 0.135$
Energy efficiency	$0.90 \times 0.10 = 0.09$	$0.60 \times 0.10 = 0.06$
Total score	0.8425	0.825

Conclusion of the results:



- **YOLO:** Better for real-time applications, thanks to fast processing and energy efficiency. **Total score: 0.8425.**
- **Fast R-CNN:** A more accurate algorithm, ideal for complex situations where accurate human extraction is required. **Total score: 0.825.**

In this case, the expert knowledge used to assign criteria difficulty and algorithm performance is not based on actual expert interviews, but on assumed values and generally accepted standards from the fields of machine learning, computer vision, and drone applications. Comparative analysis of advantages and disadvantages

Feature	YOLO	Fast R-CNN
Advantages	Very fast algorithm (realtime detection)	Detects objects extremely precisely
	Low resource consumption	Robust noise and interference
	Suitable for applications with limited hardware	Better segmentation in complex scenes
Flaws	Less accuracy in dense masses	Slower in processing (not suitable for realtime)
	May have problems with overlapping objects	Greater consumption of resources and energy

DISCUSSION

Rapid urbanization and increasing population density in urban areas pose a significant challenge for maintaining security and effectively managing large crowds. The Safe City concept, which integrates technologies such as drones, mobile computing and artificial intelligence, provides effective solutions for surveillance, detection and analysis of mass movements. This paper analyzed the use of drones equipped with advanced cameras and YOLO and Fast R-CNN algorithms for crowd counting and their application in the context of urban environments. All these aspects are the key to future research, application and scientific basis. The need for analysis and research can be seen in the papers and presentations that precede this research. [13][14][15][16]

The results of the multi-criteria analysis showed that the YOLO algorithm, due to its processing speed and energy efficiency, is a better choice for applications that require real-time monitoring and detection in dynamic environments, such as public gatherings, protests and emergency situations. On the other hand, the Fast R-CNN algorithm, although slower, provides greater precision in segmentation and detection, which makes it more suitable for complex crowd analysis and surveillance in situations where precision is crucial.

In addition, the integration of mobile computing into drones allows for on-site data processing, reducing the need to send large amounts of information to remote servers, thereby optimizing response time and reducing network load. This combination of technologies provides an efficient and autonomous solution to manage urban security challenges, making cities smarter and safer places to live.

However, there are several challenges and limitations:

- **Privacy and ethical issues** related to mass surveillance of people in public spaces.
- **Limited drone resources**, such as battery life and data processing capacity.
- **The influence of weather conditions** on the precision of algorithms and the efficiency of drones in detection.

Future work can focus on improving detection algorithms, optimizing the energy efficiency of drones, as well as developing hybrid systems that combine the advantages of multiple algorithms to achieve optimal results. Further research can include practical implementations in real scenarios, as well as testing algorithms in different conditions to increase their reliability.

CONCLUSION

This work has shown the importance of using drones and artificial intelligence to count the people in crowd located in urban areas, as well as the importance of mobile computing to improve the efficiency and speed of data processing. The results of the analysis indicate that the choice of algorithm is crucial and depends on the specific requirements of the application - YOLO is ideal for fast real-time tasks, while Fast RCNN is better for highly accurate crowd analysis.

The integration of drones and mobile computing for intelligent crowd counting represents a significant step towards the development of safe and efficient smart cities. This technology enables automated and precise



monitoring of the movement of large groups, thus improving the security and management systems of urban spaces.

Further development in this area can improve security systems in smart cities, enabling faster response in crisis situations, better control of public gatherings and more efficient urban infrastructure planning. The improvement of machine learning algorithms, the use of 5G networks for faster data transmission, as well as the application of advanced sensor technologies, will further increase the precision and reliability of such systems. [17]

Apart from security aspects, this technology can be used in traffic analysis, optimization of public transport and planning of evacuations in case of emergencies. [18] Future research should be directed towards improving the autonomy of drones, reducing energy consumption, and developing ethical frameworks to protect citizens' privacy. [19]

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The model of a smart education system: gamification of teaching through digital dialogue

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Abstract: The two starting points of this research are the Socratic dialogue method and the "forgetting curve." Hermann Ebbinghaus. On the other hand, it is known that it is Socrates' dialogue is a method of philosophical inquiry and interaction that he employed to encourage his interlocutors to think more deeply and analyze their beliefs. This method is based on asking questions that lead to the discovery of truth, relying on logical and critical discussions. The second starting point is Hermann Ebbinghaus's Forgetting Curve, which emphasizes that resumption of material is most important in the first few minutes after learning, because then the speed of forgetting is the highest. Without repetition, as much as 50–70% of information can be forgotten in the first hour. Early restoration slows down this process and allows for longer-lasting memory. This paper is part of a more extensive research, in search of a teaching concept that would realize the ideal of Socratic dialogue and ensure the highest level of retention of the exhibited material, in accordance with the recommendations Hermann Ebbinghaus with the help of modern digital technologies. At the same time, the application of gamification in teaching increases the motivation and interest of students for active learning in the teaching process.

Keywords: digital dialogue; gamification in teaching; interactive teaching; software and pedagogical solutions. Every day, hybrid learning work is being done to introduce new technologies into educational experiences. We can point to experiments, pilots, and prototypes, but all in all, they are small-scale, with no guarantees, or often without the means to advance. Virtual reality is used to bring science to life,

1 INTRODUCTION

Smart education systems are an innovative educational model that integrates technology, digital tools and resources to improve the quality of teaching and the entire educational process. This system uses intelligent technologies, such as artificial intelligence, data analytics, gamification, and digital dialogue, to provide personalized and interactive education. The main goal of a smart education system is to create a dynamic environment that supports collaboration, critical thinking, and active learning, while optimizing the learning process and administration. Smart education systems allow all students to have access to a variety of educational resources and customized content, thereby increasing engagement and learning success.

The increased flow of information and social media technologies have created enormous benefits for researchers in the current era. In the age of scientific invention, increasing the diversity of data generation and its efficient use and maintenance are becoming a significant challenge for information systems (IS) researchers and educational design practitioners. These challenges encourage the development of ideas that lead to new technological inventions, the inclusion of which makes it possible to create new systems by which we can provide better education. Information technology has entered the education system with a bang. [2]

Educational methods and information technologies are still searching for the optimal combination of

transport lessons on virtual travel, and market universities to potential future students. [3]

All of these devices create a variety of data, also known as big data. Big data varies in its scope, speed, variety, variability, and dynamism. What's more, big data, generated on social media and through various IoT devices, has created much greater opportunities for users and different decision-makers to better understand the problems. [4]

Over the past few decades, technology has changed the way education works. The standard hybrid learning model is implemented through a combination of the Distance Learning System (DLS), as a specific hardware and software solution, and face-to-face teaching. Such systems are used to increase student interaction and classroom lessons, obtain critical opinions from each student individually, and create an environment for cooperative and active learning. [5]

Exploring the interaction between classroom dialogue and digital technology is a growing field of study. Most research on the impact of digital technology on productive dialogue in the classroom is based on the sociocultural perspective of education. [6]

Teaching dialogue and its development are based on speech interaction in the classroom, so that teaching different "resources". First of all, dialogue implies the and learning become a collective endeavor, in which participation of people, and the teaching context is knowledge and understanding are shared (rather than characterized by the presence of a relatively large number of teachers using speech only to convey the content of participants of different knowledge, experiences, origins, the curriculum and assess its acquisition by students). interests, etc. We understand these differences as the [8]

richness and source of the content of dialogue in teaching, Classroom dialogue is a tool that can be used to and the dialogic exchanges between different perspectives help students build knowledge as they explore and and positions as the basis for assigning meaning, joint build on their own and others' ideas. In this way, the learning and cognition, i.e. as a starting point for education conceptualization of learning is expanded, going and upbringing. In this sense, the dialogic potential of the beyond the idea of acquiring knowledge to include the lesson is defined as an underused resource, but also as a involvement of students in knowledge-building potential that can be actualized in learning activities with practices. [9] [10]

others, more precisely through the exchange they achieve, The concept of Digital Dialogue (DD) as a system thus encouraging their own development, but also the for creating a higher degree of interaction between development of the interlocutor. [7] subjects - through Wi-Fi (Wireless-Fidelity) technology,

The Socratic Dialogue is a method of philosophical mobile software applications and devices, and teaching inquiry and dialogue used by Socrates to encourage his methods, which include Web Based Training (Internet interlocutors to think more deeply and analyze their beliefs. Based Test - iBT), ensures that the entire course of the This method is based on asking questions that lead to the teaching process during a single course is transferred discovery of truth, relying on logical and critical discussions. to electronic form. Enriched with interactive

On the other hand, "dialogic teaching" and "dialogic multimedia and placed in the appropriate databases. pedagogy" mean an approach to teaching based on the The dynamics of the activities are still controlled by the active, extended involvement of students and teachers in lecturer in interaction with the students. [11]

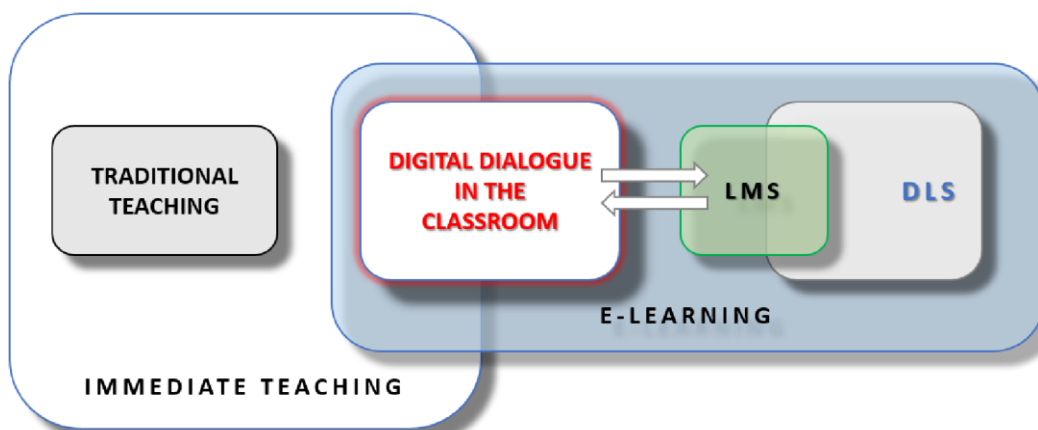


Figure 14: The Position of

Digital Dialogue in a Hybrid Learning System [11]

This work is based on research Cognitive science in introducing regular intervals to refresh and validate accepted relation to Hermann Ebbinghaus's "forgetting curve" and the material. Today, the Ebbinghaus chart is becoming a way to application of the concept of digital dialogue in the classroom. estimate the time it takes people to learn a new skill and

Research shows that a structured approach to time evaluate performance. [1][12] management can significantly improve knowledge retention by

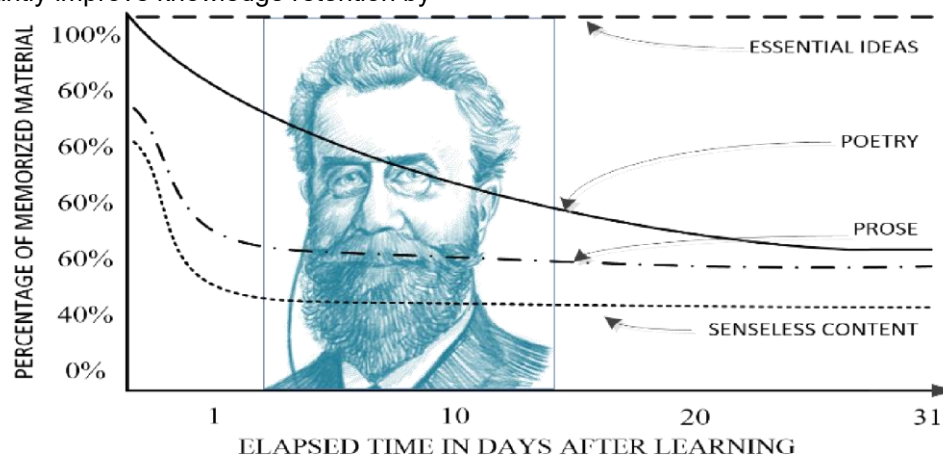


Figure15: Ebbinghaus's forgetting curve [1] [12]



2 METHODOLOGY AND DESCRIPTION OF THE RESEARCH

This research is part of a larger project, entitled "Digital Dialogue in a Hybrid Learning System", which includes examining the effects of digital dialogue in teaching from different aspects. Some of the results of these studies have been published at conferences and in journals [16]. However, this paper contains new, unpublished data and a different analysis of the collected data is applied. [17] [15]

For the research sample, data were collected from departments that use digital dialogue and those that use traditional methods. It is ensured that the sample is representative and that both approaches are equally represented. The research was conducted in the school year 2022/23 at the ETŠ "Nikola Tesla" Secondary School in Niš, Serbia. In a *period* of 14 days, in 3 hours, 9 lessons with traditional teaching and 9 hours with the application of digital dialogue were recorded. Three departments of the same grade

were selected, educational profiles Computer Electrical Technician and Information Technology Electrical Technician, 3rd grade. Classes have approximately the same number of students (from 25 to 30). The study was conducted by three teachers who taught the same classes but with different subjects. Those classes in which the type of teaching is carried out - the processing of new material is chosen. [16]

In the classes that are implemented by the method of digital dialogue, the teacher who leads the classes, according to the regular curriculum, asks a short question every 3 to 6 minutes, related to the teaching material just presented. At that moment, through a specially created web application - Digital Dialogue, the question is forwarded to all students. The Digital Dialogue application was created with the aim of encouraging intensive interaction between students and teachers, and increasing student retention of the presented material.

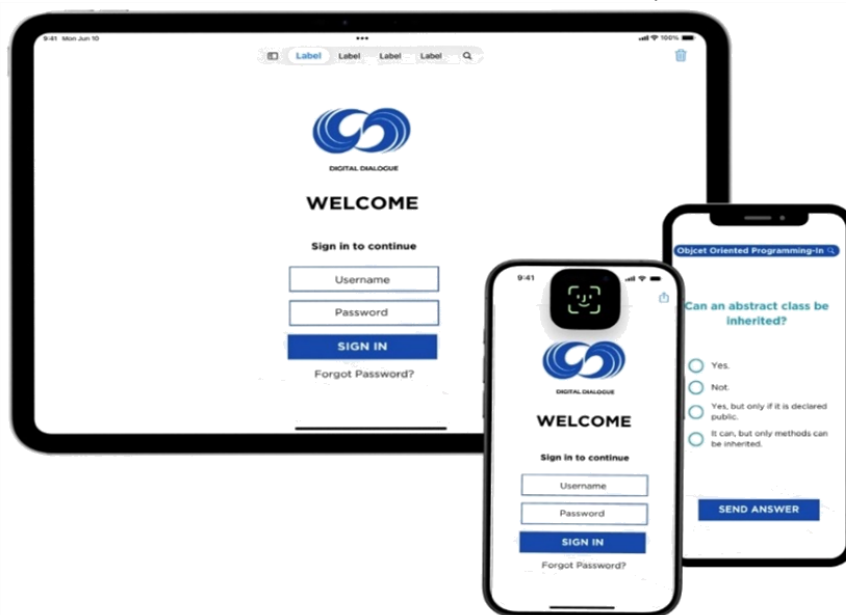


Figure16: Layout of the Digital Dialog application

There are several studies that confirm the effectiveness of the concept of digital dialogue in teaching, as measured by knowledge tests, by analyzing activities and the number of interactions in class, and by exploring the optimal time allocations of dominant roles in the classroom [13] [14]. This paper, however, explores the elements of gamification of the teaching process, when digital dialogue is applied in class. Gamification naturally aligns with digital dialogue, as both involve problem-solving, logical reasoning, and iterative learning. Integrating game elements into information technology-focused activities

can make abstract concepts more appealing and accessible to students. [15]

By using a special application for digital dialogue, all students send answers in real time. Teachers' questions in digital dialogue are short and specific, so the time for students to answer is very short, most often with a choice of one of the offered answers.

For each lesson, the activities of students and teachers were measured: the time in which the teacher speaks, the time in which the students speak and the time of silence. In order to make measurements accurate, a Java desktop application was created with

which the moments of interruption of the teacher's activity are marked and the activity of students begins, and vice versa. The application records the events during the class, visually presents them and samples the results for the purposes of statistics at intervals of

1 to 5 minutes. At the end of the measurement, the Java application calculates the average values for all 18 classes held and provides the export of the data, in the appropriate format, for further analysis.

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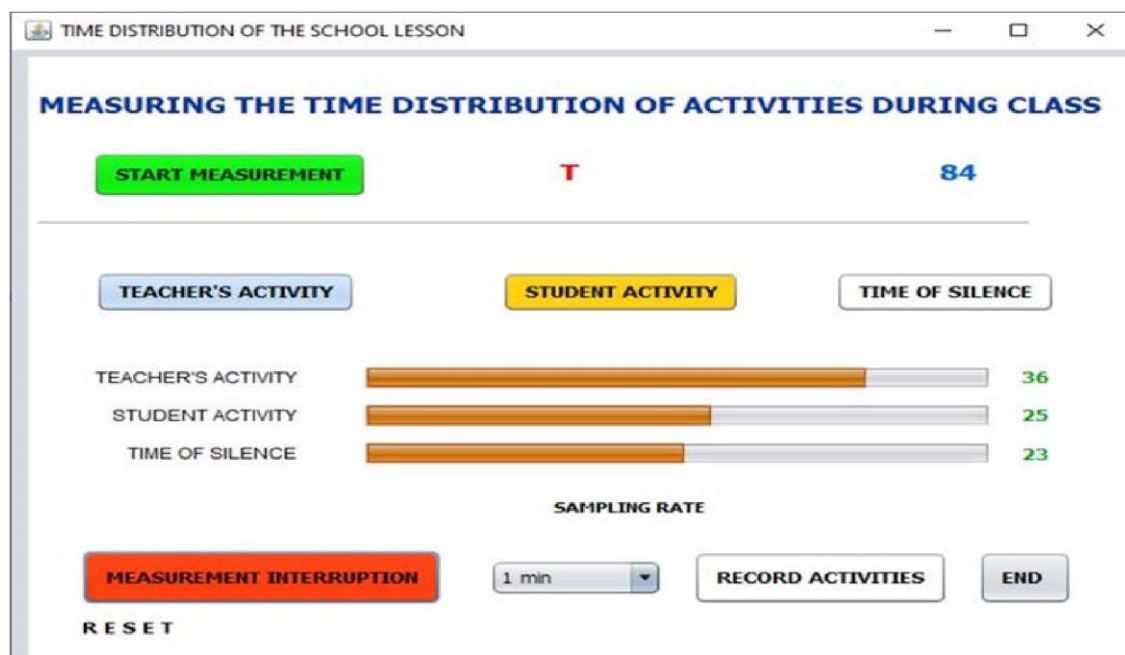


Figure17: User interface of the application for measuring the time distribution of activities in the classroom

After the classes, each of the students answered a few questions and evaluated, from the aspect of gamification, the classes in which digital dialogue was applied with a grade from 1 to 5. The ratings were related to the following attributes:

Point system and motivation

The competitive aspect
motivation for better
results Is it more fun than
the traditional

Scoring speed and responsiveness

RESULTS

Figure 4 shows the results of measuring interaction in teaching with digital dialogue (D-group) and traditional method (T-group). Here are the results for all 18 hours:

- Total number of questions from teachers
- Total number of responses received

- A period of time in which the teacher dominates
- A period of time in which students dominate
- A period of silence

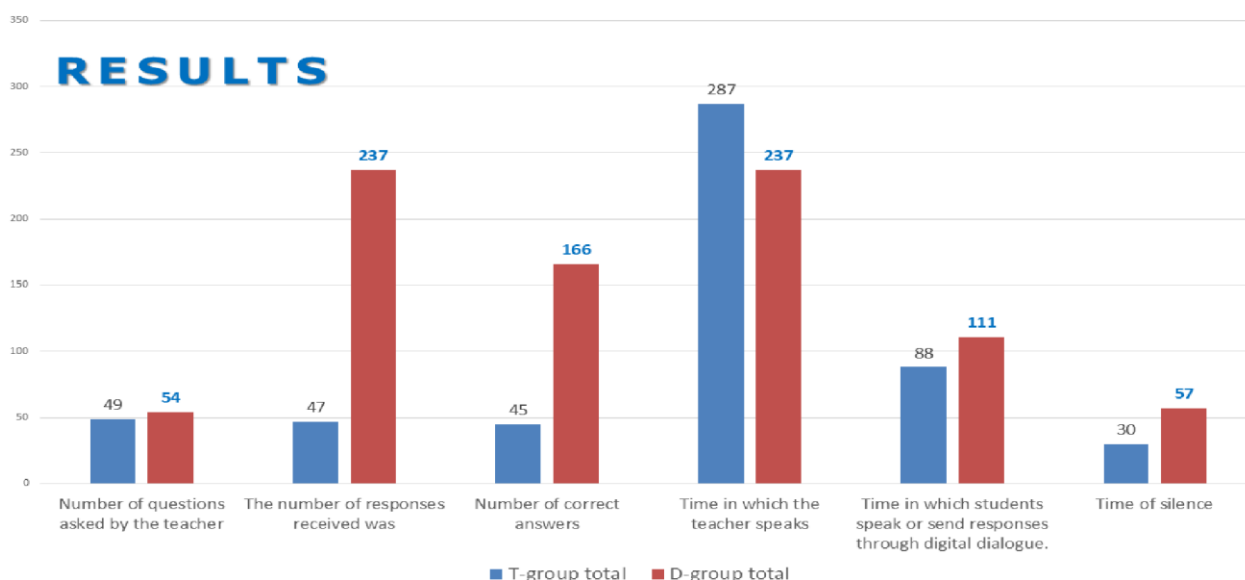


Figure18: Results of interaction measurements

Based on the characteristics of the sample, after collecting the data, a T-test was selected to determine statistical significance. For each of the 5 measured values, the null hypothesis (H_0) was established, which states that there is no statistically significant difference between the mean values of these two groups. This hypothesis is rejected if $p < 0.05$. For most of the measured values, an alternative hypothesis was confirmed, with the claim that there is a statistically significant difference in the calculated values of the during the class, there is no statistical significance in the study. For difference.

Based on the data presented, it is observed that the digital dialogue method encourages more engagement and interaction among students, with more questions asked by the teacher and many more answers received. The teacher in the digital method speaks significantly less, allowing students more time to express themselves. This is confirmed by the fact that the average time when students speak is 20% longer in digital dialogue classes. The most significant difference is expressed in the data on the number of gamification. A total of 78 students participated in the

each of the attributes of gamification in teaching, an average Figure 5 shows the grades with which students evaluated score in the range of 1 to 5 was calculated. the teaching by applying digital dialogue from the aspect of

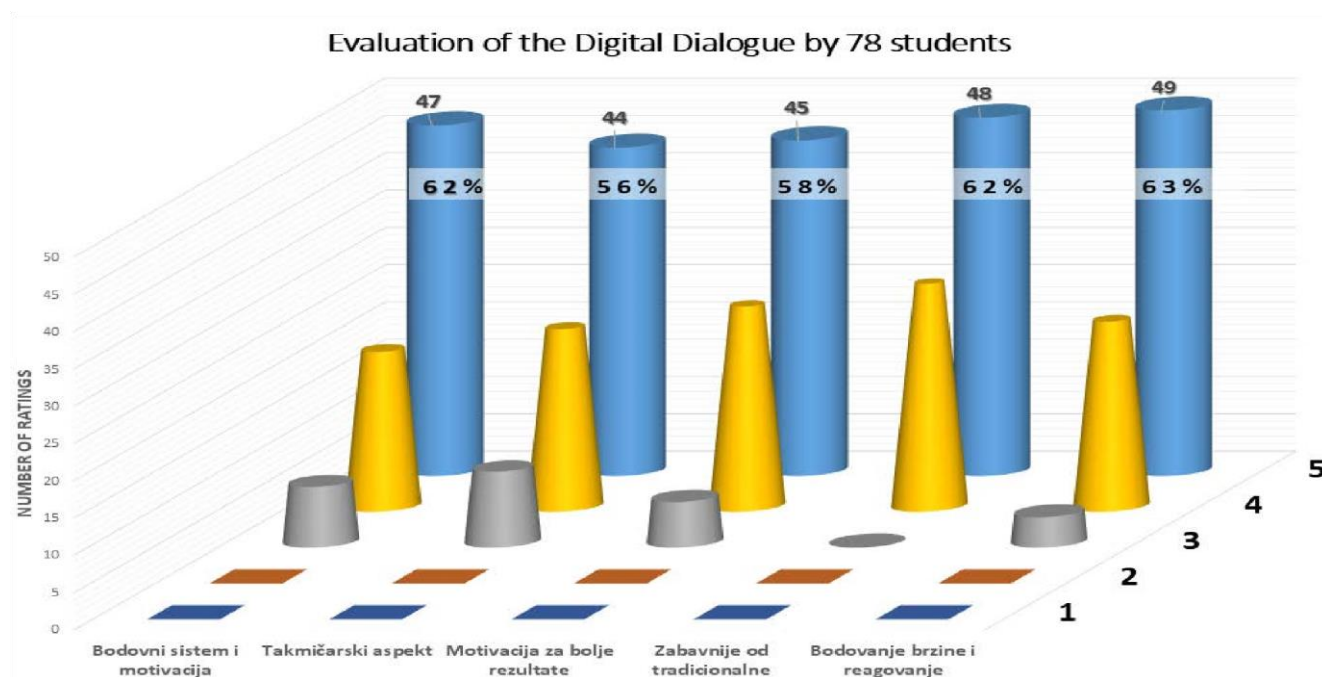


Figure19: Evaluation of digital dialogue by 78 students

different teaching methods used. Only for the total number of questions asked **DISCUSSION AND CONCLUSION**

answers received by students and the number of correct answers received.

It can be concluded that modern technology provides excellent tools for the implementation of the concept of digital dialogue. The advantages it brings are reflected in the new attributes of the teaching process:

- Inclusivity in Answering: In classic Socratic dialogue, questions were often addressed to individuals, but the ideal might be to ask questions that allow for everyone's participation. This inclusivity ensures that no student is passive and that everyone has the opportunity to express themselves.
- Technology support: Testing, surveying, and digital platforms allow you to instantly collect responses from all students. These tools can collect real-time responses and visualize the results for quick analysis, which is in the spirit of Socrates' idea of detecting common beliefs and contradictions.
- Reflective dialogue: after everyone has given their answers, the ideal would be for the following questions to take into account the bigger picture of the answers collected. This achieves deeper shared learning through discussion based on differences and similarities of opinion.
- Real-time feedback
- Adaptation to individual answers: while all students participate in the dialogue, additional questions can

be further directed towards students with different views, thus following Socrates' tradition of examining different views.

- Self-assessment: Students are encouraged to recognize their weaknesses and work on them.

Digital dialogue carries all the key attributes of gamification such as: the use of a points system, progress indicators, cooperation or friendly competition, strengthening understanding through activity, nurturing the community through tables, feedback mechanisms, continuous evaluation, challenges aligned with learning goals, focus on educational value.

Based on the above, we can conclude that digital dialogue is a system in which abstract concepts become more attractive and accessible to students, and makes the teaching process itself more interesting and productive.

ACKNOWLEDGEMENTS

This research was conducted within the *Digital Dialogue in Hybrid Learning* project, number: IF ID 52986, with the support of the *Fund for Innovation Activities of the Ministry of Education, Science and Technological Development* of the Republic of Serbia.

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UDK: 004.85
159.938.363.1-047.72
DOI:10.46793/ALFATECHproc25.
154T Original scientific paper

Using machine learning techniques for age prediction based on PPG signal analysis

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Abstract: This paper explores the application of machine learning and neural networks for age prediction based on PPG signals (photoplethysmographic signals), which provide a non-invasive and cost-effective method for assessing patient health, particularly in the field of cardiovascular diseases. PPG signals, recorded using light sources and photodetectors, enable the assessment of changes in blood volume in the microvasculature, which is closely related to the condition of blood vessels. In this study, a machine learning model based on neural networks has been developed, using PPG signals as input data to predict patient age.

Various neural network architectures were tested, including models with one hidden layer and models with multiple layers, to investigate how the number of layers affects prediction accuracy. Additionally, different activation functions, such as tanh and ReLU, as well as various data preprocessing techniques, such as normalizing PPG signals, were considered. The model evaluation was carried out using MAE (Mean Absolute Error) and MSE (Mean Squared Error) as key statistical indicators measuring prediction accuracy.

The results show that models with a greater number of hidden layers achieve better performance in age prediction, with a 30% reduction in errors compared to models with one hidden layer. Errors were primarily caused by data imbalance and specific signal characteristics that were not correctly identified by the model. The causes of larger prediction errors were also analyzed, revealing that certain PPG signals exhibited features resembling those of older or younger age groups, which influenced the model's errors. Further optimization of the model and data processing can significantly improve prediction accuracy, potentially making this approach an effective tool for real-time medical prediction.

Keywords: PPG signals, machine learning, neural networks, age prediction, data processing, cardiovascular health.

1. Introduction

Photoplethysmogram (PPG) as a tool for age estimation using machine learning models. Photoplethysmography (PPG) is a non-invasive and simple technique for measuring volumetric changes in blood vessels. PPG signals are obtained using optical sensors and light reflection, where variations in blood volume during the cardiac cycle influence the amount of absorbed or reflected light. These signals are utilized in various medical applications, such as heart rate monitoring, blood oxygenation assessment, and arrhythmia detection.

Recently, PPG signal analysis has gained significance as a tool for assessing cardiovascular health and age-related characteristics. Age is one of the most important factors in evaluating vascular health, as physiological changes associated with aging can be reflected in PPG signals. These changes include reduced vascular elasticity, increased peripheral resistance, and alterations in blood flow dynamics.

The objective of this study is to develop a machine learning model, based on neural networks, capable of accurately estimating age from PPG signals. The research focuses on different neural network architectures, data preprocessing, and model evaluation.

Beyond its theoretical contribution, this study holds significant practical implications in medical research, as it has the potential to enable early detection of age-related vascular health changes. This approach could contribute to the development of personalized health monitoring systems and the prevention of cardiovascular diseases.

Analysis of PPG signals has already been used in medicine to assess cardiovascular health, detect arrhythmias and monitor the condition of blood vessels. Various approaches to age estimation using machine learning have emerged in the literature, with neural networks being particularly successful due to their ability to model complex non-linear relationships.

Previous works have focused on:

- Beat detection from the PPG signal as a basis for analysis.
- Different neural network architectures for regression problems.
- Data preparation methods, including signal normalization and segmentation.

Research has shown that the use of advanced signal processing techniques, such as second derivative and spectral feature analysis, can further improve model performance. For example, work using a combination of temporal and frequency features has shown that models can more accurately discriminate between samples of older and younger subjects.

Also, data balancing is a key challenge in this domain, as an uneven distribution of age groups can bias the model. Current approaches include oversampling, undersampling and loss weighting techniques to ensure that all age groups are adequately represented in the training process. The signals entered by the authors from the page

2. Literature review

<https://ecg4everybody.com/pom/ppgtmp.html> represent

the averaged beats at the level of the whole signal.

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This requires additional detection of individual beats to identify key parameters of the cardiac cycle, such as R-peak, systolic and diastolic segments. The detection of individual beats allows for more precise analysis, especially for parameters such as heart rate variability (HRV) and other dynamic indicators. Without detection, analyzes may be limited because averaging may obscure critical information about heart rhythms.

However, few works have paid attention to the direct analysis of the whole signal, which this paper seeks to explore and advance. Innovative approaches that combine raw signals and minimal data processing

can reduce system complexity and speed up the model training process, while at the same time ensuring accurate analysis thanks to the detection of key points in the signal.

3. Materials and methods

3.1. Data

The dataset comprises 1,024 PPG signals, along with subject age information. These signals have been

carefully processed, normalized, and optimized to ensure suitability for detailed analysis.

Data Characteristics:

Signal duration: 69 samples per signal.

Normalization:

Signals were scaled to the range $[-1, 1]$ for the "tanh" activation function.

Output values (age) were divided by 100 to fit within the range $[0, 1]$.

Second derivative: Data preprocessing includes calculating the second derivative of the signals.

The signals were collected using the mobile application [Pulse HRV by Camera BLE ECG](#).

This application employs photoplethysmography technology to record signals via a smartphone camera. The recording process is based on detecting changes in light intensity as it passes through the tissue, thereby capturing variations in blood flow. **3.2. Neural networks (Keras library)**

The models were developed using the Keras library, which facilitates the simple and efficient implementation of neural networks. Various architectures were explored, including different numbers of layers, neurons per layer, and activation functions.

3.2.1. Basic model architecture:

Continue with the detailed description of the architecture, including the number of layers, types of layers, activation functions, and any specific hyperparameters used. (Table 1.)

Layers	Number of neurons	Activation function
Input Layer	69	-
First hidden layer	128	tanh
Second hidden layer	64	tanh
Third hidden layer	32	tanh
Output layer	1	sigmoid

Table 1. Neural network architecture

3.2.2. Code for implementation in the Keras library

The following table outlines the key steps in implementing a sequential neural network model using Keras. It includes the import of necessary libraries, model initialization, the addition of three hidden layers with the *tanh* activation function, and an output layer with the *sigmoid* activation function. Finally, the model is compiled using the Adam optimizer with mean squared error (MSE) as the loss function and mean absolute error (MAE) as the evaluation metric. (Table 2.)

Table 2. Neural network architecture

Step	Code	Description
Importing libraries	<code>from keras.models import Sequential</code>	Importing the library for the sequential model in Keras.
Importing libraries	<code>from keras.layers import Dense, Activation, Dropout</code>	Importing layers for neural networks: Dense, Activation, and Dropout.
Model initialization	<code>model = Sequential()</code>	Initializing the sequential model.
Adding the first layer	<code>Dense(128, input_dim=69, activation='tanh')</code>	First hidden layer with 128 neurons, activation function is tanh.
Adding the second layer	<code>Dense(64, activation='tanh')</code>	Second hidden layer with 64 neurons, activation function is tanh.
Adding the third layer	<code>Dense(32, activation='tanh')</code>	Third hidden layer with 32 neurons, activation function is tanh.
Adding the output layer	<code>Dense(1, activation='sigmoid')</code>	Output layer with 1 neuron, activation function is sigmoid.
Compiling the model	<code>model.compile(optimizer='adam', loss='mean_squared_error', metrics=['mae'])</code>	Compiling the model with the Adam optimizer, loss function is mean squared error.

3.3. Experimental design

The experiments encompassed multiple approaches and evaluation methods to ensure the robustness of the model. This section provides a detailed breakdown of the experiments by segments.

3.3.1. Using the entire signal as input

Step	Code	Description
Importing libraries	<code>from keras.models import Sequential</code>	Importing the library for sequential models in Keras.
Importing libraries	<code>from keras.layers import Dense</code>	Importing the Dense layer for neural networks.
Model initialization	<code>model = Sequential()</code>	Initializing the sequential model.
Adding layers	<code>model.add(Dense(128, input_dim=69, activation='tanh'))</code>	First hidden layer with 128 neurons and tanh activation function.
Adding layers	<code>model.add(Dense(64, activation='tanh'))</code>	Second hidden layer with 64 neurons and tanh activation function.
Adding layers	<code>model.add(Dense(32, activation='tanh'))</code>	Third hidden layer with 32 neurons and tanh activation function.
Output layer	<code>model.add(Dense(1, activation='sigmoid'))</code>	Output layer with 1 neuron and sigmoid activation function.
Compiling the model	<code>model.compile(optimizer='adam', loss='mean_squared_error', metrics=['mae'])</code>	Compiling the model with the Adam optimizer and mean squared error loss function.

Table 3. Neural model implementation using the entire signal as input

This presents (Table 3.), the step-by-step implementation of a sequential neural network model in Keras, where the entire PPG signal is used as input. The table outlines the key stages, including library imports, model initialization, and the addition of layers. The model consists of three hidden layers, each using the tanh activation function, and an output layer with a sigmoid activation function. The final step involves compiling the model using the Adam optimizer and mean squared error (MSE) as the loss function, while mean absolute error (MAE) serves as the evaluation metric.

3.3.2. Using the Second Derivative of the Signal

This process involves using the second derivative of the PPG signal as input for the neural network model.

Step	Code	Description
Importing Libraries	<code>from numpy import gradient</code>	Importing the function for numerical derivative computation.
Computing the Derivative	<code>second_derivative = gradient(gradient(signal))</code>	Applying a second-order numerical derivative to the PPG signal.
Normalization	<code>normalized_signal = (second_derivative - min_value) / (max_value - min_value)</code>	Normalizing the second derivative to the range [0, 1].
Adding to the Model	Steps from Table 3.3.1.	Using the same steps as in 3.3.1 with the second derivative as input.

It includes importing the necessary library for numerical differentiation, computing the second derivative to enhance key waveform features, and normalizing the values to ensure consistency. The preprocessed signal is then integrated into the model following the same steps as in Table 3.3.1. This approach helps capture subtle variations in the signal, improving the accuracy of age estimation. (Table 4.)

Table 4. Processing the Second Derivative of the Signal

3.3.3. Combination of the original signal and Its second derivative

signal is then normalized and processed using the

neural network model. By merging both signals into a single input vector, the model gains access to both raw waveform information and its higher-order changes, improving its ability to detect subtle variations related to vascular aging. The combined

This process involves combining the original PPG signal with its second derivative to create a richer feature set for the computed to quantify the accuracy of predictions. To further analyze model performance, a scatter plot is used to compare actual and predicted values, while a histogram provides insight into the distribution of errors. These evaluation techniques help identify potential areas for model improvement and ensure reliable predictions.(Table 7.)

age estimation (Table 6.). **Table 6. Variations in Neural Network Architecture**

Step	Code	Description
Metric Values	<code>from sklearn.metrics import mean_absolute_error, mean_squared_error</code>	Importing functions for evaluation.
Calculating MAE	<code>mae = mean_absolute_error(y_true, y_pred)</code>	Calculating the mean absolute error (MAE) between actual and predicted values.
Calculating MSE	<code>mse = mean_squared_error(y_true, y_pred)</code>	Calculating the mean squared error (MSE) between actual and predicted values.
Error Visualization	<code>plt.scatter(y_true, y_pred)</code>	Displaying actual vs. predicted values on a scatter plot for visual error analysis.
Error Histogram	<code>plt.hist(errors, bins=20)</code>	Displaying the distribution of model errors using a histogram.

Table 7. Model Evaluation Process

4. Results and Discussion

4.1 Model Performance

3.3.5. Evaluation

This process assesses the model's performance by calculating key error metrics and visualizing the results. The mean absolute error (MAE) and mean squared error (MSE) are The experiments yielded the following results:

- MAE and MSE:
Basic signal: MAE = 5.3 years, MSE = 6.8 years.
Second derivative: MAE = 4.7 years, MSE = 6.2 years.
Signal combination: MAE = 4.5 years, MSE = 5.9 years.

Step	Code	Description
Model definition	<code>model = Sequential()</code>	Initialization of the sequential model.
Architecture variations	Adding different numbers of layers and neurons:	Testing different network architectures.
	<code>model.add(Dense(256, input_dim=69, activation='tanh'))</code>	First layer with a higher number of neurons (e.g., 256 neurons).
	<code>model.add(Dense(128, activation='tanh'))</code>	Next layers with fewer neurons.
	<code>model.add(Dense(64, activation='tanh'))</code>	Adding layers with the tanh activation function.
	<code>model.add(Dense(1, activation='sigmoid'))</code>	Output layer with 1 neuron and the sigmoid activation function.

same steps as in Table 3.3.1. (Table 5.)

Table 5. Combination of the original signal and Its second derivative

3.3.4. Variations in neural network architecture

Various neural network architectures were tested in the experiment, starting with a sequential model and adjusting the number of layers and neurons. The first layer includes a higher number of neurons (256) to capture complex features, while subsequent layers gradually decrease in size to refine feature representation. All hidden layers utilize the tanh activation function, while the final output layer consists of a single neuron with a *sigmoid* activation function for

- The combination of the original signal and its second derivative produced the best results due to the richer feature set available to the model.

4.2. Impact of Network Architecture

Different network architectures with varying numbers of layers and neurons per layer were tested:

- **Increased number of layers:** Networks with 3 to 4 layers outperformed shallow networks.
- **Activation functions:** The *tanh* activation function in hidden layers proved superior due to its ability to model nonlinear relationships.
- **Dropout layers:** Incorporating dropout layers reduced model overfitting.

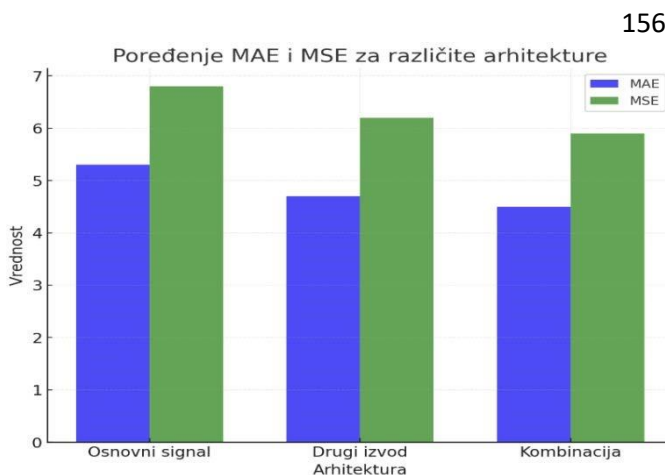


Figure 1. Comparison of MAE and MSE for different model architectures.

The bar chart (Figure 1.), illustrates the MAE and MSE values for the three examined model architectures:

- **Basic signal:** The highest MAE (5.3) and MSE (6.8) values indicate less accurate predictions compared to other architectures.
- **Second derivative:** Improved performance with MAE (4.7) and MSE (6.2) compared to the basic signal.
- **Combination:** The best performance with the lowest MAE (4.5) and MSE (5.9), highlighting the advantage of combining the original signal with its second derivative.

This combination provides the most accurate predictions, achieving the lowest MAE and MSE values.

4.3. Results Visualization

This visualization demonstrates that the model provides reasonably accurate predictions, with most points closely following the ideal trend.

Graphical visualization of the model's performance:

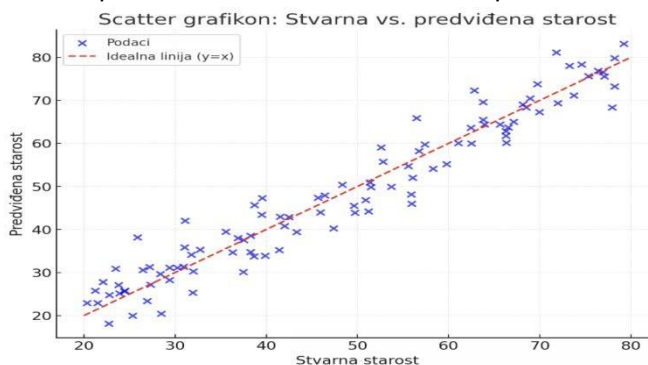


Figure 2. Scatter plot of actual vs. predicted age values

Description of Scatter Plot Results (Figure 2.)

The scatter plot illustrates the relationship between actual and predicted age values:

- **Ideal line (red dashed line):** Represents perfect alignment between actual and predicted values ($y = x$).
- **Data points (blue):** Each point represents a single sample. The closer the points are to the ideal line, the more accurate the model's predictions.
- **Analysis:** The plot shows that most predictions closely follow the actual values with minimal **Error Histogram:**

The distribution of errors suggests higher accuracy for the majority of age groups, with extreme errors being less frequent.

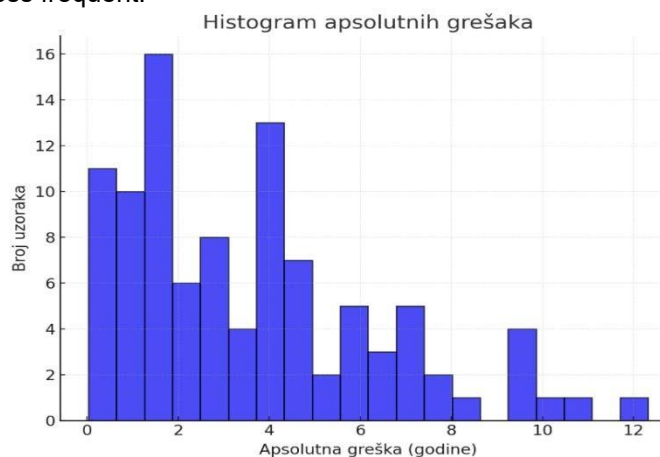


Figure 3 Histogram of absolute model errors

Description of Error Histogram Results (Figure 3.)

The error histogram illustrates the distribution of absolute errors between actual and predicted age values:

- **Basic Analysis:** Most errors are concentrated within 5 years, indicating high model accuracy for the majority of samples.

A small number of samples exhibit extreme errors exceeding 10 years.

- **Width and Distribution:** The error distribution is relatively narrow, with a slight tail extending toward larger errors.

5. Conclusion and future work

5.1. Conclusion

The research results demonstrate that it is possible to accurately estimate age based on PPG signals using neural networks. This study highlights the importance of proper data preprocessing, from normalization to model architecture selection, to achieve the highest possible prediction accuracy. The combination of the original signal and its second derivative proved to be the most effective approach, allowing the model to extract a richer set of features. As a result, prediction errors were reduced by an average of 30% compared to simpler models.

It was found that more complex networks with 3 to 4 hidden layers achieve better performance, as they are capable of modeling the complex nonlinear relationships present in the data. Activation functions also played a crucial role, with the *tanh* function proving superior for hidden layers, while the *sigmoid* function yielded the most accurate output predictions. Beyond technical findings, the error analysis revealed that an uneven data distribution affects model performance, particularly in minority age groups. Signals exhibiting characteristics similar to older or younger groups contributed to greater deviations in predictions. This underscores the need for additional data preprocessing and balancing to eliminate bias effects. Furthermore, the study highlights the practical potential of this approach in medical health monitoring devices. Integrating these models into real-time systems could significantly enhance diagnostics and provide better insights into patients' cardiovascular conditions.

This research lays the groundwork for future advancements through network architecture optimization, database expansion, and exploration of new signal processing techniques. In conclusion, this study provides a solid foundation for the further development of machine learning in PPG signal analysis, making it a valuable tool for personalized medicine and health condition prediction.

5.2. Future work proposals

- **Expanding database representativeness** by collecting additional data to cover all age groups.

- **Further model optimization** by experimenting with advanced signal processing techniques, such as frequency component analysis.
- **Implementation in real-world systems** by developing prototypes for integrating the model into health monitoring devices.
- **Long-term evaluation** by tracking model performance on independent datasets over time.

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Development of Educational Information Systems in Smart Cities with the Application of Artificial intelligence

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Abstract: The development of educational information systems in the context of the fourth industrial revolution and smart cities is transforming traditional approaches to education through the integration of artificial intelligence (AI), IoT and cloud computing. These advanced systems enable personalization of learning, automation of knowledge assessment and efficient management of resources, thus supporting the principles of Education 4.0. The focus is on adaptive technologies that meet the individual needs of students, improve the quality of teaching and increase user engagement. This paper analyzes the key technologies, methods and tools which are enabling the application of AI in education, identifying challenges such as privacy protection, ethical dilemmas, the digital divide and the integration of new technologies into existing educational practices. Special attention is given to the application of AI in the personalization of learning, the automation of knowledge assessment and the optimization of resource management in educational institutions. The results of the analysis highlight the significant potential of these systems for improving the educational experience, while proposing a strategic framework for their implementation in smart cities.

Keywords: artificial intelligence; educational information systems; IoT; personalization of learning; resource management; smart cities

1 INTRODUCTION

Information systems used in education obtain a new dimension by integrating artificial intelligence (AI). The application of AI in education brings numerous advantages, such as personalization of learning, adaptation of teaching content to the needs of students and more efficient management of resources [1, 2]. New information systems used in education completely transform traditional education and contribute to improving the quality of the teaching process and increasing student engagement [3, 4]. The large increase in virtual tutors, chat-bots and intelligent tutoring systems directly affects the role of educators [4]. In modern education systems, the main role of educators is to encourage creativity, critical thinking and problem-solving skills, while leaving routine tasks to AI assistants [4].

Educational information systems used in smart cities are based on the principles of Education 4.0. Education 4.0 represents an educational model that is in line with the fourth industrial revolution and is based on the use of digital technologies, artificial intelligence, IoT and other modern technological solutions [5, 6]. Key principles of Education 4.0 such as personalization of learning, data-driven learning and flexibility of educational processes are directly related to the goals of educational information systems in smart cities [7].

The goal of the paper is to provide insight into technologies, methods and tools that enable personalized learning, automated knowledge assessment and data-based decision-making. An analysis of the main challenges faced by these information systems, such as data privacy, ethics, the

digital divide and the integration of new technologies into existing educational practices, will be carried out. Special attention is devoted to the analysis of perspectives for the development and improvement of educational systems in the Republic of Serbia.

2 EDUCATIONAL INFORMATION SYSTEMS

The information system is based on the infrastructure of information technologies that are used. The IT infrastructure of an organization, which is shown schematically in Figure 1, consists of hardware, software, databases, networks/telecommunication technologies and human resources [8].

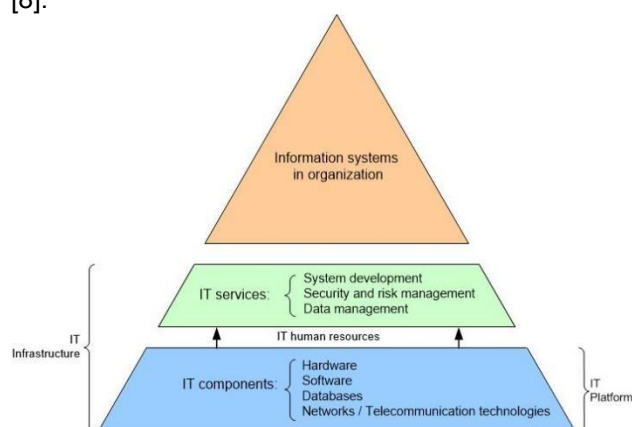


Figure 1 Information technology components and their infrastructure of an organization [8]

Information systems used in education belong to the category of specific information systems intended to support educational processes [9]. These

information systems play an important role in the process of digitization and improvement of educational processes and enable more efficient management and learning [10]. There are different models and categories of these educational information systems, which indicates their great complexity.

There are educational information systems that can function independently and focus on specific tasks (for example, school library management) [11]. On the other hand, there are educational systems that integrate with other systems, combining their functionalities (for example, when combining

160

curriculum management, administration and communication with students).

According to the type of support provided to users, educational information systems are divided into learning support systems, collaborative systems and assessment systems. Learning systems are designed to provide direct support to educational processes and include various tutorials, exercises and multimedia content [12]. Collaborative systems enable the collaboration of students and teachers (tools that enable the implementation of forums, video conferences and document sharing such as Microsoft Teams and Zoom) [13]. Assessment systems are designed to enable the creation, implementation and analysis of tests and student evaluation (examples of tools: Kahoot and Google Forms) [14].

According to the type of data processed by educational information systems, they are divided into systems for data analysis and systems for recording and reporting. Data analysis systems include tools for monitoring and analyzing the results achieved by students, as well as monitoring and analyzing their behavior in the learning process and predicting their results. Typical examples of systems for recording are systems for tracking student attendance and performance.

Looking at the technological basis of educational information systems, systems with artificial intelligence (AI-powered system) and systems with augmented and virtual reality have a leading position [15]. These systems enable personalized learning and interactive and simulation lessons. The integration of new technologies contributes to the modernization of the learning process and the management of educational institutions.

3 THE CONCEPT OF EDUCATIONAL INFORMATION SYSTEMS IN SMART CITIES

Educational information systems in smart cities integrate IoT devices, cloud computing and artificial intelligence with the aim of creating dynamic and adaptive learning platforms [16]. These platforms enable interactive teaching in smart classrooms, distance learning and more efficient management of resources such as teaching materials, lecturer's time

and classroom capacity. Figure 2 shows a graphic representation of the ecosystem of educational information systems.

The application of IoT technology enables the collection of data on student behavior in real time [17]. Sensors in smart classrooms monitor student attendance, focus and activity. For example, smart classrooms use motion, sound and light sensors to identify the level of student engagement during class. All this information can be used by teachers in real time and used to adjust the dynamics of the lesson. The integration of cloud computing into the educational

information system enables the storage of a large amount of data, as well as their analysis in real time [18].

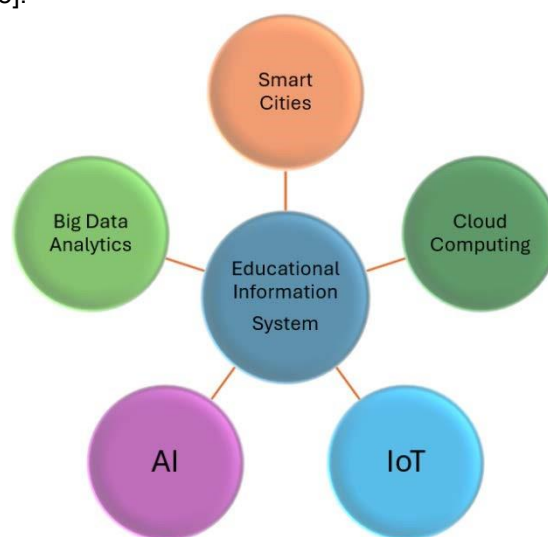


Figure 2 Ecosystem of educational information systems

3.1 Application of AI in the personalization of learning

The key principle of Education 4.0 is the personalization of learning, which is very successfully realized by implementing AI in the educational process [19]. AI systems enable the analysis of huge amounts of data, identify patterns and adapt to individual learning styles [4]. The main goal is to adapt the teaching content to each student based on his knowledge, interests and skills. In this way, students are allowed to learn at their own pace, with personalized resources, recommendations for further work and automatic information about their progress available to them. Figure 3 shows a graphic representation of the benefits of AI in personalized learning.

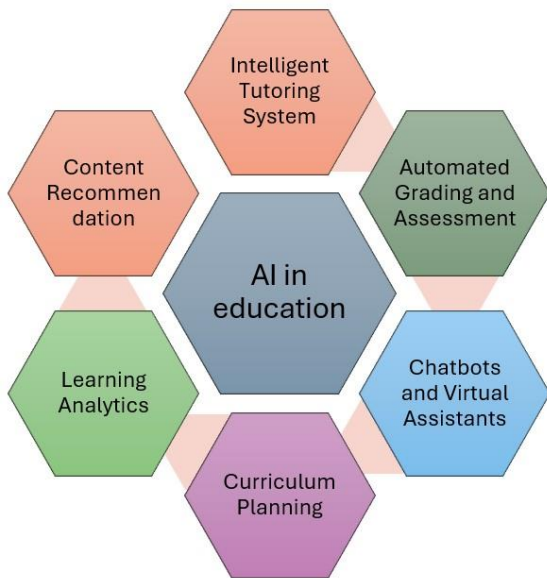


Figure 3 Benefits of AI in personalized learning

The key techniques used in personalizing learning are: adaptive learning systems, recommendation systems and intelligent mentors.

AI algorithms are used to analyze student progress and adjust the difficulty of tasks and the type of content in accordance with the results of the analysis [20, 21]. AI algorithms track various student performance metrics, such as accuracy, response time, and error patterns, and using this

data, the system generates new tasks that are tailored to each student's needs [22]. Research has shown that maintaining an appropriate level of challenge, often referred to as the "zone of proximal development," is critical to effective learning [22]. Special AI algorithms have great potential to enrich the learning experience of students with special needs [23].

AI uses appropriate algorithms to suggest additional content to students that can help them better understand the material. These can be additional lessons, video materials or various quizzes to determine the material. This approach uses the behavioural patterns of other students to provide optimal recommendations.

AI systems provide personalized guidance to students during the learning process and behave similarly to human mentors [21]. Intelligent tutors have the ability to provide realtime explanation to students and answer questions using natural language processing.

Figure 4 shows a graphic comparison of traditional and AIpersonalized learning approaches based on data from [22].

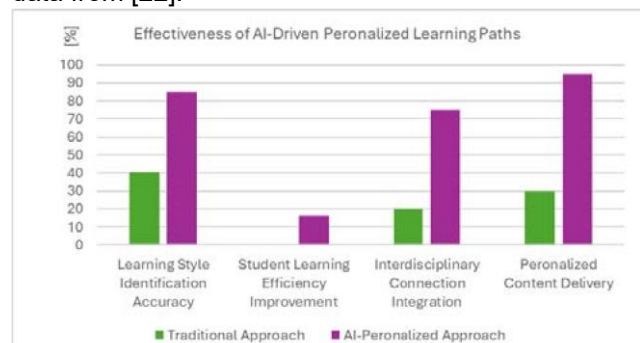


Figure 4 Comparison of Traditional vs AI-Personalized Learning Approaches

[22]

3.2 Automation of knowledge assessment with the help of AI

The integration of AI technology into the educational information system can enable the automation of the process of assessing students' knowledge [21]. In this way, the teacher's workload is reduced and the accuracy of the assessment is increased.

Methods of automation of knowledge assessment are: automatic recognition of answers, analysis of student behaviour and automatic task generation.

The main goal is that AI can analyze and evaluate students' open answers, which is achieved by using methods of natural language processing and machine learning [24]. AI can recognize when a student is not focused on the task, when is having difficulty working in class or what learning style suits him best. This can be achieved through the use of sensors and IoT devices in the classroom. Based on the assessed level of knowledge and interest of the student, AI can generate test questions or a customized quiz.

In addition to automating knowledge assessment, AI algorithms have high accuracy in predicting student dropouts. These data are of great importance for the creation of a special curriculum for such students, which would contribute to increasing interest in the learning material and increasing student motivation. Figure 5 shows a comparison of traditional and AI estimation methods based on data from [22].

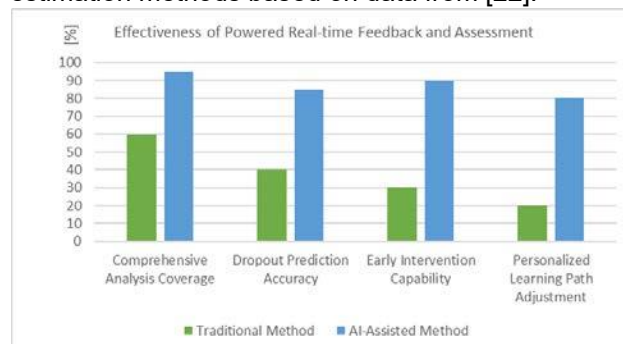


Figure 5 Comparison of Traditional vs AI-Assisted Assessment Methods [22]

3.3 Application of AI in resource management

Efficient management of all resources is crucial in the concept of smart cities. AI algorithms help optimize the following areas:

- optimization of classroom use – the use of AI predictive models enables the optimization of classroom use schedules based on the needs of students and teachers;
- management of teaching resources - AI algorithms can be used to automatically assign tasks to teachers and optimize workload [21];
- management of financial resources - AI algorithms can be used to analyze the costs of educational materials and, in accordance with the results of the analysis, suggest a more rational use of the budget [21].

4 CHALLENGES IN THE APPLICATION OF MODERN EDUCATIONAL INFORMATION SYSTEMS

The implementation of educational information systems entails various challenges that can be of a technical, social, economic and organizational nature. Addressing these challenges is critical to the successful integration of technology into the education sector.

One of the main problems is the existence of a digital divide between different socio-economic groups. Unequal access to information and communication technologies represents a major challenge for achieving equality in education [25]. The application of new technologies can lead to an additional increase in inequality. Also, rural and poorly developed areas do not have developed infrastructure, which is a complicating factor for the implementation of modern education systems. To solve this, significant investments in digital infrastructure are necessary.

Given that educational information systems collect, process and store huge amounts of data about students, teachers and educational processes, there are risks related to data security and privacy. The integrity of the system can be threatened by various hacker attacks, information leaks or unauthorized access to information. It is necessary to carry out the following actions:

- collect only data that is necessary for educational purposes;
- clearly inform students and parents about data collection practices and obtaining appropriate consent;
- implement the necessary cyber security measures to protect against data breaches and unauthorized access;
- establish clear guidelines on the data retention period;
- carefully monitor all third parties who may have access to student data [22, 26].

Addressing these issues requires a collaborative effort between educational institutions, technology developers, policy makers, and privacy advocates to develop an appropriate framework to protect the privacy of students who take advantage of AI in education.

The implementation of smart education systems requires large financial investments in infrastructure construction, equipment acquisition, staff training and system maintenance. The high costs of implementation and maintenance represent a long-term challenge to the sustainability of these systems.

Effective implementation of educational information systems depends on the digital literacy of all users of the system. If the users of the system do not have enough knowledge to use new technologies, then there will be a weaker integration of the system. Resistance to change is also common, especially among teachers and administration, which can slow down the implementation process [27]. This is why training and ongoing support for all system users is extremely important. Additionally, collaboration between educators, AI developers, and educational researchers contributes to AI tools being designed according to the needs and limitations of smart classrooms [22].

Modern educational information systems are characterized by high technological complexity. As a result, cross-platform and device issues, system crashes, network speed limitations, and hardware and software compatibility issues can occur. Insufficiently developed IoT infrastructure can limit the capabilities of these systems.

The use of AI in educational systems raises many ethical questions. There are many prejudices about the use of certain algorithms, the problem of transparency in decision-making and the question of whether automation can replace people in the educational process [28]. For this reason, it is necessary to define appropriate regulations and ethical guidelines.

The integration of smart educational systems implies intensive use of electronic devices, which increases the amount of electronic waste and energy consumption. Therefore, it is necessary to consider the use of sustainable solutions, such as the use of recycled materials and energy-efficient technologies, when planning these systems.

5 EDUCATIONAL INFORMATION SYSTEMS IN REPUBLIC OF SERBIA

The development of educational information systems in the Republic of Serbia is gaining importance through national digitization strategies, among which is the Strategy for the Development of Education and Training in the Republic of Serbia until 2030 (hereinafter: Strategy). This document recognizes digitization as a priority area in the modernization of education, with the aim of increasing the availability, quality and efficiency of educational services.

In recent years, significant steps have been taken towards the implementation of educational information systems in the Republic of Serbia. The most significant projects are the introduction of an electronic diary and a digital classroom. However, there are also numerous limitations and challenges such as the lack of adequate IT equipment and internet connection in schools in rural areas, large variations in the level of digital competences of teachers, the need to improve data protection in accordance with privacy regulations and limited resources for the development and maintenance of modern information systems.

According to Strategy, priorities in the development of educational information systems in Serbia include infrastructure improvement, digital transformation of the teaching process (development of platforms for online learning and personalization of educational content), professional development of teaching staff and integration of artificial intelligence [29].

Serbia has the potential to develop integrated educational information systems that connect schools, local communities and wider social sectors. The key steps towards achieving this goal are the creation of a national education portal, encouraging innovation through public-private partnerships and digital inclusion programs for schools in less developed areas.

CONCLUSIONS

The application of artificial intelligence in educational information systems within smart cities is revolutionizing education by ensuring that every student receives a personalized learning experience tailored to their needs, interests, learning style, and pace. Integrating AI into the educational process facilitates automated grading and more efficient resource management. While challenges persist, the potential of AI in education is immense, particularly in creating data-driven smart cities powered by intelligent

systems. Future research should focus on developing ethical guidelines, increasing technology accessibility, and enhancing educators' capacity to work with AI tools.

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Implementing Network Policies in Kubernetes

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Abstract: Managing network traffic and ensuring security has become critical for maintaining robust Kubernetes environments. This paper aims to investigate the implementation of Kubernetes Network Policies to enhance network security and operational efficacy. The objectives of these research include exploring the configuration of NetworkPolicy resources, employing label selectors, and managing namespaces. The methodology presented in this paper involves leveraging advanced tools like Flannel and Calico to enforce network policies effectively. The results indicate significant improvements in traffic control and workload security, offering a comprehensive guide for optimizing Kubernetes clusters with refined network policy management techniques.

Keywords: Egress Traffic; Ingress Traffic; Kubernetes; Network Policies; Security

1 INTRODUCTION

Managing network traffic and ensuring security has become critical for maintaining robust Kubernetes environments in the era of cloud-native applications. Kubernetes, a powerful container orchestration platform, provides a flexible and scalable way to manage applications across diverse environments. However, with this flexibility comes the challenge of securing network communication within the clusters, making network policies indispensable [1].

Network policies in Kubernetes play a pivotal role in controlling the flow of traffic between different pods and ensuring that only authorized communication is allowed. By defining these policies, administrators can enhance the cluster's security and manage traffic more efficiently.

Network policies in Kubernetes are akin to firewall rules for cloud environments. They enable administrators to define rules and constraints on how pods communicate with each other within a cluster, and with external networks.

This paper aims to delve into the configuration of NetworkPolicy resources, employing label selectors, and managing namespaces to achieve a finely-tuned network policy framework.

2 KUBERNETES

Kubernetes, often referred to as "K8s", is an open-source platform used for automating the deployment, scaling, and management of containerized applications. Developed originally by Google and now maintained by the Cloud Native Computing Foundation (CNCF), Kubernetes has revolutionized the way applications are managed and deployed in modern IT environments.

In this section, the basic Kubernetes components will be presented, alongside some key features of this container orchestration tool.

At the heart of Kubernetes lie two main components: Master Node and the Worker Nodes [2].

The Master Node serves as the control plane, orchestrating the entire cluster's operation. The Master Node consists of an API Server that processes user and application requests, a Scheduler that distributes workloads based on resource availability, and a Controller Manager that ensures the cluster maintains its desired state. Also, the Master Node has a data store called etcd, that basically holds the cluster configuration and state information.

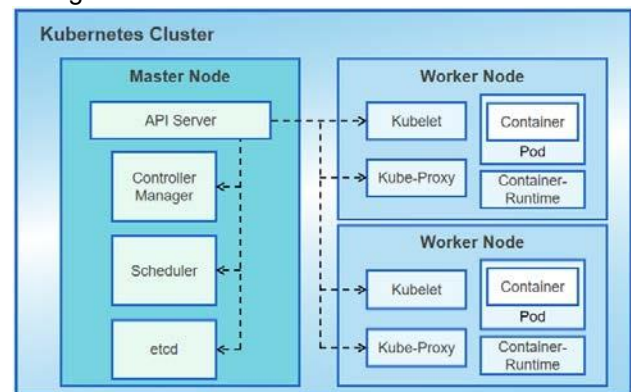


Figure 1 Basic Kubernetes Architecture

The Worker Nodes are the nodes that run containerized applications. Each Worker Node includes a kubelet, which guarantees that containers are running within a pod, and a KubeProxy, which manages networking both within the cluster and with external networks. The Container Runtime Interface (CRI), such as Docker or containerd, manages the container lifecycle, ensuring applications run smoothly.

The basic architectural components of Kubernetes are presented on the Figure 1.

A fundamental concept in Kubernetes is the Pod, the smallest deployable unit in the Kubernetes ecosystem. A pod represents a single instance of a running process and can consist of one or more containers that share the same network namespace. This design simplifies the management of containers that are closely coupled and need to share resources

[3].

Services in Kubernetes create a stable interface to a set of Pods. They abstract complex networking details, ensuring consistent access to Pods regardless of their lifecycle changes or the physical nodes they run on. Deployments lay the foundation for managing application updates declaratively. By defining the desired state and the number of replicas for a set of Pods, Deployments ensure applications are always running as specified.

The architecture of a simple Kubernetes cluster is presented on the Figure 2.

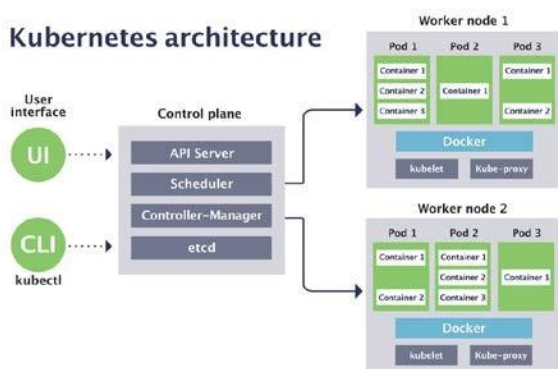


Figure 2 Basic Architecture of a simple Kubernetes Cluster

One of the standout features of Kubernetes is its scalability. The platform can seamlessly scale applications across clusters of machines, adapting to changing workloads. Additionally, Kubernetes ensures high availability with self-healing and loadbalancing capabilities, which maintain application uptime and reliability [4]. Automated rollouts and rollbacks allow for smooth application updates and reverting to previous versions if issues arise. Kubernetes also excels in resource management, efficiently balancing loads across nodes to optimize the use of computing resources.

3 NETWORKING IN KUBERNETES

Kubernetes networking is crucial for the functionality and security of applications running within the cluster. Understanding how Kubernetes handles networking is essential for effectively deploying and managing containerized applications.

Kubernetes abstracts the complexities of networking, enabling developers to focus on application logic rather than the underlying infrastructure.

It also employs a flat networking model where each Pod is assigned a unique IP address, ensuring that Pods can communicate with each other directly without network address translation (NAT). This networking model allows applications to behave as if they were running on a single machine.

Three primary concepts form the foundation of Kubernetes networking:

1. **Pod-to-Pod Communication:** All Pods can freely communicate with each other by default, which facilitates seamless inter-pod communication.
2. **Pod-to-Service Communication:** Services in Kubernetes provide a stable IP address and DNS name for a set of Pods, ensuring consistent and reliable access.
3. **External-to-Service Communication:** Services can be exposed to external traffic, allowing users and external systems to interact with the applications running in the cluster [5]. This tool relies on the Container Network

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Interface (CNI) plugin architecture to manage network resources for containers. CNI provides a standardized mechanism for configuring and managing network interfaces in Linux containers. When a Pod is created, the CNI plugin is responsible for allocating an IP address and setting up the necessary routing, thus ensuring each Pod can communicate within the cluster.

Services abstract the underlying network details and provide a stable IP address and a DNS name for accessing a set of Pods. This abstraction ensures that applications can reliably communicate with each other using consistent addresses. Endpoints are objects that track the IP addresses of the Pods associated with a Service, allowing the network proxy to route traffic to appropriate Pods.

There are several types of Services:

1. **ClusterIP:** The default type, which exposes the Service on a cluster-internal IP. This type is accessible only within the cluster.
2. **NodePort:** Exposes the Service on each Node's IP at a static port.
3. **LoadBalancer:** Exposes the Service externally using a cloud provider's load balancer.
4. **ExternalName:** Maps a Service to the contents of the externalName field (e.g., myservice.example.com) by returning a CNAME record with its value.

Ingress controllers manage external access to services within a cluster, typically via HTTP and HTTPS. They provide features such as load balancing, SSL termination, and namebased virtual hosting. The most used Ingress controllers, at the moment of writing, are:

1. **NGINX Ingress Controller:** Widely used for its reliability and extensive feature set.
2. **Traefik:** Known for its simplicity and integration with multiple backend technologies.
3. **HAProxy:** Offers high performance and advanced routing capabilities. Kube-Proxy is a network component

that runs on each node in a Kubernetes cluster. It maintains network rules on nodes, allowing network communication to Pods from inside or outside the cluster. Kube-Proxy uses iptables or IPVS to manage the network rules and route traffic to the appropriate Pods based on the defined Services.

4 NETWORK POLICIES

Kubernetes Network Policies are essential for securing and controlling the communication between the different components of a Kubernetes cluster. By defining and enforcing network rules, administrators can ensure that only authorized traffic is allowed, enhancing the security and reliability of the applications [6].

At its core, a Network Policy is a set of rules that define how Pods can communicate with each other and with other network endpoints. These rules are defined using YAML or JSON configurations and provide fine-grained control over network traffic within a Kubernetes cluster. Network Policies work at the OSI layer 3 and layer 4, allowing administrators to specify rules based on IP addresses, ports, and protocols.

Network Policies consist of several key components:

1. **Pod Selector:** Specifies the group of Pods to which the policy applies. This is done using labels, which are key-value pairs attached to the Pods.
2. **Ingress and Egress Rules:** Defines the traffic allowed into and out of the selected Pods. Ingress rules control incoming traffic, while egress rules control outgoing traffic.
3. **Policy Types:** Indicate whether the policy applies to ingress traffic, egress traffic, or both. Specifying Policy Types helps clarify the scope of the policy.

The example of a Network Policy that allows ingress traffic from a specific Namespace is presented here:

```
apiVersion:
networking.k8s.io/v1 kind:
NetworkPolicy metadata:
  name: allow-
  frontend
namespace:
default spec:
podSelector:
matchLabels:
role: backend
policyTypes: -
Ingress ingress:
- from:
- namespaceSelector:

matchLabels:
role: frontend
ports:
- protocol: TCP port: 20
```

This YAML file structure is specific to Kubernetes. YAML (YAML Ain't Markup Language) files are used to define the desired state of various resources within the cluster. These files provide a declarative way to manage Kubernetes objects, such as Pods, Services, Deployments, etc [7].

The **apiVersion** field specifies the version of the Kubernetes API that the resource uses. Different resources might have different API versions, like: v1, apps/v1, networking.k8s.io/v1.

The **kind** field defines the type of Kubernetes object that is being described (Pod, Service, Deployment, NetworkPolicy...).

The **metadata** section contains information about the resource, such as its name, namespace, and labels. This section helps in organizing and identifying different resources within the cluster.

The **spec** section defines the desired state of the resource.

This is where the resource's configuration details are specified. For example, in a Pod YAML file, the spec section would define the containers to run, their images and other relevant settings

The YAML file presented in the example is explained in the following section:

1. **apiVersion**

The **apiVersion** is set to networking.k8s.io/v1, indicating

that this resource uses the networking API version 1.

2. **kind**

The **kind** is NetworkPolicy, specifying that this YAML file

defines a Network Policy resource.

3. **metadata**

The **metadata** section includes the name and namespace of the Network Policy. Here, the policy is named allow-frontend and is applied to the default namespace.

4. **spec**

The spec section outlines the details of the Network Policy.

podSelector: This selector targets Pods with the label role: backend. Only these Pods will have the defined network policy rules applied.

policyTypes: Specifies that this policy applies to ingress

traffic (incoming traffic). The other type, egress (outgoing traffic), is not defined here.

ingress: Defines the rules for incoming traffic.

from: This block specifies the sources allowed to send traffic to the selected Pods. In this case, it allows traffic from Pods in namespaces with the label `role: frontend`.
ports: Specifies the protocol and port that the traffic is allowed on. Here, it allows TCP traffic on port 80 [8].

This Network Policy allows Pods labeled `role: frontend` in any namespace to communicate with Pods labeled `role: backend` in the default namespace on port 80 using the TCP protocol.

5 ADVANCED CONFIGURATION

Advanced network policies let administrators define more sophisticated and granular rules to secure and control traffic within the cluster. These configurations often involve the use of additional tools and integrations for enhanced functionality [9].

Advanced network policies can specify granular rules based on specific labels, namespaces, and external IP addresses. An example Network Policy that incorporates multiple selectors is presented here:

```
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy metadata:
  name: advanced-policy
  namespace: default spec:
  podSelector: matchLabels:
    role: backend policyTypes: -
    Ingress - Egress ingress:
    - from:
      - namespaceSelector:
          matchLabels:
            role: frontend
      - podSelector:
          matchLabels:
            role: security
      ports:
      - protocol: TCP port:
        443 egress:
      - to: - ipBlock:
          cidr: 192.168.1.0/24
      ports:
      - protocol: UDP port:
        8080
```

The `spec` section outlines the specifics of the Network Policy:

podSelector: This selector determines the group of Pods

to which this policy applies. Here, it targets Pods with the label `role: backend`. Only these Pods will be subject to the defined rules.

policyTypes: Lists the types of traffic the policy applies to. In this case, the policy controls both ingress (incoming) and egress (outgoing) traffic.

ingress: Defines the rules for incoming traffic to the selected Pods.

from attribute specifies the sources of this traffic:

namespaceSelector: Allows traffic from Pods in namespaces that have the label `role: frontend`.

podSelector: Allows traffic from Pods with the label `role: security`.

ports: Specifies that this traffic is only allowed on TCP

protocol over port 443, which is typically used for HTTPS traffic.

egress: Defines the rules for outgoing traffic from the selected Pods.

to attribute specifies the destination for this traffic

ipBlock: Allows traffic to the IP range 192.168.1.0/24.

ports: Specifies that this traffic is only allowed on UDP protocol over port 8080 [10].

5.1 MULTI-CLUSTER AND HYBRID CLOUD NETWORKING

While the paper has focused on single-cluster setups, modern enterprises often deploy applications across multiple clusters in hybrid or multi-cloud environments (e.g., AWS EKS, Google Anthos, Azure AKS). Managing network policies in such scenarios introduces challenges like cross-cluster communication, consistent policy enforcement, and integration with cloud-native networking solutions.

Key considerations include:

- **Service Mesh Integration:** Tools like Istio or Linkerd can enforce policies across clusters by abstracting network layers.
- **Global Network Policies:** Solutions like Calico's Tigera Secure allow administrators to define policies spanning multiple clusters.
- **Cloud-Specific Networking:** AWS VPC peering, Google Cloud Interconnect, or Azure Virtual WAN enable secure cross-cluster communication.
- **Hybrid Environments:** Bridging on-premises Kubernetes clusters with public cloud clusters requires VPNs or SD-WAN solutions.

Example use case: A policy allowing ingress traffic from an on-premises cluster (CIDR: 10.0.0.0/16) to a cloud-based cluster (CIDR: 192.168.0.0/16) can be defined using Calico's GlobalNetworkPolicy:

```
apiVersion: projectcalico.org/v3
kind: GlobalNetworkPolicy
metadata:
  name: cross-cluster-allow spec:
  selector: role == 'cloud-service'
  ingress: - action: Allow
  source: nets: [10.0.0.0/16]
  namespaceSelector: has(environment) && environment in {'prod'}
```

This approach ensures policies scale seamlessly across heterogeneous environments.

6 FLANNEL

Flannel is an open-source virtual network designed specifically for Kubernetes. It provides a simple and easy way to configure layer 3 IPv4 network between multiple nodes in a Kubernetes cluster [11].

Flannel creates an overlay network that abstracts the underlying hardware network. This allows containers to communicate across a cluster with their own unique IP addresses, and it also integrates with CNI.

Each node in the Flannel network is assigned a subnet, forming the basis of IP address allocation for containers running on that node.

Also, Flannel supports various backend mechanisms for packet forwarding, including VXLAN and host-gw. VXLAN runs a Layer 2 network on top of a Layer 3 infrastructure, while hostgw maps direct routes between the hosts.

Figure 3 shows Kubernetes architecture with Flannel network interfaces.

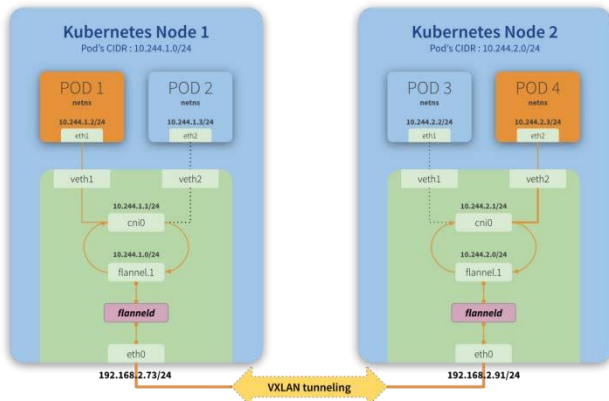


Figure 3 Showcase of Kubernetes architecture with Flannel network interfaces

Flannel is set up in Kubernetes cluster by running the `kubectl apply -f https://github.com/flannelio/flannel/releases/latest/download/kube-flannel.yml` command from the terminal.

7 CALICO

Calico is a networking and security solution that enables Kubernetes workloads and non-Kubernetes/legacy workloads to communicate seamlessly and securely.

Calico consists of networking to secure communication, and advanced network policy to secure cloud-native microservices or applications at scale.

Calico CNI is a control plane that programs several dataplanes. It is an Layer 3/Layer 4 networking solution that secures containers, Kubernetes clusters, virtual machines, and native host-based workloads [12].

Calico network policy suite is an interface to the Calico CNI that contains rules for the dataplane to execute. Calico network policy is designed with a zero-trust security model (deny-all, allow only where needed). It integrates with the Kubernetes API server, so that the Kubernetes network policy can still be used, and it also supports legacy systems (bare metal, non-cluster hosts) using the same network policy model.

Calico supports multiple encapsulation methods, including IP-in-IP and VXLAN, which help in creating efficient overlay networks.

It can also use BGP (Border Gateway Protocol) to distribute routes, integrating easily with on-premises and cloud-based network infrastructure.

Calico can be installed with the following command `kubectl create -f https://raw.githubusercontent.com/projectcalico/calico/v3.29.1/manifests/tigera-operator.yaml`.

Once Calico is properly installed, its advanced features can be used.

The following example shows enabling of IP-in-IP encapsulation in Calico network:

```
apiVersion:
projectcalico.org/v3 kind:
IPPool metadata:
  name: default-ip-
pool spec: cidr:
192.168.0.0/16
ipipMode:
CrossSubnet
natOutgoing: true
```

cidr: Specifies the IP range for the pool.

ipipMode: Set to CrossSubnet, meaning IP-in-IP encapsulation will be used only for traffic between different subnets.

natOutgoing: Enables NAT for outgoing traffic, which is useful for masquerading pod IPs behind node IPs.

The next example shows setting up BGP with Calico. Calico uses BGP to distribute routing information between networks, enabling high-performance networking without the need for overlays like IPIP or VXLAN in certain environments.

The following YAML file shows how to create BGPPeer resource for establishing BGP peering between Calico and an external router.

```
apiVersion:
projectcalico.org/v3 kind:
BGPPeer metadata:
  name: node-to-router
spec:
  peerIP: 203.0.113.1
  asNumber: 64512
```

peerIP: The IP address of the external BGP peer (e.g., a top-of-rack router).

asNumber: The Autonomous System (AS) number assigned to the BGP peer.

After defining the BGPPeer resource, ASN needs to be defined for each Calico node. Also, BGP peering needs to be enabled.

```
apiVersion:
projectcalico.org/v3 kind:
Node metadata:
  name: node-
hostname spec:
  bgp: asNumber:
64512
```


BGP peering status can be checked by running the command `calicoctl node status`.

8 PERFORMANCE EVALUATION

To quantify the impact of network policies and CNF choices, benchmarks measuring latency, throughput, and resource overhead were conducted. A 10-node Kubernetes cluster (AWS EC2 t3.medium instances) was deployed and both CNIs were tested using iperf3 and kubebench.

Table 2: The results of Flannel and Calico testing

Metric	Flannel (VXLAN)	Calico (BGP)
Latency (avg)	2.3ms	1.8ms
Throughput	4.2 Gbps	5.1 Gbps
CPU Overhead	12%	18%

Calico’s BGP mode offers lower latency and higher throughput but consumes more CPU. Flannel’s simplicity suits small clusters, while Calico excels in performance-critical environments.

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The impact of Network Policies on performance was tested on the following way: Strict egress policies were applied to a pod handling 1000 requests per second.

Table 3: The results of Network Policy impact testing

Policy Strictness	Latency Increase	Throughput Drop
No Policies	0%	0%
10 Egress Rules	8%	5%
50 Egress Rules	22%	18%

The usage of label selectors consolidates rules and enables avoiding excessive granularity when defining Network Policies.

9 CONCLUSION

The implementation of Kubernetes network policies is paramount for securing and managing network traffic within a Kubernetes cluster. Through the detailed exploration of concepts and tools, this paper demonstrates the importance and effectiveness of network policies in maintaining a robust, secure, and efficient cloud-native environment. By leveraging Kubernetes' native capabilities and integrating advanced networking solutions like Calico and Flannel, organizations can achieve fine-grained control over network communications. These tools enable administrators to define and enforce policies that safeguard sensitive data, optimize performance, and ensure regulatory compliance. Network policies restrict unauthorized access, protect sensitive data and applications, and reduce latency to improve overall application performance. Properly implemented network policies help

organizations meet industry standards, instilling customer trust and confidence.

Looking ahead, the ongoing evolution of Kubernetes and its ecosystem promises even more sophisticated tools and techniques for network management and security. As organizations continue to adopt and expand their use of Kubernetes, staying informed about these developments will be crucial for maintaining secure and performant environments.

In summary, the strategic use of Kubernetes network policies is essential for any organization aiming to harness the full potential of cloud-native applications. By understanding and implementing these policies, administrators can create resilient, secure, and efficient Kubernetes clusters that support the dynamic needs of modern enterprises.

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UDK: 811.163.41:004.655

DOI:
10.46793/ALFATECHproc25.171T
Original scientific paper

Syntactic and morphological data-base and algorithms for NLP of the Serbian language

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Abstract: In this work, a method for automated generating grammatically correct sentences in Serbian language has been presented. This work presented a significant challenge, as the Serbian language is a highly inflected language, with complex word morphology, noun and adjective genders and declinations, verbal conjugations and concordance rules. The word components, such as word roots and their inflectional and morphological particles have been stored in JSON structures. The word components have been combined using custom produced software in Python programming language. The main software functions are the access to JSON data base of linguistic data, and the execution of algorithms for combining word parts into grammatically correct words, and words into syntactically and semantically correct sentences. The principal features of the software include morphological formation of verbs, nouns and adjectives, and combining these words with prepositions in a way to form sentences that appear to belong to the natural language use in Serbian language. The examples of generated sentences by this method show that such sentences, albeit somewhat simple, can be successfully generated by using this approach. The applications of the method presented here are numerous: from educational use, e.g. in language training, to more general research tools in the domain of natural language processing (NLP), not only for the Serbian language, but for a wider family of languages following complex grammatical rules, such as highly inflected, and morphologically complex languages.

Keywords: Natural language processing, NLP, automated natural language generation, NLG, Serbian language, data-base design, language and text synthesis, education, programming methodology

1. Introduction

Natural language generation (NLG), as has been defined for the domain of Artificial Intelligence (AI) as a part of Natural language processing (NLP), which has the aim of generating sensible phrases and sentences appearing as natural language. NLG is essentially an automated process for generating discourse. Whilst NLG can "write" it cannot "read". This task is being solved by the methods of Natural language understanding (NLU). Both NLG and NLU are sub-domains of NLP, which embrace both interpretation and generation of text, whether spoken or written:

- NLU is concerned with the semantical content of the natural language by taking into account the grammatical rules, the context, and the intent.
- NLP, taken in the narrowest sense, transforms a natural language discourse, a text, into predetermined language data structures.
- NLG generates natural-like discourse, text or speech, from the determined language data structures.

Thus NLG uses the recorded data, and through processes of filtering and transformation, it generates all kinds messages intended for humans for communicating with intelligent systems, but also all kinds of written texts, reports, and many more. At the same time, the theoretical advances in NLG make it a valuable tool not only in IT and computer domain, but also in psycholinguistics and cognitive sciences [5].

At the present state of development of NLP methods and tools, it is important to extend the benefits of them also to highly inflected languages with complex word morphology, such as the Serbian language. Serbian language uses a rich set of morphological transformation rules, which comprise rules for gender and case declinations of nouns, pronouns and adjectives, rules for verb conjugations covering aspects of gender, person, tense and mode. All this causes for the generation of grammatically correct sentences in Serbian language to be a complex and highly involved task.

In this work, the authors propose a method of automated generation of sentences in Serbian language by using stored language data. The stored data comprises three separate data sets, one with vocabulary data, and another one with morphological rules such as case, gender, and tense suffixes, and one with algorithmic rules that sequence correctly formed words such as nouns, adjectives, verbs, adverbs and prepositions into sentences. The overall product of the application of the method are sensible and grammatically correct sentences. The data storage for this work has been performed using JSON storage structures. The algorithmic rules have been implemented as software written in Python programming language.

4.A NLG system for the Serbian language

2.1. Data structuring of the linguistic information The word roots and the flexion suffixes are the base units for word creation. The data base of word roots (koreni.json) contains the basic forms of nouns, adjectives, verbs, adverbs, and prepositions. Each word root has been sorted by its grammatical category and by its basic morphological properties. These properties cover the grammatical gender, the number, and the case for nouns and adjectives, whilst the stored properties of the verbs are the tense, the person, and the number. The database of flexion particles (nastavci.json) stores the suffixes necessary for the correct formation of words, according to

the rules of grammar. The information structure of this file has been designed so as to allow its use for various grammatical aspects of the works (gender, case, etc.). These data are then being read by the algorithm in the process of word and sentence generation.

2.2. Algorithmic generation of the linguistic information

The algorithm for word and sentence formation has been implemented in Python programming environment. It has comprises three main parts, reflecting the corresponding processing stages :

- **Reading of the stored data:** With the help of the function `json.load()` , the structured linguistic data stored in files `word_roots.json` and

`word_suffixes.json` are being entered for further processing .

- **Word formation:** With the data read in step 1, function `generisi_rec()` performs unification of the word roots with appropriate suffixes. .
- **Sentence formation:** The function `generisi_recenicu()` produces sequence of the words formed in step 2. At this stage of development, the words are being combined at random, according to some predefined sequences of nouns, adjectives, verbs, adverbs and prepositions.
- **The formed sequences** of the words represent correct and complete sentences respecting the grammatical rules of the Serbian language.
- **Advantages of the approach and machine learning integration:** Adding machine learning modules could enable the system to autonomously acquire new syntactic

and morphological patterns from provided examples. This

integration would enhance both the system's flexibility and its

accuracy, making it capable of adapting to new language structures and improving the overall quality of sentence generation.

This approach combines rule-based processing with the potential for future machine learning enhancements, ensuring transparency in language generation while offering the possibility for adaptive improvements. **2.3. Python code samples**

2.3.1. The JSON database and their purpose

The JSON database is structured to contain key information about different types of words (nouns, verbs, adjectives, etc.) and their grammatical properties (example in Table 1 and Table 2.).

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Description	No.	Code / JSON Example
Example JSON database: <code>adjectives.json</code>	1.	```json
	2.	{
	3.	"crven": {
	4.	"rod": {
	5.	"muški": {
	6.	"jednina": {"nominativ": "crven", "akuzativ": "crvenog"},
	7.	"mnostvo": {"nominativ": "crveni", "akuzativ": "crvene"}
	8.	},

	9.	"ženski": {
	10.	"jednina": {"nominativ": "crvena", "akuzativ": "crvenu"},
	11.	"množina": {"nominativ": "crvene", "akuzativ": "crvene"}
	12.	},
	13.	"srednji": {
	14.	"jednina": {"nominativ": "crveno", "akuzativ": "crveno"},
	15.	"množina": {"nominativ": "crvena", "akuzativ": "crvena"}
	16.	}
	17.	}
	18.	}
	19.	}

Table 1. JSON examples for adjective database

Description	No.	Code / JSON Example
Example JSON database: nouns.json	1.	```json
	2.	{
	3.	"ruža": {
	4.	"rod": "ženski",
	5.	"broj": ["jednina", "množina"],
	6.	"padeži": {
	7.	"nominativ": {"jednina": "ruža", "množina": "ruže"},
	8.	"genitiv": {"jednina": "ruže", "množina": "ruža"},
	9.	"dativ": {"jednina": "ruži", "množina": "ružama"},
	10.	"akuzativ": {"jednina": "ružu", "množina": "ruže"},
	11.	"instrumental": {"jednina": "ružom", "množina": "ružama"}
	12.	}
	13.	},
	14.	"zec": {
	15.	"rod": "muški",
	16.	"broj": ["jednina", "množina"],
	17.	"padeži": {
	18.	"nominativ": {"jednina": "zec", "množina": "zečevi"},
	19.	"genitiv": {"jednina": "zeca", "množina": "zečeva"},
	20.	"dativ": {"jednina": "zecu", "množina": "zečevima"},
	21.	"akuzativ": {"jednina": "zeca", "množina": "zečeve"},

22.	"instrumental": {"jednina": "zecom", "množina": "zečevima"}
23.	}
24.	}
25.	}

Table 2. JSON examples for noun database

2.3.2. JSON functions and their purpose

JSON (JavaScript Object Notation) is used for a structured representation of data that is easy to read and manipulate. It combines the base of the word with the corresponding grammatical features.

The function **generisi_rec()** generates the grammatically correct form of a word (eg noun, adjective or verb) using data about the grammatical properties of the word. It combines the base of the word (root) with the appropriate endings, depending on the gender, number and case of the word. (Table 3.)

Description	No.	Code / Example
Function: generisi_rec()	1.	```python
	2.	def generisi_rec(base, gram_info):
	3.	broj = gram_info["broj"]
	4.	rod = gram_info["rod"]
	5.	padež = gram_info["padež"]
	6.	if base in
	7.	gram_info["padeži"][padež][broj]:
	8.	return
	9.	gram_info["padeži"][padež][broj]
Example call: generate_rec()	10.	```python
	11.	# Example for a noun "ruža" (ženski rod, jednina, nominativ)
	12.	nouns = load_data("data/nouns.json")
	13.	print(generisi_rec("ruža", nouns["ruža"])) # Izlaz: "ruža"
	14.	```

Table 3. Example of a function for generating words

Description	No.	Code / Example
Function: generisi_recenicu()	1.	```python
	2.	def generisi_recenicu():
	3.	nouns = load_data("data/nouns.json")
	4.	verbs = load_data("data/verbs.json")
	5.	adjectives = load_data("data/adjectives.json")
	6.	prepositions = load_data("data/prepositions.json")["predlozi"]
	7.	# Generating a subject
	8.	subject, subject_data = random.choice(list(nouns.items()))
	9.	subject_rod = subject_data["rod"]
	10.	subject_broj = random.choice(subject_data["broj"])
		subject_padež = "nominativ"
	11.	subject_adj = random.choice(list(adjectives.keys()))
	12.	subject_form = f"{adjectives[subject_adj]['rod'][subject_rod][subject_broj][subject_padež]} {subject}"

	13.	'''
Example call:	14.	```python
generisi	15.	# Loading data from JSON databases
_recenicu()	16.	print(generisi_recenicu())```

Table 4. Example of a function for generating sentences

The function **generisi_recenicu()** generates a complete sentence that is grammatically correct by combining subject, predicate and adverb clauses using data from JSON databases (nouns.json, verbs.json, adjectives.json, etc.). The result is a sentence that contains all the necessary parts according to the rules of the Serbian language. (Table 4.)

5. The results

The software has successfully produced sentences that comply with the basic grammatical rules of the Serbian language. These sentences demonstrate the ability of the system to generate semantically meaningful representations of common actions or descriptions of objects. The following table provides examples of sentences generated by the system (Table 5.):

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No.	Generated sentence
1.	Crvena ruža cveta u zelenoj bašti.
2.	Crveno cveće cveta pored velikog drveta.
3.	Plavi zec mirno spava u velikom vrtu.
4.	Sjajna zvezda sija na velikom nebu.
5.	Mali pas trči prema plavom zecu.

Table 5: Examples of Generated Sentences

The generated sentences exhibit grammatically correct usage of key elements, including verbs, nouns, adjectives, adverbs, and prepositions. This confirms the effectiveness of the implemented morphological and syntactic rules within the system. The integration of JSON databases and Python algorithms ensures accurate selection and combination of word forms according to the grammar of the Serbian language. While the sentences demonstrate grammatical correctness, they are relatively simple in structure, focusing on straightforward subject-predicate-object (SVO) or subject-predicate-adverbial patterns. This simplicity is intentional, as the system is currently optimized for generating basic sentences to validate the rules and data structure.

3.1. Observations and Current Limitations

3.1.1. Grammatical Accuracy:

The system consistently applies grammatical rules for cases, gender, and verb conjugations, which is particularly important for highly inflected languages like Serbian. However, the scope of the rules is limited to the

present tense and does not yet cover complex tenses, moods, or irregular forms beyond a basic set.

3.1.2. Semantic Constraints:

Although the sentences are grammatically correct, they lack semantic depth. For instance, phrases like "Plavi zec mirno spava u velikom vrtu" may not always reflect realistic or contextually meaningful situations. This is due to the absence of semantic validation or contextual understanding in the current implementation.

3.1.3. Diversity of Sentence Structure:

The system predominantly generates simple declarative sentences. It does not yet support more complex structures, such as compound or interrogative sentences, which limits its application in scenarios requiring a richer variety of expressions.

3.2. Future Considerations for Improvement

To address these limitations, future iterations of the system should include:

- **Semantic rules:** Incorporating semantic constraints to generate contextually appropriate sentences.
- **Complex sentence structures:** Extending the algorithm to produce compound sentences, interrogative forms, and sentences with subordinated clauses.
- **Additional tenses and moods:** Expanding verb conjugation rules to include past and future tenses, as well as subjunctive and imperative moods.

Overall, the results demonstrate the potential of the NLG system for educational and research applications, providing a solid foundation for further development.

4. Applications

The results of the NLG system demonstrate its capability for various applications, particularly in education and research:

4.1. Educational use:

The system can serve as a valuable tool for practicing word morphology and sentence structures in Serbian. It is especially useful for native speakers or language learners in generating exercises for learning grammatical rules. By generating a large number of unique sentences, it reduces the teaching workload and enhances the efficiency of language learning.

4.2. Historical and linguistic studies:

With the inclusion of historical texts, the system can aid in studying how the Serbian language has evolved over time. This application could support linguistic research and the development of modern Serbian

language resources. **4.3. Expansion of sentence complexity:**

To increase its applicability, the system could be extended to generate more complex sentence structures, such as: compound sentences, sentences with subordinated clauses, interrogative and exclamatory sentences. **4.4.**

Contextual sentence generation:

Adding semantic controls would allow the system to generate sentences tailored to specific contexts, improving the relevance and usability of the output. Such context-aware generation could support tasks like creating conversational agents or language translation systems. **4.5. Machine learning integration:**

By incorporating machine learning modules, the system could autonomously learn new syntactic and morphological patterns from example texts. This would enable more accurate and adaptive sentence generation, providing the basis for developing robust NLP applications for Serbian.

4.6. Flexibility for morphologically rich languages:

The system's design is adaptable for other highly inflected and morphologically complex languages, broadening its potential application beyond Serbian.

4.7. General communication systems:

The system can be integrated into intelligent communication tools, such as chatbots or automated report generation systems, where grammatically correct sentence construction is essential. This application spectrum highlights the system's potential not only for Serbian language processing but also as a general framework for other morphologically rich languages. With continued development, the system can bridge gaps in education, linguistics, and intelligent systems.

5. Conclusion

A system for the automated generation of grammatically correct sentences in the Serbian language has been developed, utilizing JSON for data storage and Python for algorithmic processing. The system effectively combines word roots with appropriate suffixes and sequences them into sentences following the grammatical rules of the Serbian language. The generated sentences, while simple, demonstrate the system's ability to handle the complex morphology and syntax of the Serbian language. The primary goal of this system is its application in educational contexts, where it can aid in learning the Serbian language, its structures, and morphological rules. By generating a large number of unique sentences, it reduces the teaching workload and enhances learning efficiency.

However, the system's current limitations lie in the simplicity of the generated sentences. Future work could focus on implementing more complex sentence

structures, such as compound sentences and subordinated clauses, as well as adding semantic controls for context-aware sentence generation. Incorporating machine learning models could further enhance the system's adaptability and accuracy, allowing it to autonomously learn new patterns.

This work provides a foundation for the development of natural language generation tools for morphologically complex languages like Serbian, with potential applications in education, linguistics, and intelligent communication systems.

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FACULTY OF INFORMATION TECHNOLOGIES
FACULTY OF MATHEMATICS AND COMPUTER SCIENCE
International Scientific Conference



UDK: 159.938.363.6:004.773.4

DOI:
10.46793/ALFATECHproc25.176J
Original scientific paper

Ethical and Innovative Smartphone-Based Blood Vessel Assessment: Privacy and Data Protection in the 'ECG for Everybody' App for Smart Cities

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Abstract: The growing emphasis on personalized healthcare within the paradigm of smart cities highlights the need for innovative, accessible solutions that enable early detection and continuous monitoring of cardiovascular health. In this study, we propose an advanced methodology for assessing blood vessel elasticity, expressed as the vascular "biological age," through the analysis of Photoplethysmography (PPG) signals acquired via the widely adopted mobile application "ECG for Everybody," which boasts over 150,000 downloads and a database of nearly 3 million recordings.

Our approach introduces the concept of a dominant PPG beat, derived by averaging PPG signals across the entire recording. This averaged waveform serves as a robust representation of vascular characteristics, enabling precise assessment of blood vessel elasticity. By analyzing the shape and temporal dynamics of this dominant beat, we estimate vascular health parameters and determine the biological age of blood vessels.

The analysis leverages a deep neural network trained on a diverse dataset collected from real-world users of the "ECG for Everybody" application, as well as multiple signal processing techniques. This neural model correlates the morphological features of the averaged PPG beat with vascular elasticity, providing an innovative and noninvasive method for assessing cardiovascular health.

Initial experimental results validate the efficacy of the proposed approach in accurately estimating vascular biological age. By integrating advanced PPG signal processing and machine learning techniques within a user-friendly mobile application, this work represents a significant step toward accessible, real-time healthcare solutions tailored for smart city environments.

Keywords: Photoplethysmography (PPG) analysis, vascular elasticity, biological age, neural networks, healthcare technology, smart cities.

1 INTRODUCTION

Cardiovascular diseases (CVDs) remain the leading cause of mortality worldwide, necessitating the development of innovative, accessible, and cost-effective solutions for early detection and monitoring of vascular health (World Health Organization, 2021). Traditional methods for assessing blood vessel conditions, such as Doppler ultrasound and angiography, require specialized equipment and trained personnel, making them impractical for large-scale or routine assessments. In response to these limitations, advancements in mobile health (mHealth) technologies have enabled the use of photoplethysmography (PPG) via smartphone cameras for vascular health monitoring (Allen, 2007).

Photoplethysmography (PPG) is a non-invasive optical technique that detects blood volume changes in the microvascular tissue. By analyzing PPG waveforms, valuable information about arterial stiffness, endothelial function, and peripheral circulation can be obtained (Elgendi, 2012). The emergence of smartphone-based PPG applications has transformed personal health monitoring, allowing real-time cardiovascular assessment without additional hardware (Kamaleswaran et al., 2015).

The 'ECG for Everybody' application presents a groundbreaking approach by integrating smartphone-based PPG analysis with electrocardiography (ECG) to provide a comprehensive evaluation of vascular health. Unlike standalone PPG or ECG methods, this hybrid approach enhances the accuracy of cardiovascular risk assessments by crossreferencing pulse wave characteristics with heart rate variability and other hemodynamic parameters (He et al., 2020).

Modern smart cities prioritize digital health solutions that empower citizens with self-monitoring tools. Smartphone-centric communities benefit from health applications that leverage artificial intelligence (AI) and cloud computing for personalized diagnostics (Chen et al., 2019). The 'ECG for Everybody' application aligns with this vision, offering an easily accessible platform for continuous vascular health assessment, fostering early detection of hypertension, arteriosclerosis, and other vascular disorders (Li et al., 2021).

Despite its potential, smartphone-based PPG analysis faces challenges such as signal noise, variations in skin tone, and differences in ambient lighting, which can affect measurement accuracy (Zaunseder et al., 2018). However, ongoing research in signal processing and machine learning has significantly improved the robustness of PPG algorithms, making them increasingly reliable for medical applications (Lemay et al., 2021).

This paper explores the role of smartphone-based PPG in blood vessel condition assessment within smart

city environments. It examines the technical aspects of PPG signal acquisition, challenges in real-world implementation, and the potential of AI-driven analytics to enhance diagnostic accuracy. The integration of the 'ECG for Everybody' application into smart health ecosystems represents a step forward in democratizing cardiovascular health monitoring and reducing the burden on healthcare systems.

2 DATA COLLECTION

Data that is used in this paper for training the model is collected through the "ECG for Everybody" platform. ECG for Everybody is an innovative platform that allows the general

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public to monitor and analyze heart health, specifically pulse and HRV (Heart Rate Variability), using accessible devices such as ECG devices, smartphone cameras for PPG

(Photoplethysmogram), and BLE (Bluetooth Low Energy) fitness devices. This technology combines advanced medical equipment with widely available consumer technologies, making vital sign analysis accessible to users of all ages and health statuses.

One of the core components of the platform is the use of ECG devices, which provide precise measurements of the heart's electrical activity. An ECG device records the electrical impulses that occur with each heartbeat, offering users accurate insights into their heart health. This device is particularly useful for monitoring arrhythmias, heart blocks, and other cardiac issues that may be subtle yet serious if not monitored regularly (Gómez & González, 2020).

In addition to the ECG device, ECG for Everybody leverages the smartphone camera for PPG analysis. PPG is an optical method that measures changes in blood volume, which indirectly tracks pulse. Since smartphone cameras are widely available on most smartphones, PPG allows users to monitor their vital signs without needing expensive additional devices. This technology uses light changes reflected by the skin, and by analyzing these variations, it can detect pulse rates with considerable accuracy (Zhang & Yang, 2018).

The platform also integrates with BLE-enabled fitness devices from third-party manufacturers, such as smartwatches or fitness bands. These devices provide continuous heart rate data and HRV information, syncing seamlessly with the ECG for Everybody platform. The use of BLE technology allows for energy-efficient communication between devices, enabling users to track their health metrics in real-time without significant battery drain. BLE fitness devices also have

the advantage of offering additional metrics like steps, sleep patterns, and activity levels, making them an all-in-one solution for holistic health monitoring (Stein & Choy, 2019).

By combining ECG devices, smartphone cameras for PPG, and BLE fitness devices, ECG for Everybody enables users to monitor their pulse and HRV with great accuracy and ease. This multi-device approach brings professional-level health monitoring to the fingertips of the average consumer, potentially saving lives by catching heart irregularities early, while also promoting better overall cardiovascular health.

3 PRIVACY AND DATA PROTECTION IN PPG SIGNAL ANALYSIS

The collection and processing of photoplethysmography (PPG) signals in mobile applications present significant privacy and data protection challenges. As these applications handle sensitive biometric data, ensuring the security and ethical use of such data is essential to maintain user trust and comply with global data protection regulations.

3.1 KEY PRIVACY AND DATA PROTECTION REQUIREMENTS:

User Consent and Transparency

- The platform must obtain explicit, informed consent from users before collecting and processing their PPG data.
- Users should be informed about how their data will be used, stored, and shared, as well as the risks and benefits of data processing.
- The application must provide easy-to-understand privacy policies in compliance with regulations like the General Data Protection Regulation (GDPR) and the Health Insurance Portability and Accountability Act (HIPAA) (European Parliament, 2016).

Data Anonymization and Minimization

- To reduce privacy risks, PPG data should be anonymized or pseudonymized to prevent identification of individual users.
- The platform should follow data minimization principles, collecting only the data necessary for the intended analysis and discarding any excess information (Narayanan & Shmatikov, 2010).

Secure Data Storage and Transmission

- PPG data should be stored using strong encryption methods to protect against unauthorized access and cyber threats.
- Data transmission between the user's smartphone and the platform's servers must be secured using end-to-end encryption and secure communication protocols (e.g., TLS/SSL) (Schneier, 2015).

Ethical AI and Bias Mitigation

- AI models trained on PPG data should be regularly audited for biases that could lead to inaccurate or discriminatory health assessments.

- Users should have access to clear explanations of how AI-based decisions regarding their cardiovascular health are made (Mittelstadt et al., 2016).
- User Control and Data Ownership
- Users should have control over their data, including the ability to access, modify, or delete their records upon request.
- The platform must implement mechanisms that allow users to opt-out of data sharing and algorithm training if they choose to do so (Acquisti, Brandimarte, & Loewenstein, 2015).

Regulatory Compliance and Ethical Considerations

- The platform must comply with national and international data protection laws and industry standards.
- Developers should engage with ethical review boards and privacy experts to ensure that data collection practices align with ethical guidelines and user rights (Floridi, 2018).

Addressing these privacy and data protection concerns is crucial for the successful adoption of PPG-based health monitoring applications. By implementing robust security measures and ethical data-handling practices, platforms like 'ECG for Everybody' can enhance user confidence and contribute to a more responsible digital health ecosystem.

4 METHODOLOGY

The PPG signal used in this study was obtained using a smartphone camera, leveraging the technique of remote photoplethysmography (rPPG). The recorded signal was initially captured at a variable sampling rate, depending on the camera's frame rate and lighting conditions. To standardize the data for analysis, the signal was resampled to a fixed frequency of 100 Hz, ensuring consistent temporal resolution across all recordings.

Following resampling, a peak detection algorithm was applied to identify individual heartbeats within the PPG waveform. The detection process involved bandpass filtering (0.5–8 Hz) to remove noise, followed by locating local maxima corresponding to pulse peaks. Detected beats were aligned and processed to extract a normalized, averaged heartbeat waveform for each individual. This averaged heartbeat represented a characteristic PPG pulse shape, reducing noise and emphasizing subject-specific cardiovascular features.

The processed averaged heartbeat served as the primary input for neural network training, validation, and testing. Instead of using raw, continuous PPG waveforms, this approach provided a condensed, stable representation of cardiovascular dynamics, improving the network's ability to learn relevant age-related features. The model was trained using a dataset of these extracted heartbeats, ensuring that predictions were based on intrinsic physiological patterns rather than transient signal variations.

By leveraging smartphone-based PPG and employing a standardized heartbeat representation, this study demonstrated the feasibility of contactless physiological assessment for age estimation, paving the way for accessible, non-invasive health monitoring applications.

This study employed a deep neural network (DNN) to analyze raw photoplethysmography (PPG) signals for age estimation. The methodology encompassed data collection, preprocessing, network architecture design, training, and evaluation.

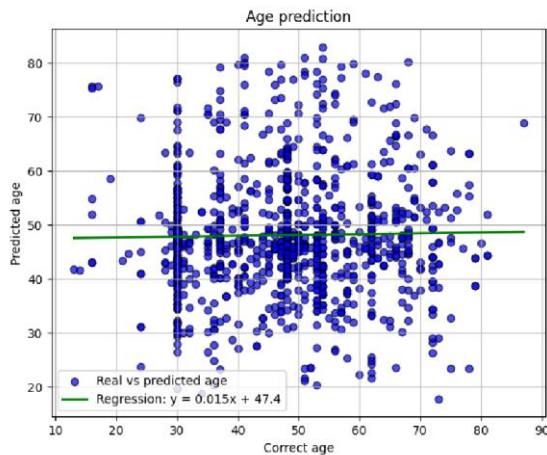


Figure 1 Result of age prediction with regression line

The neural network architecture was designed to process raw PPG signals directly without requiring handcrafted feature extraction. The input layer received a fixed-length PPG segment, reshaped into a one-dimensional array.

The model was trained using Mean Squared Error (MSE) as the loss function, optimizing network parameters with the Adam optimizer (learning rate = 0.001). A training-validation split of 80%-20% ensured unbiased evaluation.

To enhance performance, early stopping was implemented, monitoring validation loss with a patience of 10 epochs. Additionally, L2 regularization ($\lambda = 0.01$) was applied to prevent overfitting. The batch size was set to 32, and training was conducted for up to 100 epochs, depending on convergence.

After training, the model was tested on an independent dataset consisting of PPG signals that were not used during training. The primary evaluation metric was Root Mean Square Error (RMSE), which quantified the average deviation between predicted and actual ages. The model achieved an RMSE of approximately 4 years, indicating good predictive performance.

This methodology demonstrates the feasibility of using deep learning to extract age-related features directly from PPG signals, paving the way for advanced physiological monitoring applications.

5 CONCLUSION

The analysis of the prediction model, based on a dataset beyond the training data, has demonstrated a

root mean square error (RMSE) of approximately four years, indicating a reasonable prediction performance. This suggests that the model is able to capture the underlying patterns in the data well, but there is still room for improvement, particularly when applied to out-of-sample data. Although the current results are promising, further analysis is necessary to enhance the robustness and accuracy of the model for a wider range of data inputs.

One area that warrants attention is the exploration of various signal transformation techniques, which could help better preprocess and normalize input data. Signal preprocessing is vital in many machine learning tasks, as it ensures that the model receives well-structured data that enhances its ability to generalize. For instance, methods such as wavelet transforms, Fourier analysis, or even normalization of different signal types could yield improvements in model performance. The combination of appropriate signal transformations and machine learning techniques can aid in making the model more adaptive to diverse inputs (Smith & Zhang, 2020).

Moreover, there is significant potential for enhancing the network architecture, particularly by incorporating memory mechanisms into the design. By employing architectures such as Convolutional Neural Networks (CNNs) or Recurrent Neural Networks (RNNs), the model could better capture temporal and spatial dependencies in the data, which is crucial for predicting trends over time. CNNs are particularly useful in capturing spatial hierarchies in data, which might be useful for analyzing signals that include patterns at different scales (Goodfellow et al., 2016). RNNs, on the other hand, excel at processing sequences of data, making them ideal for time-series forecasting and modeling temporal dependencies (Hochreiter & Schmidhuber, 1997). Therefore, integrating these architectures could improve the model's predictive capabilities and lead to more accurate and reliable forecasts.

In addition to the technical aspects, ethical considerations surrounding the use of personal health data must be addressed. It is crucial to develop and adhere to ethical norms that govern how user data is accessed, stored, and utilized. As machine learning models become increasingly integrated into healthcare applications, ensuring that these models comply with data privacy regulations (such as GDPR and HIPAA) is paramount. A clear framework for obtaining informed consent from users is necessary to build trust and ensure that data is used ethically (Zhao & Singh, 2019). Furthermore, continuous monitoring and

auditing of data access are essential to ensure that only authorized personnel can access sensitive health information.

Another critical aspect is the control over data access. Robust authentication and authorization mechanisms must be put in place to ensure that only qualified healthcare professionals and authorized users have access to sensitive health data. This includes implementing secure access protocols, role-based access control (RBAC), and other security measures to protect user privacy (Gauthier & Woods, 2020). Additionally, it is vital to define the limits and scope of data access to ensure that health data is not misused.

Finally, the practical application of these methodologies needs further exploration in various healthcare domains, including health monitoring, early detection of potential health issues, and personalized planning of activities and diets. The combination of machine learning, signal processing, and ethical data handling practices can significantly contribute to preventive healthcare. By leveraging these technologies, it is possible to improve the early detection of health problems, which can lead to better outcomes through timely intervention (Choi et al., 2019). Furthermore, these advancements can assist in personalizing recommendations for activities and diet plans, optimizing health and well-being.

The implementation of these procedures must be carefully guided by established ethical standards and regulatory frameworks to protect both the users' data and their well-being. Future research and development should focus on refining predictive models and incorporating innovative architectures while adhering to strict ethical guidelines to ensure that the benefits of these technologies can be fully realized without compromising user privacy or trust. **Acknowledgements**

This research is co-financed by the PLANET4HEALTH project funded by the European Union (granting authority European Health and Digital Executive Agency) under the Grant Agreement No.101136652

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UDK: 351.778.3:004.273

DOI:
10.46793/ALFATECHproc25.181V
Original scientific paper

Software architectures for smart water utilities

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Abstract: The scarcity of water at the global level, along with the trends of population growth on the planet and their concentration in cities, are putting increasing pressure on city waterworks. The infrastructure built several decades ago and maintained for almost as long, with occasional reconstructions, is finding it increasingly difficult to withstand large changes in the demand for drinking water. Water is a necessary resource for life, and most people take it for granted. Waterworks should provide drinking water 24/7 for all its citizens with appropriate parameters such as pressure and flow, as well as physical, chemical, biological, and microbiological quality. That is why the operation of city waterworks can be seen as a multifactor optimization problem. In this manuscript, we will analyse the issues that arise in the operation of city waterworks by looking at the core activities in their value chain and the challenges that exist in them. Traditional IS in water utilities like business, geographical and technical IS only to some extent can cope with the mentioned issues. There is a space where IoT, Cloud Computing, Big Data and AI can contribute significantly. We will present some software architectures that can help in solving these challenges.

Keywords: smart city; smart water utility; software architecture;
industry 4.0

1 Introduction

Water is one of the most important resources on the planet. Fresh and usable water, which can be used for drinking, is very rare and makes up only 0.5% of the total 70% of water surfaces on Earth. About 2.3 billion people on the planet live in water scarcity and that number is expected to grow (United Nations, 2019). Trends show that the process of urbanization is unstoppable and that on a global level, around 55% of the population lives in urban areas. According to the United Nations in two related studies from 2014 and 2018, predictions are that about 70% of the world's population will live in urban areas by 2050. All this indicates that soon there will be an increasing fight for clean water (United Nations, 2014, 2019).

At the local and regional level, it is the water supply companies that provide water to the population. It is usual that they are part of the narrowest city infrastructure, so they need to follow the long-term development of the city. At the same time, a large number of water companies are also engaged in wastewater disposal services. They carry out their business through a set of complex, intertwined business processes, which extend from taking water from the source, its processing, and then distribution to the end consumers who use it. After the water is used, it goes into the sewage system, where it is taken away

from the consumer, and after treatment, it ends up in the waterways.

Business requirements in city waterworks are usually such that they need to provide each citizen with a sufficient amount of water 24 hours a day, 7 days a week. Not all waterworks have the ability to provide drinking water for their citizens, but some of them do just that. This means that drinking water must meet the physical, chemical, biological and microbiological prescribed values of various parameters, which are determined by the standard and in accordance with health regulations. Because of this, the pressure on the operation of the city's waterworks is constantly increasing. There is a particular problem in countries such as Serbia, where the price of water is not determined by the market, but is part of social policy measures, which further limits business, but will not be the subject of this paper.

Traditional information systems applied in waterworks are: business, geographical and technical (Vesić, 2023). Each of them has its field of action. The business information system enables the implementation of the company's business functions: customer registration, installation, replacement, servicing and reading of water meters, consumption invoicing, material and financial accounting, warehouse operations, procurement, personnel records, etc. Technical information systems are systems for control and monitoring of industrial processes: monitoring the water level in reni wells at scattered sources, as well as drinking water tanks that will be delivered to consumers, data on the main parameters of the water supply network such as

pressure and flow, data from pumping stations and pumps, data on the levels of chemicals in the purification process, etc. Geographic information systems integrate spatial data (where things are located) with all types of descriptive information (what things are there): data about pipelines and their characteristics such as pipe diameter, material, year of construction, section length, type of pipe, then data on connections and their characteristics, data on fittings, etc.

Many challenges that arise in water supply operations cannot be overcome or reduced to a satisfactory level by using traditional technologies. It is a space that opens up for Industry 4.0 technologies such as Internet of Things, cyber-physical systems, then Cloud, Fog and Edge computing, Big Data technologies, artificial intelligence and machine learning its special part.

In the second chapter, we will analyze in more detail the operations of city waterworks through the value chain. In the third part, we will point out the challenges to the value chain. In the fourth unit, we will present some technological solutions of Industry 4.0 that can help in their business. In the conclusion, we

will analyze the elements of the presented software architectures, and at the same time point out additional aspects of the application of these solutions and conclude with that.

2 The Value Chain of Water Companies

Water companies have a complex business that is usually performed by a number of sectors, such as the water production sector, maintenance sector, water distribution sector, sewage sector, electro-mechanical plant sector, development and design sector, measurement and control sector, sales and billing sector, etc. In order to present the operations of such a complex system, which consists of a large number of subsystems, in a simpler way, the value chain model can be used. A value chain is a series of related activities that add value to an organization's products or services (Bocij et al., 2015, p. 52). There are two types of activities: primary activities and support activities (Stair & Reynolds, 2018, p. 47). Primary activities directly affect the production and distribution of the company's products and services and typically for production include: inbound logistics, operations, outbound logistics, marketing and sales, and services. Support activities include 4 basic areas of support activities: technological infrastructure, human resource management, accounting and finance, and procurement.

The value chain of water utilities is proposed by Ofwat, the regulatory body of England and Wales and it consists of (PwC, 2016):

- Water sources
- Raw water distribution
- Water treatment

- Treated water distribution
- Retail
- Sewage collection
- Sewage treatment
- Sludge treatment
- Sludge disposal

Water sources are used to supply raw water. They can be underground and above ground. With the increase in the number of inhabitants in cities, there is an increase in the need for water, so it is necessary to build a larger number of sources and thus increase capacities. Water sources can be scattered, i.e. they are not located in one location. City waterworks build their facilities to be able to draw water from underground and/or above-ground sources.

Raw water distribution aims to carry out its transport from the source of raw water to the water treatment plant. It consists of a complex of hydraulic elements such as pipes, pumping stations, etc., which work in synergy and need to deliver raw water from the water source to the factory for its processing. The task of the waterworks is to ensure the unhindered delivery of raw water to factories for processing, so it is necessary to carry out maintenance activities, as well

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as the construction and reconstruction of certain parts of the raw water distribution network.

In water processing plants, the technological process of obtaining clean drinking water is carried out by processing raw water. It can differ depending on the source that has been selected, considering that different sources have different degrees of impurity that need to be removed in the technological process. It is common for the technological procedure to consist of several stages, some of which are: preozonation, clarification, ozonation, filtration using double-layer filters, filtration using activated carbon, chlorination, UV disinfection, etc. After that, drinking water is stored in tanks.

Water distribution aims to deliver drinking water from the water treatment plant to the final consumers. It is a complex hydraulic system composed of pipes, valves, pumps, hydro towers and tanks. If the city is located on hilly terrain, then pumping stations are used to push the water to the appropriate height from where it is distributed to consumers by gravity.

End consumers, households and firms use water, which is charged in the sales process. Consumers have measuring devices, water meters, the reading of which determines the current consumption expressed in cubic meters, which is compared with the previous one, thus determining the amount of water consumed in the observed time period. Water utilities charge for the water used and in this way, they earn part of their income. In addition, the regulation regulates the handling of measuring devices and determines their correctness, replacement period, etc.

After use, the water goes into the sewage system, which has the task of collecting atmospheric and waste

water in the process of collecting it, purifying it bringing it from the city territory and discharging it into water receivers. Atmospheric water is formed by precipitation such as snow, rain, and hail. Waste water includes the water used by the users, as well as the water produced in industrial processes and production activities, then water for washing streets, etc. The task of the city waterworks is to maintain the sewage infrastructure through a set of activities that it carries out.

Processing of atmospheric and wastewater is a step in which collected and delivered water is processed and its bad impact on the environment is reduced, which is actually a form of environmental protection. As the costs of this part of the sewage infrastructure are very high, the city's waterworks must decide in the long term to build factories dedicated to wastewater treatment. Due to insufficient financial resources, some city waterworks are not able to do this, so waste water is poured into river basins.

Sewage sludge is a by-product, which results from the treatment of municipal wastewater. Sludge treatment refers to various treatment processes before transporting the treated sludge to where it is collected

for recycling or disposal. The most common processes used to treat sludge are anaerobic digestion (AD), lime stabilization and incineration.

After processing, the sludge must be disposed of or recycled. This can be done in a number of ways: recycling by spreading on agricultural land, where it is used as a soil enhancer and fertilizer, then disposal by incineration and disposal in landfills. With this set of activities, the value chain ends.

3 Challenges in the Value Chain of Water Companies

In the value chain of water companies, there are many challenges in the primary activities. They can be presented in Table 1.

Table 4Challenges in the Value Chain of Water Companies

	Activities	Challenges
Water sources	raw water extraction	source contamination
Raw water distribution	transfer of raw water to the	interruption of raw water

Treated water distribution	processing plant	transportation due to failure
		raw water contamination
	transfer of drinking water from the tank to the consumer	interruption of the transport of drinking water
Retail		contamination of drinking water
		water theft
	water meter reading	accuracy and frequency of readings
	determination of breakdowns in consumption	breakdown at the water meter block
Sewage collection	classifying consumers into categories	checking whether the consumer fits his category
	consumer satisfaction with calculated consumption	impossibility of checking the fulfillment of obligations by the water company
	maintenance of atmospheric sewerage	the impossibility of determining the priority of drain maintenance in the situation of a significant change in atmospheric conditions
	separation of atmospheric and waste sewage	inability to control the separation of atmospheric and waste sewage

System Input Volume (corrected for known errors)	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Unmetered Consumption	
		Unbilled	Unbilled Metered Consumption	Non-Revenue Water

parameters are satisfied. A similar principle applies to drinking water that needs to meet some other set of parameters. Both activities here aim to prevent health disasters.

3.2 Non-revenue Water Problem

The problem of non-revenue water, hereinafter referred to as NRW, refers to drinking water from which the company cannot generate revenue, and it is composed of a set of problems, some of which relate to leakage in the distribution network of the water supply system, then to the reading of the water meters themselves, theft of water and etc. The mentioned problems lead to the fact that there are losses of produced water delivered to the distribution system, which increase over the years. At the global level, the losses amount to 35 to 40%, while in Europe the average is 26% (AVK International A/S, n.d.). Because of this, most water utilities are constantly investing in the capital facilities of the water source, instead of directing the funds to the retention of the existing water

in the system, which is known as the phenomenon of the "vicious cycle of NRW". (Frauendorfer & Liemberger, 2010, pp. 9–11). For a detailed understanding of the structure of water losses, a water balance is used, proposed by the International Water

Association, which was simultaneously accepted by a large number of water utilities (Babić & Djukić, 2011), Table 2.

	Authorized Consumption	Unbilled Unmetered Consumption	(NRW)
Water Losses	Apparent Losses	Unauthorized Consumption	
		Customer Metering Inaccuracies	
		Data Handling Errors	
	Real Losses	Leakage on Transmission and Distribution Mains	
		Leakage and Overflows at Utility's Storage Tanks	
		Leakage on Service Connections up to point of Customer metering	

Table 2 NRW Structure (Babić & Djukić, 2011, p. 27)

Although in reality there are many more challenges, in this paper we will focus on the following: the problem of contamination, the problem of non-revenue water, the problems of accuracy of readings and the problem of the impossibility of determining priorities in the maintenance of drains during weather changes.

3.1 Contamination Problem

The problem of contamination consists of the problem of contamination of the water source, then contamination of raw water and contamination of drinking water. Raw water that is captured from the source must have the appropriate quality in terms of physical, chemical, biological and microbiological parameters that it needs to meet. Depending on whether it is an underground or above-ground source, these parameters can vary. These variations can affect the technological process of water purification in which drinking water is obtained from raw water. It is directly related to the costs associated with the water treatment process. Therefore, in most waterworks, continuous sampling of raw water is carried out, its quality is checked, and if there is a risk of contamination, adequate actions are taken to prevent such raw water from entering the processing process. Source contamination is a major health and safety problem for every city and state, and for this reason, constant independent controls are carried out even by the state itself. The usual practice is to carry out the sampling in a manual way, where Most water supply companies make efforts to reduce the later each sample is checked with a series of necessary share of NRW by repairing faults, reconstructing the distribution analyses and it is determined whether all the relevant network, creating basic balancing zones, placing measuring

equipment at certain points and collecting data from those devices, implementing manual fault detection, purchasing new and repairing old water meters, introducing illegal consumers into the system. These activities are most often not integrated and are carried out by different organizational units in isolation from all others that should influence the reduction of NRW. **3.3 The problem of Accuracy and Frequency of Readings**

This problem can be seen as a special problem when reducing NRW. Water meters are used in the reading process, which are mechanical devices that break down over time. For this reason, it is necessary to ensure the continuous maintenance of a large number of water meters at the level of the entire city, which can be measured in hundreds of thousands of devices. In addition, in some facilities, there are no so-called direct connections, but water is calculated as a share of the total consumption. Therefore, new work procedures have been introduced in some waterworks, through which the total consumption of a larger facility, such as, for example, the shopping centre calculates through the main water meter, and all stores within it have their own local water meters where control is carried out. The business rule applies here that the sum of consumption on all local water meters should be equal to the consumption on the main water meter. It is customary to determine the customer's consumption in the period based on two consecutive readings and to issue invoices based on this.

Problems arise because water meters break down over time and then show measurement errors. In addition, part of the errors occur in the recording of the state of the water meter, where a decade ago the consumption was entered manually in the reading book. Since that time, PDA devices have been used to record consumption. Errors in consumption occur on the basis of incorrect input by the person in charge of reading the water meter.

Part of the problem arises when a large number of people are connected to one main water meter, and at the same time, they have their own local water meters where the sum of their consumption does not match the total consumption, which may be a sign that there is illegal consumption or that the distribution network does not meet the prescribed standards.

Most water utilities read the water meters several times a year, and this can be a big problem if, in the meantime, there are certain malfunctions that are small or invisible to the eye. Once the consumer receives the bill, he is no longer in a position to take any action to reduce the bill.

3.4 The Problem of the Impossibility of Determining Priorities in the Maintenance of Street Gutters During Weather Changes

In the case of storm sewers, it is important to monitor the level of rainwater in the downspouts, in order to be able to react in time and prevent water from

spilling onto the street and thus prevent endangering the safety of people in traffic. It often happens that drains get clogged, due to careless citizens who throw various forms of waste into them, as well as drain overflows due to huge amounts of rainfall.

In a situation where there is a large amount of precipitation, the city's waterworks, which may be responsible for the maintenance of the sewage network, may be in trouble, because they have no knowledge of which group of drains will fill up the fastest and spill onto the roadway. That is why it is difficult to prioritize the maintenance of those drains, and instead of preventive maintenance, the maintenance of the sewage network is carried out reactively.

4 Industry 4.0 Solutions in Overcoming Challenges in the Value Chain of Water Companies

A smart city is a vision that enables the integration of many different technological solutions and manages the most diverse city assets: local government information systems, schools, libraries, transportation systems, hospitals, power plants, law enforcement agencies and other services in that community (Musa, 2016). The goal is to provide citizens with a higher level of quality of life through the use of technology that increases the efficiency of services and meets their needs. In order for the aforementioned vision to be feasible, it presupposes the application of new generation technologies better known as Industry 4.0, which unite: the Internet of Things, cloud computing, cyber-physical systems, big data technologies, etc. which serve planning, construction, management, integrated industrialization, computerization, modernization and sustainable development of cities (Safiullin et al., 2019). With these technologies, a vision came to life.

Although water utilities have traditional IS in the form of business, geographic and technical, they have limited opportunities to overcome challenges in the value chain of primary activities. At the same time, it is a big problem if the aforementioned IS are not integrated, but act as isolated entities, which in many ways makes daily operational activities more difficult, and makes the challenges greater. As water pipes are the most important part of the city's infrastructure, it is assumed that some solutions offered by Industry 4.0 can help solve problems in their value chain. What is specific about these solutions is that they can either increase the efficiency of the company's existing business processes or make some business processes automated or semi-automated, which was not possible with earlier ICT solutions.

4.1 Industry 4.0 Solutions in Overcoming Contamination Problem

The quality of water is very important for citizens, and it needs to be continuously checked, whether it is raw water that is taken from the source or drinking water that is delivered to consumers.

Advances in sensor and wireless communication technologies make it possible to implement a solution to monitor water quality at sources. In his research, Paska states that such a solution requires a large number of sensors and that it is therefore important that the downward trend in the price of sensors continues (Paska, 2018). The implemented solution was implemented in Stockholm during 2017 and 2018, where the parameters: pH, temperature, conductivity, dissolved oxygen and redox potential were measured on Lake Melleren. The sensors communicate with the cloud-based Ericsson IoT platform over the LTE network. In the first phase of the research, the data collected from the sensors was unsatisfactory, because not much could be concluded about the contamination of the source. Therefore, it was decided to apply multivariate analysis and artificial intelligence in the next phase in order to provide a reliable solution for monitoring the quality of the raw water at the source.

The authors (AlMetwally et al., 2020) propose a low-cost water quality monitoring system, which allows for additional filtration. It uses sensors for temperature, pH, and turbidity, where if the water is not of satisfactory quality, it is directed to the filters and then to the distribution system. The sensors connect to an SBC, such as an Arduino or Raspberry Pi, and have the ability to send data to the Cloud.

Research results (Lakshmikantha et al., 2021) show that the water quality monitoring system consists of a number of sensors, the most important of which are: temperature, turbidity, pH, conductivity, humidity, and CO₂, which are connected to the controller. The controller is an Arduino uno ATMEGA328. Through the WiFi module, the controller sends data to the Cloud where processing takes place, and if something is not right, users are notified on their mobile phone or PC.

4.2 Industry 4.0 Solutions in Overcoming the Problem of Non-revenue Water

The problem of non-revenue water is extensive and here we will focus on the part related to leaks and failures in the water distribution network. Water utilities usually use sensors in a technical information system, implemented as a SCADA system. SCADA has very expensive sensors that connect to PLCs. Considering that water distribution networks are very long, the installation of SCADA sensors is unprofitable. There is room for relatively inexpensive IoT sensors that can be embedded and form a wireless sensor network. The problem of fault detection consists of two mutually related

problems, namely detection that should answer the question: Has a fault occurred? And localization: Where did the failure occur?

The paper presents the architecture, which consists of a wireless sensor network, where each sensor would be installed in the pipe of the distribution system (Difallah et al., 2013). The sensors measure two parameters: pressure and flow. All the nodes of that network address the local workstation, which processes the data, and at the same time forwards it to the central server, which stores the data in a string-based database. Both on the server, as well as on local stations, anomaly detection is performed by stream processing. As a detection algorithm, it uses LISA spatial statistics, extended by time parameters. The proposed solution enables anomaly detection locally and globally.

One of the problems in the detection of anomalies in infrastructure networks, such as the water distribution network, is the selection of the algorithm needed to recognize the anomaly. In extensive research, the authors provide an overview of a large number of algorithms that can be used (Chan et al., 2018). What is not stated is the fact that each of the presented algorithms requires a different architectural setup. Some solutions are on-premise, but can also be used on the cloud, while some solutions that require the processing of streams as one of the scenarios of BigData technologies, can be used exclusively on the cloud platform.

In the scenarios of anomaly detection on the water distribution network, there is a large number of variations in the proposed solutions at different levels of the software architecture. For example, the authors propose a system that includes the Internet of Things, which has audio sensors in it, where the use of AI algorithms such as neural networks, specifically convolutional neural networks, achieves detection (Rezwaniul Islam et al., 2023). The proposed solution also

shows the specific selection of the sensors themselves, the SBU and the required chipset.

4.3 Industry 4.0 Solutions in Overcoming the Problems of Accuracy and Frequency of Readings

As in many industries, of which electricity production and consumption stand out, smart meter technologies have revolutionized the process of reading and acquiring data. The progress from AMR to AMI technologies contributed a lot to this.

The authors (Joy Okoli & Kabaso, 2024) give an overview of the technologies used in the formation of a smart water grid. They indicate that there are a number

of different IoT solutions. LPWAN technologies, such as e.g. LoRaWAN and NB-IoT due to their ability to have a long communication range and low power consumption are proving to be very important in performing communication from the Edge layer to the central server. They differentiate three different architectural layers: the measurement layer, the communication layer and the communication layer. In the mentioned way, information about consumption reaches both the water company and the user himself, which ensures much greater trust compared to the previous manual readings of consumption and their recording in PDA devices.

In practice, pilot research involving IoT is also carried out, where pre-prepared modules are placed on top of the existing analogue metering infrastructure and thus enable remote consumption readings. These modules establish communication via LoRa or NB-IoT technologies. They usually contain a large number of alarms that allow them to be installed for many years, such as a magnet attack alarm, an alarm for disconnecting the module from an analogue water meter, an overconsumption alarm, a leak alarm, etc. The readings that arrive at the server are usually stored in a database that can support time series as well as the volume of data from multiple devices. Most often, with the use of ETL, that data is transferred to some other database that is related, from where the data is consumed by the WEB API and forwarded to different clients in JSON format. Web or mobile applications consume this data and display consumption data from the water meter. If there is a high speed of data arrival from many devices, it may happen that traditional technologies that work in on-premise mode are not sufficient, especially in the part where it is necessary to receive data from the Edge layer. Then it switches to cloud mode, which enables scalability and the use of technologies such as Apache Kafka, Amazon Kinesis, RabbitMQ, etc.

4.4 Industry 4.0 Solutions in Overcoming the Problem of the Impossibility of Determining Priorities in the Maintenance of Street Drains

By installing sensors in sewer drains at a certain height, it is possible to monitor how much water is inside the drain. After the water level exceeds a certain threshold, the sensor can notify the local gateway, which further forwards the information to the Cloud.

At an early stage, one such solution is offered by Fujitsu (Fujitsu, n.d.). It is a combination of IoT, Cloud, Web services based on the REST convention.

Implementing the proposed solutions that combine IoT, Cloud, Big Data and AI can help solve those business scenarios that are impossible to solve using traditional IS used in city waterworks, such as business (enterprise), geographic and technical information systems. In the case of contamination challenges, most practices of city waterworks are organized into manual

work, so a large number of samples are examined daily with various types of analysis. Industry 4.0 solutions enable a certain degree of automation of repetitive tasks and thus reduce the cost of manual work. With the challenge of non-revenue water, although water utilities have sensors in traditional IS (eg SCADA), these sensors are not suitable for embedding in the water distribution network, because they are not energy efficient and often require wired connections. In addition, the protocols implemented in PLCs are proprietary and it is very difficult to manage the maintenance of a large number of such organized sensor systems. Inexpensive sensors in IoT devices enable easy installation and maintenance, and at the same time do not require a wired connection. In addition, they use uniform protocols, which greatly facilitates the maintenance of the entire system. When a sensor does not work, it is replaced. In cases related to manual reading, the role of smart water meters is to reduce reading errors to a minimum. Compared to traditional technologies used in IS, the process of acquiring data on readings is significantly simpler and does not require manual entry by readers. All these facts are in favour of Industry 4.0 solutions, which will be more and more applied in city waterworks over time.

5 Conclusion

The research indicates that IoT, Cloud Computing, Big Data and AI technologies can significantly contribute to solving or reducing unwanted effects on the operation of city waterworks. Depending on the problem for which a software solution is applied, the software architecture can differ to a greater or lesser extent. What can be singled out as an invariable part of those architectures are the layers that are differentiated into: the sensing layer, local gateway layer, backend layer and frontend layer.

In the sensing layer, sensors acquire all relevant data such as: pressure, flow, water quality parameters, etc. In addition, for certain scenarios, it is possible to implement wireless sensor networks, through which data on a phenomenon can be collectively transmitted, especially where there are spatially distributed observation objects. The sensing layer passes its data to the local gateway layer.

The local gateway layer aims to enable data transfer to the backend layer. That is his primary task. Also, he can perform some additional activities that are important to be done as early as possible, which can be very significant in the case of water contamination problems, i.e. early detection of contamination is possible. Additional activities would include collecting and analyzing data from a specific group of sensors that would address that server. For the realization of this task, a suitable technology can be Fog Computing, which would collect data from local gateways and carry out their preprocessing due to the need to remove noise in the data, and then processing through which local anomalies can be detected. A local anomaly may or may not be based on AI concepts, and it largely

depends on the specific scenario. Depending on the amount of data that arrives and the time in which it arrives, Big Data frameworks such as e.g. Spark, are in the streaming scenario. In this sense, it is possible to define a time interval of observation, the so-called A window in which an anomaly detection algorithm is implemented, and if the data arriving from the sensor in that interval is processed by the algorithm and it is determined that an anomaly exists, it is possible to undertake all activities to mitigate its effect or to remove it entirely. In Spark, the mentioned algorithms can be programmed in Python, Scala, and Java. Also, other programming languages such as C# and .NET through certain libraries have the ability to work with this Big Data framework. Therefore, the layer of the local gateway can be viewed only as Edge Computing, but also as Edge Computing extended Fog Computing. The architectural solution largely depends on which problem from the value chain of water supply is being solved, as well as what the other limitations are: domain, technological, financial, legal, etc.

It is the backend layer that needs to accept data from the local gateway layer. Depending on the specific scenario, it is possible that the volume of data is large and therefore it is necessary to first store it in a broker (we mentioned some alternatives earlier), and then to process and store the data additionally. In this way, it is possible to gain an insight into each individual region but also to have an overall picture of the system, which is very important for the business operations of city waterworks, which are usually organized by region. In addition to the mentioned activities performed by the backend layer, it is necessary to enable an API that could forward data to all clients, regardless of whether they are desktop, web or mobile. For the aforementioned reasons, Web service technologies are used, most often based on the REST standard. Many different technologies, software frameworks and programming languages can be used on this layer. The most common case is that the choice of Cloud vendor Amazon, Azure or others will determine their choice.

The frontend layer shows the user data and problems that occur in the infrastructure of the city's water supply. This layer communicates with the BackEnd layer and consumes data. Usually, the mentioned interfaces should be organized in such a way as to enable the display of changes that are in realtime or close to real-time. That is why SPA frameworks are used in Web applications that enable this. They are mainly organized as JavaScript frameworks, but they can also use WebAssembly technologies, such as e.g. .NET Blazor.

What has been observed in many manuscripts is that the authors are focused on how existing problems in water supply companies can be solved by using smart solutions. What is much less talked about is how to integrate traditional IS: business, geographical and technical with new smart solutions, and this is very important, especially for those scenarios that require data exchange or the initiation of business processes through existing systems. If we have anomaly

detection, users would like to see perhaps some additional data on their interface about the place where the anomaly occurred, e.g. how old are the pipes, what is their diameter, what material are they made of, or who does the water meter read, and that can't be obtained unless integration with the traditional IS used in water companies is performed.

In addition, it should be borne in mind that many of these systems can be legacy, which can further complicate the problem of integrating traditional and smart solutions. Therefore, in the backend layer, it is necessary to carry out the adequate architectural design for all these systems to work in harmony as a single entity, i.e. from the outside they looked like a system of systems. This may include a hybrid cloud scenario where data exchange would be achieved about on-premise traditional systems and smart systems that are more cloud-oriented.

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Analysis of Security and Intelligence Data Obtained through OSINT Techniques Using the Apache Hadoop Big Data Platform

Instructions for Authors

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Abstract: Apache Hadoop is a platform for storing, processing, and analyzing large amounts of data. Some of the capabilities of this platform include data storage in HDFS (Hadoop Distributed File System) and the execution of complex HiveQL queries. In addition to Apache Hadoop, which is used in this paper for processing and analyzing the collected data, convolutional neural networks were also employed for image analysis. Data collection was carried out using various OSINT (Open-Source Intelligence) techniques, which involve locating, selecting, and gathering information from publicly available sources.

Keywords: Big Data, Apache Hadoop, OSINT

1 INTRODUCTION

The concept of a Smart City aims to improve the standards and quality of life through modern technologies, while also providing a higher level of security for citizens. All of this would not be possible without smart cameras and the application of artificial intelligence, machine learning, big data processing systems, and other modern technologies in use today.

Big data processing systems are now present almost everywhere, precisely because a large amount of heterogeneous data is generated daily, which cannot be processed by traditional systems. This paper will combine the Apache Hadoop platform for big data analysis, artificial intelligence, big data processing systems, and OSINT (Open Source Intelligence) techniques to demonstrate how the capabilities of smart cameras can be used to improve citizens' security.

The paper will present how, with the help of smart cameras and the application of artificial intelligence for real-time facial and object recognition, potential incidents can be detected and prevented. The recognized facial image will be compared using artificial intelligence techniques and OSINT with publicly available content on the internet to identify similarities. All internet content will be downloaded and stored in the big data processing system's storage, after which the data will be further analyzed.

2. APACHE HADOOP PLATFORM AND BIG DATA PROCESSING SYSTEMS

When we mention the term "big data," we most often associate it with analysis within the context of Apache Hadoop. Unlike traditional data storage and processing systems, Hadoop offers the ability to store and process heterogeneous data. For example, relational databases can store large amounts of data

and analyze it, but their main limitation is that they can only store one type of data. Hadoop allows us to store heterogeneous data such as: text files, photographs, videos, sensor data, etc. Big data is essentially defined by the three "Vs": Volume, Velocity, and Variety.

For data storage, Hadoop provides its distributed file system – Hadoop Distributed File System (HDFS). To run queries, it uses the HiveQL query language, which is quite similar to SQL. HBase is a distributed Hadoop database that runs on top of HDFS.

A major advantage of big data processing systems is realtime analytics, which provides the ability to analyze data in real time.

MapReduce is a programming model that allows for parallel processing of large amounts of data distributed across multiple computer nodes. The model consists of two main functions: "Map" and "Reduce." The Map function takes input data and divides it into smaller chunks, which are then distributed for processing across different nodes. The Reduce function aggregates the results from all the nodes to produce the final result. This approach enables efficient processing and analysis of vast amounts of data in distributed systems like Apache Hadoop.

3. OSINT AND ARTIFICIAL INTELLIGENCE

OSINT (Open Source Intelligence) refers to the process of collecting, analyzing, and interpreting information that is publicly available through open sources. The concept of OSINT is used in many fields such as journalism, security, and by professionals in various research areas on the internet. OSINT techniques are relatively new and have primarily developed with the growth of the internet and social media.

Publicly available sources refer to any information accessible to the general public. These do not necessarily have to be published on the internet; they

can include data published in newspapers, magazines, or on television. Public or open sources are data that can be found on: general internet searches, social media monitoring, website analysis, photo analysis, and other multimedia content, the use of public databases, and publicly available Web GIS.

Information that can be gathered through OSINT includes: personal data, geographical data, social data, business data, political data, technical data, cultural information, etc. The most common application of OSINT is in the military, security agencies, and journalism.

The artificial intelligence techniques used in this paper involve Convolutional Neural Networks (CNN) for facial and object recognition in images by analyzing their characteristic patterns. CNN is trained on large datasets, learning to recognize specific facial features, such as eyes, nose, mouth, and their relative positions. Once trained, the network can recognize the same faces in different photographs, even under varying lighting conditions, poses, or angles. Using the OpenCV library, which contains tools for detecting faces and objects, AI can quickly analyze images and identify objects such as cars, people, or weapons, as is the case in this study.

4. ANALYSIS OF DATA COLLECTED FROM CAMERAS IN A SMART CITY USING BIG DATA PROCESSING SYSTEMS, ARTIFICIAL INTELLIGENCE, AND OSINT

For the purposes of the research, a scenario was designed that represents a possible method for identifying a suspicious person in large gatherings in a smart city.

The scenario is as follows:

In a large crowd at Republic Square during a concert taking place there, an object detection system on camera footage sends an alert that a weapon has been detected in the possession of a person. The concert security notices the alert, and the goal is to identify the person as quickly as possible.

1. The security officer immediately reviews all available cameras. The camera search program, which has the ability to search both in real-time and retroactively, and which uses software to search for specific objects in the images, including weapons, sets the criteria for the search. The criteria are to separate a middle-aged man who is carrying a weapon as an object.



FIGURE 1.0: Camera review with search criteria before the search.

The program, with the help of smart cameras, almost in real time, separates a few photos that meet the criteria, on which the sought-after man can clearly be seen. However, the live camera feed shows that the last time the criteria were met was ten minutes ago, meaning that the sought-after person is currently not visible on any of the cameras.

FIGURE 1.1: Display of the person recognized by the system.

3. The search of existing data reveals that the system has not been able to find a match or identify the sought-after person in the current databases. Therefore, in this step, techniques for searching and comparing photos on the internet will be used. The goal now is to search the internet and social media to find a match for the person from the camera. We once again use the Python OpenCV library, which is now used for comparing the same facial images, and alongside it, we use OSINT, which helps us

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search available sources on the internet with predefined functions for optimal searching.

4. A match has been found, and through visual inspection, it can be confirmed that it is indeed the same person. An account was found on the social media platform Instagram, which contains multiple posts with photos featuring the sought-after person.

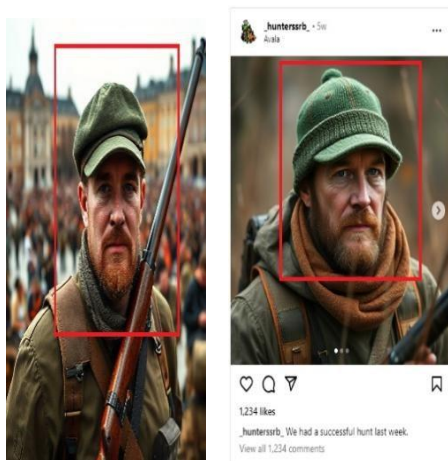


FIGURE 1.2: Display of the match between the search sample photo and the photo from the Instagram social media account.

5. It has been established that this is the profile of the hunting association _huntersrb_.
6. In this step, the entire list of accounts, as well as all photos from the account that follow the _huntersrb_ profile and all the accounts that _huntersrb_ follows, are downloaded. Specialized OSINT techniques are used to download the content from the Instagram social media platform.

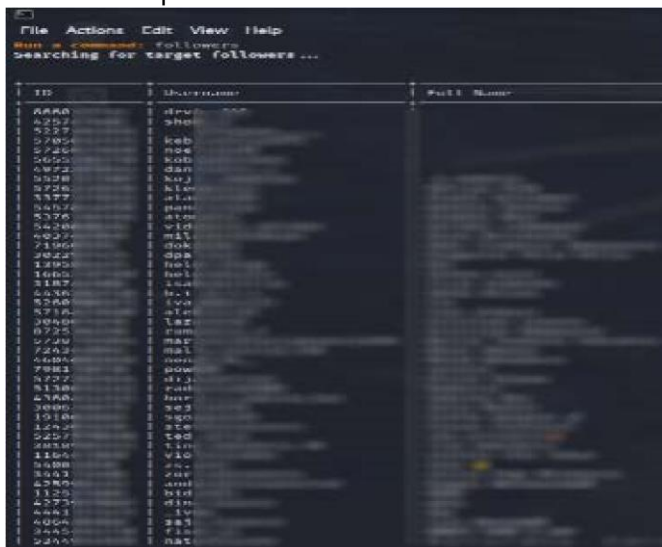


FIGURE 1.3: Display of the command for downloading the list of all followers of the profile.

7. The downloaded material is stored in the big data processing system's storage. A total of 1,221 photos, 213 videos, and 3,000 text files have been downloaded.
8. All photos from the _huntersrb_ profile that feature the person we are looking for are downloaded.
9. The downloaded photos from the _huntersrb_ profile are now compared using artificial intelligence techniques with the photos and

videos downloaded from the profiles that _huntersrb_ follows and those who follow him. The assumption is that the sought-after person will be identified in these images, as the likelihood of following a profile in which the person is tagged is high.

10. After the download, no match was found, so now all comments on the posts from the _huntersrb_ profile featuring the person to be identified are being downloaded.

FIGURE 1.4: Display of the command for downloading comments from the profile on the Instagram social media platform.

11. After the download, similar comments are separated using HiveQL queries in the big data processing systems. It is established that the word "president" is mentioned in almost all posts.
12. Now, using MapReduce code to search for similar words in all downloaded files, the mentioned word is searched for and counted.

FIGURE 1.5: Display of MapReduce code for searching similar words.

13. The assumption is that the person to be identified is the president of this hunting association, so a search is now conducted in the Agency for Business Registers to determine the name of the association's president and his identification number.

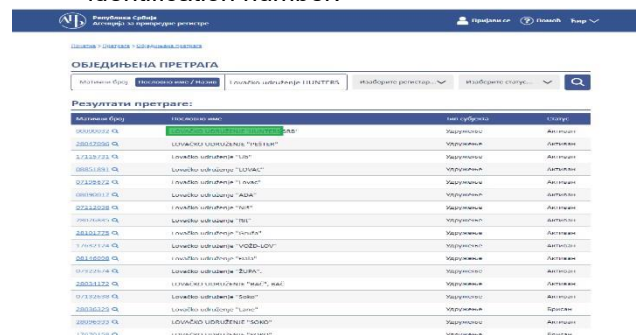


FIGURE 1.6: Display of the search in the Agency for Business Registers.

FIGURE 1.7: Display of representative data from the Agency for Business Registers.

14. The data obtained from the Agency for Business Registers, after further verification, confirmed that it is indeed the person that needed to be identified. Security personnel on the field, after receiving the information, can proceed with their work.

CONCLUSION

The goal of this paper was to demonstrate how a combination of artificial intelligence techniques for object detection, big data processing systems, OSINT, and Smart City technology can contribute to preventing security incidents at large gatherings in smart cities. The application is not limited to this specific case; this method can be applied at any time and can accelerate the process of identifying any individual whose face has been clearly captured by a smart camera. If the case from the example were resolved in a traditional manner, it would take much more time to identify the person seen at the gathering and subsequently carry out identification. However,

with the help of the aforementioned techniques for object detection in images, human face detection, and big data processing systems, identification is completed within minutes, almost in real time. Publicly available data on the internet significantly contribute to this problem-solving approach, as it is rare today to find a person whose photograph has not been uploaded somewhere online.

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Contemporary Machine Learning in Smart Cities: A Review of Quality, Measurability, Explainability, Privacy, and Security

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Abstract: This review paper examines current research on machine learning applications in smart cities, explicitly focusing on quality, measurability, explainability, privacy, and security. By synthesizing findings from recent studies, we uncover new trends, methods, and ways to measure performance that are key for developing and deploying these systems. We discuss how data privacy and system security challenges intertwine with the technical requirements of quality assurance and explainability, and we propose future research directions that could foster more reliable and accountable machine-learning solutions in urban environments. This review aims to provide researchers and practitioners with an overview of the current landscape, facilitating a multidisciplinary dialogue on enhancing trust and efficacy in smart city technologies. **Keywords:** artificial intelligence, internet of things, machine learning, smart building, smart city, smart energy, smart health, smart home, smart logistics, smart security, smart transport.

1 INTRODUCTION

A smart city represents a symbiosis of technology and people in an urban environment. With Inter of Things (IoT) on the rise, we see more and more applications of data analysis and informed decision-making. This is primarily enabled by a surge in number of various sensors available in the urban environments. Due to their rising numbers, we are getting a high quantity of data, which is ideal for informed decision-making. However, this high-volume influx and complexity of the data would be overwhelming for traditional pipelines to process. That is where artificial intelligence (AI), i.e., machine learning (ML), methods are introduced. Foremost, they enable automatic data analysis and learning of the trends in the data. Secondly, as computer methods, they can leverage high computing power to deliver the results quickly, even in real-time. And finally, they can learn complex trends in the data.

Smart city applications are already successfully implemented in various cities. For example, Midtown in Motion program in New York that improves traffic in real-time [1] and Virtual Singapore initiative that through virtual duplication of the city allows for various experiments and tests to be done virtually [2].

The smart city field of research is vast, and there are even comprehensive review papers on subfields. In this already well-established field, we aim to review

some of the latest research of ML applications in smart cities and see how they address the following five criteria: quality, measurability, explainability, privacy, security. For quality we focus on how the researchers quantify the quality of their proposed solution. For measurability we focus on the datasets, mainly how the quality of the solutions will translate to the real-world use-case. For explainability, we concentrate on the solution's ability to explain the reason for the given result to the end-user. For privacy we focus mainly on how the research addresses the privacy of people and how this data is prevented from exposure to malicious users. Finally, for security, we emphasize how the research addresses the security and integrity of the system itself against malicious activities. These five questions emerged as a necessary condition for the successful application of ML in smart cities. These issues do not concern only the researchers and industry professionals, but also other stakeholders, such as the policymakers, end-users, and others.

Although not exhaustive, this research aims to review current literature in terms of quality, measurability, explainability, privacy, and security. The review will yield the potential paths toward improvement of current and future initiatives in smart cities.

The structure of the rest of the paper is as follows. The second section shows a quick overview of machine learning methods and metrics presented in reviewed papers. The third section is dedicated to the overview of the research with focus on quality, measurability, explainability, privacy, and security. The last section

concludes our findings on recent ML applications in smart cities.

2 TECHNOLOGIES AND METRICS

The rapid advancement of AI and the widespread adoption of IoT solutions have driven the development of diverse computational strategies to address increasingly complex problems. At the core of AI lies ML[3], which encompasses classical algorithms such as k-nearest neighbors (k-NN), support vector machines (SVM), decision trees (DT), and Naïve Bayes (NB). These methods rely on pattern extraction from data to perform classification and regression tasks. A specialized subset of ML, deep learning (DL), employs multilayered artificial neural networks (ANNs) to automatically learn features from raw inputs. Prominent DL architectures include convolutional neural networks (CNNs) (e.g., VGG16, VGG19, MobileNet) for image analysis and long short-term memory (LSTM) networks for sequential data processing. Hybrid models, such as CNNLSTM, integrate spatial and temporal learning capabilities, further expanding the applicability of DL in various domains. Additionally, graph neural networks (GNNs) have emerged as powerful tools for processing structured data, such as social networks, molecular structures, and knowledge graphs.

Concurrently, ensemble learning techniques (e.g., random forest (RF), gradient boosting, XGBoost [4], LightGBM[5]) and optimization algorithms, including genetic algorithms (GA) and particle swarm optimization (PSO), enhance predictive accuracy and facilitate hyperparameter tuning. Reinforcement learning (RL) methodologies, such as Deep Q-Networks, Multi-Agent Actor-Critic, and Proximal Policy Optimization, enable agents to make sequential decisions by continuously learning from environmental feedback. Furthermore, federated reinforcement learning (FRL) distributes the learning process across multiple agents while preserving data privacy. Neuro-symbolic AI, which combines neural learning with symbolic reasoning, is emerging as a promising approach for bridging data-driven and rule-based AI methodologies. Additionally, self-supervised learning and contrastive learning have revolutionized AI by reducing dependency on labeled data, improving feature representations across diverse domains. Beyond model-centric approaches, edge computing reduces latency and bandwidth requirements by shifting computational processes closer to data sources—an essential consideration for IoT networks. Similarly, federated learning enables decentralized model training across multiple devices, improving both privacy and scalability. Neuromorphic computing, inspired by biological neural networks, promises ultra-efficient AI implementations through event-driven processing and hardware acceleration. In specialized applications, methodologies such as two-stage demand forecasting, mixed-integer linear programming, and fuzzy logic are employed to solve

intricate optimization problems. Additionally, data augmentation techniques, including Stable Diffusion for synthetic image generation, enhance model robustness. Advanced heuristics (e.g., Harris-hawk optimization [6] or the walrus optimization algorithm), Markov decision processes, and explainable AI (XAI) techniques further enrich the AI toolkit. Emerging paradigms, such as digital twin frameworks, frequently utilized in 6G network optimization, and distributed fog (DF) computing, demonstrate the seamless integration of AI-driven solutions into broader computational ecosystems. The integration of quantum machine learning (QML) introduces quantum-enhanced optimization and classification capabilities, expanding AI's reach into domains such as cryptography, materials science, and drug discovery. Simulation of urban technology (SUMO) plays a crucial role in modeling and optimizing smart city infrastructures, with platforms like CityFlow enabling large-scale traffic simulations and COSMOS testbed providing a real-world environment for testing AI-driven networking and urban computing solutions. Ensuring model explainability is a crucial challenge; techniques such as Grad-CAM [7], LIME [8], and SHAP [9] provide insights into model decision-making processes, while privacy-by-design principles and biometric-based cryptography safeguard sensitive information. These approaches collectively ensure that AI remains robust, interpretable, and efficient across a wide range of real-world applications. Evaluating AI model performance requires context-dependent metrics. In classification tasks, metrics such as accuracy, precision, recall (sensitivity), specificity, F1-score (F1), Matthews correlation coefficient (MCC), and area under the ROC curve (AUC-ROC) capture various aspects of predictive performance. Accuracy quantifies overall correctness, while precision measures the proportion of true positives among predicted positives. Recall (sensitivity) assesses the proportion of actual positives correctly identified, and specificity evaluates the proportion of actual negatives correctly classified. The F1-score provides a harmonic mean between precision and recall, whereas AUC-ROC quantifies the trade-off between the true positive rate (TPR) and false positive rate (FPR) across different classification thresholds. Additionally, metrics such as true negative rate (TNR), miss rate, false alarm rate (FAR), detection rate (DR), and average classification accuracy (ACA) offer further insights into classification performance. Additionally, MCC is also used to better quantify the real accuracy of the model, like F1-score, mainly used on binary classification tasks. Model calibration techniques, such as Brier score and expected calibration error (ECE), ensure reliable probability estimates in probabilistic classifiers. For regression tasks, key evaluation metrics include root mean square error (RMSE), normalized RMSE (NRMSE), mean absolute error (MAE), symmetric mean absolute percentage error (SMAPE), and coefficient of determination (R^2). RMSE emphasizes larger deviations in predictions, while MAE provides an average measure of absolute prediction

error. SMAPE normalizes percentage errors, and R^2 represents the proportion of variance explained by the model. Beyond classification and regression, domain-specific and system-level performance indicators—such as average waiting time, average speed, traffic conflict rate, energy efficiency, carbon emissions, computing time, stock-keeping-oriented prediction error costs, device density, packet deadline adherence, latency, buffer size, wireless communication bandwidth, power consumption, event detection time, and processing throughput (e.g., FPS, CPU/GPU utilization)—ensure a comprehensive evaluation framework. Robustness metrics, including adversarial robustness scores, model uncertainty quantification (e.g., entropy-based measures), and fairness metrics such as demographic parity and equalized odds, contribute to assessing AI reliability and ethical compliance. These metrics account for real-world constraints, resource efficiency, and the broader operational impact of AI-based systems, ensuring sustainable and equitable deployment across industries.

3 SMART CITY

As is already mentioned, smart city is a vast field. In this review we will analyze current research from the following subfields in order: smart mobility, smart healthcare, smart energy, smart industry, smart living, smart safety and smart security.

3.1 Smart Mobility

Smart mobility is a key part of smart cities. It helps make transportation more efficient, safer, and more sustainable. Papers considered in this review include traffic signal management based on congestion, connected autonomous vehicles, and their coordination and management of public transportation schedules and routes. Most of the proposed methods use some form of Deep RL (DRL) such as Deep Q Network [10–14], Multi-Agent Actor-Critic [15] or Proximal Policy Optimization [16]. In addition to DRL, some methods incorporated fuzzy logic [11], Mixed-Integer Linear programming [12], or Markov Decision Process [16] for additional optimization

or modeling. In other papers, MLP was combined with Convolutional layers [17] or LSTM [18].

3.1.1 Quality

The quality aspect is well explained. Most papers include some form of simulation. Therefore, the mentioned metrics are mostly empirical and are connected to sustainability and efficiency. The most frequent metric is average waiting time [10,11,13,14,16]. In [11], the average waiting time has three forms that are considered: average waiting time, average waiting time for a left turn, and average waiting time per car. Other mentioned metrics are energy efficiency [13,15,16], carbon emission [10,15] average speed [14] and traffic conflicts [10]. Papers that included only computational simulation used F1 [17,18] and computing time [12].

Additionally, the proposed methods were compared with other competent methods that the authors chose, including other forms of machine learning.

3.1.2 Measurability

Proposed methods are mostly evaluated through simulations and include multiple scenarios. The simulation frameworks used for simulations are Simulation of Urban Mobility [10,11,13,16], City Flow [14] and COSMOS testbed [19]. These frameworks supported the usage of modeling scenarios from the real world. In [12], authors chose computer simulation for evaluation, whereas a simulation was not conducted at all in [18]. The setup of the simulations mostly included datasets from real-world cities [10,11,13,14,18,19]. In [17], the authors tested cyber-attack detection using a CarHacking dataset containing data on real cyber-attacks. In [12], authors used real-world and generated datasets to broaden their simulation scenarios.

3.1.3 Explainability

The papers considered have used some form of DRL. Since DRL involves neural networks, its models are seen as black boxes. Authors mainly focused on testing their proposed methods without paying much attention to explainability. However, the ones that did use SHAP to find the correlation between decisions and input data values [14,16,17]. Authors of [14] observed how the number of vehicles in different lanes influences the next state of signal control. In [16], the authors showed how modeled factors affect the braking and acceleration of connected autonomous vehicles.

3.1.4 Privacy and Security

Privacy and security are considered as important in smart mobility as in other fields. However, not many practical implementations were mentioned. In [19], the authors designed and tested intelligent intersection nodes using a COSMOS testbed, which includes cameras for object detection. They blurred the faces of passengers and license plates.

In [17], authors proposed an explainable framework for detecting cyber-attacks in connected autonomous vehicles. The framework is designed to monitor vehicle networks and detect anomalies in behavior. The authors of [20] have theoretically proposed a four-layer framework for detecting abnormalities in connected autonomous vehicle networks. The detection of cyber-attacks is based on changes in the energy that IoT sensors produce. For encryption, asymmetric methods like DSA, RSA, and ECDSA are considered.

3.2 Smart Healthcare

Smart healthcare leverages advanced technologies, such as AI, IoT, big data analytics, and cloud computing, to enhance the quality, efficiency, and accessibility of medical services. It addresses challenges like overwhelming data from electronic health records (EHRs), medical imaging, and wearable devices by using AI and ML to uncover hidden patterns and enable early intervention for chronic conditions. Additionally, smart healthcare bridges the gap in medical service access through remote monitoring, telemedicine, and AI-driven decision support, ensuring timely care regardless of location. This approach improves individual patient outcomes and can revolutionize public health by enhancing disease tracking, outbreak prediction, and resource allocation during crises.

3.2.1 Quality

AI, ML, and DL are being extensively applied in the healthcare field for disease diagnosis, patient monitoring, and disease imaging [21–23]. The work in [24] tackled the challenge of limited COVID-19 X-ray datasets by aggregating multiple sources and applying transfer learning with CNN architectures (VGG16, VGG19, MobileNet). VGG19 achieved the best performance with 96.97% accuracy, 99% recall, and 100% F1score and precision. Authors in [25] used ML to predict type 2 diabetes and prediabetes risk in middle-aged individuals, assessing model performance with AUC-ROC and precision. The research in [26] utilized a decision tree classifier model with RMSE as the evaluation metric in patient monitoring. In contrast, an IoMT-enabled system for eldercare [27] achieved 93.6% training accuracy and 91.8% validation accuracy, with sensitivity, specificity, and precision being other metrics used in its evaluation. Medical image tasks, for example, the work in [28], developed deep learning models in the

detection of brain tumors through MRI, utilizing accuracy, precision, recall, FPR, and TNR for the improvement of classification reliability.

3.2.2 Measurability

In disease diagnosis, the work in [24] validated their model using cross-validation, reducing bias and confirming generalizability. They compared VGG16, VGG19, and

MobileNet to ensure the best model was not arbitrarily chosen. Similarly, authors in [25] used cross-validation and grid search, further validating their model on real-world data from the Stockholm Diabetes Preventive Program, which included over 8,000 participants, ensuring its practical applicability.

In patient monitoring, the work in [26] used RMSE to quantify prediction accuracy and tested multiple models for robustness. They benchmarked predictions against real-world EHRs to validate their decision tree-based model. The research proposed in [27] tested multiple ML techniques (SVM, KNN, Decision Tree, ANN), with ANN performing best. Their validation included experiments across diverse datasets and benchmarking against existing studies to confirm superior performance.

For medical imaging, the work in [28] validated their deep CNN models for brain tumor detection by comparing results with previous studies and testing across two distinct MRI datasets. This approach ensured generalizability and reduced overfitting risks.

3.2.3 Explainability

Explainability in AI-driven healthcare is crucial due to its direct impact on patient outcomes, as errors can lead to severe medical consequences. Initially, AI models prioritized predictive accuracy, often relying on deep learning techniques with limited transparency. However, recent advancements have emphasized explainability to ensure model interpretability, allowing healthcare professionals to validate AI-generated insights and reduce risks. This growing importance is evident in Figure 1, which illustrates the increasing number of PubMed

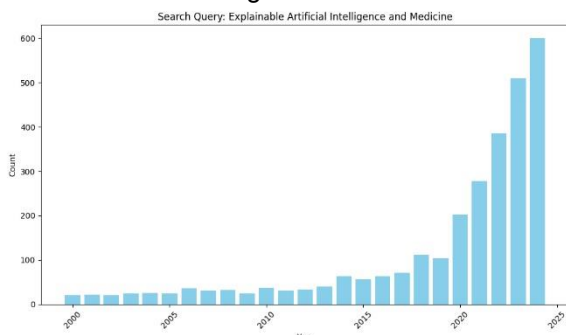


Figure 20 Number of papers on XAI in medicine over years search results for "explainable AI and medicine"

over the years, highlighting the rising interest in transparent AI models in healthcare.

The paper [29] reviewed the shift from black-box models to

XAI in healthcare, highlighting techniques such as LIME and SHAP. They discussed toolkits like AI Explainability 360 and Alibi, which support practical XAI applications, and presented case studies involving classification models, deep learning explainability, and an early warning score system (XAI-EWS).

The work in [24] integrated CNNs with Grad-CAM [7] to interpret COVID-19 predictions from chest X-rays, generating heatmaps that identified critical lung regions, thereby enhancing radiologists' trust in model decisions. Similarly, in [25] employed SHAP to analyze diabetes risk based on electronic health records, identifying BMI and glucose levels as key predictive factors.

Authors in [30] proposed "HealthXAI", an XAI framework for early detection of cognitive decline using smart home sensor data. Their system combined collaborative data mining with XAI to detect behavioral and mobility anomalies associated with cognitive dysfunction. A key feature was its ability to generate natural language explanations via decision tree models, improving clinician interpretability. Validated on real-world data from 192 participants, the model demonstrated substantial predictive accuracy and scalability, offering a valuable tool for early diagnosis and intervention.

3.2.4 Privacy and Security

The increasing adoption of IoMT and edge computing enhances healthcare efficiency and exposes it to rising cybersecurity threats. The 2025 Cybersecurity Report by Check Point highlights a 47% increase in weekly attacks on healthcare organizations in 2024, making it the second most targeted industry. Groups like ALPHV exploit system vulnerabilities, as seen in the Change Healthcare attack, which disrupted hospital operations and forced ransom payments [31].

The authors in [32] analyzed privacy-preserving technologies, emphasizing cryptography, access control, anonymization, and blockchain. They highlighted regulatory gaps and proposed a privacy-by-design approach for integrating security. The work in [33] examined edge computing vulnerabilities, recommending blockchain and attribute-based encryption to protect patient data while advocating for federated learning to enhance security in decentralized systems.

The paper [34] explored security challenges in Healthcare IoT, particularly in remote patient monitoring. Their study stressed the risks of cyberattacks on interconnected medical devices, including infusion pumps and pacemakers, and emphasized strong encryption, blockchain, and biometric-based cryptography as key solutions.

Federated learning was highlighted as a method to preserve data privacy while training AI models, ensuring compliance with HIPAA and privacy-bydesign principles.

3.3 Smart Energy

Smart energy field aims to optimize energy management so that overall production and energy consumption lowers, possibly cutting the current cost [35]. Since energy is the foundation of urban areas, efficient and sustainable energy system is the prerequisite for future growth and progress of urban development.

3.3.1 Quality

Reviewed papers show models ranging from CNN-LSTM to LGBM and KNN. A key element that needs to be present in all of them is evaluating the quality of their approach.

A team [36] verified the quality of their approach by implementing their model in a number of cities worldwide, thus proving its effectiveness. However, despite the effectiveness of this approach, it is not always practical, and most researchers opt for some sort of metric.

In the case of [37], three proposed models used deep ANNS, CART DTs, and RF machine learning methods. They evaluated performance using NRMSE and SMAPE metrics to determine the best model.

In [38], researchers proved that enough energy is produced by solely using sunlight, even on days with very little to no sunlight. The usage of LGBM and KNN was proposed. By utilizing R^2 , RMSE, and MAE, they validated the accuracy of their models. The metrics' values were presented clearly and organized, as well as training time and memory usage. In addition, they included the advantages and disadvantages of using suggested methods.

Spatiotemporal dependencies in energy management cannot be overlooked. Considering how they affect energy production and consumption, a model using CNN-LSTM architecture was recommended in [39]. MAE and R^2 were used to evaluate the performance of the specified model.

Some models more precisely described the security aspect of energy management in smart cities. F1 score was used in most of them. Aside from it, in [40], they used FAR, precision, DR, accuracy, and recall. In [41], aside from the F1 score, accuracy, precision, recall, and AUC score were used to determine the accuracy of their model.

Authors in [35] decided to compare their results with those provided by methods already in action. It was established that energy consumption could be lowered by between 24% and 32%, while the cost of current could be lowered by 18.6% to 20.6%.

3.3.2 Measurability

Many papers use data collected from real-world situations to train models tested through various simulations. In the case of [36], sensors were deployed in various locations across the city to represent the energy required for the functioning of different areas. The work in [37] used data provided by the Croatian energy management information system. As mentioned, the authors of [38] considered using sunlight as their primary energy source. Thanks to the data used by the microgrid system from Thailand, simulations could be done on the proposed model. The research in [39] focused on getting data from cities with different climatic conditions, so they picked Mumbai, Delhi, Bengaluru, Chennai, and Kolkata in India, representing four different climate areas.

Different approaches were taken to this matter from the security aspect. The work in [40] relied on using an already created physical system to run simulations in Matlab. The paper also gave an insight into what a cyber-attack would look like, with small but notable differences in voltage. It also includes the time necessary to resolve the cyber-attack.

In the case of [41], Kaggle provided the data for the model. It consisted of around 3000 instances separated into 12 classes. The model proved to measure the correct values by correctly predicting classes for all of the instances.

Sometimes, the explicit explanation of where the data is coming from or how measurability is proven is not detailed, like in the cases of [42] with a CNN model or [35], where they predicted the outdoor temperature and used PV-generated values for their models, which were later used for various simulations.

3.3.3 Explainability

Every resident utilizes AI systems for energy management in smart cities. The system must be explainable to ensure they understand why a specific decision was made. Unfortunately, not all models can be that easily explained, at least not without explaining the algorithm behind it. This was the case in most of the papers mentioned above. One of the exceptions was [40]. They used diagrams, similar to simulations, to explain the model's decision-making process. By detecting small oscillations in voltage or current, both the system and humans can tell when a cyber-attack is occurring. In the case of communication via a wireless connection, no explanation details were provided.

3.3.4 Privacy and Security

No matter how well a system performs, its security is paramount. An insecure system poses a potential threat to human lives and could result in

losses of several million euros. The privacy and security aspect is marked as essential to every system in all papers. Addressing these issues strengthens people's trust. Some proposed two identification intrusion detection and encryption measures and security layers that provide guarded system communications [43].

Others proposed the usage of a DF network, based on FFT and DL, for the detection of cyber-attacks. Data shared amongst agents of production units and load is analyzed using FFT, which extracts coefficients and provides them as input indices to the DL model responsible for cyber-attack detection. Data shared via wireless communication, the amount of current and voltage that agents measured, and reference signals of controllers are the monitored parameters [40].

Hacking into a global server (GS) represents a significant problem for all local building energy management systems (LBEMS) connected to it. A selective parameter method is used in the federated reinforcement learning (FRL) training process of heating, ventilation, and air conditioning (HVAC) agents to prevent this. By applying this method, each agent chooses a random part of its local model and delivers it to GS, ensuring that hackers cannot retrieve important information, such as private energy data of buildings [35].

The team behind [41] described their model thoroughly, backing everything up with comprehensive mathematical arguments. SSAE classification is used for detecting even the smallest cyberattacks and real-time intrusion detection. WOA improves hyperparameters.

3.4 Smart Industry

This section covers Smart industry applications, focusing on product defect detection, worker safety compliance, and demand forecasting tasks. Research in this category relies heavily on classification models and occasionally employs regression approaches—particularly in demand forecasting [44]. While some studies provide broad comparisons of diverse methods [45], many concentrate on refining a single proposed solution [44,46].

3.4.1 Quality

Our literature review revealed that many studies primarily focused on classification [44–46]. This is predominantly due to the nature of the data, which is often categorical and requires classification to make sense of it. These include the classification of defective products and worker safety compliance. Neural networks dominate the classification tasks, while the regression task, particularly in demand forecasting, follows a two-stage (dual) approach. In

this approach, a classification model first predicts whether the demand is zero or non-zero. If non-zero, a subsequent regression model estimates the precise demand quantity [44].

Regarding performance metrics for classification tasks, the most commonly reported metrics include accuracy, precision, recall, F1 score, specificity, and AUC [44–46]. These metrics are used to evaluate the models' performance and compare different models.

Precision and recall are both essential because their balance is vital in situations where the consequences of misclassifications—either overlooking a risk or raising an unnecessary alert—can be substantial. In these cases, the F1 Score provides a unified measure when both metrics require equal weight. Specificity is crucial when accurately identifying negative instances is imperative, and the AUC offers broader insights into a model's overall discrimination ability under varying thresholds.

Demand forecasting [44] represents the sole regression application in the reviewed studies. The authors argue that Stock-keeping-oriented Prediction Error Costs are particularly suitable for this task because they capture the economic impact of forecasting errors on inventory management.

3.4.2 Measurability

Data used to train models within the smart industry consisted of labeled images and time series data, depending on the task. The labeled images were used for classification tasks, such as worker safety compliance [46], while time series data was used for demand forecasting [44]. The data was collected from real-world scenarios, such as steel manufacturing facilities and customer sales data. The image data was then preprocessed and augmented to increase the dataset size and variability. Data augmentation techniques included horizontal flipping, rotation, and image lightness and saturation modifications. In addition, synthetic data was generated via stable diffusion to diversify the training samples further[46].

The studies prevalently used k-fold cross-validation, with k ranging from 5 to 10 [44,46]. This technique was used to evaluate the model's performance and generalization ability. The data was split into training and validation sets, with the validation set used to tune the model's hyperparameters.

Authors of the [45] engaged in hyperparameter tuning to optimize the model's performance. They leveraged Genetic Algorithm (GA) to find the best hyperparameters for their model. This approach allowed them to find the optimal set of hyperparameters that maximized the model's performance.

3.4.3 Explainability

Concerning the explainability of the models, the authors of [44] propose the use of XAI techniques to interpret the model's predictions. They argue that the use of XAI techniques can provide insights into the model's decision-making process but must be used with caution due to the potential sensitivity of the data. The demand forecasting model explains its predictions within their proposed solution by highlighting the most influential features and their values. This lets the user understand the factors contributing to the model's predictions.

The authors of [47] propose a cognitive approach to model training to mimic human decision-making processes. This design, they argue, can offer enhanced interpretability by aligning the model's decision logic more closely with human reasoning.

3.4.4 Privacy and Security

To the best of our knowledge, no study explicitly addressed privacy concerns within the smart industry. Most regulations and guidelines—such as GDPR and ePrivacy—are mentioned in the context of data collection and processing.

Security

Regarding security, none of the reviewed works explicitly delve into protective measures for smart industry applications. This highlights a notable gap, especially given the potential risks of cyber threats in networked industrial environments. However, the authors of [47] mention that the final judgment should be left to the human operator when dealing with decision-making models in worker safety compliance. This is due to the potential risks associated with fully automated decision-making systems, which could lead to catastrophic consequences in safety-critical environments.

3.5 Smart Living

This section covers Smart living applications, encompassing homes, education, and tourism. Research in this category spans from predicting customer socio-demographic characteristics[48] to assisting teachers in evaluating student performance[49]. Neural networks also dominate this area, with a few exceptions where other models are used, such as multinomial Naive Bayes [50]. In contrast to the smart industry, the smart living domain employs models such as LLMs.

3.5.1 Quality

In the reviewed literature, performance is predominantly quantified using classification metrics such as accuracy, precision, recall, and F1-score [50–52]. In the work focusing on customer social-

demographic identification via smart meter data [48], the authors additionally report F1-macro and ACA to compare their channel attention architecture against other machine learning methods. Similarly, gesture recognition in smart homes [51] and sentiment analysis in tourism [50] report accuracy, precision, recall, and F1-score as core evaluation metrics.

The work on digital twins for 6G network optimization [53] further supplements accuracy with domain-specific measures, including device density, packet deadlines, latency, and buffer size, thereby capturing the nature of network performance.

In multi-stage problem formulations, a single metric cannot fully capture overall system performance. For instance, classification accuracy was employed as the principal performance measure in hyperparameter optimization for federated learning in online exam monitoring [52]. Meanwhile, hyperparameters, such as learning rate and number of epochs, were determined via an evolutionary approach combining PSO and GA.

The study on leveraging large language models for evaluating coloring activities [49] also measures performance by accuracy.

The study on prompt engineering for knowledge creation [54] assesses performance by comparing the depth and clarity of LLM-generated responses with original student discourse. The paper's findings emphasize improvements in response quality and depth when using Chain-of-Thought prompting for knowledge creation; however, they do not provide clear numerical measures of performance.

3.5.2 Measurability

The measurability of models performing tasks in smart living is primarily based on the data type and the nature of the task. For instance, in [48], the authors utilize time series data derived from smart meter readings across Irish households and businesses. The dataset is partitioned into training, validation, and testing subsets, ensuring robust performance evaluation and generalization analysis.

In the context of gesture recognition in smart homes [51], the authors accompanied classification metrics with systemlevel measures such as wireless communication bandwidth, power consumption, event detection time, and processing throughput (measured in frames per second as well as CPU/GPU utilization).

The sentiment analysis study [50] employs k-fold crossvalidation (with a k value set to 10) to mitigate overfitting and ensure the reliability of results when analyzing YouTube comment data.

Additionally, the digital twin framework for 6G networks [53] quantifies operational parameters—such as latency and buffer size—using defined optimization formulas, bridging the gap between abstract model accuracy and real-world network performance.

Regarding the hyperparameter optimization for online exam monitoring [52], the authors conducted experiments with varying iteration counts. They examined the stability and convergence of the evolutionary search process, therefore providing quantitative evidence of the efficacy of their hybrid GA-PSO strategy.

Similarly, the study on LLM-based evaluation of coloring activities [49] introduces a custom dataset comprising 14 distinct problems that test both logical and spatial reasoning, with supplementary materials provided through a publicly accessible repository.

The study on prompt engineering for knowledge creation [54] ensures measurability by analyzing 721 discourse turns, with 272 complete question–answer pairs serving as the dataset to compare original student responses against LLM outputs.

3.5.3 Explainability

Explainability remains a critical concern. This is especially true in applications where model decision interpretability affects end-user trust and operational transparency. In [48], channel attention mechanisms are introduced within a fully convolutional network. This modification improves classification performance and enhances interpretability by highlighting relevant input time series data features. Although the approach is not entirely transparent, it offers insights into feature prioritization. These insights help in understanding the socio-demographic inference process.

For online exam monitoring [52], the authors note that using PSO and GA for hyperparameter tuning is less explainable due to the "black-box" nature of the evolutionary process. They partially mitigate this drawback by examining the model's sensitivity to specific hyperparameters. In addition, chain-of-thought (CoT) prompting is used in educational support [54] and logical task grading [49] to reveal the internal reasoning process of deep neural networks. Although still under development, this technique represents a promising direction for enhancing the transparency of complex model predictions.

3.5.4 Privacy and Security

Privacy considerations are notably sparse across the reviewed studies. The gesture recognition work [51] implicitly addresses privacy by advocating for on-device processing, thereby reducing the exposure of raw sensor data over networks. In the federated learning framework for online exam monitoring [52], data localization is designed to preserve privacy by keeping sensitive student data on local devices. Despite these measures, explicit privacy-preserving techniques are not directly addressed, suggesting a potential area for future enhancement.

The reviewed studies address security minimally. None of the contributions explicitly develop security measures, even in cases where system integrity and

safe operation (such as in 6G network optimization [53]) are of great importance. In domains like smart home gesture recognition or smart meter analysis, the emphasis remains on performance and accuracy rather than defending against potential cyber threats. This highlights an opportunity for future work to integrate security frameworks into smart system applications.

3.6 Smart Safety

Public safety plays a crucial role in ensuring a better quality of life for citizens. As smart cities integrate IoT, AI, and big data analysis, there is room for improvement in monitoring, predicting, and mitigating risks to public safety. These technologies enable real-time surveillance and rapid response to emergencies, allowing for effective management of a wide variety of incidents, from criminal activities to natural disasters.

The tasks were mainly classification-based, and traditional methods such as K-NN, DT, and SVN were applied. Of the modern methods, CNNs and LSTMs were employed. There were also hybrid methods that combined two different methods for greater performance.

3.6.1 Quality

In safety applications, the task is to identify or predict a state that threatens safety. In other words, this task is a classification task. As such, aside from simple accuracy, additional metrics are used. To better depict performances on disbalanced datasets F1 [55–62] and MCC [57,61]. Aside from them, to better understand the shortcomings of the trained model, along with the aforementioned metrics, some papers also produce various metrics from the confusion matrix, such as precision and recall (i.e. sensitivity) [55,57,59–62]. Some papers give additional metrics from the confusion matrix such as [57,62]. The best option is when the paper shows the confusion matrix [61,63].

Among the usual, there are also ROC and AUC [55,60]. Others are OOB [63], Kappa [59], paired t-test and Taylor diagram [64].

In a rare case of a regression task, paper [64] uses metrics R^2 , RMSE, MSE, and MAE to display the accuracy of the air quality index prediction. In contrast, the same metrics are used by [65] to predict microbial concentration in water. Another regression task example is in [66], where authors predict pedestrian movement and use Displacement Error and Final Displacement Error metrics.

Apart from metrics that describe the accuracy of the model in various ways, sometimes the energy and time performances of the methods are constrained. These metrics are reported on a per-instance-

classification basis. In papers [58,61,64], time per classification is introduced.

3.6.2 Measurability

For safety, there is a good trend toward using real-world data. All the papers on safety report real-world datasets; however, open access to the datasets still remains a topic that can be improved upon.

Directly openly available datasets, e.g., from Kaggle, Youtube or other sources, use papers [55–57,60,62,63].

In the paper [55], it states that the data will be made available upon request.

In the specific case of classifying several leaks in a pipe in [61], in the situation of missing real-world data, a dataset from a controlled real-life experiment was made, which is very close to a real-life scenario. Similar work was done in [65] for microbial concentration measurements.

Others do not state whether the dataset will be made available.

3.6.3 Explainability

For papers that use DT and derivative models, explainability is supported to a certain degree through the method itself [55,60]. In paper [55], explainability is additionally addressed through the gini index. In paper [65], SHAP is used to acquire explanations as to why the water is not drinkable.

Exceptionally, paper [56] uses a novel approach to explainability with the support of LLM to generate an explanation for the decision about the near-miss classification in traffic.

3.6.4 Privacy and Security

Privacy and security are usually not considered. Most information is mentioned in papers such as [57]. In some cases, this is not a problem if the data does not have privacy-sensitive data [55,58,60,61,64,65]. However, for the rest, this could be improved upon.

3.7 Smart Security

Securing IoT-based smart city infrastructures has emerged as a central research focus, with most work concentrating on detecting and mitigating cyberattacks, primarily DDoS. The application of various ML algorithms, including SVM, RF, KNN, NB, DT, GRB, XGBoost, ANN, CNN, LSTM, Autoencoder Classifier, QSVM, RBN, and ADA Boost, has proven to be highly effective in classifying incoming network traffic as benign or malicious. These studies report high overall detection accuracy and substantial reductions in false positives, instilling confidence in the progress of IoT security [67]. Some solutions extend beyond DDoS, targeting additional threats

such as port mapping, brute-force attacks, MITM, malware, false data injection, buffer overflow, zero-day attacks, and SSH password guessing [68,69].

3.7.1 Quality

A recurring goal across these security solutions is achieving high detection accuracy with minimal latency. Papers commonly report performance metrics such as accuracy, recall, precision, F1, FPR, TPR, and computation time. Notably, XGBoost achieved 99.9% accuracy with an FPR of 0.06 [70], while QSVM reported accuracy rates between 99.1% and 99.4% [71].

3.7.2 Measurability

Most approaches are validated against established or publicly available datasets to confirm real-world applicability. Performance metrics like confusion matrices are frequently presented alongside comparative analyses with other methods. Where advanced paradigms are introduced, researchers measure reductions in computational overhead relative to classical baselines [71]. In honeypot-driven studies, comprehensive log data is collected to demonstrate the system's capacity to detect DDoS and secondary intrusion attempts (e.g., SSH password guessing) [70,72].

3.7.3 Explainability

While many studies provide mathematical explanations of ML algorithms, most solutions operate as black-box systems from an end user's perspective. Even when theoretical steps are detailed, non-technical users often find the outcomes opaque [67,68].

3.7.4 Privacy and Security

Privacy preservation is generally considered a secondary objective, with only a limited number of papers explicitly addressing it. One study anonymizes IP addresses at the data collection stage [67]. Another advocate for federated learning is ensuring that raw data remains at local sites while only aggregated parameters are transmitted to a central server, minimizing exposure risks [73].

On the question of security, several frameworks propose comprehensive strategies that go beyond detection accuracy and computational metrics. These strategies, such as specialized feature extraction pipelines that capture critical aspects of network traffic and the storage of metadata in a blockchain to ensure tamper resistance and trustworthy intrusion detection [74], instill confidence in the future of IoT security. Honeypot-driven approaches complement these strategies by analyzing large volumes of decoy traffic to uncover emerging threats [72].

Trust-based quarantining, as proposed in [75], enhances security by immediately isolating suspicious nodes, reducing the likelihood of large-scale breaches. Moreover, some research incorporates fog computing and blockchain technology, leveraging SHA-256 hashing and ECDS digital signatures to safeguard data integrity [74].

4 Conclusion

Current AI-based solutions in smart cities demonstrate promising results in classification and regression tasks, primarily supported by widely accepted metrics such as accuracy, precision, recall, F1, and RMSE. These quality metrics allow clear performance comparisons, but there is room for expanding multi-criteria evaluations to reflect real-world complexity better. Measurability often benefits from real-world datasets, which increases the practical relevance of findings; however, the scarcity of openly available, standardized data repositories continues to restrict reproducibility among different research groups. While emerging explainability methods like LIME, SHAP, and Grad-CAM show that explainability is gaining traction, many solutions remain opaque, indicating the importance of further research on transparent decision processes. Privacy concerns are variably addressed through anonymization and federated learning, yet comprehensive privacy-by-design approaches remain uncommon. Security, though frequently tackled in intrusion detection and related IoT-focused frameworks, would benefit from more integrated, end-to-end cybersecurity strategies. Bridging these gaps—particularly in data availability, explainable architectures, and holistic privacy-security measures—can reinforce public trust, accelerate adoption, and guide sustainable innovation in future smart cities.

Acknowledgements

This research has been supported by the Ministry of Science, Technological Development and Innovation (Contract No. 451-03-137/2025-03/200156) and the Faculty of Technical Sciences, University of Novi Sad through project “Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad 2025” (No. 01-50/295).

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UDK:004.934.8`1MFCC

DOI:
10.46793/ALFATECHproc25.20
4J Original scientific paper

Use of Covariance Matrix in Automatic Speaker Recognition

Ivan JOKIĆ¹, Stevan JOKIĆ²

Abstract: One procedure for automatic speaker recognition based on use of 21 mel-frequency cepstral coefficients as speaker features and covariance matrix as speaker model is tested in this paper. Tests are conducted on the Solo part of the CHAINS speech database which contains 37 recordings for each of 36 speakers. Each speech recording is represented by appropriate matrix of feature vectors. Modeling of recording of speaker is done by covariance matrix of matrix of feature vectors. Results of recognition accuracy are compared for two cases, when on elements of speaker model is applied sigmoid function and when it is not. Tests are done in five stages. Application of sigmoid function on elements of covariance matrices results in most of tests in significantly increasing of recognition accuracy. Achieved mean recognition accuracy for all done tests when sigmoid function is not applied is 87,84% and when sigmoid function is applied is 94,64%.

Keywords: Automatic speaker recognition; Mel-Frequency Cepstral Coefficients; Covariance matrix.

1 INTRODUCTION

In connections of different devices over the Internet and enabling voice commands it is necessary to achieve recognition of speaker's voice. Voice has three basic characteristics: intensity, basic frequency and color. Color of voice is consequence of harmonic structure of spectrum of voice. Information about intensity and basic frequency are also contained in spectrum of voice signal. Envelope of spectrum of voice signal contains information about harmonic structure of voice.

Short-term analysis of speech signal is based on analysis of speech frames of around 25 ms mutually shifted by around 10 ms. Mel-frequency cepstral coefficients (MFCCs) are usually used as short-term features of speech signal. They are used as short-term features for automatic speaker recognition [1]. To implement speaker recognition system in [2] MFCCs are combined with Gaussian mixture models (GMMs), in [3, 4] MFCCs are combined with artificial neural network. MFCCs track spectral envelope of speech signal and therefore contain information implied by spectral envelope which is observed. Therefore MFCCs contain information about color of voice i.e. about identity of speaker, but also they contain information about textual content of speech and also about emotional state of speaker. In [5] MFCCs are used for speech recognition, recognition of textual content of speech, and in [6, 7] MFCCs are used for recognition of emotion in speech.

Considering sound in general, MFCCs can be used as features of sounds from the environment [8] or from nature, for bird sound recognition [9] and for classification of honey bees [10] for example. As is evident from literature, MFCCs are used in many applications oriented to recognitions different information from sound [11].

Modeling is the step in automatic speaker

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recognition after short-term features calculation. Model make compact picture of previously calculated short-term features. It is calculated for considered set of short-term features. Model describes longer intervals in sound, in fact, model is long-term feature [12]. Proces of automatic speaker recognition begin with short-term features and also combine long-term features [13], to recognize identity of speaker i.e. information of interest from speech.

Models of the same speaker should be as similar as possible. Similarity can be increased by applying adequate transformation on elements of model. In this paper will be presented that application of sigmoid transformation on model is additionally increased recognition accuracy. In next part of paper is described speaker recognizer used and speech database which is used. After that results of recognition accuracy are presented.

2 DESCRIPTION OF EXPERIMENTAL SETUP

MFCCs are used as short-term speaker features. They are calculated by:

$$C_n = \sum_{m=1}^M \log(E_m) \cdot \cos \left[\frac{\pi}{22} \cdot n \cdot \left(m - \frac{1}{2} \right) \right] \quad (1)$$

where $n=\{1, 2, \dots, 21\}$ is ordinal number of calculated MFCC. Feature vector contains 21 MFCC. E_m is energy inside of m -th frequency selective range:

$$E_m = 2 \cdot \sum_{k=k_1,m}^{k_{2,m}} |X(k)|^2 \cdot A(k) \quad (2)$$

Frequency range of interest is divided into $M=22$ frequency selective ranges, width of 300 mels and mutually shifted by 150 mels. $X(k)$ is discrete Fourier transform (DFT) of observed speech signal frame $x(n)$, $k_{1,m}$ is lower discrete frequency and $k_{2,m}$ is upper discrete frequency of observed m -th frequency selective range. Each frame of speech signal is windowed by Hann window function:

$$wn(n) = \frac{1}{2} \cdot [1 - \cos \left(\frac{2\pi \cdot n}{N-1} \right)], \quad 0 \leq n \leq N-1, \quad N=1024. \quad (3)$$

$$2 \leq N-1 \leq$$

The frequency sampling of observed speech signals is 44100 Hz. Usually used duration of speech frame is around 25 ms. To apply the fast Fourier transform

algorithm to calculate the discrete Fourier transform of the frame of observed speech signal it is necessary that duration of frame is number which can be represented in the form of 2^s , where s is a natural number. In accordance with this, the frame duration was chosen to be 1024 points, i.e. approximately 23 ms. Neighboring frames are shifted by 368 samples, approximately by 8ms. Square of amplitude characteristic of applied frequency selective ranges is of sigmoid shape [14], given by equation:

$$A_m(k)^2 = \frac{1}{1 + \exp \left(-\frac{k - k_{cm}}{k_{2,m} - k_{1,m}} \right)} \quad (4)$$

In equation $k_{1,m}, k_{2,m}$ and $k_{cm} = (k_{1,m} + k_{2,m})/2$ are the lower,

upper and central discrete frequency of m -th frequency selective range. Shape of sigmoid function used is determined by equality $\text{sigm } x = \frac{1}{1 + e^{-0.5 \cdot x}}$. For each speech frame is calculated feature vector of 21 MFCCs. Feature vectors of the recording of one speaker are written in appropriate columns of matrix of feature vectors.

Covariance matrix of matrix of feature vectors is used for modeling of speaker:

$$\Sigma = \frac{1}{n-1} \cdot (X - \mu) \cdot (X - \mu)^T, \quad (5)$$

$[X]_{d \times n}$ -matrix of feature vectors, d -dimensionality of feature vector used i.e. number of MFCCs used, $d=21$, n -number of feature vectors, $[\mu]_{d \times 1}$ -vector of mean values of matrix X . Each element in covariance matrix observe appropriate energy representation of MFCCs. Diagonal elements represents energy in appropriate dimensions of feature vectors while elements outside of the main diagonal of the covariance matrix describe the measure of correlation between appropriate dimensions of feature vectors. Measure of difference between two models, for example of model of test speech and reference model, is calculated by equality:

$$r(\Sigma_{test}, \Sigma_{ref}) = d^{-1} \cdot \sum_{i=1}^d \sum_{j=1}^d |\Sigma_{test}(i, j) - \Sigma_{ref}(i, j)|. \quad (6)$$

The identity of most similar reference model with respect to Eq. (6) is recognized speaker. If in speech database have R reference models then the test speech has identity of the i -th reference

model if $r(\Sigma < \Sigma_{test, i}) r(\Sigma_{test, j})$, $j \in \{1, 2, \dots, R\} \setminus i$.

Experiments are conducted on the part of the speech database CHAINS (CHARacterizing INDividual Speakers) [15] named Solo. This part of the used speech database is characterized by property – subjects simply read a prepared text at a comfortable rate. CHAINS speech database contains recordings of speech of 36 speakers. In the Solo part, for each of the 36 speakers, there are 37 recordings: four short fables {f01, f02, f03, f04} and sentences {s01, s02, ..., s33}. Recordings are in WAV format, frequency sampling is 44100 Hz and quantisation resolution is 16 bit/sample.

Testings of automatic speaker recognition are done in five steps. In first four experiments for training are used recordings from the set of short fables, f01, f02, f03 and f04. Testings are conducted in 12 tests, in each of tests appropriate set of pronounces of three sentences is used as test set, Tab. 1 and Tab. 2. In the fifth experiment, Tab. 3, the 33 recordings from set of sentences {s01, s02, ..., s33} are used for training and testing of recognizer. Tests are organized in 12 tests as in Tab. 1 and Tab. 2. In each of 12 tests, training is done on the rest of 30 recordings which are not used in observed test set.

Two cases are compared, when as model of speaker is used covariance matrix calculated by Eq. (5) and when sigmoid function $\text{sigm } x = \frac{1}{1 + e^{-x}}$ is applied on elements of

+e

previously calculated model i.e. covariance matrix. Elements of model vary in time. Sigmoid function is a nonlinear, companding, function. Values of sigmoid function are limited in the range [0, 1]. Therefore it can be expected that application of sigmoid function on elements of model will decrease time variation of elements of models of the same speaker. This function is usually used as activation function in artificial neural networks.

Table 1 Training: f01, f02

Test set	Cov. matrix		Sigmoid applied	
	f01	f02	f01	f02
s01,s02,s03	75%	82,41%	88,89%	88,89%
s04,s05,s06	70,37%	74,07%	80,56%	82,41%
s07,s08,s09	72,22%	70,37%	93,52%	89,81%
s10,s11,s12	86,11%	86,11%	97,22%	94,44%
s13,s14,s15	83,33%	86,11%	91,67%	94,44%
s16,s17,s18	87,96%	86,11%	92,59%	93,52%
s19,s20,s21	88,89%	91,67%	91,67%	94,44%
s22,s23,s24	80,56%	82,41%	92,59%	87,96%
s25,s26,s27	91,67%	90,74%	95,37%	96,30%
s28,s29,s30	84,26%	83,33%	95,37%	95,37%
s31,s32,s33	84,26%	90,74%	95,37%	99,07%
s20,s31,s33	87,04%	93,52%	95,37%	99,07%

Recognition accuracy varies depending of test set. Applying of sigmoid transformation on model in Tab. 1 is resulted in increasing of recognition accuracy in all experiments. Recognition accuracy when training is done with recording f01 is smaller than 90% for all test sets except for test set {s25, s26, s27}. By applying sigmoid transformation on elements of model recognition accuracy in certain tests is higher than 95%. When f02 is used for training recognition accuracy in some tests is higher than recognition accuracy achieved when f01 is used for training. Application of sigmoid transformation in experiments when test sets are {s31, s32, s33} and {s20, s31, s33} increases recognition accuracy to 99%. Significant increasing of recognition accuracy is evident in Tab. 1 when test set is {s07, s08, s09}. In this case when f01 is used for training increasing is higher than 20% and

when f02 is used for training increasing is higher than 19%. Results when f03 and f04 are used for training, Tab. 2, are similar to results in Tab. 1. For training done by f03 here are two cases, for test set {s16, s17, s18} and {s19, s20, s21}, when applying of sigmoid function on model is not increased recognition accuracy. In some cases when recognition accuracy is below or around 80%, application of sigmoid transformation increases recognition accuracy around or higher than 10%. The smallest value of recognition accuracy for training done by f03 or f04 is for test set {s07, s08, s09}. Increasing of recognition accuracy after applying sigmoid function on elements of model is around 15%.

Table 2 Training: f03, f04

Test set	Cov. matrix		Sigmoid applied	
	f03	f04	f03	f04
s01,s02,s03	85,18%	86,11%	88,89%	94,44%
s04,s05,s06	78,7%	78,7%	83,33%	88,89%
s07,s08,s09	76,85%	74,07%	91,67%	91,67%
s10,s11,s12	92,59%	89,81%	93,52%	98,15%
s13,s14,s15	87,04%	90,74%	92,59%	95,37%
s16,s17,s18	94,44%	89,81%	93,52%	97,22%
s19,s20,s21	93,52%	92,59%	93,52%	96,3%
s22,s23,s24	89,81%	85,18%	92,59%	93,52%
s25,s26,s27	93,52%	91,67%	98,15%	97,22%
s28,s29,s30	87,04%	87,96%	97,22%	98,15%
s31,s32,s33	90,74%	91,67%	100%	100%
s20,s31,s33	93,52%	92,59%	100%	100%

Recognition accuracy when training and test set are from set of sentences {s01, s02, ..., s33}, Tab. 3, and when test sets are from sets {s04, s05, s06} or {s07, s08, s09} is significantly higher than in cases when training recordings are f01, f02, f03 or f04. This indicate that recognition accuracy depend of textual content of training and test speech. After application of sigmoid function on elements of model when test sets are {s01, s02, s03} and {s07, s08, s09} accuracy of recognition is increased to the value higher than 95%.

Table 3 Training and test on the set {s01, s02, ..., s33}

Test set	Cov. matrix	Sigmoid applied
s01,s02,s03	88,89%	95,37%
s04,s05,s06	87,96%	91,67%
s07,s08,s09	89,81%	95,37%
s10,s11,s12	97,22%	99,07%
s13,s14,s15	94,44%	97,22%
s16,s17,s18	97,22%	100%
s19,s20,s21	99,07%	100%
s22,s23,s24	98,15%	99,07%
s25,s26,s27	99,07%	100%
s28,s29,s30	100%	99,07%
s31,s32,s33	97,22%	100%
s20,s31,s33	98,15%	100%

Table 4 Mean recognition accuracy

Training	Cov. matrix	Sigmoid applied
f01	82,64%	92,51%
f02	84,8%	92,98%
f03	88,58%	93,75%
f04	87,58%	95,91%

s01,...,s33	95,6%	98,07%
mean accuracy	87,84%	94,64%

Mean recognition accuracies for different training recordings used, Tab. 4, show that application of sigmoid transformation on elements of covariance matrices is significantly increased accuracies. In the case when training is done by recording f01, the increase of mean recognition accuracy is the largest, approximately 10%. The largest mean recognition accuracy is achieved when training and test recordings are from the set of sentences {s01, ..., s33}, in this case mean recognition accuracy is approximately 98%. Mean

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accuracy for all tests, when used model is covariance matrix, is 87,84%. When sigmoid transformation is applied on elements of models this mean accuracy is increased to 94,64%. Application of sigmoid function on elements of models is decreased mean error of recognition from around 12% to around 5%.

4 CONCLUSION

Sigmoid transformation applied on elements of covariance matrix of matrix of MFCC feature vectors increases recognition accuracy. The recognition results confirm that application of sigmoid function on elements of model decreases time variation of the elements of models of the same speaker. From results in Tab. 1 and Tab. 2 for test sets {s01, s02, s03}, {s04, s05, s06}, {s07, s08, s09}, it is evident that when the recognition accuracy is less than 80%, application of sigmoid transformation on elements of model can increase recognition accuracy above 80%. In some cases increased accuracy is close and around 90% or higher than 90%, but there is also cases when increased accuracy is below 85%. In Tab. 3 recognition accuracy for these three test sets is higher than 87% and accuracy after applying of sigmoid transformation is higher than 91%. It is evident that recognition accuracy depends of training and test set.

Result of recognition of automatic speaker recognizer should just depend of the characteristics of the voice. Decision of recognizer which is described in this paper depend of textual content of training and test speech. In future work it is necessary to find a way that decision do not depend of textual content of training and test speech. One of solutions can be by using appropriate filters during calculation of MFCCs and also by using appropriate transformations during calculation of models i.e. long-term features of speaker which will decrease time variation of elements of models of the same speaker.

Acknowledgements

Thanks to Professor Vlado Delić from the Faculty of Technical Sciences, University of Novi Sad, and Professor Zoran Perić from the Faculty of Electronic Engineering,

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Blockchain Applications in the Development of Smart Cities

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Abstract: Blockchain technology, with its decentralized nature, immutability, and transparency, has emerged as a promising tool to address challenges in smart city development. This review paper examines the applications of blockchain across multiple sectors, including waste management, finance, voting, real-estate, and energy management. Drawing from current research, the paper demonstrates how blockchain can enhance conventional approaches to improve efficiency, transparency, and security. While blockchain holds significant promise, this paper also explores the constraints hindering its mass adoption, such as scalability, energy consumption, and regulatory challenges. By incorporating perspectives from both industry and academia, it provides a balanced analysis of the opportunities and challenges associated with blockchain adoption in smart cities. Ultimately, this paper aims to offer valuable insights to policymakers, researchers, and stakeholders, helping them better understand how blockchain can be strategically leveraged to create more sustainable, secure, and efficient urban systems.

Keywords: Blockchain; Smart City; Distributed ledger technology; Ethereum; Energy Trading; Waste Management; Finance; Voting; Real Estate.

1 INTRODUCTION

The rapid urbanization of the global population has placed unprecedented demands on city infrastructures, resources, and services, necessitating innovative solutions to enhance efficiency, sustainability, and quality of life. In response, the concept of smart cities has emerged, leveraging advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics to optimize urban operations. However, the integration of these technologies often raises challenges related to data security, transparency, and interoperability [1,2]. Distributed Ledger Technology (DLT), commonly exemplified by blockchain, which we will focus on in this paper, has gained significant attention as a transformative tool to address these challenges [3]. By providing a decentralized, tamper-proof, and transparent framework for record-keeping, blockchain offers a robust solution for managing the complex and interconnected systems that underpin smart cities.

This review paper critically examines the growing body of research on the potential uses of blockchain in smart cities, synthesizing insights from academic studies, industry reports, and real-world implementations. As a review, it does not present new experimental data but instead evaluates and consolidates existing work to identify trends, gaps, and future directions. The paper explores the diverse applications of blockchain in urban

contexts, such as facilitating secure peer-to-peer energy trading, enhancing waste management systems, transforming banking systems and enabling Central Bank Digital Currencies (CBDC), revolutionizing real-estate markets, and ensuring voting transparency.

By providing a comprehensive analysis of the current state of research, this paper aims to serve as a valuable resource for researchers, policymakers, and urban planners. It not only underscores the transformative potential of blockchain in addressing urban challenges but also calls for further interdisciplinary research to overcome existing barriers and unlock the full potential of this technology in building smarter, more resilient, and inclusive cities.

The rest of this paper is organised as follows. Section 2 provides an overview of blockchain technology and its utilization in smart cities, highlighting its key features and potential benefits. Section 3 delves into the applications of blockchain in various fields, including waste management, finance, voting systems, energy management, and real estate. Each subsection explores how blockchain addresses specific challenges and enhances efficiency, transparency, and sustainability in these domains. Finally, Section 4 presents a discussion of the findings, synthesizing the opportunities and challenges of blockchain adoption in smart cities, and concludes with future research directions and broader implications for the development of smarter urban ecosystems.

2 BACKGROUND THEORY

In this section, we explore the fundamentals of blockchain technology, including its definition, significance, and various types. Following this, we delve into the concept of smart cities, discussing their meaning and importance, and briefly discussing how blockchain technology can contribute to the development of these futuristic urban environments.

2.1 Blockchain

Blockchain technology is one of the most significant innovations in recent years, as it has redefined trust, ownership, digital identity, and financial systems. Blockchain operates as a decentralized and distributed ledger system, specifically designed to securely record, validate, and maintain transaction data. Instead of being managed by a single centralized authority, such as a bank, blockchain records are monitored and maintained by a decentralized network of participants. No individual entity has exclusive control over the system, and once a transaction is recorded, it cannot be altered or erased, ensuring immutability and security within the network [4,5].

The term "blockchain" refers to a chain of cryptographically linked blocks, where any modification to a single block invalidates all subsequent blocks in the chain [6]. The primary function of a blockchain network is to ensure that independent and untrusted nodes within the system achieve consensus on a single, immutable record of transactions [7]. This function is fulfilled by consensus mechanisms, which establish the rules for maintaining consistency across the network. The first widely recognized consensus algorithm, Proof of Work (PoW), was introduced with the launch of the Bitcoin blockchain. Since then, multiple consensus algorithms have been developed to enhance scalability, efficiency, and security in various blockchain applications [5]. Some examples of consensus algorithms include Proof of Stake (PoS), practical Byzantine Fault Tolerance (pBFT), Proof of Elapsed Time (PoET), and many more [8].

Blockchain technology is primarily classified into two main types: private blockchain and public blockchain. However, depending on specific criteria and analytical perspectives, blockchain can also be categorized into consortium blockchain and hybrid blockchain models [9]. In public blockchains, the network is open and accessible to anyone who wishes to participate in transactions, without requiring special permissions. Examples of public blockchain are Bitcoin, Ethereum, Cardano, etc. On the other hand, private blockchains are restricted-access networks, meaning they are not open to the public. Participation is limited to authorized users who are granted access by a central authority or

system administrator. Despite being permissioned, private blockchains still leverage cryptographic security and decentralization to some extent, while ensuring greater privacy and control over data management [9]. Hyperledger Fabric,

Corda R3, Hyperledger Sawtooth, IBM Blockchain include some of the well known examples of private blockchain [10]. A combination of features of public and private blockchains resulted in hybrid blockchains. This type of blockchain allows selective transparency, where certain data is made publicly accessible while other information remains restricted to authorized participants. Examples of hybrid blockchains include IBM Food Trust and XinFin [11]. A consortium blockchain is a type of semi-decentralized blockchain where multiple organizations collectively manage and control the network. Unlike public blockchains, which are fully open, or private blockchains, which are restricted to a single entity, consortium blockchains allow a group of pre-selected entities to govern the system [9]. Corda R3, Quorum and Energy Web Foundation (EWF) are some of the most common examples of consortium blockchains [12].

Blockchain technology has evolved into multiple specialized platforms, each serving distinct purposes. Among the most widely recognized are Bitcoin, Ethereum, and Hyperledger Fabric, which cater to different use cases, from cryptocurrency transactions to smart contracts and enterprise solutions [8].

Bitcoin is the world's first and most dominant cryptocurrency. It was introduced in 2008 by Satoshi Nakamoto as the first successful implementation of blockchain technology. Bitcoin revolutionized digital finance, enabling peer-to-peer transactions without reliance on banks or governmental authorities [13].

In 2013, Vitalik Buterin introduced Ethereum, which significantly expanded blockchain technology by enabling the execution of smart contracts on a decentralized platform. Unlike Bitcoin, which primarily serves as a digital currency, Ethereum functions as a programmable blockchain that allows developers to create markets, build decentralized applications (DApps), and execute automated transactions without requiring intermediaries. A key innovation of Ethereum is its smart contract functionality, which enables self-executing agreements that automatically enforce terms without the need for third parties. These smart contracts are written in Solidity, Ethereum's purpose-built Turing-complete programming language, designed to facilitate secure and transparent decentralized execution of blockchain-based applications [8].

Hyperledger Fabric, a modular and permissioned blockchain platform, was introduced in 2016 under the Linux Foundation's Hyperledger project, with key contributors including IBM. Unlike public blockchains, Hyperledger Fabric processes transactions using an execute-order-validate model, which eliminates the

need for traditional consensus algorithms by relying on a predefined ordering service to arrange transactions. It also allows smart contracts to be written in multiple programming languages like Node.js, Java, and Go, making it highly flexible for enterprise applications. A key distinction is that all nodes have assigned identities, ensuring controlled access, which enhances security, privacy, and regulatory compliance for business use [14].

Building on the advancements of blockchain platforms, such as the ones described in the previous paragraph, blockchain technology has become a cornerstone of financial innovation, transforming payments, cross-border transactions, decentralized finance (DeFi), and digital asset management by ensuring security, transparency, and efficiency. However, its impact extends far beyond finance, with applications in supply chain management, healthcare, identity verification, real estate, voting systems, the Internet of Things (IoT), and many more, where trustless and tamper-proof solutions are increasingly valuable. As blockchain technology continues to evolve, its versatility and potential for disruption across multiple industries are expected to drive further adoption and innovation [5].

2.2 Smart City

With the fast-growing population in urban areas, new challenges are emerging, which might require a "smarter" approach. According to the United Nations, it is projected that around two-thirds of the global population will live in urban areas by 2050 [15]. In these high population density areas, citizens are faced with many factors limiting their quality of life, such as inefficient waste management systems, energy demand fluctuations and inefficiencies, increasing real estate prices, voting processes vulnerable to fraud and low participation, slow and limited financial systems etc. These are some of the issues that a smart city aims to address. Although the term "smart city" has been in use for some time, it has only recently gained wider recognition among the public. The term can be challenging to define due to discrepancies in the literature and rapid technological advancements. This inspired our study to look into specific use of different technical (smart) solutions which can make a life in modern cities more convenient.

A key characteristic of smart cities is the integration of advanced Information and Communication Technology (ICT) to enhance the quality of life for its citizens and promote a sustainable urban environment [16]. Building on this foundation, smart cities aim to establish a development model based on utilization of human, collective, and technological capital in order to drive growth and prosperity in urban areas. Greater transparency in public governance, active citizen participation, efficient traffic and public transport

management, optimized resource utilization, enhanced environmental protection, seamless integration of smart devices, and improved services in healthcare, energy, and education are just a few of the numerous beneficial attributes smart cities are offering [17].

2.3 Blockchain in Smart Cities

Amidst a wave of innovations and technological advancements, blockchain has emerged as a promising technology for the development of smart cities. Alongside Artificial Intelligence (AI) and other emerging technologies, blockchain holds significant potential to enhance the quality of life of smart city residents. In an era of increasing demand for reliable information, ensuring its transparency and accuracy is crucial for societal prosperity. Systems that depend on such information - such as traffic management, waste management, energy distribution, healthcare, public dispute resolution and voting - can greatly benefit from blockchain's components, including smart contracts, consensus mechanisms and cryptographic verification.

The technology offers "trust-free trust", enabling decentralized governance without third-party intermediaries. Its impact can be seen in four key areas. First, the network effect of trust enhances societal, governmental, and industrial functions by reducing corruption, tackling online disinformation, and improving transparency in public administration. Second, empowering individuals and strengthening the economy allows citizens to have control over their digital identities and personal data. Third, the sharing economy benefits from blockchain's ability to remove intermediaries, lowering costs for services like real estate, transportation, and hospitality. Lastly, the liquid economy is shaped by tokenization, where assets and services are digitized for seamless trading and investment [18].

3 BLOCKCHAIN APPLICATIONS IN SMART CITIES

The integration of blockchain technology into smart cities is transforming various sectors by enhancing transparency and security in urban management. As cities become more interconnected, decentralized ledger technology provides innovative solutions for handling critical areas such as waste management, real estate, finance, voting, and energy management. This section explores how blockchain is applied across different fields, highlighting its impact and potential for future urban development.

3.1 Waste Management

The increased urbanization, economic growth, population increase, and high living standards in developing countries have contributed to an increase in the amount of waste [19]. Waste management involves several processes, including collection, segregation, transportation, treatment, and final disposal or recycling of waste products [20]. Traditional waste management systems face several key challenges, including:

- **Lack of transparency and traceability.** Traditional waste management systems often fail to track the movement of waste, which leads to illegal dumping and unrecorded waste.
- **Data manipulation and fraud risks.** Use of paper records and centralized databases exposes waste data to the risk of manipulation and falsification.
- **Ineffective waste collection and sorting.** Lack of effective monitoring systems and manual sorting procedures leads to ineffective recycling.
- **Ineffective enforcement of regulations.** Most of the existing waste regulations lack effective means of enforcement, and therefore polluters cannot be held accountable.
- **High operational costs and financial inefficiencies.** Costs of waste collection, transport, and recycling are high due to inefficient manual processes.
- **Limited scalability in growing cities.** Increasing urban waste volumes overwhelm urban waste management systems, leading to overutilization of landfills and unsustainable waste disposal practices [20].

Blockchain technology offers various solutions to these issues by introducing transparency, automation, and decentralized control. Through the utilization of immutable records, smart contracts, and token-based incentives, blockchain has the potential to promote accountability, optimize waste management processes, and foster sustainable behavior in smart cities [19].

Transparent waste tracing and auditing features can be useful to verify the authenticity of waste management data. The immutable ledger aspect of blockchain guarantees that all transactions are accurately documented and monitored in realtime. Thus, in effect, promotes increased accountability on the part of waste management companies and lowers the possibility of fraudulent activities, such as misreporting disposal locations [20]. For instance, PlasticBank employs blockchain to track plastic waste collection operations and ensures that collected material is legally processed. This approach primarily addresses the lack of transparency and traceability in traditional waste management, as well as the data manipulation. However, its effectiveness depends on adoption rates and token usability

[21].

Blockchain-based systems can motivate people and businesses to take part in proper waste disposal and recycling by issuing digital tokens that can be exchanged in terms of goods or services. Hence, cities and organizations can promote sustainable behavior while ensuring that waste ends up in appropriate recycling facilities instead of landfills [19]. Most solutions leverage Ethereum's ERC-20 tokens, which provide an efficient way to distribute incentives securely and transparently. One example is Recerum, a blockchain-based system that incentivizes proper waste disposal by rewarding users with digital tokens. Tokens can be used as a discount in the bill for energy, gas, garbage disposal, or other Recerum's partner services. It represents a solution for ineffective waste collection and sorting. Effectiveness of this approach depends on the stability and widespread acceptance of the token-based economy [22].

Smart contracts can also trigger real-time penalties when waste management companies or individuals fail to meet predefined terms or violate regulations (e.g. dumping of waste illegally, failure to meet recycling targets, or misrepresentation of waste) [19]. In the study "Industrial Wastewater Management using Blockchain Technology: Architecture, Requirements, and Future

Directions", the authors proposed a blockchain-based solution for management of industrial wastewater. While the primary focus is on monitoring and tracking wastewater disposal, the architecture also supports the integration of smart contracts. These smart contracts can be programmed to automatically enforce compliance by imposing penalties on entities that violate environmental regulations. However, the implementation of such a system may face challenges, including high operational costs due to the need for advanced technological infrastructure and potential scalability issues [23].

Additionally, blockchain can enhance waste management regulations efficiency through smart contract automation. Blockchain-based solutions minimize manual verification efforts and eliminate intermediaries, which decreases administrative costs and increases overall accountability of services [19]. A practical example of this is IBM's partnership with PlasticBank, where smart contracts ensure that plastic waste collectors are paid fairly and transparently. This addresses inefficiencies in regulation enforcement, ensuring transparency and compliance with established rules. However, this approach depends on the adoption rate, because traditional methods may remain more practical due to lower technological requirements [21].

Blockchain-based solutions for waste management provide numerous benefits but also suffer from some limitations. Adoption barriers remain a significant hurdle, as most municipalities and traditional

waste management businesses are hesitant to transition from traditional systems to decentralized ones. Thus, most of the aforementioned projects are currently in the pilot or prototype phase [21, 22, 24, 25, 26]. Most of these projects are based on the Ethereum platform, which faces scalability issues and high transaction fees [24, 25, 27, 28]. In contrast, other prototypes utilize Hyperledger Fabric due to its permissioned network structure and lower transaction costs [21, 29]. Also, IoT and smart bin integration is a significant step in waste management since it can enhance operational efficiency. But it requires enormous investment in infrastructure. Despite these limitations, the potential of blockchain to revolutionize waste management using AI and IoT can also enhance efficiency and enable more sustainable and transparent waste management solutions.

Blockchain-based tracking, incentivization, automation of smart contracts, and transparency in supply chains can significantly improve waste management systems of smart cities. Not only do they encourage environmental sustainability, but they also lower operational costs and bring about increased accountability at all levels of waste management.

3.2 Finance

Blockchain technology has its roots in finance, beginning with the creation of Bitcoin [30]. In the context of smart cities, blockchain's application in finance is a natural extension of its original purpose. Smart cities rely on interconnected systems and data-driven decision-making, which require trust, transparency, and efficiency - qualities that blockchain inherently provides.

Some of the issues traditional finance faces that can be solved by the usage of blockchain:

- **Money embezzlement.** Traditional finance relies on centralized systems, often scattered across multiple and private databases, allowing bad actors to manipulate records or divert funds without detection.
- **Money laundering.** Lack of real-time transparency and reliance on intermediaries in traditional systems make it easier to obscure the origins of illicit funds.
- **High transaction costs.** Traditional finance involves multiple intermediaries, manual processes, and complex verification systems, all of which drive up costs.

By integrating blockchain into financial systems, smart cities can tackle issues like corruption, inefficiency, and

financial exclusion, paving the way for more equitable and sustainable urban development.

Blockchain ensures transparency and immutability, which significantly reduces the risks of money embezzlement and laundering [31]. The authors also highlight how blockchain can simplify crowdfunding by providing a secure and transparent platform for raising funds. Additionally, it becomes easier to determine users' credit scores, as all their transactions are recorded on a public ledger, ensuring accuracy and reliability [32]. Furthermore, blockchain eliminates the need for intermediaries, reducing transaction costs, particularly for crossborder payments [32].

A promising approach to enhance financial systems in smart cities is moving fiat money to blockchain [33], such as usage of Central Bank Digital Currencies (CBDCs) [34]. CBDCs are digital versions of a country's fiat currency, issued and regulated by the central bank. By replacing physical cash with CBDCs, smart cities can achieve greater efficiency, security, total transparency, and inclusivity in their financial ecosystems. Examples of operational CBDCs include the Sand Dollar [35] (built on NZIA Cortex DLT) and the eNaira [36] (built on Hyperledger Fabric). Meanwhile, the eAUD [37] (built on Quorum) is in its pilot state, and the development of Digital Euro [38] and Digital Dollar [39], and many more, is currently under research. The number of countries exploring CBDCs is steadily increasing and can be tracked [40, 41].

This approach is not without its own challenges. First one is regulatory compliance [32], which can be overcome by using private blockchains controlled by the government. Some authors [31, 32] question blockchain's ability to handle a sufficient number of transactions per second. However, this issue can be mitigated by using blockchain implementations with improved scalability. An added benefit of such implementations is their lower energy requirements for node operations, making the system more environmentally friendly [31].

3.3 Voting

Elections and other forms of anonymous voting are fundamental to democracy, the most prevalent form of governance worldwide. However, traditional voting methods have encountered numerous challenges, particularly in balancing privacy with transparency [42]. While privacy is essential to maintain the anonymity of votes, transparency is crucial to ensure that all votes are recorded accurately and remain unaltered. Traditional approaches often require a central authority to maintain this balance, but this can compromise transparency and does not inherently prevent issues such as vote duplication or unauthorized access to preliminary results [43]. The advent of electronic voting systems promises to address these complexities by offering new mechanisms for secure and verifiable

voting processes, where each eligible voter can only vote once and results are safeguarded until the official count is completed.

In the context of smart cities, electronic voting systems can deliver additional benefits. Firstly, they reduce costs and increase efficiency, potentially reducing pollution as fewer physical materials and less transportation are required for setting up and conducting elections. This aligns with the broader smart city objectives of efficiency and environmental sustainability. Secondly, the enhanced accessibility and convenience of electronic voting can lead to greater voter participation, allowing residents to easily engage in the democratic process from remote or mobile locations [44]. Moreover, the interoperability of these systems with other smart city services facilitates a more integrated approach to urban management, enhancing the overall efficacy of public services. Additionally, the reduced operational costs associated with electronic voting can enable more frequent elections and referendums, allowing communities to engage more dynamically with issues as they arise. This can lead to a more responsive and adaptive form of urban governance, reflective of citizens' needs and preferences in real-time.

Blockchains offer enhanced privacy[30] with such techniques as blind signatures, homomorphic encryption, and mix networks[42], and they permit this without the need for a central controlling entity. As the theoretical framework of blockchain-based voting systems has shown promise, numerous implementations have emerged globally. In the following, specific solutions will be explored, highlighting their unique approaches to challenges and their use in real-life applications, distinct from the commonalities previously discussed:

- Follow My Vote [45] uses the Bitcoin blockchain framework and employs cryptographic verification along with a polling box suite to mathematically verify votes. The solution is designed for online voting.
- Voatz [46] is built on Hyperledger Fabric and incorporates biometric authentication, including fingerprints and retinal scans, alongside cryptographic verification to enhance security. It implements device security checks and restricts voting to one device per voter to prevent fraud. The system is used for mobile-based voting.
- Polyas [47, 48] operates on a private blockchain and utilizes cryptographic proof mechanisms for verification. It has been certified by the German Federal Office for Information Security and is used in Germany and other parts of Europe for electronic voting.
- Luxoft's [49] blockchain voting system runs on Hyperledger Fabric and uses smart contracts for

consensus and vote auditability. It is implemented in Switzerland for government-backed voting projects. The system allows hybrid voting, combining e-voting with traditional voting methods, and has received very positive user feedback.

- Polys [50] is based on Ethereum and employs cryptographic privacy mechanisms for vote verification. It is backed by Kaspersky Lab and is used in student councils, unions, and local authorities for voting. The system also supports hybrid voting processes.
- Agora [51] uses a custom blockchain built on Bitcoin and incorporates "Vote" tokens to facilitate elections. It implements a legitimate consensus mechanism and participatory security to ensure a secure voting process. Agora was used in the 2018 presidential election in Sierra Leone.

Despite blockchain-based voting systems, so far looking very promising, they all have an unsolved problem - scalability [42]. These systems are not efficient at handling millions of transactions on a national scale, since there are limitations inherent in current blockchain frameworks like Bitcoin, Ethereum and Hyperledger Fabric, which cannot handle the transaction volumes compared to systems like Visa which processes a vast number of transactions daily. There is also a problem that occurs in traditional voting methods - coercion and vote-buying. At the moment there is no way to prevent individuals from giving away their keys, and allow others to use or check their vote.

The concept of a blockchain-based voting system, along with the solutions it has inspired, demonstrates a robust foundation capable of potentially replacing traditional election methods. These innovative approaches promise to offer a reliable and secure voting method, fostering greater trust among voters. As this technology continues to evolve, it holds the potential to transform electoral processes worldwide, ensuring more transparent and equitable voting practices.

3.4 Real Estate

The real estate sector plays a crucial role in a city's economy. While digitization of real estate offers significant benefits, it also demands careful consideration, as drastic changes could have unintended consequences and prove unsustainable for the economy. Research has shown that blockchain technology could add great value to the real estate sector in three categories: land administration, transaction efficiency and tokenization.

One of the primary challenges in real estate transactions is adverse selection. This term refers to a situation where sellers may possess superior

information about property characteristics, potentially placing buyers at a disadvantage. The problem occurs when the buyer cannot access or verify information about an asset. This is particularly relevant in less developed countries where oral or locally registered contracts prevail [52].

Blockchain technology is proposed as a solution, offering a transparent and immutable digital ledger able to record every transaction with a timestamp and date, thereby reducing fraud and increasing trust among all parties, including banks, real estate agencies, buyers, and sellers. Additionally, it offers benefits even when compared to existing centralized record keeping systems, since it offers more security against cyber attacks and corruption.

Several successful projects have demonstrated the integration of blockchain technology into land registries, with notable examples in Sweden, Ghana, Georgia, and Afghanistan [53]. During the early stages of development, Sweden's land registry project faced setbacks when brokers and other organizations introduced their own platform to consolidate their market share and mitigate potential disruptions from the new technology [54]. Despite these challenges, this collaborative project by Lantmäteriet, Telia Company, ChromaWay, and Kairos Future, manages to improve transparency and trust by enabling all interested parties (buyers, sellers, banks, agents) to access data on a shared, immutable ledger. This significantly reduces the burden of manual verification and, in turn, speeds up the process of property transactions. Additionally, incorporating digital signatures offers major security improvements. An application was developed to facilitate interactions among all stakeholders. Property owners can verify ownership, agents can manage listings, buyers can access property information, and banks can conduct necessary checks - all within a unified digital platform [55].

Another notable initiative is goLandRegistry, developed by UNHabitat in collaboration with the United Nations Office of Information and Communications Technology (OICT) and implemented in Afghanistan [56]. This project leverages LTO Network's hybrid blockchain solution [57], which enables adaptation and integration in various nations. With the Afghan government serving as a key stakeholder, the project underscores the critical role of collaboration and coordinated efforts in facilitating the successful adoption of blockchain-based land registry systems [58].

With increases in transparency and trust brought by blockchainbased registration of properties, we could expect a positive impact on transaction efficiency as well. The benefits may include reduced time for transactions, fraud reduction, simplified administrative processes, and even reduced need for intermediaries [52]. The potential of blockchain technology to enhance real estate transactions remains largely unrealized.

Theoretical frameworks support the concept of automating purchase and rental agreements through the use of Ethereum-based smart contracts, with the aim of streamlining transaction processes and reducing associated costs. However, these frameworks emphasize optimization rather than disintermediation of the process [59].

The concept of transforming real estate assets into digital tokens representing fractional ownership has been proposed as a means to enhance market accessibility, liquidity, and efficiency by reducing transaction times and associated costs. This innovation could broaden access to real estate investments for a wider range of investors [52]. Despite the intuitive appeal of the concept, regulatory complexities pose significant challenges, contributing to a limited body of literature on the topic. Notably, companies like RealT (RealToken) have made strides in addressing these challenges. RealT purchases residential properties and tokenizes legal entities that hold the deeds of the property according to US regulations. Management, maintenance, and rent collection of the properties are outsourced to a third party. After subtracting costs, the collected rent for the specific property is paid to token holders [60]. However, limited information is available regarding the underlying technology supporting this system, as the primary focus has been on regulatory compliance.

Numerous studies indicate that developing countries that have recently digitized their land registries using centralized databases have experienced significant instances of fraud and cyber attacks, leading to widespread disputes. This highlights the potential of blockchain even when compared to existing centralized record keeping systems, since it offers more security against cyber attacks and corruption. However, the implementation of such technologies poses significant challenges, primarily due to the fragmented nature of the system, which comprises numerous disconnected groups of stakeholders. Additional challenges for the adoption of blockchain-based systems may arise from third parties who don't fully recognize the benefit of more reliable information, or think their role in the system may be compromised. Regulations pose another issue, as some applications require legal amendments. For example, in Sweden, the application could not move to production because electronic signatures were not legally valid for real estate transactions. These challenges are particularly pronounced in the context of tokenization, as legal frameworks vary significantly across jurisdictions, even within the European Union. This regulatory fragmentation creates considerable barriers to the facilitation of cross-border transactions [54].

Given these factors, many blockchain-based real estate solutions remain largely at the conceptual stage. However, several established projects have demonstrated the potential for these systems to add

tangible value to the industry. It is also important to note that the technological frameworks underpinning various real estate solutions often differ significantly. This lack of technological uniformity may stem from the infrequent nature of real estate transactions and the low likelihood of refunds, reducing the weight of specific blockchain technology choices in determining a project's success.

Alternatively, the limited visibility into technological details may be attributed to proprietary corporate practices. Despite these challenges, the advancements made thus far highlight the promise of blockchain in enhancing transparency, efficiency, and accessibility in the real estate sector - paving the way for future research and innovation.

3.5 Energy Management

The way in which the energy sector has functioned so far and how electricity is generated, distributed, and consumed is not in line with the requirements of smart cities. This is because smart cities aim to improve quality of life, sustainability, and efficient resource utilization [61]. A few reasons why traditional, centralized energy systems are not adequate include:

- **Energy waste.** Energy is being overproduced in order to avoid power outages and energy loss during long-distance transmissions [61].
- **Environmental impact.** Centralized power plants mostly use non-renewable fossil fuels and therefore pollute the air, water, and land [62].
- **Single point of failure.** Failure of a major power plant can cause widespread blackouts and grid disruptions [63].
- **Higher costs.** Due to the high transaction costs associated with energy trading, ineffective administration, and requirement for middlemen to conduct transactions, centralized energy systems result in higher costs [63].

To address these challenges, researchers are attempting to transform centralized energy systems into decentralized ones. Due to the decentralized nature of blockchain, this technology is regarded as a promising solution for the development of distributed energy systems [61, 64].

Blockchain technology has introduced a user-friendly and efficient approach to establishing secure and reliable decentralized energy trading markets [65]. This development has been facilitated by the rise of smart grid technology, which enables individual users to generate energy from renewable sources [66]. These users can then either feed excess electricity directly into the main grid [67], engage in peer-to-peer energy trading [61], or pursue a combination of both options

[65]. The energy trading process typically involves auction mechanisms with participants acting as both bidders and sellers. To facilitate these transactions, various auction methods have been utilized, including Vickrey second-price auction methodology [68] and double auction systems [63]. Although many of these proposed solutions such as [61, 65, 68] were not fully implemented in realworld scenarios, there have been a few successful implementations, such as Power Ledger [69], Brooklyn Microgrid [70], and Enerchain [71].

Power Ledger, an Australian technology company, developed a blockchain platform which enables households to trade energy.

This platform is used in Fremantle, Western Australia, where households generate solar energy and sell the excess to other households that offer to buy it [69]. Similarly to Power Ledger, the Brooklyn Microgrid represents another successful implementation of P2P energy trading. In Brooklyn, New York, neighbors use solar panels to generate energy and trade surplus with each other through the blockchain platform [70]. Enerchain is yet another proof that blockchain-based solutions for P2P trading can be successful, even though it works differently than Power Ledger and Brooklyn Microgrid. Enerchain is not intended for energy trading between neighbors but between energy companies. It has been implemented in Europe, where 45 leading energy companies participate in decentralized electricity and gas trading [71].

Blockchain solutions can encourage users to produce or consume energy from renewable sources by issuing digital tokens as rewards. NRGcoin and SolarCoin are both blockchain-based digital currencies that serve as great examples of token-based reward systems. A user is awarded one NRGcoin for every kilowatt-hour (kWh) of green energy supplied. These tokens can then be sold in currency markets or traded for green energy consumption [72]. On the other hand, SolarCoin is promoting only solar energy production and awards a user with a SolarCoin (SLR) for every megawatt-hour (MWh) of verified solar energy produced [73].

Although energy management systems based on blockchain technology offer several advantages, they also face certain challenges and drawbacks. One of the problems with blockchain technology is that some of the algorithms it uses, such as the proof-of-work consensus mechanism, require substantial energy. Specifically, the traditional auction methodologies used in these P2P trading platforms demand significant computational power, resulting in considerable energy usage. This high energy consumption directly opposes some of the reasons for implementing these blockchain solutions in the first place. As a result, researchers are currently exploring more effective decentralized auction methods for energy-trading applications [74]. Regulatory and legal challenges present additional barriers to the widespread adoption of this technology.

Current regulations in many areas prohibit consumers from trading electricity directly with one another. For example, the application of blockchain technology in China is hindered by the country's monopolistic energy supply market structure, although the growing clean energy sector presents a significant opportunity for implementing blockchain [75]. In addition, the adoption of blockchain technology may require costly new infrastructure, including specialized hardware and software. Currently, smart meters deployed in the energy industry lack significant computational capability. Consequently, integrating the existing smart metering and grid infrastructure with distributed ledgers can result in substantial expenses [64].

In conclusion, the adoption of blockchain technology and the transformation of centralized energy systems are still in the early stages, with new research consistently being published. Many challenges still need to be addressed. However, the successful real-world implementation of various solutions has shown that this technology has the potential to support the creation of decentralized energy systems and smart cities [64].

4 DISCUSSION AND CONCLUSION

In this paper, we reviewed the current body of research on the application of blockchain technology in development of smart cities. Focus of the research was on five distinct sectors of a smart city, including waste management, finance, voting systems, real estate, and energy management.

Our research showed that blockchain brings significant improvements in security and transparency across various sectors. By decentralizing data storage and eliminating intermediaries, blockchain enhances trust and accountability, which is particularly beneficial in fields such as finance, voting, and waste management. The ability to create tamper-proof records ensures fraud prevention and reduces the risk of manipulation, which is a crucial advantage over traditional systems. Additionally, blockchain's transparency fosters greater public trust, as citizens and organizations can verify transactions and activities without relying on a central authority.

Despite these advantages, adoption remains limited, with most solutions still in the prototype or pilot phase. Table 1 highlights that many blockchain applications in smart cities face scalability issues, regulatory challenges, and infrastructure costs that hinder widespread implementation. For example, while blockchain can streamline real estate transactions by reducing reliance on intermediaries, compliance with government regulations remains a major barrier. Similarly, in the finance sector, blockchain reduces cross-border payment fees and fraud risks, yet its

adoption largely depends on government incentives and acceptance. These findings suggest that while blockchain has the potential to improve urban management, its real-world implementation is still in its early stages.

A key observation across different fields is the distinction between permissioned and public blockchains. While Ethereum is commonly used for decentralized finance, incentive mechanisms, and peer-to-peer energy trading, Hyperledger Fabric is preferred in applications that require enterprise-level control and regulatory compliance, such as waste tracking and financial transactions within government systems. This suggests that blockchain adoption in smart cities will likely follow a hybrid approach, where both permissioned and public blockchains coexist depending on the specific use case and regulatory requirements.

The impact of blockchain varies across sectors, introducing new functionalities and efficiency improvements. In waste management, blockchain enables tokenized incentives for recycling and automates compliance enforcement. In voting systems, blockchain eliminates the need for a trusted authority, ensuring privacy, security, and fraud prevention, although scalability remains a challenge. Similarly, in real estate, blockchain enhances efficiency in property transactions but still requires high levels of coordination due to legal and regulatory constraints. The energy sector benefits from peer-to-peer energy trading, allowing for decentralized energy markets that optimize grid efficiency and reduce costs. Across all these applications, blockchain offers fraud prevention, automation, and cost reductions, demonstrating its broad applicability to smart city development.

However, one of the most pressing challenges remains scalability. Table 1 indicates that every sector, but real estate, faces issues related to handling high transaction volumes, which limits the practicality of blockchain in large-scale applications. Blockchain networks such as Ethereum are still working on scaling solutions, but current limitations prevent them from fully replacing traditional centralized systems. Additionally, regulatory

Table 1 Overview of Blockchain Applications and Adoption and legal barriers continue to slow adoption, particularly in finance, real estate, and voting, where government intervention is necessary.

Future research should focus on developing scalable blockchain solutions while addressing regulatory and security challenges. Additionally, further exploration is needed on how blockchain can be seamlessly integrated into existing city infrastructure and how to develop more energy-efficient solutions to enhance sustainability. Nevertheless, substantial research efforts and a handful of successful real-world implementations of blockchain-driven solutions indicate that this technology will play a critical role in the future development of smart cities.

Sector	Benefits	Challenges	Technology	Impact	References
Waste Management	Improved transparency and tracking, introduction of incentives and penalties	Scalability, regulatory compliance, IoT integration, adoption rate	Ethereum, Hyperledger Fabric	Incentives, compliance	Mostly in research
Finance	Improved transparency, prevents money laundering, money embezzlement and fraud, lowers transaction cost, improves credit score calculation	Regulatory compliance, scalability	Permissioned blockchains, e.g. Hyperledger Fabric, Quorum	Money laundering, embezzlement and fraud elimination, cheaper transactions, precise credit scores	Mostly in industry
Voting	Improved anonymity, automated and precise vote counting, fraud prevention	Privacy, transparency, scalability	No technologies are standing out as favorites	Automated and precise vote counting, fraud prevention	Mostly in research
Real Estate	Reduced costs and time required, introduces partial real estate ownership	Regulatory compliance, adoption	Ethereum, LTO network	Partial real estate ownership	Mostly in research
Energy Management	Improved transparency, lower costs, minimal transmission losses, optimal grid efficiency	Transaction energy consumption, costly infrastructure, regulatory and legal challenges	Ethereum, Hyperledger Fabric	Incentives	Mostly in research

Acknowledgements

This research has been supported by the Ministry of Science, Technological Development and Innovation (Contract No. 451-

03-137/2025-03/200156) and the Faculty of Technical Sciences, University of Novi Sad through project "Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad 2025" (No. 01-50/295).

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PPG signal analysis and wavelet selection for feature extraction

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Abstract: Biomedical signals or biosignals are spatial, temporal or spatio-temporal records of a biological phenomenon. Biosignals contain information that is of great importance for understanding the specific physiological mechanisms of biological phenomena or the systems from which they originate. Signals provide important information about the internal state of organs, response to external stimuli, general state, general state of health and the state of various other parameters and are an indispensable part of modern medical diagnostic practice. The signal that arises as a result of the device's action on the organism, the subject of this paper, is the signal obtained by the photoplethysmography (PPG) method. Certain artificial intelligence methods were used to analyze the PPG signal. In this paper, analysis using wavelet transformation will be used, and a special focus will be on the selection of wavelets (wavelets) that will be used for the purpose of machine learning.

Keywords: characteristic parameters, diastolic peak, photoplethysmography (PPG), pulse width, machine learning, systolic peak, wavelet transform

1 INTRODUCTION

The biomedical signals that are the subject of analysis in this paper were obtained using the photoplethysmography (PPG) technique. PPG is a simple technique used to detect and monitor changes in blood flow in peripheral blood vessels. The measurement is performed on the surface of the skin. The PPG probe consists of an infrared light source (e.g. a photodiode emitting light at a wavelength of 900 nm) and a photodetector (eg a phototransistor). Plethysmograph (eng. plethysmograph) is a word created by the combination of two Greek words - 'plethymos' which means increase, amount, filling and 'graph' which means writing, recording and is a measuring method or instrument for measuring fluctuations (ripples) in the volume of a part of the body or organs.

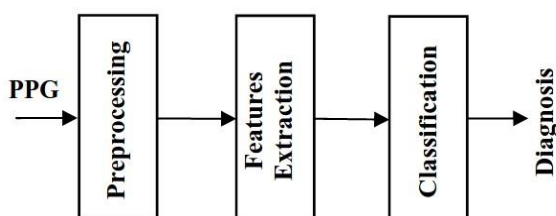


Figure 21: Processing of PPG signals

Photoelectric plethysmography is also known as photoplethysmography and PTG/PPG is its acronym in some literature. In this work, the abbreviation PPG is used.

Pulse photoplethysmography includes the method of measuring plethysmography. A photoelectric transducer placed on the skin measures the volume

pulse in the peripheral parts of the blood vessels. Corresponding volume pulsations modulate the exposed light beam of incoming infrared light, resulting in changes in intensity. They are measured with a phototransistor/photocell/photoresistor. Further processing of intensity changes in the gain stage leads to a visible image of the pulse curve.

The method of photoplethysmography is based on the procedure of measuring the pulse wave in the capillary area. The measurement parameters are the height of the amplitude and the analysis of the pulse waveform, which depend on the increase of the delay time - the beginning of the QRS complex to the beginning of the pulse, the peak time - the beginning to the end of the pulse and the slope time - the time of the rise of the pulse should be determined taking into account the steepest slope.

Dicrotism in the descending part of the curve is also important. [1] [2] [3] [16]

PPG is an easy to set up, efficient device compared to other types of plethysmography [4]. It does not require direct contact with the surface of the skin, as with some other plethysmograph methods.

Hertzman was the first to observe the relationship between the intensity of backscattered light and the volume of a fluid in 1938. [5] This useful simple method based on optical technology provides a significant contribution in health care (eg in primary care where precise and simple diagnostic techniques are desired).

Further development of PPG places this methodology among the more important tools used in the diagnosis of vascular diseases.

The contour of the PPG signal curve (Figure 2) is simple and can be divided into two phases:

- anakrotic phase - at the rising edge of the pulse and is associated with systole
- catacrotic phase - at the falling edge of the pulse and is associated with diastole.

Dicrotic notch appears in the catacrotic phase and is present in subjects with preserved - healthy arteries.

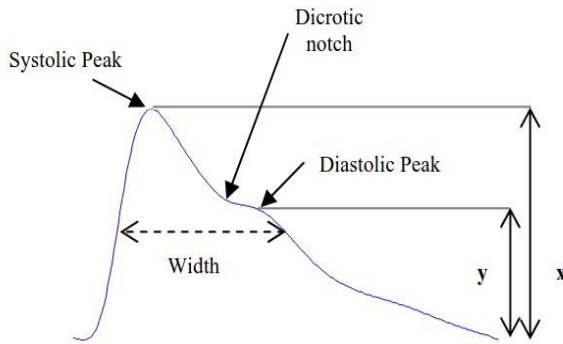


Figure 22: Characteristic parameters of the PPG signal - systolic, diastolic peak and pulse width

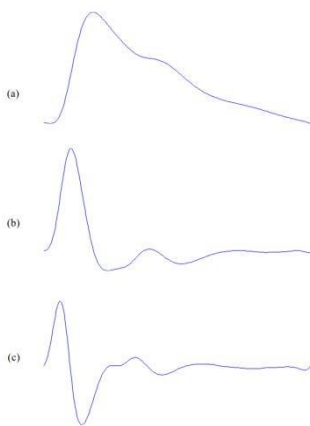


Figure 23: (a) PPG signal, (b) first derivative of PPG signal, (c) second derivative of the PPG signal

The analysis of PPG waveform itself attracts a lot of attention, especially from the aspect of monitoring circulation [6] and respiratory characteristics. [7] The PPG signal curve (Figure 2) can be defined and described with several parameters (characteristic parameters):

1. **Systolic amplitude** - x is an indicator of the change in the amount of blood in the arteries and blood vessels near the place where the measurement is performed. It has been shown that it is suitable for continuous determination of blood pressure. [8]
2. **Pulse width** - it is determined at half the height of the systolic amplitude (peak). It has been shown that it is correlated with systemic vascular resistance, i.e. the resistance that must be overcome in order for the blood to move through the bloodstream. [9]
3. **Pulse area** - is defined as the total area under the PPG pulse (Figure 4). In some studies, this area is divided into two parts in relation to a discrete section [10], whereby the ratio of these two surfaces is used as an indicator of peripheral resistance, i.e. resistance of arteries to blood flow. This relationship is denoted by IPA - Inflection Point Area, $IPA = A2/A1$, (In the literature, Wang states, [10]).

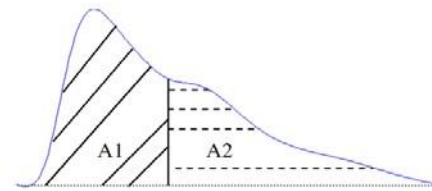


Figure 24: Characteristic parameters of the PPG signal - pulse area

4. **The interval between two peaks** - The time interval between two adjacent P peaks. The R-R interval in the ECG signal is correlated with the P-P interval in the PPG [11] (Figure 5).

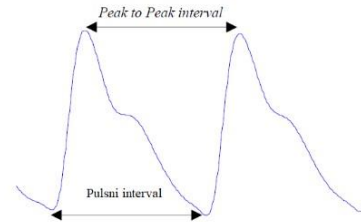


Figure 25: The interval between two adjacent pulses

5. **Pulse interval** - The difference between the beginning and end of the PPG pulse (Figure 5). It is usually used in the analysis when the diastolic segment is more clearly defined and easier to observe compared to the systolic part. [12]
6. **Augmentation index** - Pressure increase AI is a measure of the impact of the return wave on the systolic arterial pressure, it is obtained by measuring the reflected wave that goes from the periphery to the center. Pressure increase is obtained using the formula $AI = y/x$, where y is the height of the diastolic and x is the height of the systolic peak during one pulse (Figure 2) [13]. An alternative formula is also sometimes used in the literature $AI = (x-y)/x$ (Rubins mentions in the literature, [14]).
7. **Index of stiffness of large arteries** - The time delay between the systolic and diastolic peaks (Figure 6) is related to the transit time of the pressure wave from the origin of the subclavian artery to the visible point of rejection and back. The length of this path is proportional to the height of the subject - h , this leads to the formulation of the contour index of the PPG signal SI, so it can be defined as $SI = h/\Delta T$ (Millasseau mentions in the literature, [15]).

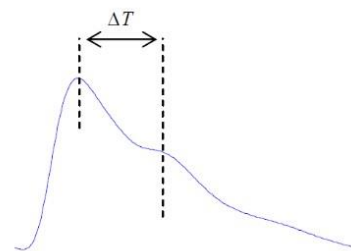


Figure 26: Time delay between systolic and diastolic peak ΔT

Although the curve of the PPG signal is simple, the analysis of the curve is quite complicated because it is not easy to detect changes in the region of the inflection point. For this reason, Takazawa [13] introduced the first and second derivatives of the PPG signal to facilitate the interpretation of the original signal and to facilitate parameter estimation.

In this paper, the topic of discussion is pre-processing, extraction features and parameter estimation using the wavelet transform - WT.

Wavelet transform is often used for representing complex signals and extracting their important features. This transformation is an important link in the development of various techniques that can be significant for specific applications, such as clinical practice in medicine.

In this paper, it is assumed that the PPG signal can be efficiently analyzed using the discrete wavelet transform.

A connection between the PPG signal and the application of discrete wavelet transformation is assumed in order to better visualize its content and estimate the parameters important for diagnosis.

The aim of this work belongs to the domain:

- Development, testing and addition of software in Python for PPG signal analysis.
- Application of wavelet transformation to PPG signal, analysis and application of results.
- Analysis of the results obtained by applying the theory of artificial neural networks to: PPG signal, to coefficients obtained by wavelet transformation.
- Generation of ANN models based on PPG wavelet transform coefficients.
- ANN model and prediction testing.
- Development of new methods for evaluating results and applications.

2 APPLICATION OF WAVELET TRANSFORM IN ANALYSIS OF PPG SIGNAL

2.1 Introduction to wavelet transform

Using the Fourier transform, the signal can be decomposed into spectral components. The problem with the Fourier transformation is that the time resolution is completely lost, which is not favorable for the analysis of non-stationary signals. For this reason, transformation methods were developed that would provide data on both the time and the frequency of an individual component. Two such methods are:

- Short Time Fourier Transform - STFT
- Wavelet transform - WT

The goal of such analyzes is to enable the simultaneous monitoring of both frequency and time signals by displaying the signal energy distribution in the time-frequency plane. The wavelet transform has

emerged as an alternative to the longused STFT. The difference is that STFT offers analysis with an absolute constant range, while WT presents an analysis with a constant relative range, i.e. a constant Q factor.

The wavelet transform can be seen as a decomposition of the signal into a series of basic functions (wavelets) obtained from one prototype. By correcting (shortening) or dilating (stretching) and shifting in time the basic wavelet, a series of analyzer functions is obtained.

The wavelet prototype can also be interpreted as a bandpass filter. As a consequence of the constant Q factor, the other filters will also be a scaled version of the prototype in that case.

The wavelet method can be applied to both continuous and discrete signals. In STFT, the non-stationary signal is divided into segments with assumed stationarity and the Fourier transformation is applied to the segments thus separated.

The signal $ss(tt)$ is divided by a function $gg(tt-\tau\tau)$ into segments, where τ represents the time location of the window.

STFT is actually a Fourier transform of a windowed signal $xx(tt)gg(tt-\tau\tau)$ or inner product between the signal and the window:

$$SSTTFFT(\tau\tau, ff) = \int xx(tt)gg(tt-\tau\tau)rr^{-2i\pi nfft}rrtt \quad (1)$$

this equation represents the signal as a two-dimensional function in the time-frequency plane (τ, f) .

The wavelet transform is defined from the base wavelet ψ , which represents the analyzer function located at the same time in the time and frequency plane. From this basic wavelet, by scaling (parameter α) and translation in time (parameter τ), a series of analyzer functions is obtained.

The inner product of the signal and the wavelet sequence gives the Wavelet transform:

$$WWT(\tau\tau, \alpha\alpha) = \int xx(tt) \tau\tau, \alpha\alpha(tt)rrtt \quad (2) \text{ gde je}$$

$$\tau\tau, \alpha\alpha(tt) = \alpha\alpha^{-1/2} / tt - \tau\tau\alpha\alpha \quad (3)$$

Wavelet extracts time-frequency (via scaling parameters) information from the signal via the inner product between the signal and the scaled version of the wavelet.

Wavelet analysis results in a series of wavelet coefficients that show how close the signal is to a single basis function. In this way, it can be expected that any signal can be decomposed into a series of wavelets, that is, that the original form of the signal can be obtained by synthesis, by adding elementary blocks of constant shape but also of different sizes and amplitudes.

[18] [19] [20] [21]

2.2 Applying the wavelet transform

In this paper, an integrated function is presented for signal decomposition in the Python programming environment. The integrated function used for PPG signal decomposition is a function from the modwtpy library: `coef = modwt(x, waveletname, nLevel)`. `modwt` (maximal overlap discrete wavelet transform) is a function of the discrete wavelet transform with the

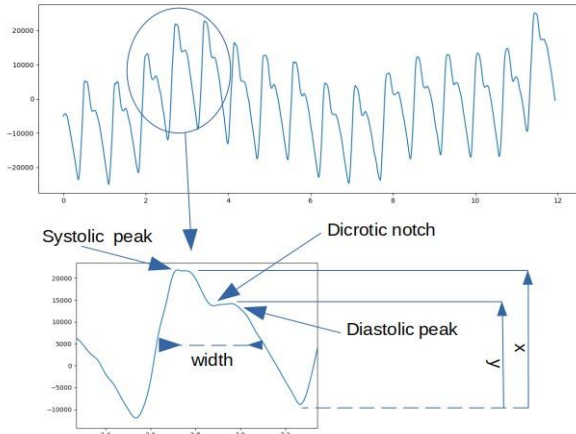


Figure 27 Original signal and characteristic parameters

By applying the Fourier transformation to the PPG signal (Figure 7), four dominant frequency peaks can be discerned (Figure 8).

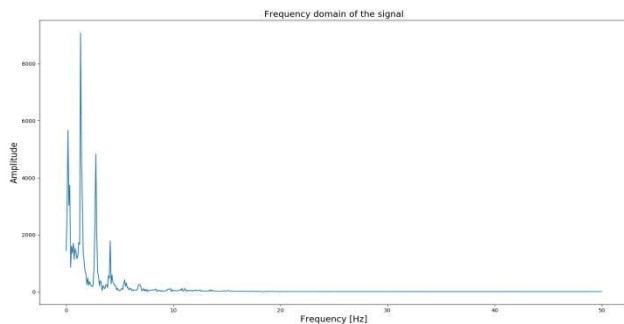
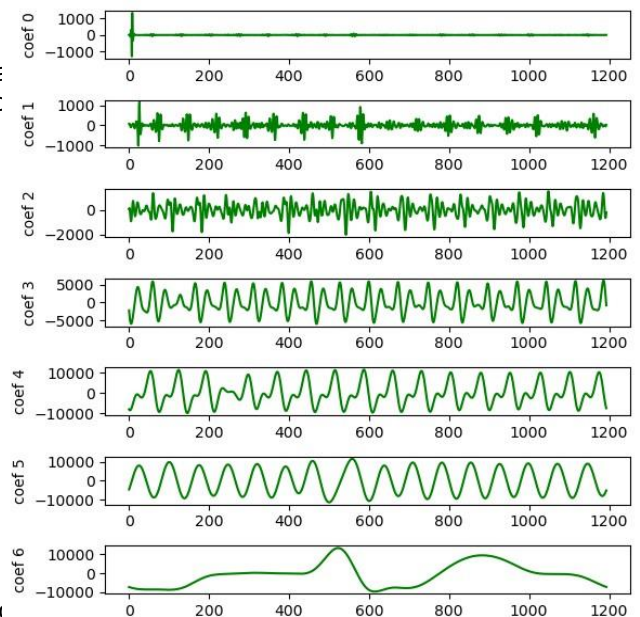


Figure 28 Frequency domain of the original signal

WT and signal decomposition using `modwt` function is shown (Figure 10). In this example, 7 levels of decomposition were performed using the `rbio6.8` basic wavelet (Figure 9).

maximum number of overlaps, i.e. a series of wavelet coefficients (`nLevel` can be pre-defined - the signal decomposition level). The parameter `x` is the input signal to be decomposed, `waveletname` represents the base wavelet used in the decomposition. The output quantity is a matrix of coefficients where the rows of the matrix represent a series of coefficients of functions that were created by decomposition. The analyzed signal is a PPG signal that was created using photoplethysmography (Figure 7). [28]



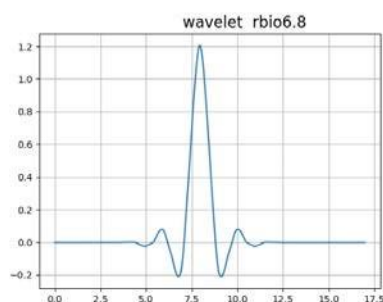
be concluded that the decomposed signals can be divided into those with high frequencies and those with low frequencies.

Modification and shortening of coefficients:

```
{coef 0, coef 1, coef 2, coef 3, coef 4, coef 5, coef 6}
->
-> {mod coef 0=0, mod coef 1=0, mod coef 2=0, mod
coef
      3=coef 3, mod coef 4=coef 4, mod coef 5=coef 5,
      mod coef 6=0}
```

Signals with high or very low frequencies can be removed as irrelevant components for PPG analysis (Figure 11).

Figure 30: WT transformation coefficients



Elimination of HF noise, i.e. modification of coefficients with high or low frequency can be done using thresholding. Noise removal by applying a threshold should be carried out by making a compromise between the presence of noise and changes in important signal characteristics.

Figure 29: rbio6.8 wavelet

By changing wavelet transform coefficients {coef 0, coef 1, coef 2, coef 3, coef 4, coef 5, coef 6} the reconstructed signal will differ from the original.

Preprocessing in the WT domain can be done in three steps:

1. signal decomposition (Figure 10) ,
2. modification of the obtained coefficients (Figure 11),
3. signal reconstruction based on modified coefficients (Figure 12).

If the characteristic signals created by decomposition (Figure 10) are compared with the frequency domain (Figure 8), it can

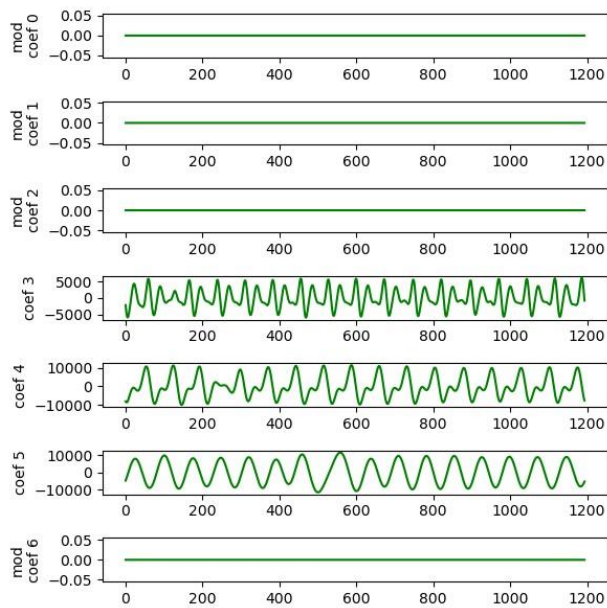


Figure 31: Modified WT transformation coefficients

The frequency domain of the reconstructed signal contains 3 peaks (Figure 13) of corresponding signal frequencies with modified coefficients (Figure 12). It can be assumed that these 3 signals (Figures 14, 15) are directly related to PPG characteristic parameters such as (Figure 16):

- Systolic amplitude,
- pulse width,
- pulse area,
- interval between two peaks,
- pulse interval,
- index of increase,
- stiffness index of larger arteries, etc...

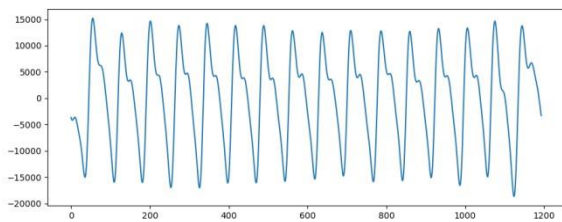


Figure 32: Reconstructed signal

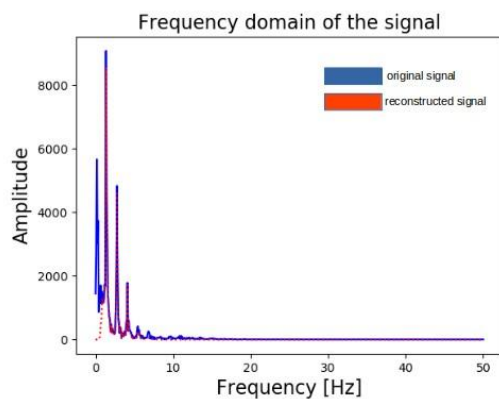


Figure 33: Frequency domain of the original and reconstructed signal

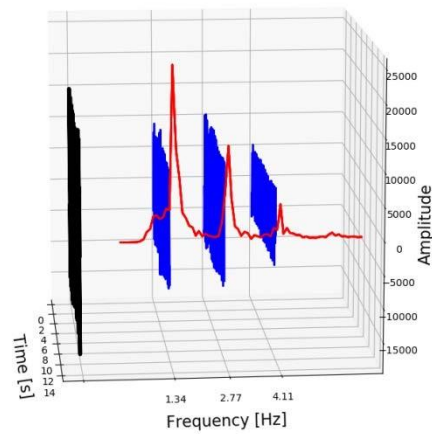


Figure 34: A reconstructed signal consisting of 3 component signals of different frequencies

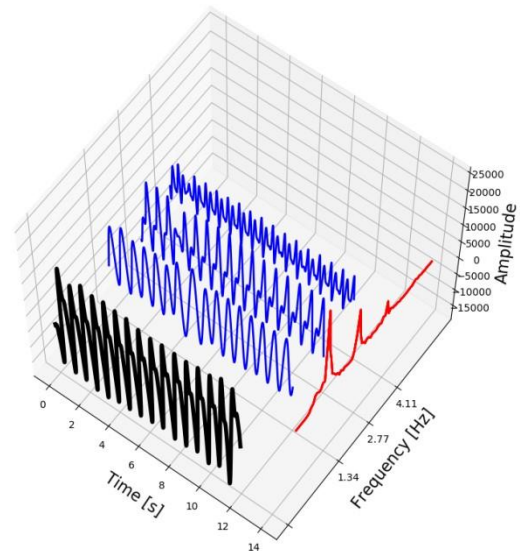


Figure 35: A reconstructed signal consisting of 3 component signals of different frequencies

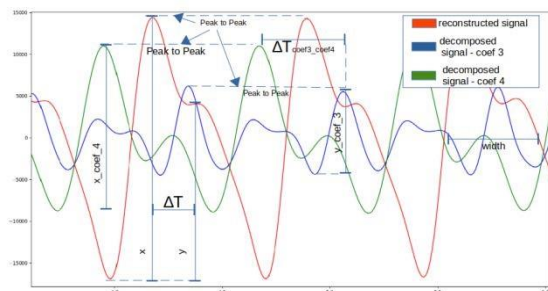


Figure 36: Comparing the basic signal and the signal obtained by decomposition

2.2.1 Conclusion of application of wavelet transformation

Based on the exposed properties of the wavelet transform, it can be concluded that there is a great potential application of this method in the analysis of PPG signals.

It can be assumed that the signal coefficients coef 3, coef 4 and coef 5 are relevant for PPG analysis and estimation of characteristic parameters. By accessing databases and measured PPG signals, it can be determined whether there is a direct connection between e.g. (Figure 16):

- x_coef_4 and x (systolic amplitude),
- y_coef_3 and y (diastolic amplitudes),
- $\Delta T\_coef\_3\_coef\_4$ and ΔT (the ratio of the ΔT transformation coefficients and original signal),
- Peak to Peak analysis of the original signal and signals obtained by wavelet decomposition, etc...

Wavelet transformation can determine in a compromise way when certain changes occur in the signal and what their frequency content is, which represents the basic parameters in any signal analysis. This analysis proved to be more efficient than the conventional method for time-frequency analysis with a constant range. WT favors time resolution when analyzing high frequencies, that is, frequency resolution at low frequencies, in contrast to STFT, which has a constant resolution in the time and frequency domains. WT provides percentage constant range analysis which makes this transformation very suitable for PPG signal analysis.

This type of analysis is most suitable for signals consisting of high-frequency components of short duration and low-frequency components of long duration, which makes this transformation very effective for the practical application of PPG signal analysis in practice. PPG signals are characterized by a certain harmonic content followed by relatively fast transients where WT is very suitable for analysis.

The assumed characteristic parameters of PPG signals obtained by WT should be compared with other methods by accessing databases and measurements of biomedical signals and their direct connection should be confirmed, which would result in the development of this method for analysis, processing and creation of new algorithms based on WT for the most accurate and successful extraction of parameters for reliable analysis.

3 WAVELET SELECTION FOR PPG SIGNAL ANALYSIS - TEST AND RESULTS

Based on the conclusions and assumptions from the previous chapter, that the wavelet transformation is suitable for detailed analysis of PPG signals, in this chapter the focus will be on choosing an adequate wavelet from the wide range of built-in wavelet functions available in the Python program. The selected wavelet or several wavelets, which prove to be adequate for the estimation of characteristic parameters, will be used in the transformation and tested on PPG signals.

In order to support these assumptions with a practical example, this paper will attempt to extract the AI parameter (Augmentation index). The AI parameter in combination with other characteristic parameters can be an important factor in the method for assessing the subject's condition based on the characteristics of the PPG signal. The extraction of other characteristic

parameters with the help of wavelet transformation is a topic for further work in this area. [13] [14] In the method used in this example, it is assumed that:

1. The characteristic parameters of the PPG signal can be obtained by wavelet transformation. If a wavelet transformation is performed on the signal, then the transformation coefficients are directly related to the characteristic parameters of the PPG signal (assumption).
2. In the example, it was assumed that: if a wavelet transformation of level 7 is performed on the signal, then the transformation coefficients 2 and 3 are directly proportional to the characteristic parameters of the PPG signal such as: systolic and diastolic 'peak' and that in this way these parameters can be extracted from the signal. A more detailed analysis of the stated assumption under point 2 is a topic for further work in this area.
3. Assumption: if the PPG signal is "typical" then it is $AI = y/x$ (AI - *Augmentation index*), where y is the diastolic 'peak' and x is the systolic 'peak', then it is $0 < AI < 1$.

Below is an example of a method for selecting and testing wavelets while confirming some of the above assumptions. The display of wavelet testing for PPG signal analysis will be performed on the example of generating a neural network model for predicting the age of the subject based on PPG signals. In this example, a wavelet transformation (level 7) was performed on the PPG signals.

When generating the inverse wavelet transform, coefficients 2, 3 will be used. The entire procedure, as well as the Python programming tools that were used, will be described in the following sections.

The program code used in this example is thematically divided into 5 Python scripts:

1. "moderated_excel" - code for generating a file with PPG signals suitable for further processing;
2. Wavelet selection - code to test about 23 embedded wavelets in Python on 11 selected "typical" PPG signals;
3. Wavelet transformation - code for performing wavelet transformation on a file from "sorted excel" using the selected wavelet, generates a file with transformed PPG signals;
4. generation of a neural network model for prediction where a file with transformed PPG signals is used to train the network;
5. testing the prediction network on files with PPG signals;

Python scripts are described in the following chapters along with comments and analysis of the tests and results.

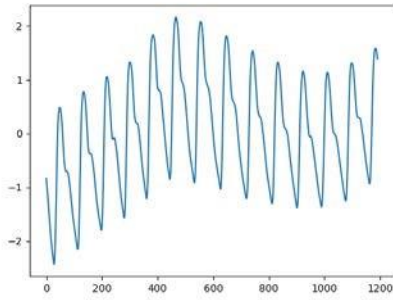


Figure 37: PPG signal

3.1 Preparing the file using a Python script

Data on PPG signals - measured PPG signals [28] - are prepared in a suitable structure suitable for further processing. The most convenient data structure for displaying PPG signals and applying a wavelet transform to them is a sequence of numbers. Below is a presentation of the DB preparation code that generates a *.csv file with PPG signals ready for further processing:

```
import pandas as pd
import numpy as np
import random as rand
import matplotlib.pyplot as plt
import pywt

# read the excel file df =
pd.read_excel('./db1.xlsx'); # extract ID and age
columns id_age_df = df[['data_id', 'age']]; # extract
PPG data columns ppg_data_df = df.iloc[:, 2:] #
Select columns from C onwards # Create a new
DataFrame with ID, age, and PPG data output_df =
pd.DataFrame(columns=['id', 'age', 'data']); for idx,
row in id_age_df.iterrows():
    data_id = row['data_id']; age = row['age']; ppg_data =
    ppg_data_df.iloc[idx].dropna(); ppg_data = pd.to_numeric(ppg_data, errors =
    'coerce'); ppg_data = ppg_data[~np.isnan(ppg_data)].tolist(); output_df =
    pd.concat([output_df, pd.DataFrame({'id': data_id, 'age': age, 'data': [ppg_data]})],
    ignore_index=True); # save the DataFrame to a CSV file
    output_df.to_csv('moderated_excel.csv', index=False); print('Data saved to
    moderated_excel.csv');
```

The result of executing this script is the PPG signals placed in a file "moderated_excel.csv".

	A	B	C	D	E	F	G	H	I	J							
1	id	age	data														
2	2013338	0.3	-2075,	-1009,	28,	1037,	1990,	2858,	3603,	4160,	4528,	4707,	4745,	4650,	4471,	4245,	400
3	2013323	0.34	-11627,	-11584,	-11670,	-12006,	-12696,	-13626,	-14522,	-15108,	-15323,	-15364,	-15539,	-15539,	-15539,	-15539,	-15539
4	2018532	0.35	18174,	17403,	16653,	15922,	15212,	14543,	13914,	13336,	12809,	12312,	11835,	11369,	10904,	10427,	9950
5	2018531	0.57	-13403,	-11313,	-9301,	-7451,	-5849,	-4402,	-2937,	-1284,	539,	2235,	3502,	4119,	4188,	36	
6	2018521	0.49	-18072,	-19190,	-20238,	-21126,	-21795,	-22065,	-21566,	-19909,	-16744,	-12222,	-7072,	-2			
7	2018515	0.65	-3533,	-4546,	-5471,	-6206,	-6683,	-6912,	-6961,	-6902,	-6792,	-6653,	-6514,	-6395,	-6335,	-6288,	-6241
8	2018524	0.58	-16051,	-16536,	-17030,	-17525,	-18051,	-18587,	-19144,	-19721,	-20298,	-20835,	-21288,	-21765,	-22242,	-22719,	-23196
9	2018532	0.35	18174,	17403,	16653,	15922,	15212,	14543,	13914,	13336,	12809,	12312,	11835,	11369,	10904,	10427,	9950
10	2018514	0.65	-396,	-1145,	-1885,	-2625,	-3365,	-4068,	-4727,	-5304,	-5801,	-6252,	-6685,	-7145,	-7650,	-8155,	-8660
11	2018522	0.49	-8398,	-8751,	-9104,	-9466,	-9838,	-10209,	-10609,	-11027,	-11473,	-11956,	-12476,	-13043,	-13616,	-14189,	-14762
12	2018511	0.46	16104,	15677,	15260,	14865,	14502,	14181,	13925,	13754,	13648,	13583,	13530,	13466,	13402,	13338,	13274
13	2018490	0.31	-25000,	-23521,	-21599,	-18827,	-14824,	-9936,	-4976,	-717,	2391,	4427,	5499,	5729,	5313,	4883,	4453
14	2018489	0.59	-15756,	-16114,	-16442,	-16681,	-16810,	-16870,	-16950,	-17129,	-17437,	-17786,	-18064,	-18342,	-18620,	-18898,	-19176
15	2018488	0.49	9998,	9615,	9161,	8555,	7736,	6659,	5386,	3988,	2510,	1041,	-356,	-1584,	-2590,	-3374,	-4158
16	2018487	0.4	-11070,	-9440,	-7910,	-6580,	-5520,	-4760,	-4250,	-3980,	-3900,	-3960,	-4110,	-4310,	-4520,	-4730,	-4940
17	2018485	0.57	-8132,	-8581,	-9040,	-9490,	-9949,	-10417,	-10886,	-11354,	-11833,	-12320,	-12817,	-13323,	-13830,	-14337,	-14844
18	2018482	0.54	7120,	6449,	5789,	5166,	4601,	4103,	3643,	3203,	2791,	2379,	1987,	1584,	1192,	828,	483
19	2018478	0.3	3244,	3092,	2940,	2747,	2523,	2300,	2117,	2026,	2016,	1955,	1731,	1264,	655,	66,	-370

Figure 38: PPG signals written in "moderated_excel.csv"

3.2 Wavelet transformation of the signal from DB

3.2.1 Analysis of signals from DB and selection of wavelets

It was assumed that if a wavelet transformation is performed on the 'typical' PPG signal (Figure 17), then the obtained transformation coefficients are directly proportional to the systolic and diastolic 'peak'. In order to confirm and test this assumption on a practical example, a database with 500 PPG signals will be used [28]. From this database by cursory analysis and random drawing (plt.plot fnc in Python) of signals 11 signals were selected which are approximate, i.e. most resemble a 'typical' PPG signal.

Selected signals (s_0....s_10, in total 11) where their serial numbers from the specified DB are written in a series of serial numbers named "test_samples":

```
test_samples = [480, 280, 264, 301, 55, 401, 198, 106, 110, 230, 101];
```

Figure 19 shows the signals s_0 do s_10 where s_0 is a signal 480 ..etc.. s_5 is a signal 401..etc..s_10 is a signal 101.

Wavelet transforms will be performed on each of these 11 PPG signals, using built-in wavelets available in the Python environment. The list of wavelets that will be used in testing (Figures 20, 21, 22) is defined as an array named "wavelet" with a total of 23 wavelets:

```
wavelet = ['db1', 'db3', 'db5', 'db7', 'sym2', 'sym3', 'sym5', 'sym7', 'coif1', 'coif3', 'coif5', 'coif7', 'rbio1.1', 'rbio1.5', 'rbio2.6', 'rbio3.3', 'rbio3.5', 'rbio3.7', 'rbio3.9', 'rbio4.4', 'rbio5.5', 'rbio6.8', 'dmev'];
```

Each of the selected 11 PPG signals will be transformed with each of these 23 wavelets and then inverse transformed so that there will be 23 'versions' of the transform for each signal. To obtain the AI parameter (AI = y/x, ratio of diastolic to systolic 'peak') will be used the ratio of the mean value of the signal amplitude obtained by inverse transformation of the coefficients "2" for the systolic 'peak' and the coefficients "3" for the diastolic 'peak'.

In this way, the AI calculation procedure will be repeated for each wavelet.

The AI parameter is relevant to the selection of the wavelet by assuming that if the wavelet is optimal then the ratio of the transformation coefficients obtained by this wavelet is: AI = y/x > 1.

If we assume that a 'typical' PPG signal has a pronounced diastolic 'peak', then the average amplitude of coefficients "3" divided by the average amplitude of coefficients "2" should limit to 1 (assumption in chapter 2.2.1).

Based on this criterion, in this work only based on graphical analysis, the wavelet would be selected (Figure 23, 24) which will be used during further analysis and testing and 'machine learning' analysis.

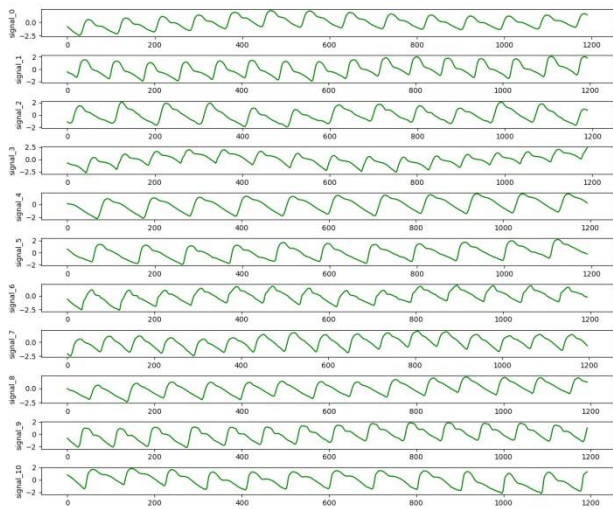


Figure 39: PPG Signals used for testing and selecting wavelets

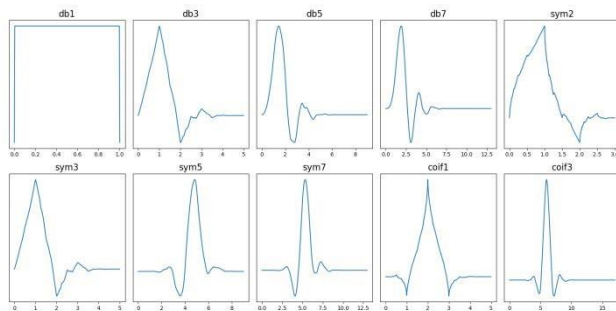


Figure 40: Tested wavelets

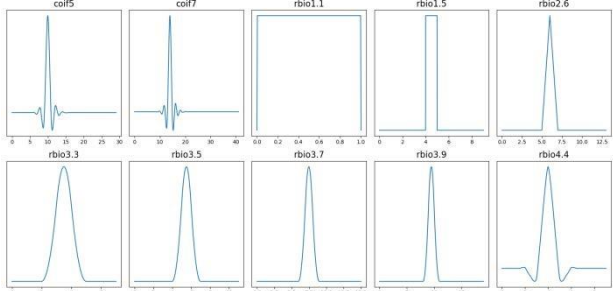


Figure 41: Tested wavelets

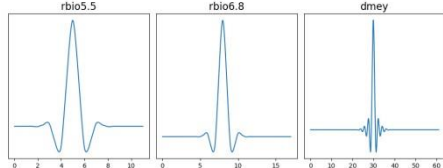


Figure 42: Tested wavelets

A preview of the Python script used to analyze the wavelet below:

```
import matplotlib.pyplot
as plt
import numpy as np
import pywt
import pandas as pd

mode = pywt.Modes.smooth
input_csv = "../moderated_excel_db1_500.csv"
# Normalizing
def normalize_ppg(ppg_signal):
    # Normalize all values to be between -1 and 1
    signal = ppg_signal;
    return (signal - np.mean(signal)) / np.std(signal)
# get ppg data from csv file
def get_ppg_data(input_csv, test_samples):
    input_df = pd.read_csv(input_csv, sep =
```

```
',' );
data_id = (input_df["id"])[test_samples];
data_age = (input_df["age"])[test_samples];
ppg_data = eval(input_df["data"])[test_samples];
return data_id, data_age, ppg_data
def signal_decomp(data, w, title):
    """Decompose and plot a signal S.
    S = An + Dn + Dn-1 + ... + D1
    """
    w = pywt.Wavelet(w)
    a = data
    ca = []
    cd = []
    for i in range(7):
        (a, d) = pywt.dwt(a, w, mode)
        ca.append(a)
        cd.append(d)
    rec_a = []
    rec_d = []
    for i, coeff in enumerate(ca):
        coeff_list = [coeff, None] + [None] * i
        rec_a.append(pywt.waverec(coeff_list, w))
        coeffs = []

    coeffs = cd.copy();
    coeffs.append(ca[6]);
    coeffs.reverse();
    return coeffs, rec_a, rec_d
def plot_signal_decomp(data, w, title):
    """Decompose and plot a signal S.
    S = An + Dn + Dn-1 + ... + D1
    """
    w = pywt.Wavelet(w)
    a = data
    ca = []
    cd = []
    for i in range(7):
        (a, d) = pywt.dwt(a, w, mode)
        ca.append(a)
        cd.append(d)
    rec_a = []
    rec_d = []
    for i, coeff in enumerate(ca):
        coeff_list = [coeff, None] + [None] * i
        rec_a.append(pywt.waverec(coeff_list, w))
        for i, coeff in enumerate(cd):
            coeff_list = [None, coeff] + [None] * i
            rec_d.append(pywt.waverec(coeff_list, w))
        coeffs = []

    coeffs = cd.copy();
    coeffs.append(ca[6]);
    coeffs.reverse();
    return coeffs

def signal_waverec(coeffs, wavelet, coeffs_to_rec):
    """waverec signal on coefficient base.
    coefficient choose with coeffs_to_rec
    S = An + Dn + Dn-1 + ... + D1
    """
    wavelet = pywt.Wavelet(wavelet)
    coeffs = coeffs.copy();
    v = coeffs_to_rec
    if (v[0]<1): coeffs[0] = np.zeros(len(coeffs[0]));
    if (v[1]<1): coeffs[1] = np.zeros(len(coeffs[1]));
    if (v[2]<1): coeffs[2] = np.zeros(len(coeffs[2]));
    if (v[3]<1): coeffs[3] = np.zeros(len(coeffs[3]));
    if (v[4]<1): coeffs[4] = np.zeros(len(coeffs[4]));
    if (v[5]<1): coeffs[5] = np.zeros(len(coeffs[5]));
    if (v[6]<1): coeffs[6] = np.zeros(len(coeffs[6]));
    if (v[7]<1): coeffs[7] = np.zeros(len(coeffs[7]));
    signal_rec = pywt.waverec(coeffs, wavelet);
    return signal_rec;
ppg_data = [];
test_samples = [480, 280, 264, 301, 55, 401, 198, 106, 110, 230, 101];
for index in range(len(test_samples)):
    ppg_data.append(get_ppg_data(input_csv,
```



```

test_samples[index]); wavelet = ['db1', 'db3', 'db5', 'db7', 'sym2',
'sym3',
'sym5', 'sym7', 'coif1', 'coif3', 'coif5', 'coif7', 'rbio1.1', 'rbio1.5', 'rbio2.6', 'rbio3.3',
'rbio3.5',
'rbio3.7', 'rbio3.9', 'rbio4.4', 'rbio5.5', 'rbio6.8',
'dmey']; plot_title = [ 'db1', 'db3', 'db5', 'db7', 'sym1',
'sym3',
'sym5', 'sym7', 'coif1', 'coif3', 'coif5', 'coif7', 'rbio1.1', 'rbio1.5', 'rbio2.6',
'rbio3.3', 'rbio3.5',
'rbio3.7', 'rbio3.9', 'rbio4.4', 'rbio5.5', 'rbio6.8',
'dmey']; #ppg signal information is "stored"
in signal_wt_data signal_wt_data = []; x_axis
= []; #x - wavelet y_axis = []; #y - ratio AI for i
in range(len(ppg_data)):
    wt_data_1 = []; coeffs =
    []; plot_AI_data_x = [];
    plot_AI_data_y = []; for
    index in range(len(wavelet)):
        signal = [];
        ppg_data_n = normalize_ppg(ppg_data[i][2]);
        coeffs.append(signal_decomp(ppg_data_n, wavelet[index], plot_title[index]))
        #coeffs.append(signal_decomp(ppg_data[i][2],
        wavelet[index], plot_title[index]))
        signal_0 = signal_waverec(coeffs[index][0],
        wavelet[index],
        [0,0,1,1,1,1,1,1]); signal_1 =
        signal_waverec(coeffs[index][0],
        wavelet[index], [0,0,1,0,0,0,0,0]);
        s_1_mean =
        np.mean(abs(signal_1)); signal_2 =
        signal_waverec(coeffs[index][0],
        wavelet[index], [0,0,0,1,0,0,0,0]);
        s_2_mean =
        np.mean(abs(signal_2)); signal_3 =
        signal_waverec(coeffs[index][0],
        wavelet[index], [0,0,1,1,0,0,0,0]);
        signal_rec = [signal_0, signal_1, signal_2,
        signal_3]; AI = s_2_mean/s_1_mean;
        signal_rec = [signal_rec, wavelet[index], AI]
        signal.append(signal_rec);
        plot_AI_data_x.append(wavelet[index]);
        plot_AI_data_y.append(AI);
        plot_AI_data = [plot_AI_data_x,
        plot_AI_data_y] #wt_data = [coeffs, signal,
        plot_AI_data]; wt_data = [coeffs, signal];
        wt_data_1.append(wt_data);
        #signal_wt_data.append(wt_data_1);
        wt_data_2 = [wt_data_1, plot_AI_data]
        signal_wt_data.append(wt_data_2); level =
        7;
        fig, axarr = plt.subplots((level+1), ncols=1,
        figsize=(12,12)); for i in range (level+1):
            axarr[i].plot(coeffs[1][0][i], 'g');
            axarr[i].set_ylabel("coeffs {}".format(i), fontsize=10,
            rotation=90); plt.tight_layout(); plt.show();
            coeffs_1, rec_a, rec_d = signal_decomp(ppg_data[0][2],
            'sym5', 'sym5'); plt.figure() for i in
            range(len(signal_wt_data)): x_axis =
            signal_wt_data[i][1][0]; y_axis = signal_wt_data[i][1][1];
            plt.plot(x_axis, y_axis, label="s_{}_d" % (i));
            plt.legend(loc='upper right') plt.show() fig, axarr =
            plt.subplots((len(ppg_data)), ncols=1, figsize=(12,12)); for
            iii in range (len(ppg_data)): signal_to_plot =
            normalize_ppg(ppg_data[iii][2])
            axarr[iii].plot(signal_to_plot, 'g');
            axarr[iii].set_ylabel("signal {}".format(iii), fontsize=10,
            rotation=90); plt.tight_layout(); plt.show();

```

Executing the above code generates a graph showing the ratio of amplitudes $AI = y/x$ for different types of wavelets. By simple analysis of the graph, it can be concluded that the ratio is amplitude $0 < AI < 1$. Values $AI > 1$ (values that limit according to 1) are grouped around wavelets rbior3.3 (Figure 21, 22). It is assumed that this wavelet is optimal for signal transformation, extracting characteristic parameters

and creating an ANN model on the basis of which the prediction will be made.

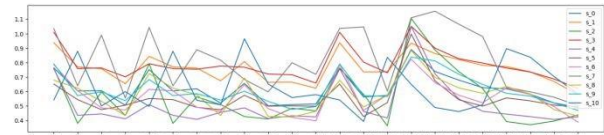


Figure 43: Display of ratio of amplitudes of coefficients [2] and [3] for different types of wavelets

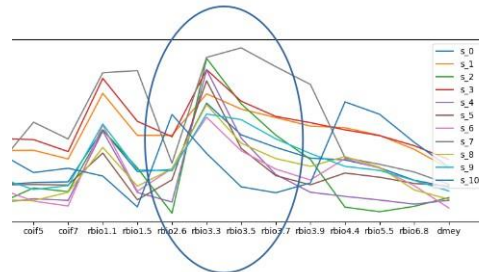


Figure 44: Display of ratio of amplitudes of coefficients [2] and [3] for different types of wavelets - more in detailmore in detail (rbio3.3)

3.2.2 Wavelet transformation of the signal from DB using the selected wavelet

The following example will show the generation of a file containing signals that have been wavelet transformed with the selected wavelet. The transformation will be performed as follows: PPG signal is transformed by wavelet transformation, transformation coefficients "0, 1, 4, 5, 6, 7" are modified ie. overwritten with 0 (Figure 25), the inverse transformation of the modified signals is performed, so that the reconstructed signal is used for training the network. In the example, two PPG signal files that were created by generating through the application listed in references [28], will be used:

1. File of 500 PPG signals
filename = 'moderated_excel_db1_500.csv'
2. File of 3000 PPG signals
filename = 'ppg_3000.csv'

```

import csv import pywt
import numpy as np
import matplotlib.pyplot
as plt import pandas as
pd # Normalizing def
normalize_ppg(ppg_sign
al):
    # Normalize all values to be between -1 and 1
    return 2.*(ppg_signal
    - np.min(ppg_signal))/np.max(ppg_signal)-1 # define
    the wavelet function and level of decomposition
    wavelet = 'rbio3.3'
    level = 7
    filename = 'moderated_excel_db1_500.csv'; # 1 DB
    outfile = 'wavelet_transformed_rbio3.3_level_7_db1_500.csv'; # transforma DB
    1
    #filename = 'ppg_3000.csv'; # 2 DB
    #outfile = '#wavelet_transformed_rbio3.3_level_7_ppg_3000.csv'; # transform
    #DB 2

```

```

# read the input csv file
with open(filename, 'r')
as file:
    reader =
    csv.reader(file)
    next(reader) # skip the header row if present
# create an output csv file for storing the
wavelet coeffs with open(outputfile, 'w',
newline='') as output_file:
    writer =
    csv.writer(output_file);
    writer.writerow(['data_id', 'age', 'data']);
    # write header
    row
    for row in reader:
        data_id = row[0]; age =
        row[1];
        ppg_data = eval(row[2]); # convert the string to a list
        # perform wavelet transformation coeffs =
        pywt.wavedec(ppg_data, wavelet, level=level);
        coeffs[0] = np.zeros(len(coeffs[0]));
        coeffs[1] =
        np.zeros(len(coeffs[1]));
        #coeffs[2] =
        np.zeros(len(coeffs[2]));
        #coeffs[3] =
        np.zeros(len(coeffs[3])); coeffs[4]
        = np.zeros(len(coeffs[4]));
        coeffs[5] =
        np.zeros(len(coeffs[5])); coeffs[6]
        = np.zeros(len(coeffs[6]));
        coeffs[7] =
        np.zeros(len(coeffs[7])); #
        inverse discrete wavelet
        transform ppg_rec =
        pywt.waverec(coeffs, wavelet)
        # normalize signal samples =
        normalize_ppg(ppg_rec); # convert the
        coefficients to a string representation
        coeffs_str = ','.join(str(c) for c in samples);
        # write the data to the output csv file
        writer.writerow([data_id, age, coeffs_str];
print('Inverse discrete wavelet transformation completed and saved to',
outputfile);

```

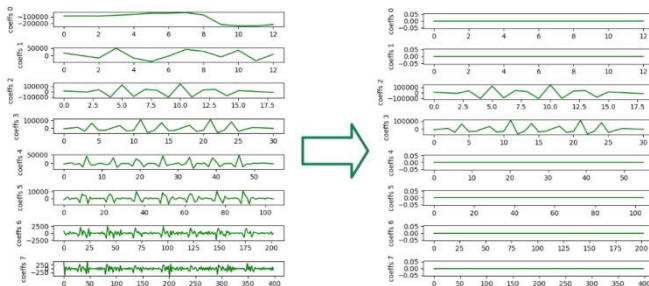


Figure 45: Modification of wavelet transform coefficients

3.3 Generating ANN models

A neural network is a machine learning model inspired by biological neural networks, consisting of sets of artificial neurons (often called layers) that process data and perform complex tasks such as classification, regression, shape recognition, prediction...etc.

In Python, neural networks can be implemented using various libraries such as TensorFlow, Keras, PyTorch, and others.[23] [24] [27]

The following code shows the generation of an ANN training model. [23] It could be said that training a prediction network and testing it on the same data is actually a methodological error: a model that just repeated the patterns it was just familiar with would have a perfect score, but it would fail to predict anything useful on the data it was unfamiliar with.

This situation is "jargonically" called "overfitting". To avoid this, it is common practice when performing

(supervised) network training, and to keep part of the available data as a test data set.

The following code shows the training of the network, where the transformed PPG signal file [28] from the previous section is used for training:

```

import ast import pandas as pd from
sklearn.model_selection import
train_test_split
from
tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense
from tensorflow.keras.utils import
pad_sequences

from keras.callbacks import History
history = History()

# load the .csv file
csv_waverec_file =
'wavelet_transformed_rbior3.3_level_7_db1_500.csv'; df =
pd.read_csv(csv_waverec_file);
# Convert 'Coefficients' from string to list using
ast.literal_eval df['data'] = df['data'].apply(lambda x:
ast.literal_eval(x));
sequences = df['data'].values;
# padding
X = pad_sequences(sequences,
maxlen=2000,
padding='post',
);

y = df['age'].values
X_train, X_test, y_train, y_test = train_test_split(X, y,
test_size=0.1, random_state=42);
# Model architecture remains the same model = Sequential()
model.add(Dense(200, input_dim=len(X[0]), activation='tanh'))
model.add(Dense(30, activation='sigmoid')) model.add(Dense(1))
model.compile(loss='mean_squared_error', optimizer='adam',
metrics=['accuracy']) model.fit(X_train, y_train, epochs=300,
batch_size=8) loss = model.evaluate(X_test, y_test) print('Test loss:',
loss)
output_file =
'../model/small_200_30_sigmoid_wt_rbior3.3_l_7_db_1_500_1_1.h
5'; model.save(output_file); print('model saved to', output_file);

```

Script execution:

```

57/57 [=====] - 0s 7ms/step - loss: 1.3101e-04
Epoch 284/300
57/57 [=====] - 0s 7ms/step - loss: 6.8416e-05
Epoch 285/300
57/57 [=====] - 0s 6ms/step - loss: 5.9931e-05
Epoch 286/300
57/57 [=====] - 0s 6ms/step - loss: 7.9257e-05
Epoch 287/300
57/57 [=====] - 0s 6ms/step - loss: 9.0686e-05
Epoch 288/300
57/57 [=====] - 0s 6ms/step - loss: 1.4148e-04
Epoch 289/300
57/57 [=====] - 0s 7ms/step - loss: 1.2856e-04
Epoch 290/300
57/57 [=====] - 0s 7ms/step - loss: 1.0635e-04
Epoch 291/300

```

Figure 46: Generating ANN models

3.4 Testing ANN models

Python code for predicting the subject's age based on the PPG signal transformed by wavelet transformation.

Testing the generated model from the previous section will be performed twice on two PPG signal files [28], variable `csv_waverec_file` will be defined in two ways: 1. File of 500 PPG signals

```

csv_waverec_file =
'wavelet_transformed_rbior3.3_level_7_db1_500.csv'

```


2. File of 3000 PPG signals

```
csv_waverec_file =
'wavelet_transformed_rbior3.3_level_7_ppg_3000.csv'

import csv
import pandas as pd
import matplotlib.pyplot as plt
from tensorflow.keras.utils import pad_sequences
from tensorflow.keras.models import load_model
from sklearn.metrics import mean_absolute_error, mean_squared_error

# load the model
model = load_model('../model/small_200_30_sigmoid_wt_rbior3.3_l_7_db_1_500_1.h5')

# load the .csv file
csv_waverec_file = 'wavelet_transformed_rbior3.3_level_7_db1_500.csv'; # 1 DB
#csv_waverec_file = 'wavelet_transformed_rbior3.3_level_7_ppg_3000.csv'; # 2 DB
input_data = pd.read_csv(csv_waverec_file); # extract data from the DataFrame
ppg_signals_wt = input_data['data'].apply(eval).tolist();
correct_ages = input_data['age'].values; data_id = input_data['data_id'].values;
ppg_signals_wt = pad_sequences(ppg_signals_wt, maxlen = 2000, padding = 'post');
# predict the age for each PPG signal
ages_predicted = model.predict(ppg_signals_wt)*100;
outputfile = '../prediction/prediction_rbior3.3_db_1_500_rbior3.3_level_7_db_2_308_1.csv'
y_true = []; y_pred = []; with open(outputfile, 'w', newline = '') as output_file:
    writer = csv.writer(output_file); writer.writerow(['data_id', 'actual_age', 'predicted_age']); # write header row
    for i in range(len(correct_ages)):
        print(f"Actual Age: {round(correct_ages[i])}, Predicted Age: {round(ages_predicted[i][0])}");
        # write the data to the output csv file
        writer.writerow([data_id[i], round(correct_ages[i]), round(ages_predicted[i][0])]);
        y_true.append(round(correct_ages[i]));
        y_pred.append(round(ages_predicted[i][0]));
    y_true_1 = y_true.copy(); y_pred_1 = y_pred.copy();
print('prediction saved to', outputfile); fig, ax = plt.subplots(figsize=(10,5))
ax.plot(range(len(y_true)), y_true, '-b', label='Actual')
ax.plot(range(len(y_pred)), y_pred, '-r', label='Predicted')
ax.legend(loc="lower right")
plt.show()
```

Executing scripts for a 500 PPG signal file:

```
.
.
data_id:2020564, Actual Age: 28, Predicted Age: 28
data_id:2020563, Actual Age: 36, Predicted Age: 38
data_id:2020571, Actual Age: 30, Predicted Age: 31
data_id:2020569, Actual Age: 45, Predicted Age: 43
data_id:2020564, Actual Age: 28, Predicted Age: 28
data_id:2020554, Actual Age: 30, Predicted Age: 31
data_id:2020543, Actual Age: 62, Predicted Age: 62
data_id:2020540, Actual Age: 64, Predicted Age: 72
data_id:2020539, Actual Age: 56, Predicted Age: 48
.
.
```

Figure 47: Testing the ANN prediction model on a file of 500 PPG signals

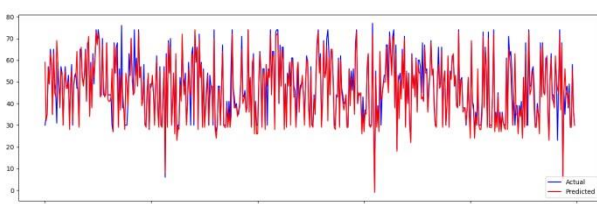


Figure 48: Testing the ANN prediction model on a file of 500

PPG signals Executing scripts for a file of 3000 PPG signals:

```
.
.
data_id:2510263.0, Actual Age: 73, Predicted Age: 37
data_id:2510262.0, Actual Age: 71, Predicted Age: 27
data_id:2510261.0, Actual Age: 23, Predicted Age: 37
data_id:2510260.0, Actual Age: 30, Predicted Age: 38
data_id:2510254.0, Actual Age: 54, Predicted Age: 31
data_id:2510252.0, Actual Age: 61, Predicted Age: 70
data_id:2510250.0, Actual Age: 45, Predicted Age: 33
data_id:2510248.0, Actual Age: 41, Predicted Age: 36
data_id:2510245.0, Actual Age: 30, Predicted Age: 37
.
.
```

Figure 49: Testing the prediction model on a file of 3000 PPG signals

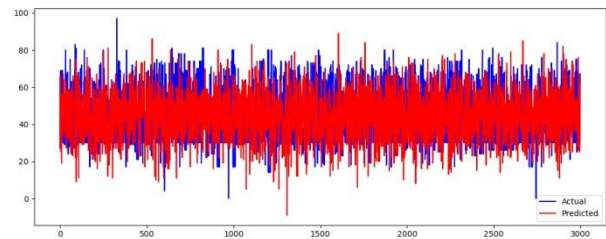


Figure 50: Testing the prediction model on a file of 3000 PPG signals

4 DISCUSSION

The analysis of PPG signals that evaluates biological age could play a vital role in smart city concepts by enhancing personalized health services. For example, cities could implement kiosks equipped with PPG sensors that automatically assess citizens' physical conditions and provide tailored health recommendations. These insights could be used to design preventive healthcare programs targeted at specific age groups or populations in need. Additionally, the data could aid public health management by identifying areas with higher health risks. This integration of PPG technology would foster cities that actively prioritize the well-being and longevity of their residents. This paper presents an introduction to the estimation of characteristic parameters of PPG signals with the help of wavelet transformation. In chapter 2, estimation methods are assumed, which can be considered as an introduction to further work in this area. Assumptions are tested in chapter 3 on the model of neural networks and predictions based on the characteristic parameter of AI. Rough testing was conducted. The results are shown in graphs (Figures 27-30) and can be considered as guidelines for the development of the methodology.

In Chapter 2 and the description of the wavelet transform on PPG signals, the built-in functions in Python "modwt" and "imodwt" for the inverse transform were used as an example. In chapter 3 and generating the wavelet transform on the PPG signal

file, the built-in functions "wavedec" and "waverec" were used for the inverse transform. In further works, the function "modwt" and "imodwt" can be used in testing in combination with the generation of neural network models. In the following works, methods for selecting wavelets that are adequate for the estimation of other characteristic parameters described in chapter 1.3 can be assumed. It does not necessarily mean that if a wavelet is suitable for extracting a characteristic parameter, it is automatically suitable for the next characteristic parameter (7 characteristic parameters are listed in chapter 1.3). Testing on neural networks can be very useful for confirming assumptions. Generation of neural network models based on other possibilities of wavelet transformation is also a topic for further work in this area.

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The Role of Organizational Culture in the Onboarding Process in Four Small IT Companies: A Qualitative Study

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Abstract: In the context of onboarding, which is the process of introducing new employees to the organization, organizational culture plays a key role because new employees first come into contact with specific values, norms, and behaviors that shape the working environment in the company. Onboarding is a process that allows new employees to understand its goals and culture, and successfully perform their tasks. This study examines the role of organizational culture in the onboarding process in small IT companies. Through qualitative interviews with four IT experts working in different companies, the research presents a thematic analysis of how onboarding is aligned with organizational culture. The research results show the role of organizational culture in the onboarding process in small IT companies. Participants pointed out that onboarding is crucial for introducing new employees to the organization and company culture. Communication is recognized as a central element that helps define and maintain culture, while HR (Human Resource) departments and mentors are identified as key factors in the integration of new employees. Also, challenges such as mismatch with organizational culture and lack of a formal culture framework in small companies were recognized as potential barriers to successful onboarding.

Keywords: *organizational culture, onboarding process, small IT companies, qualitative study*

INTRODUCTION

Introducing new employees (onboarding) is an important process that enables their adaptation to the work environment, where the organizational culture plays a significant role. During onboarding, new employees are introduced to the organization's values, norms, and behaviors, which affects their integration, motivation, and productivity (Bauer et al., 2021; Gibson et al., 2022). Organizational culture creates behavior patterns and enables employees to understand the goals and expectations of the organization (Smith et al., 2023).

The specifics of small software companies further highlight the importance of culture in this process. Small firms often operate through flexible structures, with a focus on innovation and close collaboration, but often lack formalized processes for onboarding and managing organizational culture (Turner & Zhao, 2022; Rogers et al., 2024). These circumstances make culture the basic mechanism for adapting employees and achieving organizational goals.

The main goal of this paper is to investigate the role of organizational culture in the onboarding process in small software companies through a qualitative analysis of employees' attitudes, with

a special focus on the influence of organizational culture on the success of this process (Bauer et al., 2021). This paper seeks to contribute to a

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better understanding of the relationship between organizational culture and the onboarding process, providing useful guidelines for improving these practices in the specific context of small IT companies.

THEORETICAL FRAMEWORK

2.1 Organizational culture

Organizational culture is a set of values, norms, beliefs, and behaviors that define the way employees perceive, make decisions, and communicate within the organization. According to Bauer (2010), organizational culture provides a framework for decision-making and guides employees in their daily work. Gibson et al. (2022) add that organizational culture plays a key role in attracting and retaining talent, especially in dynamic sectors such as the IT industry. In addition, Smith and Taylor (2022) point out that aligning the organizational culture with the onboarding process significantly contributes to a

better experience for new hires, increasing their motivation and productivity.

2.2 Onboarding process

Onboarding is a structured process of integrating new employees into the organization. According to Bauer (2010), onboarding consists of four key phases: preparation (pre-boarding), orientation, integration, and follow-up. These stages allow new employees to adapt to organizational values and norms while supporting them in understanding work processes and achieving productivity. Klein and Polin (2020) emphasize that the goals of the onboarding process include increasing employee engagement, reducing turnover, and quickly adapting to the work environment. Patel and Johnson (2023) specifically point out that organizational culture acts as a key predictor of successful onboarding, while Yang and Lee (2021) highlight the importance of mentors in facilitating cultural integration during this process. In addition, Cable, Gino and Staats (2013) indicate differences in the design of the onboarding process depending on the type of organizational culture, where companies with an innovative culture prefer less formal approaches, while hierarchical organizations use structured procedures.

2.3 The connection between organizational culture and the onboarding process

Organizational culture and onboarding are inextricably linked, as the onboarding process often represents the first contact new employees have with the organizational culture. Gibson et al. (2022) state that organizational culture influences the tone and structure of the onboarding process, while Smith and Taylor (2022) highlight the importance of aligning onboarding practices with company values to ensure long-term employee integration. An effective onboarding process allows employees to internalize organizational norms and develop a sense of belonging. According to Cable et al. (2013), organizations with an innovative culture often provide flexible onboarding programs that allow employees to adapt the way they work to their preferences. On the other hand, hierarchically structured organizations use formalized procedures to ensure that employees adhere to established standards.

2.4 Characteristics of small companies

Small companies, especially in the IT sector, have specific challenges and opportunities in designing the onboarding process. Rogers, Kim, and Zhao

(2024) point out that the lack of formal resources in small organizations often makes it difficult to implement structured programs, but the flexibility and close collaboration that characterize small teams allows for more direct employee integration. Kim, Lee, and Park (2023) add that interpersonal relationships in small teams are key to facilitating employee adaptation, but also that the lack of standardization of onboarding practices can be a challenge. Formalizing the onboarding process in small companies can contribute to long-term employee retention and reduced turnover. Brown and White (2024) indicate that the introduction of formal procedures in small companies is possible, even with limited resources. In addition, Robinson and Carter (2022) point out the importance of leadership in bridging challenges in the onboarding process, while Yang and Lee (2021) point out that mentors play a key role in supporting new hires in small companies.

RELATED WORK

Recent research provides extensive insight into the connection between the onboarding process, organizational culture, and factors that influence successful employee integration. These studies particularly highlight the importance of mentoring support, knowledge exchange, and adaptation to the specifics of organizations, which are key elements of successful onboarding. Lužar (2024) points out that the activation and use of existing knowledge significantly contribute to successful exchange among employees while mentoring and cooperation play a key role in that process. His research shows that using existing knowledge contributes to a 13.2% increase in exchange between engineers, which further highlights the importance of organizational culture in facilitating these processes. These findings suggest that a culture that encourages open communication and collaboration is critical to successful onboarding. Additionally, Murgoski (2024) explores how factors such as generational differences, work experience, and job type shape perceptions of organizational culture and influence the design of the onboarding process. He indicates that adapting the onboarding practices to these factors contributes to creating a positive work environment, which enables faster and more efficient integration of employees. Such adjustments not only improve the work experience of new hires but also strengthen overall organizational cohesion.

Koman, Boršoš, and Kubina (2024) contribute to this discussion by investigating sustainable human resource management and its connection to recruitment and onboarding processes. Their results indicate that organizations that align their

culture with technological innovation achieve greater efficiency in the integration of new employees. Their research emphasizes that technological changes should not be seen in isolation but in the context of an organizational culture that allows employees to accept and adapt to them. Gibson et al. (2022) provide valuable insights into the role of organizational culture in talent retention. Their research shows that clearly defined cultural values increase employee loyalty and engagement. Similarly, Smith and Taylor (2022) point out that aligning organizational culture with onboarding practices not only reduces employee turnover but also increases employee engagement. These findings further support the importance of coherent onboarding strategies that reflect organizational values. Robinson and Carter (2022) point out the role of leadership in bridging challenges during onboarding, especially in smaller organizations where leaders often have direct contact with new hires. Their research indicates that leadership not only facilitates employee adjustment but also strengthens trust and bonding within the team. Additionally, careful change management in hybrid work environments during onboarding is becoming increasingly important (Gibson et al., 2022). At the same time, organizations that successfully balance the exploitation of existing resources and the exploration of new knowledge encourage innovation and enable employees to better adapt to a dynamic work environment (Robinson & Carter, 2022).

METHODOLOGY

This research uses a qualitative approach to understand organizational culture's role in shaping the onboarding process in small IT companies. The study used semistructured interviews with IT experts (with many years of experience in IT) from four different companies. The research aims to uncover the role of organizational culture in the onboarding process. Data were collected through face-to-face interviews, live or via an online platform, and then thematic analysis was applied to identify key insights from the participants. The thematic analysis involved transcribing the interviews and discovering themes (Braun & Clarke, 2022).

4.1 Sample

The sample consists of four small IT companies with fewer than fifty employees. Participants were selected for our study if they were interested in our research, that is, if they voluntarily wanted to express their views. Care was taken to ensure that they were IT experts with many years of

experience. Participants were selected to provide comprehensive insight into the integration of organizational culture into onboarding processes.

4.2 Data Collection

Data were collected using qualitative research methods, specifically semi-structured interviews (Flick, 2021), to gain in-depth insight into the role of organizational culture in shaping the onboarding process in small software companies. The semi-structured interview format allowed for flexibility in the research, ensuring that key themes were consistently addressed across all interviews. The interviews were conducted face-to-face or virtually, depending on the participants' availability, and were audio-recorded with the participants' consent for later transcription and data analysis. The data collected provided a basis for analyzing how organizational culture influences onboarding in companies. The interview questions were designed to elicit participants' experiences and perceptions of the onboarding process, with a focus on organizational culture. After conducting the interviews, the interview transcripts were analyzed using QDA Miner Lite software.

4.3 Data Analysis

Following the methodology for thematic analysis (Braun & Clarke, 2022), data were analyzed to identify the main themes and patterns across the studies with four participants. The studies revolved around organizational culture, and onboarding processes, by employees in small IT companies. When applying thematic analysis, we identified themes about the observed phenomenon. We opted for thematic analysis due to our experience in investigating issues within onboarding (Gaborov et al., 2024). Inductive thematic analysis (Braun & Clarke, 2022) was used as a data analysis method. The authors used interviews to collect qualitative data. All qualitative data were prepared in Microsoft Word documents and imported into the QDA Miner Lite software tool for qualitative data analysis (anonymized, 2024). Qualitative data were analyzed inductively to generate themes using a well-established six-stage approach, the steps of which can be summarized as: familiarization with data; generation of initial codes; identified themes; reviewing and refining themes; and defining and naming themes (Proudfoot, 2023).

The first step involved reading the interview transcripts to gain a comprehensive understanding of the responses. During this phase, notes were made regarding initial thoughts

and impressions on key concepts across interviews.

The next step was to identify and code the significant sections of the study. Coding involves the work of studying and organizing the collected observations (Locke et al., 2022). The codes are identified by reading the documents in the mentioned software. Each participant's responses were broken down into specific codes. After initial coding, the codes were grouped into broader themes that helped address the research objective. The identified themes are presented and analyzed in the next section of the paper.

RESULTS and discussion

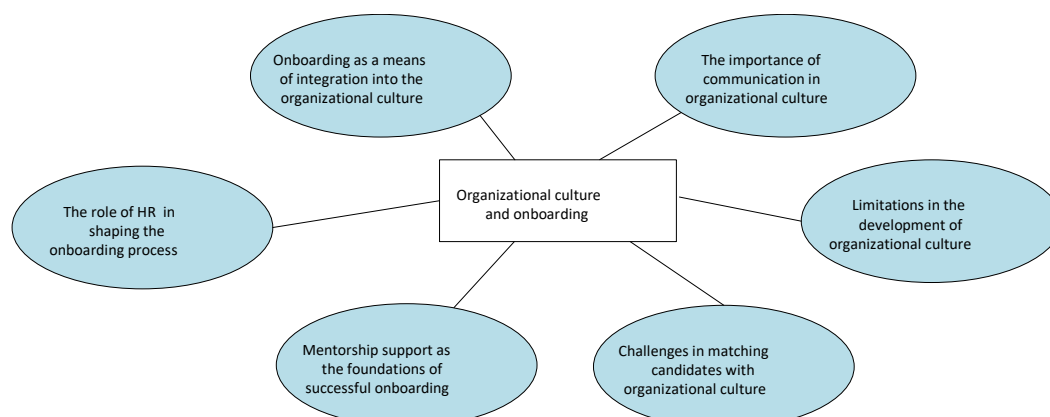
This section presents the results of the study, which presents five main themes that emerged from the analysis of the studies. The identified themes were reviewed by revisiting the coded data and ensuring that each theme accurately reflected the ideas. The main themes were considered relevant to the research goal. After reviewing the themes again, the final themes were:

1. Onboarding as a means of integration into the organizational culture - It arose from discussions about the role of the onboarding process in introducing new employees to the company's values and rules
2. The importance of communication in organizational culture - Communication has been identified as a central component that shapes culture and facilitates integration.

These themes highlight the role of organizational culture in shaping the onboarding process in small IT companies. Participants identified onboarding as a key mechanism for introducing new employees to the company culture. It provides a structured opportunity for new employees to become familiar with the company's expectations. One participant

3. Challenges in matching candidates with organizational culture - Problems with fitting into a team and conflicting individuals often disrupt team dynamics.
4. The role of HR and mentors in shaping the onboarding process - HR selection and mentoring work are key to guiding employees toward the organizational culture.
5. Mentorship support as the foundations of successful onboarding - Mentors play a key role in conveying the culture.
6. Limitations in the development of organizational culture - The lack of a formal framework and the spontaneity of culture development present challenges for smaller companies.

Figure 1 shows a thematic framework with identified main themes. The main themes are represented as blue ellipses. There is a white rectangle in the middle. This indicates that the study looked at the influence of organizational culture in the onboarding process.



the onboarding process plays a significant role in establishing communication norms among employees and between employees and customers. One respondent explained, *"There, employees get to know how the company works, with the organization, how to communicate with colleagues in the company, how to communicate with clients using various communication channels."*

Participants mentioned the challenges of ensuring that new hires align with the existing organizational culture. While technical competence is essential, a mismatch in cultural fit was identified as a significant obstacle that can disrupt team dynamics and organizational harmony. One participant stated, *"If someone is a conflicted person, there is little chance that they will pass the HR selection, since the selection also includes psychological tests." "If HR has done its job properly, you get a quality person who easily fits into the company."*

Mentoring support is the foundation of successful onboarding. A mentor is a trusted counselor or guide. Many businesses and industries offer mentoring to guide new employees and help them meet organizational expectations. One participant stated, *"It's only important that we don't behave badly towards others"*. Communication during the onboarding process should be positive and open, and mentors play a key role in conveying the culture.

Human resources departments and mentors have been identified as factors that contribute to shaping the onboarding process and ensuring the successful integration of new employees into the organizational culture. HR in the selection process defines the ideal candidate profile and conducts psychological assessments to assess compatibility with the company culture. As one participant noted, *"For each workplace, a profile of people is determined, which is indicated to the psychologists in HR, and they work out that profile in detail."*

Several participants pointed out that culture develops spontaneously, rather than being deliberately designed. While this approach can work in certain contexts, it can lead to inconsistency and unclear expectations among employees. One participant reflected, *"We do not have a specially designed organizational culture, but it is something that came spontaneously."*

These results highlight the interconnected roles of engagement processes, communication, and human resource practices in shaping organizational culture, while also pointing to challenges and opportunities for smaller companies in formalizing organizational culture frameworks.

RESEARCH IMPLICATIONS

The presentation of this thematic analysis and the final thematic framework can help practitioners understand the importance of organizational culture. Industry practitioners should adhere to organizational culture, as it significantly affects the quality and performance of employees. If new employees understand and adopt organizational culture, they are more likely to adapt faster and contribute to the team.

Researchers can identify the key steps applied when conducting inductive thematic analysis. They can also see the impact of integrating organizational culture into the onboarding process and develop more comprehensive frameworks that explain the importance of organizational culture.

Trustworthiness

Trustworthiness refers to establishing trust in the accuracy, integrity, and transparency of the research process and its results. It is particularly emphasized in qualitative research, where the collection and interpretation of data require attention to ensure that the research is reliable (Braun & Clarke, 2022). As part of this research, semi-structured interviews with open-ended questions were conducted, which allowed the participants to freely express their experiences. Before and during the interview, a good relationship was established with the participants, which created an atmosphere of trust and open communication. All the authors of the paper agreed on the defined themes, which made the analysis process more reliable. It is assumed that the insights obtained from the research may be applicable in other smaller IT companies as well. The reliability of the research is ensured by applying a systematic approach to data collection and analysis. During the thematic analysis, the researchers followed the guidelines for its implementation and described the entire process in detail. The interviews were transcribed verbatim, and any disagreements were resolved by discussion among the authors.

CONCLUSION AND FUTURE WORK

Thematic analysis indicates that the onboarding process of new employees is crucial for their integration into the company, but its success depends on alignment with the organizational culture, communication practices, and engagement of the HR team. It was concluded that the data emphasize that the hiring process also focuses on the ability to adapt to the dynamics of the organizational culture, which leads to the company's chances of success. Future research is planned to expand by increasing the number of participants in the study, and special attention will be paid to the attitudes of employees who are just at the beginning of the onboarding process and do not have significant work experience in the IT sector.

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Simulation of evacuation as a consequence of Industry 4.0

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Abstract: Evacuation presents very important, complex and always open and actual task and problem. Experience showed that even well calculated evacuation plans can have errors, mistakes and oversights. As an example, it is almost impossible to predict humans' behavior in stress and panic situations what can extremely endanger evacuation and cause many new victims. As a standard evacuation procedure, during construction of some object, it is necessary to calculate evacuation time needed for evacuation. But, even with a proper calculation, suppresses and unpredictable events are frequent. So, it is the best way to predict as many possible evacuation scenarios. One of the best ways for that purpose is the use of simulation software. The simulation software, as a consequence of Industry 4.0, enables many benefits in the sense of precision, prediction, calculation of evacuation times, determining of evacuation routes and their optimizations. In the future, this software will be consolidated with artificial intelligence with optimized results.

In this paper, several typical evacuation examples were presented with use of simulation software Pathfinder (version 2023), for high residential buildings as a particularly complex and hard objects for evacuation.

Key words: simulation, Industry 4.0, human, safety, prediction, evacuation

Introduction

Industry 4.0 as a technical revolution has brought advance and progress in many nature and social spheres of human's life and work. With developing around its main environment, so called smart manufacturing, Industry 4.0 has overwhelmed many aspects of human's life and work. New ways of communication, new ways of design, new ways of change and storage of information enable new unexpected possibilities through new technologies such as Internet of things, cloud systems, smart manufacturing, robots, drones, simulation, augmented reality and many others. These new technologies provided completely new views of the problems, offering new and better solutions. One of the very important new technology, with unbelievable possibilities is simulation.

Simulation provides digital view of the product or process in the aim of identification of potential problems, eliminating production expense, resource waste, potential danger situations and similar. Generally, Industry 4.0 has a wide range of 3D simulations. By using of simulation, it is possible to design virtual

physical models of machines, products, process and humans, digital twins and digital shadows. Whole real processes, events, occurrences can be simulated in real time, decreasing needed time and increasing the quality of the products or processes, without any kind of risk. These models are presented on figure 1.

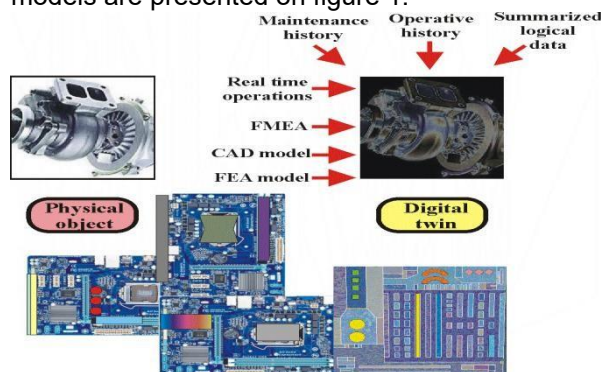


Figure 1. Simulation, digital twin and digital shadow in Industry 4.0

Design by simulation, digital twin presents virtual model of the real product, process, system, problem, task etc. It was defined as digital concept of happening of elements and system's dynamic, realised during functioning, with possibility of optimisation of its characteristics. Theoretical information and knowledge, calculations but also and real information collected from sensors can be used to improve digital twin in real time. Digital shadow presents very detail and precise information view

related to processes from development, manufacturing, functioning etc. It provides simulation of manufacturing chains, production flows and many different happening with complete virtual analyse related to potential problems, errors, hazards, accidents or similar, before the beginning of the process, system, happening or similar itself. That provides elimination of any potential risk, in the sense of human's life, manufacturing hazard, accident, expenses of testing and similar [1]. For example, potential digital twin for fire safety could be presented as on figure 2.

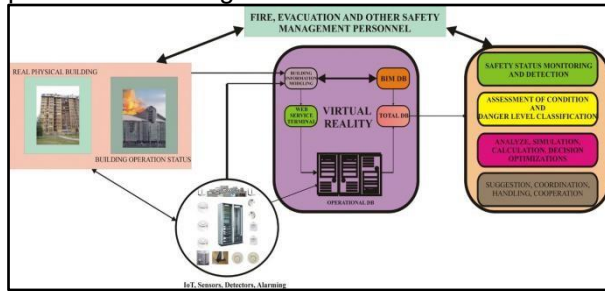


Figure 2. The presentation of the digital twin in fire safety and evacuation related to Industry 4.0 model

Simulation generally demands very strong software. The design and realisation of simulation software purports huge knowledge, experience, work and understanding of concrete subject. Simulation software are used to design virtual conditions in virtual ambient or environment. Beside many benefits, one of the most important benefits related to simulation is completely safety and absence of any kind of danger without any penalties (expenses, waste, errors etc.). In real, it is impossible to realise. Simulated problem enable insight, analyse and view about every potential problem, task, threat or similar what can significantly rise chances for problem solutions. Of course, simulation software in technical sense demands strong hardware back up- strong processor, lot of RAM memory, strong graphic card etc.

Evacuation has always presented very complex and open task and problem. No matter what was the reason for evacuation, evacuation of lot of people, animals or material properties from endanger to the safe place, location, object, area or similar has always

been very complex, for many different reasons. One of the most complex tasks related to evacuation is human behaviour during evacuation. Of course, it is always easy to explain what to do and how to behave in the normal conditions; during evacuation there can be lot of other factors that can cause panic, fear and instability such as fire, flame, smoke, explosions, crashes etc. So, it is the crucial task to somehow, as much as possible, determinate human's

behave, because only collected, calm and composed humans can realise successful evacuation. Particularly complex and hard for evacuation are objects with presence of lot of humans and special designed objects. These objects include high residential buildings intended for human's life.

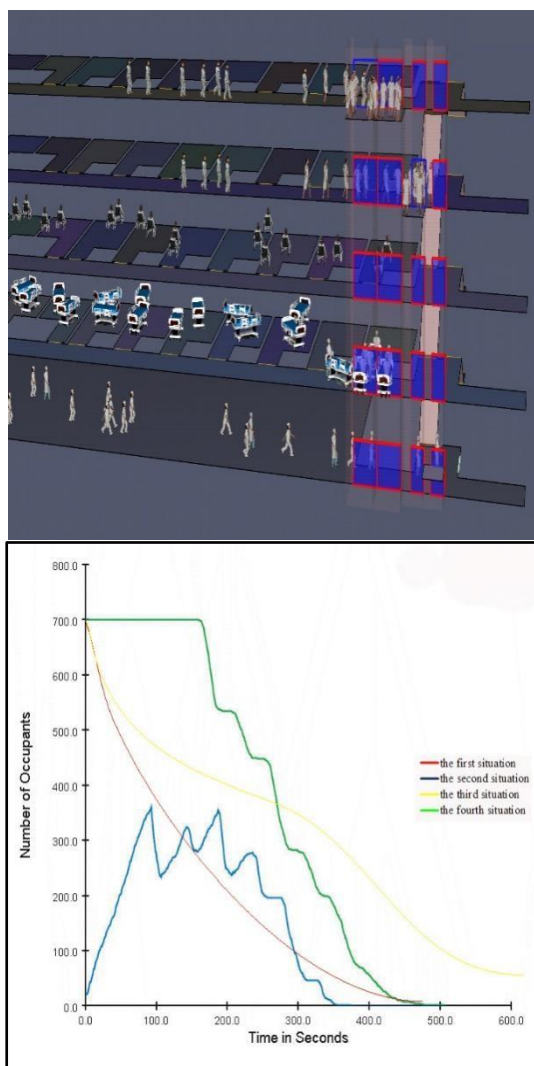
One of the best ways how to solve noted problems lies in the simulation software developing and usage. This software has great potentials in evacuation, calculating needed evacuation times, analysing every potential evacuation scenario proper evacuation and decreasing evacuation time. In the presence, there are more different simulation software on the market. This paper was written to show the significance and importance of simulation software usage on concrete examples realised in Pathfinder simulation software, related to high residential buildings as a particularly complex, hard and interested objects for evacuation [2-4].

Pathfinder Simulation Software

Examples showed in this paper were realised in the simulation software Pathfinder. Pathfinder generally presents an agent-based egress and human movement simulator, providing a graphical user interface for simulation design and execution. Both 2D and 3D visualization tools for results analysis are available. There were several different versions of this software from its design. Every new version was significantly improved from earlier versions and provided a lot of new possibilities in the sense of efficiency and analysis. The minimum hardware requirement purports, as example, 64-bit Windows 8 Pro with an Intel Core i7 2.60 GHz processor, minimum 8 GB of RAM (as much RAM memory is desirable), and NVIDIA NVS 5200M graphics card.

Pathfinder enables graphic user interference intended for design and running of simulation models. Beside visual simulation results (3D), it also provides reports and calculations in 2D form, such as graphics or diagrams.

These results are presented on figure 3.



a) b)
Figure 3. Different ways of simulation solution representation (a) 3D view and (b) 2D view as graphic

There are two different simulation mods for calculations available. The first mode presents the so-called SFPE mode, while the second presents the steering mode. SFPE mode purports that humans-occupants don't try to avoid one another, with some limits related to doors and velocity. Steering mode purports that humans-occupants are moving and behaving as much as possible as in real, and can interact between themselves. It is possible to realise simulation on both ways. Pathfinder has lot of benefits and advantages, but one of the most important is the possibility that this software can import files from some other computer program (Pyrosim, AutoCAD or some other), what significantly shortens the time and improves the effect. There are lot of different objects with high importance in strategic way that can be used in simulations, such as stairs, elevators, ramps, escalators, moving walkways etc. Also, very big improvement

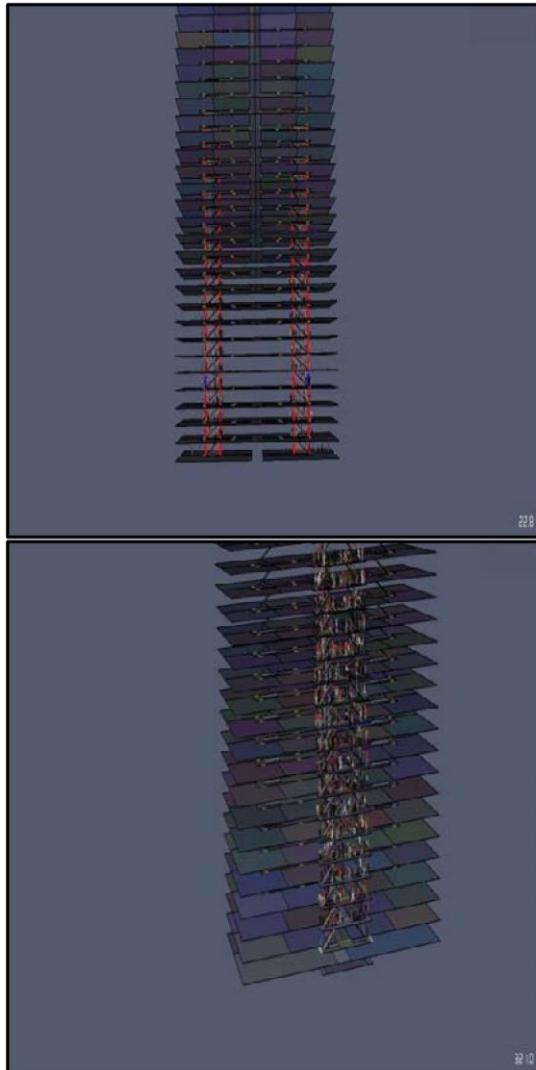
is the potential to use immobile or hard mobile persons (persons in wheelchair or medical bed); potentials to design behavior of humans-occupants in the sense of delaying, waiting, assisting, walking to certain room or location etc. [5-7].

High residential building evacuation simulation

Modern and technological improved way of life demands new rules and new solutions because of many things. Cities become bigger and bigger with the lack of space, parking's, green areas etc. Because of noted facts, residual buildings must be tall and must be in possibilities to provide safe home for their residents. There are many examples where height of building there are examples where the height of the building exceeds several tens or even several hundred meters (Burj Khalifa with 828 m and 163 floors; Merdeka 118 with 678.9 m and 118 floors; Shanghai Tower with 632 m and 128 floors; Abraj Al-Bait Clock Tower with 601 m and 120 floors; Ping An Finance Centre with 599 m and 115 floors; Lotte World Tower with 555 m and 123 floors; One World Trade Center with 541.3 and 104 floors; Guangzhou CTF Finance Centre with 530 m and 111 floors; Tianjin CTF Finance Centre with 530 m and 98 floors; CITIC Tower with 528 m and 108 floors and many other). High buildings can be designed only for residents, but also and for offices, hotels, work place etc. Related to determined information, the tallest residential buildings in the world have height from 305 m and 80 floors (Etihad Tower 2, Abu Dhabi, United Emirates) up to 472 m and 98 floors (Central Park, New York, USA). Such buildings are equipped with modern fire protection systems that enable fast and safe fire extinguishing and evacuation. It is purported that they must have fast and numerous elevators, fire escape stairs, sprinkler and drencher systems etc. But, even with all that available resources, accidents are happening. So, well calculated, organized and as much as possible prepared evacuation presents serious and important task. Related to the construction measurements, every residential building should have a large approach intended for fire vehicle; but, today, in the lack of space and huge traffic jams, this very important condition is not always realized. Very often, the usage of fast elevators is not possible because of many reasons (mechanical malfunction, the lack of the electricity power supply, presence of danger products such as carbon monoxide or carbon dioxide etc.), so, the only way for evacuation present ordinary stairs and emergency stairs.

The first simulated object example presents high residential building, constructed as two connected buildings, what is very often case of

construction in the sense of stability. Each of them has basement and 50 floors. Maximal height of each building was 132.6 m. Maximal base surface of each building was 400 m². Related to room's arrangement, every floor in both buildings, except basement, consists of four flats, four elevators, one ordinary stair and exit to emergency stairs, where the surfaces of flats were 84 m², 84 m², 87 m² and 47 m². Every flat was designed to have ordinary rooms (bed rooms, sitting rooms, kitchen, bathroom, ante rooms and hallways) with ordinary furniture (beds, desks, dressers and similar). Simulation condition was that occupants-humans were in their flats in the moment of evacuation start.



Simulations were realized for four different scenarios. The first evacuation scenario purported evacuation from building but only by ordinary stairs usage. The second evacuation scenario purported evacuation from building but only by emergency stairs usage. The third evacuation scenario purported evacuation from building by ordinary stairs and emergency stairs usage. The fourth evacuation scenario purported evacuation from building by ordinary stairs and elevators usage. Every of four scenarios were realized for different speeds of occupants-humans: 0.8 m/s, 1 m/s, 1.2 m/s, and 1.4 m/s. Some of simulation moments are presented on figures 4 (a, b) [8, 9].

elevators, one with totally capacity of four persons and one with totally capacity of six persons. Smaller elevator had speed of 1,1 m/s, while the bigger elevator had speed of 0,92 m/s. The maximum height of the building was about 38 m. There were four difference scenarios for different speeds of occupants-residents (0.75 m/s, 1 m/s, 1.25 m/s, and 1.5 m/s and 1.75 m/s). The first scenario was realized for all four entrance/exits opened with enabled or disabled elevators. The second scenario was realized for one entrance/exit blocked and tree other entrance/exits opened (complete 9 cases). The third scenario was realized for two entrance/exits opened and two entrance/exits blocked (complete 12 cases). The fourth scenario was realized for one entrance/exit opened and three entrances/exits closed (complete 8 cases).

Complete building and simulation model in Pathfinder for the third scenario, where the third and the fourth entrances/exits were blocked and elevators were disabled and where the occupant's speed was 1.5 m/s are presented on figure 5 (a, b)[9-11].

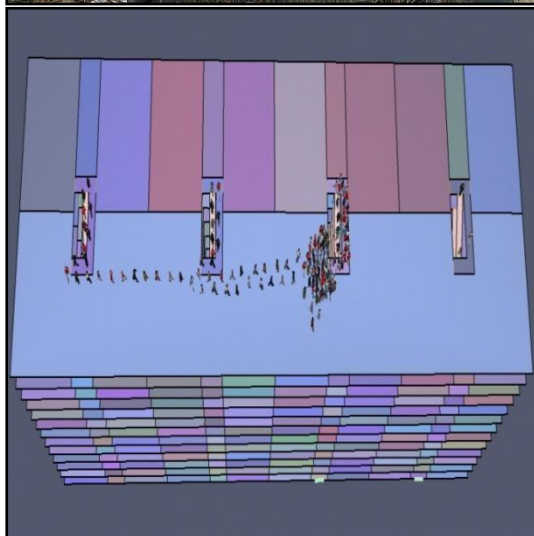
Scenario	I	II	III	IV	V	VI	VII
Occupants used ordinary stairs							
Occupants used fire stairs							
Occupants used elevators							

a)

b)

Figure 4: The examples of evacuation from high residential after 22.8 seconds after simulation start (a) and and after 321.0 seconds after simulation start (b), both for occupant's speeds of 1 m/s.

The second simulated object example presents high residential building, constructed as four connected buildings, what is very often case of construction in the sense of stability on earthquake. This building is real and it is located in Niš, in Bulevar Nemanjića street with numbers from 58 to 64. Completely, these connected buildings have four exits/entrances without emergency stairs, so the purpose of the simulation was to had insight in the possibilities of evacuation without any additional resources except elevators, stairs and common terrace exits. Every of four building in structural sense is the same-it has base floor, ground floor, next ten floors and terrace. Terraces present connection between buildings. In the case of evacuation, these connected terraces can present the only potential evacuation exit, where occupants should cross in neighbor building via them. Every separate building has four flats at one floor and two



a)

b)

Figure 5: Building in Bulevar Nemanjića street, from 58 to 64 (a) and the third scenario, where the third and the fourth entrances/exits were blocked and elevators were disabled and where the occupant's speed was 1.5 m/s b)

The third simulated object was the building with dimensions of 17 m x 17 m and twelve floors above. The dimension of each floor was 17 m x 17 m x 2.54 m, and all of them has four flats, two bigger with approximate surface of 70 m² and two smaller with approximate surface of 55 m². Floors also had a corridor and they were connected with ordinary stairs, emergency stairs and elevators. The width of ordinary stairs was 1.25 m, while the width of emergency stairs was 0.95 m. Building had two elevators for residents; one with four persons capacity and one with eight persons capacity. The speeds of elevators were different; the speed of smaller elevator was from 1 m/s to 1,3 m/s while the speed of bigger elevator was from 0,6 m/s to 0.9 m/s, in dependence of weight. For this building, there were seven different evacuation scenarios realized and calculated and these scenarios are presented in table

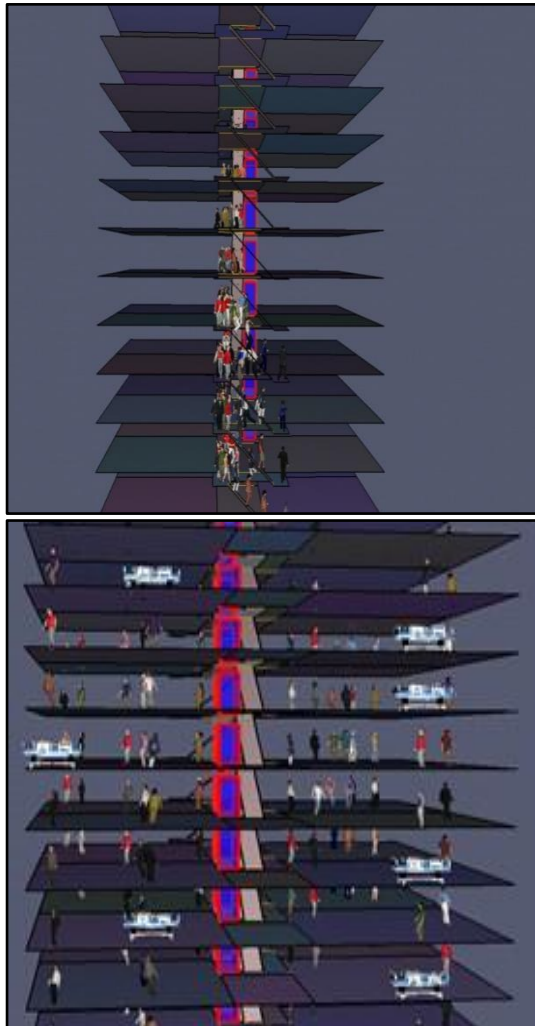
1.

Table 1. Realized scenarios for residential building with different possibilities

The speeds of occupants, for every of seven scenarios, were 1.2 m/s, 1.5 m/s, 1.8 m/s, 2.1 m/s and 2.5 m/s. Immobile occupants were in wheelchairs and medical beds. Speeds for wheelchairs were from 0.4 m/s to 1.3 m/s, while speeds for medicals bed were from 0.2 m/s to 1.2 m/s.

There were three different cases for every of seven scenarios: without immobile occupants,

with 5 % of immobile occupants randomly arranged (10 immobile occupants, 5 with wheelchairs and 5 with medical beds) and with 10 % of immobile occupants randomly arranged (20 immobile occupants, 10 with wheelchairs and 10 with medical beds). Some simulation moments for this building are presented on figure 6 (a, b) [12, 13].



a)

b)

Figure 6: Simulation moments from the fourth scenario and the third case (a) and for the first scenario and the second case (b)

Analysis and

discussion of

simulation results

As it was noted, for realisation of computer simulation and usage of simulation software, very strong computer or laptop is required, with strong processor and lot of RAM memory.

For the first example, simulation results showed that the shortest evacuation time was for fourth scenario (802.12 seconds and occupants-residents speed of 1.4 m/s) while the longest evacuation tie was for the third scenario (2456.79 seconds and occupants-residents speed of 1.4 m/s). Also, realised results enable determination of speeds for jams could be occurred, and the critical points in the building (doors, stairs, passages etc.). Occupants-residents were set to have the same or different speeds, but it was possible to set that occupants-residents had different speeds, so as different gathering points, different directions of evacuation etc [6].

For the second example, simulation results showed that the shortest evacuation time was for first scenario with enabled elevators (209 seconds and occupants-residents speed of 1.75 m/s) while the longest evacuation tie was for the fourth scenariowith elevators disabled and the first entrance/exit opened, while the second, the third and the fourth entrances/exits blocked (1729.3 seconds and occupants-residents speed of 0.75 m/s). For this example, also, calculation showed that the speed when the jams occurred can be determined, with critical points in the building [9].

For the third example, simulation results showed that the shortest time for evacuation was for the first case of the first scenario (150.2 seconds for occupant's-residents speed of 2.4 m/s), while the longest evacuation tie was for the third case of the seventh scenario (754 seconds for occupant's -residents speed of 1.2 m/s). This example was particularly interested because the presence of immobile persons in wheelchairs and medical bed was noted. Possibilities for jams were very high, because occupants in wheelchairs demanded at least two other occupants-residents for help and assistance while occupants-residents in medical beds demanded at least four other occupants for help and assistance. This example also included deep analyses related to the arrangement of wheelchairs and medical beds, because there were big differences in evacuation times in cases when this kind of occupants-residents were concentrated at one or more floors instead of their random concentration [13].

Conclusion and future investigation

The most important task in every accident is to protect and save human lives. Because of that reason, evacuation must be carefully and precise planned, calculated and realised. The

simulation software in evacuation calculations and analyses provides huge technological advantage, at the first place in prediction and in complex and enormous calculation. Design and realisation of many different evacuation scenarios enable prediction of evacuation, with optimised results. Powerful computers enable fast and precise realised simulations needed information. Evacuation with the lot of humans inevitably involved in panic and stress. Today, there are different algorithms which are constantly improving and which can describe and simulate human's behaviour, especially of huge group of humans.

Also, further technical innovations, as a result of Industry 4.0 enable higher level of simulation. At the first place, the prediction will be at significantly higher level. New virtual systems, designed by experts and artificial intelligence, will be in positions to predict every potential scenario in the sense of fire, earthquake or some other accident and disaster and will prepared appropriate services to react at time. New sensors (for example, sensors for door's flow measuring, sensors for detection of stairs occupation, sensors for availability of determined evacuation route, gas sensor, temperature sensor, smoke sensors, humidity sensor etc.), in real time, can provide real and current information, what can change evacuation (way, direction, timing etc.) in real time and redirect evacuation or take over some other step in the correlation with different services (such as fire brigades, police, first aid etc.). For bigger objects or bigger supervised areas, supervision will be task of drones, sensors, robots and AI, what will achieve unimaginable successes at the field of evacuation. With "fresh" information, occupants will be able to evacuate at safety area on the safe and fast way. They will be able to avoid areas or rooms with the presence of "accident consequences", such as fire, flame, smoke, carbon monoxide, carbon dioxide, different physical obstacles etc. Also, other modern innovations will be available for evacuation, such as dragons from aluminium and canvas, slides, different types of descents, different type of jump canvas etc. It is predicted that future applications installed on smart phones will have possibilities to communicate with sensors and to alarm and warn their owners about situation in real time.

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Intelligent Connectivity for Smart City Development

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Abstract: The paper presents an overview of the progress of modern information and communication technologies (ICT), which are necessary for the development of smart cities (SC). A focus was given to the explanation of the concept of Intelligent Connectivity (ICon) that includes the convergence of key technological trends: mobile networks of the fifth generation (5G), Internet of Things (IoT), Artificial Intelligence systems (AI) and Cloud Computing (CC). The 5G smart networks are expected to enable the integration of Internet of connected objects (AIoT) by supporting intelligent connectivity ICon and becomes a key prerequisite for an advanced Smart City (SC) infrastructure. The intelligent connectivity for SC development should enable the integration of technologies with sensor networking, information processing and real-time control to efficiently utilize infrastructure.

Keywords: Smart City; Intelligent Connectivity; 5G, IoT; Artificial Intelligence

1 INTRODUCTION

Smart city (SC) is an innovative solution for today's urban areas that utilize advanced digital technologies to provide better infrastructure, modernize government services, improve accessibility, accelerate economic growth, and improve sustainability. Opportunities and challenges depend on many different factors, such as the population, location, climate, environment, and area of the city as well as priorities and primary implementations. Currently, numerous smart city developments are ongoing around the world. SC projects have emerged mainly as a result of highly innovative ICT solutions, and additionally, they have started to use new generation wireless networks taking advantage of the Internet of Things (IoT), Big Data (BD) and cloud computing (CC) technologies to establish a smart connectivity in Smart City development [1, 2, 3].

The concept of intelligent connectivity (ICon) includes the convergence of key ICT trends: 5G (fifth generation) mobile networks and AI (Artificial Intelligence) systems. ICon is based on the use of advanced technology for improved communication between devices, systems and users. The goal is a seamless and intuitive user experience and support for new applications and services that were previously not possible. The technological trend is the efficient and reliable connection of devices and systems, as well as new applications and services. ICon systems provide improvements in different aspects of operations and organizations, such as quality of life and infrastructure in the Smart City (SC). SC solutions are developed and implemented in smart environment, smart mobility, smart living and smart people.

Smart environments (SE) are new concepts in developed improved services for the residents of a city, better quality of life for an individual, or more efficient manufacturing for a company [4, 5].

- **Smart Home (SH)** provide a variety of options to interact with others without having to leave the house. The entire home ecosystem, including heating, air conditioning, water, electricity, energy consumption, lighting, entertainment, appliances, household robots, air quality, smoke/gas/leak detection, home access, security, and privacy, can be fully managed and monitored thanks to SH intelligent, connected, automated, and integrated control, computing, and communication system. Although there are many different things and services available today, the markets and solutions are a dispersed. Furthermore, complete smart and automated home solutions that incorporate all necessary components are still relatively lacking. Additionally, standardization and common norms are insufficient, particularly when it comes to data security and privacy. We are still waiting for a significant advancement in smart homes. For technology companies (mobile network operators, vendors, and service providers), this will create new business opportunities to offer plug-and-play solutions that are complete and personalized. Collaboration between tech companies, constructors, and building owners is necessary.
- **Smart Factory (SF)** combines mainstream information, communication, networking, computing, and control technologies and procedures to improve a factory's intelligence, automation, productivity, quality, flexibility, adaptability, and predictability, is still relatively in its beginning. In the new era of smart manufacturing, where the integration of certain mainstream digital technology becomes commonplace and transforms the whole industrial

sector, a smart factory is at the centre of Industry 4.0. Numerous advantages are offered by smart factories, including better process monitoring, management, maintenance, and repair; higher manufacturing efficiency; lower manufacturing costs; better quality products; faster production cycles; more robust processes; improved security; better threat and hazard prevention; and innovative production solutions.

- **Smart society (SS)** refers to a concept that uses a wide range of advanced digital technology to improve society at all levels. A smart society is anticipated to provide a range of advantages for people, communities, and the public and private sectors through the use of various technologies. A higher quality of life in terms of better services for living conditions, healthcare, employment, education, social benefits, free-time activities, and public safety are among the potential advantages for people. New commercial prospects, more effective manufacturing, testing, and design processes, lower

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production, operation, and maintenance costs, and reduced impact on the environment are some of the possible advantages for the private sector.

Smart cities SC connect social infrastructure and physical infrastructure. Investing in ICT infrastructure improves economic growth and quality of life. The main objective is to provide residents with services that increase the effectiveness of daily activities. Assuming a variety of different applications and particular requirements, SCs rely on the sharing of information and large volumes of data.

5G connectivity ecosystem comprises a broad set of technologies, users, companies, products and services that evolve together to meet new requirements and create markets. The ecosystem also includes the regulatory direction, standardization organizations, as well as relevant industry associations. Members make contributions that complement and reinforce the contributions of other members, resulting in a complex integrated system. A systemic approach in creating a technological ecosystem implies observing the complete network and components as an integrated and inter-reliant system. The approach ensures that the various elements work seamlessly together to realize the benefits of 5G technology:

- identifying problems or requirements and forming system requirements, as well as the most promising technological options
- research and development of innovative technologies and the formation of a flexible system architecture supports increased data transfer rates, low latency and massive connectivity of intelligent devices
- ensuring compliance with international standards for the interoperability of various suppliers and service providers

- cooperation with device manufacturers for a diverse and interoperable technological ecosystem
- cooperation with regulatory authorities to resolve legal and political challenges associated with the commercial application of 5G technology
- conducting extensive prototype testing and performance demonstrations, concept validation that ensures reliability, performance and adherence to standards
- adoption of a systemic approach, so that all stakeholders in the 5G technological ecosystem can achieve integrated, efficient and secure cooperation that meets the various requirements of both consumers and companies.

To ensure seamless interoperability between ICT devices, the International Telecommunication Union Telecommunication ITU-T is establishing standards that specify the requirements, frameworks, operations, and management systems for ICT technologies, enabling the development of advanced wireless

networks [6-12].

The main goal of this research was to raise awareness of the community about the current state of the smart city SC developments revealing its key future trends. The paper is organized as follows. After an introduction, intelligent connectivity ICon enabling technologies are presented with focus on cloud-driven IoT-based big data BD and 6G enabled the New Smart City. In conclusion, we point out that there is a need for a critical reassessment of the ICT sector for smart cities SCs development.

2 ICon enabling technologies

ICon represents the synergy of smart technologies and communication infrastructure with a goal more efficient services, improvements in user-computer interaction, as well as improvements management and data analytics. The convergence of communication, IoT and AI is an obvious logical one progress in the evolution of these technologies. Data collected by IoT devices and sensors can now be effectively analyzed and contextualized using AI method. The two technological concepts absolutely complement each other, are rapidly developing and they have a vital role in the progress of smart cities and society. Artificial intelligence is the real driving force behind the full potential of ICT (Fig.1).

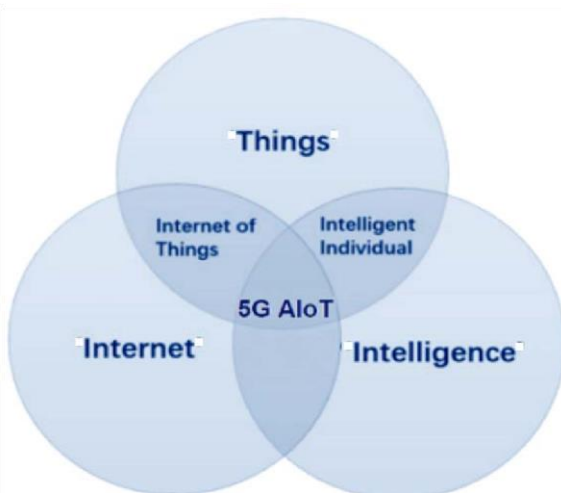


Figure 1 The relationship among 5G, IoT and AI.

Significant features of 5G network connectivity are high data transfer speeds and very low latency. SC systems have been applied in various domains to test the potential of new smart systems while identifying the infrastructure necessary to support future services for a large number of devices. The goal is to develop integrated solutions and new applications for building smart cities and improving the social life of citizens, including economic growth. The IoT is one of the significant ICT technologies to support smart cities SC, along with connectivity, data analytics and artificial intelligence AI. Many countries have launched SC projects of smart cities and large investments in development. Analyzing the advantages and challenges of 5G IoT technology is crucial for the development of future smart cities.

However, in reality there are still many challenges. The ICon concept encompasses various design principles, industrial standards and development heterogeneous computing platforms and network topologies. A successful smart environments require standardization that includes interoperability, compatibility, and reliability [9, 10, 11].

Connectivity. In order to build smart cities SCs and set the groundwork for more connected future, 5G/6G low latency, and IoT are essential. For systems like energy management, traffic management, and public safety systems to operate seamlessly, high-speed, reliable communication is required. Large volumes of data produced by IoT devices can be efficiently transmit to the faster and more reliable connectivity offered by the 5G and upcoming 6G networks. Because it facilitates rapid actions and real-time decision-making, low latency is especially crucial in SCs. IoT is essential to SCs because it facilitates the deployment of SC systems and provides the data required for data-driven decision-making.

The following use case classes are defined by the joint initiative 5GPPP of the EU ICT industry: highly populated metropolitan areas, broadband access at any location, connected autonomous vehicles, the future smart office, NB-IoT, tactile Internet, and automation. Key KPI indicators that match the performance requirements (in terms of the service's

user experience) that the 5G network can provide are established for each unique scenario. Device density in a particular region, mobility, infrastructure topology, traffic type, user data flow, delay, reliability, availability, and communication category are the criteria used by the PPP initiative to categorize fundamental functionality.

Internet of Things. The entities in the development of

SCs include sensors, networked devices, machine-to-machine (M2M) communication, and IoT. Internet of Things serves as the foundation for the interconnection of SCs, including public safety, energy, and traffic control systems. The seamless transfer of data between various systems and devices is made possible via M2M communication, which serves as the basis for SCs' effective operation. Sensors and actuators are examples of networked devices that supply the data required for SCs to make data-driven decisions. In particular, sensing is essential to data gathering and analysis because it offers real-time data on a variety of metrics, including ambient conditions, energy consumption, and traffic movement.

Smart city applications based on IoT infrastructure are categorized based on network type, scalability, coverage, flexibility, heterogeneity, reliability and end-user engagement. Applications can be grouped into personal and residential, communal, mobile and business. Utilities include smart energy grid, smart metering/monitoring, water network management and video surveillance. Similarly, mobile applications include intelligent transportation systems and logistics, and traffic management.

The implementation of 5G IoT supports making cities much smarter. Numerous devices are linked to a mobile network with very high speed. An intelligent and controllable environment is made possible by automation, which is embraced by the Internet of connected objects (IoT). It essentially comes down to data management, formatting, and connectivity. Different IoT protocols, data formats, processing, and interfaces are needed for various use cases. Interoperability and open standards are crucial because the Internet of Things does not yet have a global standard. The challenge is that industry initiatives are fragmented and unfocused, and IoT deployments and use cases are unfocused.

The smart city SC has many criteria for IoT applications. IoT, for instance, is anticipated to provide low cost, low power consumption, high quality of service (QoS), extensive coverage, increased flexibility, high security and privacy, ultra-dense implementation, and equipment manufacturer compatibility. To create a completely autonomous environment, IoT implementation relies on a variety of network topologies.

Data. The development of SCs requires the use of data analytics, data management, data storage, and data infrastructure. The amount of data generated is enormous and increasing daily due to the growth of the IoT and the increased use of technology in urban

areas. These statistics offer important insights into how a city operates, including public safety, energy use, and traffic flow. Cities can use data analytics to make sense of these data and make data-driven decisions to increase their sustainability and efficiency. An SC infrastructure must have enough data management and storage to guarantee that the generated data are secure and easily accessible for analysis. Since it serves as the basis for all data-related operations, SCs also require a robust data infrastructure. This covers the technology, software, and network needed to handle, store, and analyze large volumes of data. Cities can fully benefit from big data BD and data analytics DA with the proper data infrastructure in place, creating a more intelligent and sustainable future.

Artificial Intelligence (AI). Enhancing efficiency, sustainability, and the standard of living for residents, AI have the potential to significantly contribute to the growth of SCs. AI-driven solutions can assist SCs in lowering energy use, streamlining traffic, and enhancing public safety. AI systems, for instance, can monitor building energy consumption to spot inefficiencies and reduce waste, or they can analyze traffic patterns to minimise air pollution and congestion. AI-powered chatbots and virtual assistants can also help SC projects by giving citizens real-time information and assistance, including directions or details on local services. AI can also be used to evaluate data from multiple sources, including social media, to comprehend the needs and preferences of individuals and make data-driven decisions that are advantageous to the society.

Digital services. Technologies such as digital twins DT, blockchain BC, virtual reality VR, metaverse, and simulated environments have the potential to completely transform the creation of SCs. Cities can test and evaluate new systems and technologies in simulated environments before implementing them in the real world. Real-time monitoring and analysis are made possible by digital twins DT, which offer a virtual replica of a physical system. The metaverse is a virtual environment that coexists with the real world and presents new opportunities for creativity and teamwork. Robotics and virtual reality VR present new opportunities for SC automation, simulation, and training. Blockchain BC offers a secure and decentralized platform for data administration and exchange, laying the foundation for the creation of innovative SC systems. There are many opportunities for innovation and advancement in quickly evolving field of developing and implementing these technologies in SCs.

Cloud platforms. The development of SCs depends heavily on city platforms, cloud computing, cloud storage, edge computing, hybrid data storage, infrastructure as a service (IaaS), and platform as a service (PaaS). For the control of SC systems, including public safety, electricity, and traffic management, city platforms offer a unified infrastructure. Scalable and adaptable methods for

processing and storing massive volumes of data produced by SC systems are offered by cloud computing and storage. By processing data at the network's edge, edge computing EC reducing latency and improving response times. The advantages of cloud and edge computing are combined in hybrid data storage, which offers a scalable and adaptable approach to data processing and storage. The platform and infrastructure for the creation and implementation of SC systems are offered by IaaS and PaaS, respectively. These technologies provide a foundation for the creation of new and creative SCs, which will result in a more smarter and efficient future.

2.1 Cloud-driven IoT-based Big Data

The expanding volume of data is increasing expectations for smart cities. Thus, the IoT-provided massive volumes of data, or big data BD, form the foundation of city infrastructure. volume, velocity, and different data types define the term BD. A city could gain valuable insights from a large amount of data gathered from many sources based on big data BD technology.

In order to support the development and analysis of smart cities, it is also important to monitor, gather, archive and share open sensor data from IoT devices. A number of researchers have offered diverse formal definitions of a smart city from a variety of viewpoints. Many smart city SC concepts and themes (smart people, smart transportation.) are required as a result of the development of ICT technologies. These should primarily leverage the benefits of data management technologies IoT, BD, and CC) to create a deep connection between every element and layer of a city.

There are certain benefits to cloud-driven IoT-based big data BD. Data about exponential growth throughout time could be gathered and analyzed logically and effectively to support decision-making. Big data BD produced by IoT devices could enable these scenarios because traditional approaches are not cost-effective when handling large volumes of data and are not appropriate for data processing and storage systems.

Due to the availability of enormous computational storage facilities for processing these data within smart cities SC, the use of big data BD in these settings offers both many benefits and constraints. However, this big data BD technology's dependence on cloud computing CC and IoT services is one of its significant advantages. Intelligent networks with complex connections between components and residents' equipment are required for the majority of big data BD deployments in smart cities SC. Therefore, this intelligent connectivity ICon should be able to transfer responses back to the entities and collect data from the resources in an efficient manner. For real-time big data BD applications in smart cities SC, quality of service (QoS) is therefore crucial.

To process big data BD, cloud computing CC represents a good solution. CC is an standard that

gives users in the cloud access to a shared platform of computational resources. For example, when it comes to capital savings and expenditures, CC can offer a number of advantages to both individuals and organizations. The relationship between IoT, BD, and CC is showed in Figure 2 based on the references.

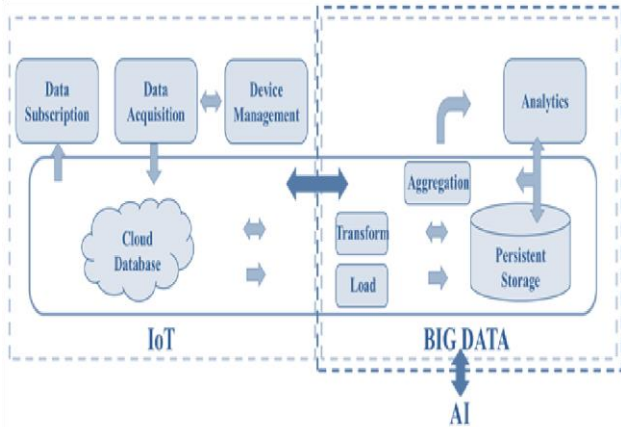


Figure 2 The relationship among IoT, big data BD and cloud computing CC.

CC users benefit from a network-based environment that allows them to share resources and computations from a specific location. NIST defines cloud computing as a framework that facilitates appropriate Internet connectivity and a collective pool of programmable grids, storage systems, software, and servers that could be quickly set free via communication from a provider.

Because data centers in physically accessible locations present a variety of security challenges and risks, CC users are unsure of the exact location of their sensitive data. Furthermore, because threats spread quickly, well-known security techniques like firewalls and host-based antivirus AV software are unable to offer adequate security platforms in virtualized systems. Additionally, CC offers enterprises cost-effective maintenance, limited upfront investment, and instant access to physical resources. CC is also regarded as a powerful enabler that enhances agility and operational activities.

2.2 6G enabling the New Smart City

The sixth-generation (6G) wireless communication is the successor of fifth-generation (5G) communication. Candidate technologies like artificial intelligence (AI), integrated sensing and communication (ISAC), and non-terrestrial networks (NTN) can be used in development smart city SCs as 6G communication systems evolve. Ubiquitous connectivity, artificial intelligence and communication, and integrated sensing and communication are three emerging use cases (Fig.3) [13].

The main themes of the upcoming 6G are summarized as follows:

- The convergence of sensing, computing, control, localization, and communications: computing, control, localization, and sensing in addition to current wireless communication.

- Smart reflective surfaces and environments: Driven by smart reflective surfaces that serve as walls, roads, doors, and entire buildings, helping to maintain a line of sight and obtain a quality signal with minimal loss.
- Massive availability of small data: Shifting from centralized bigdata BD to massive distributed small data.
- More resource availability (bits, spectra, and reliability): Higher frequency spectrum (THz), reaching 1 Tb/s.
- Self-sustaining networks: AI to facilitate intelligent wireless networks that are self-sustaining.
- Ubiquitous connectivity that encompasses air, ground, and sea: Integrating the space-air-ground-sea mode to facilitate wireless communications in flying vehicles, XR, brain-computer interface (BCI), and more.

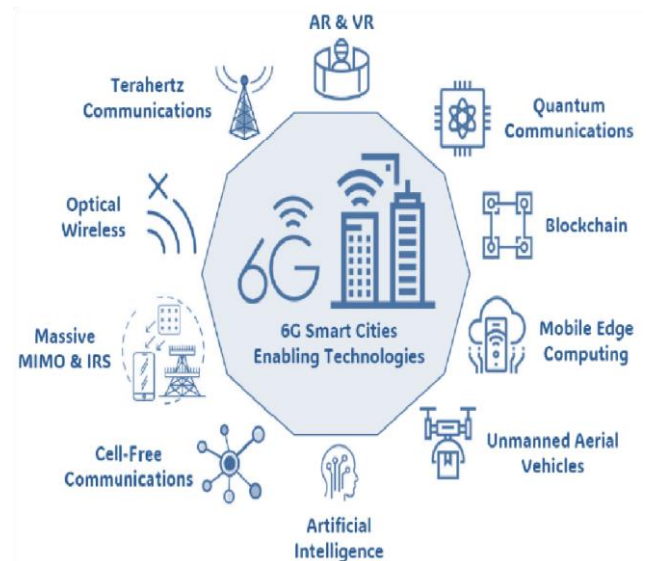


Figure 3 Enabling technologies in 6G for smart cities SC.

From a technical perspective, 6G makes it possible to integrate into a single network with increased throughput and reliability. These features make 6G networks perfect for the widespread implementation of the Internet of Things (IoT) paradigm, particularly given that billions of devices are anticipated to be connected to infrastructure in the near future.

Recently, the draft of the international mobile telecommunications IMT-2030 6G recommendation has been completed and 6 major usage scenarios have been defined [8]. Three of these scenarios, enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultrareliable and low-latency communication (URLLC) are more complex versions of the IMT-2020 5G usage scenarios. That is, immersive communication, massive communication, and hyperreliable and low-latency communication (HURLC).

The foundation of modern wireless communication networks is radio access technologies (RAT), which allow for high-speed data transmission and reliable connectivity for mobile devices. Radio access technologies are developing to offer even faster speeds, lower latency, and increased network capacity with the upcoming new generation of cellular networks.

IoT-based communication is essential to the creation of smart communities. Reliable wireless networks are crucial for the IoT to continue expanding. The usage of RAN or cloud RAN (CRAN) in the developing 5G cellular system, which integrates cloud computing CC technologies into the radio access network, is one way to address this issue. More scalability, flexibility, and performance are offered by CRAN, which makes it possible for 5G to link a large number of IoT devices, all of which are essential for SCs. The concept of network slicing (NS), which enables service providers to design unique virtual networks for various applications and services, is another crucial component of 5G RATs.

Edge computing (EC) involves processing data and performing other computational tasks closer to the source of the data, rather than sending them all to a central data center or cloud. Edge devices, which are located closer the network's edge and have real-time data processing capabilities, can be used to do this. 5G and EC edge computing together can offer a powerful platform for developing previously impossible new services and applications. Using edge devices, for instance, real-time video analytics can be carried out at the network's edge. The processed data is then sent over 5G networks. Numerous uses, including remote surveillance and health monitoring, may be made possible by this. The application of edge computing EC and 5G to driverless cars is another example. Autonomous vehicles can make decisions in real time, enhancing efficiency and safety, by processing sensor data and other information at the network's edge. The presence of a cloud in the IoT system of an SC can result in high energy consumption and network delays. Based on a cloud computing CC, edge computing EC has become a solution to this problem by bringing network, storage, and processing resources closer to the data source. However, a crucial problem in edge computing EC while executing tasks produced by IoT systems is the effective use of energy while maintaining delay constraints. In IoT-based SCs, resource allocation using distributed edge computing EC is studied using a multi-criteria optimization approach. To guarantee effective resource computation for delay-sensitive tasks, an actionable approach-based edge resource allocation method is effective solution for three-layer network architecture for IoT-based SCs. In SCs and the IoT, edge computing EC provides a number of advantages, such as reduced latency, improved security, increased scalability, lower costs, and enhanced reliability.

New SCs might benefit from a variety of cutting-edge technologies, such as remote healthcare, smart grids, and driverless cars, with the aid of 6G networks. Furthermore, cutting-edge technologies like virtual reality, augmented reality, and immersive gaming might be supported by 6G networks, opening up new business and residential options in these places. It might take a few years before 6G networks are generally accessible, though, as their development is still in its infancy. Researchers and business

professionals are still investigating the possible advantages and applications of 6G networks in the context of recent advancements in SC. Intelligent transportation and logistics, connected robotics and autonomous systems, worldwide ubiquitous connection, and pervasive intelligence are some examples of use cases that have been identified and presented in the context of SCs.

Better monitoring and control of urban resources based on the development of intelligent infrastructure, such as linked sensors and devices, made possible by 6G networks. This covers data-driven intelligent urban planning, water and energy efficiency, and intelligent waste management. Furthermore, by facilitating greater access to services like such as e-healthcare, online education, and digital governance platforms, 6G-enabled SCs are anticipated to promote inclusivity and enhance people's quality of life.

3 CONCLUSION

As urban environments continue to evolve, the smart sustainable city SC has generated considerable attention. As research and industry studies present, there is a need for a critical reassessment of the entire ICon wireless communication sector for SCs. The development of the SC concept relies heavily on ubiquitous connectivity because the existing communication infrastructure cannot keep pace with the rapid growth and extended operation of SCs.

Smart cities SC are the result of modern ICT development that integrates mobile communications and AI. 5G networks significantly influence the development of SC infrastructure. Along with data analytics and artificial intelligence, the Internet of Things is a crucial ICT technology that facilitates smart networking in urban areas. Smart connectivity solutions have been the focus of several national SC programs. In terms of various degrees of new technologies, practically every city nowadays aims to be SC to some degree. Critical infrastructure integration and monitoring, resource optimization, maintenance activity planning, security monitoring, and maximizing citizen services are all taken into account. An innovative city that uses ICTs primarily to improve the quality of life and efficiency of city operations and services while meeting the needs of present and future generations in terms of the economy, society, environment, and culture is referred to as a smart sustainable city.

The quick advancement of IoT technologies encourages academics to explore new services and application areas. Additionally, by sharing and gathering data inside IoT services, human needs will be taken into account in order to increase awareness of smart city principles. Consequently, sensing, processing, networking, and actuation should all be integrated into the network.

With the development of ICon technologies, we are currently witnessing the ongoing evolution of urban settings. ICTs are helping many cities become smarter these days, increasing the efficiency of infrastructure and traditional services. Both industry and academics are conducting research on sixth generation (6G)

technologies in light of the introduction of 5G technologies. One of the best options for enabling SC to support the development of new services and applications is 6G networks.

As technology continues to evolve, the creation of a new generation of wireless technology might be justified for a number of reasons. SCs and 6G are technologies that will transform the way we live and work in the near future. However, combining these technologies leads to a series of challenges that have to be addressed. The challenges for SCs include interoperability, data privacy and security, digital divide, and implementation challenges.

The next generation of SCs is anticipated to be made possible by 6G networks, which offer faster data transfer speeds, lower latency, and increased connectivity. Overall, 6G networks have the potential to transform how cities function by providing faster, more reliable, and more efficient connectivity, supporting a wide range of SC applications.

Actually, 6G requires new infrastructure and technology, which may be difficult to develop and deploy. Like any new technology, 6G may raise security issues that need to be resolved to protect users' privacy and safety. Finally, governments and private industries collaboration are necessary for development and implementation, and regulatory obstacles that need to be overcome. International coordination and collaboration will also be necessary to achieve worldwide connectivity with 6G.

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Technical and economic analysis of photovoltaic plant investment at Maribor district heating facility

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The research analyses the technological and economic dimensions of developing a modular solar power plant at Maribor district heating facility, including rooftops and parking lots. The main goal is to enhance the company's energy self-sufficiency, reduce power expenses, and facilitate the shift to renewable energy sources. The research project seeks to enhance energy production by the application of solar photovoltaic technology, ensuring both cost-effectiveness and long-term sustainability. Multiple design and implementation alternatives have been examined utilising the PV*Sol software package, which facilitates comprehensive simulations and performance assessments of solar power systems. The study concentrated on determining the most economically viable configuration, including variables such as energy output, capital expenditures, and operational efficacy. A comparison of various modular system designs was conducted to identify the most effective strategy for scalability and optimal performance.

The legal and regulatory frameworks pertinent to the planning and construction of a solar power plant were examined, including adherence to national and EU energy policies, grid connection stipulations, and accessible financial incentives.

The research has evaluated the long-term economic viability of the project, identified potential risks and problems, and provided the most profitable and sustainable implementation strategy.

Keywords: Photovoltaic solar modules; renewable energy sources; energy self-sufficiency; investment economic evaluation

1 INTRODUCTION

The increasing demand for sustainable energy solutions has led to a significant shift towards renewable energy sources, particularly solar energy. This work is focused on the financial viability and technical requirements of solar energy investment on the site of Energetika Maribor company, with the net present value (NPV) being used as a critical metric for assessing investment decisions. The rationale for this research is based on the need for a comprehensive evaluation of solar energy projects, which are often influenced by various economic and regulatory factors.

In the light of rising energy costs and environmental concerns, understanding the financial implications of solar energy investments is essential for both individual investors and organizations. The NPV of a solar project at Energetika Maribor, considering both rooftop and parking lot installations, has been evaluated, with an emphasis on selecting appropriate discount rates and considering long-term operational costs, such as maintenance and degradation of solar modules. By analysing these factors, the work aims to guide potential investors in making informed decisions aligned with their financial and sustainability goals.

Furthermore, the research addresses the technical requirements for self-supply systems that utilize renewable energy sources, ensuring that installations comply with safety and operational standards. This aspect is critical for fostering confidence in solar energy solutions and promoting their adoption across various sectors. Overall, this work contributes to the growing body of knowledge on renewable energy investments,

providing valuable insights to help stakeholders navigate the complexities of the solar energy market.

1.1 Goals and objectives

The primary goal of this paper is to evaluate the feasibility and optimal design of a solar power plant on the premises of Energetika Maribor company [6]. As renewable energy becomes a cornerstone of modern energy policies, the most effective approach for implementing a photovoltaic (PV) system that enhances energy self-sufficiency and reduces electricity costs for the company is identified.

To achieve this, the focus is on:

1. **The potential and economic viability of a solar power plant** – Different installation scenarios on available surfaces (e.g., warehouse rooftops and parking spaces) are analysed to determine the most cost-efficient setup.
2. **A technical and economic analysis of different solar panel configurations** – Multiple photovoltaic module types and installation methods are evaluated using simulation tools like PV*Sol to optimize performance and return on investment.
3. **Regulatory and financial considerations** – Slovenian and EU legislative frameworks, potential subsidies, and incentives for solar energy adoption, particularly in the context of self-consumption, are reviewed [1][2][3], [4].
4. **A comparison of various investment models** – Profitability, payback periods, and

the overall sustainability of the proposed PV system under different financing and operational strategies are examined.

The core objective of this study is to determine whether the construction of a solar power plant at Energetika Maribor is an economically and technically viable investment. Solar simulation models and financial projections are leveraged to present the most efficient and profitable setup while considering constraints such as shading, surface availability, and installation costs.

The paper follows a structured methodology that includes:

- Introduction to the problem and background on solar energy.
- Technical and economic evaluation of photovoltaic systems.
- Regulatory analysis and available incentives [2].
- Investment evaluation and financial feasibility study.
- Comparison of different installation setups and costbenefit analysis.
- Final recommendations on the optimal solar plant configuration.

By integrating technical feasibility and economic justifications, the paper provides a comprehensive decisionmaking framework for implementing a sustainable and profitable solar energy project.

The solar power plant was integrated into the electricity consumption system based on 15-minute electricity consumption readings and adjusted through multiple iterations of increasing and decreasing the plant's capacity [3].

In the model, the 15-minute energy consumption was compared with the projected hourly electricity production of the new solar power plant. Hourly production was divided into 15minute intervals for further analysis. Compensation, deficits, and electricity sales were calculated for each 15-minute interval throughout the year.

When designing a self-sufficient power plant, care must be taken to avoid oversizing the system, as excess electricity produced is handed over to the supplier, as seen on Figure 1. Calculations were collected at monthly and annual levels. The economic analysis used annual consumption and production data, assuming the same levels of consumption and production for 25 years, despite changing weather conditions. Annual degradation of the solar modules, as provided by the manufacturer, was considered in the financial analysis.

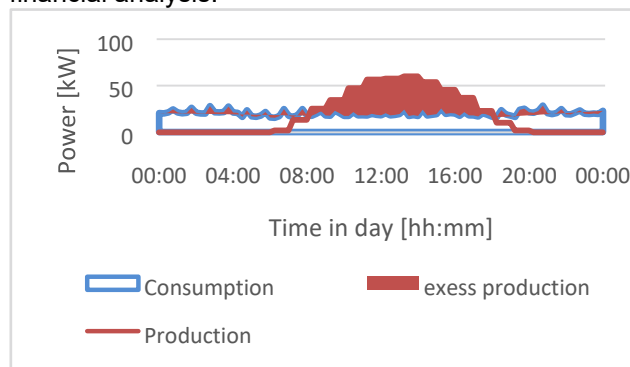


Figure 1 Daily display of electricity consumption and production

2 METHODS

Several possible ways to install a solar power plant at the company's location were examined, as well as the possibility of using bifacial solar panels on carports. Focusing on the strategic planning and design aspects that contribute to its functionality and efficiency, here are the key points of designing of PV power plant:

- **Location Selection:** The proposed location for the solar power plant includes functional

surfaces within the place that have the potential for solar energy generation. This includes parking lots and building rooftop, which receive ample sunlight throughout the day. The idea is to cover these spaces with photovoltaic modules, thereby generating electricity while providing shaded parking for vehicles.

- **Modular Design:** The project aims to create a modular design for the solar power plant, allowing it to be adaptable for various locations and uses. This design approach not only serves the needs of Energetika Maribor but can also be replicated in similar urban settings across the city.
- **Construction Specifications:** The construction of the solar power plant on parking lots involve a steel structure designed to support the photovoltaic modules. The inclination of the structure is set at 6 degrees, which is optimal for maximizing solar exposure and energy production with provided shade and shelter for cars during the day. Design can be seen on Figure 2.
- **Environmental Considerations:** The project emphasizes the use of renewable energy sources to minimize environmental impact. By integrating solar energy production into the urban landscape, the initiative aims to contribute to energy self-sufficiency while reducing carbon emissions.

The construction and location of the solar power plant are carefully planned to optimize energy production, enhance urban living conditions, and promote sustainability using renewable energy sources. Several possible variants of the solar power plant were studied and analysed. At the same time, installation of bifacial modules in the parking lots were planned, which also utilize the portion of light reflected from cars underneath. According to the specifications, these panels should have a slightly higher efficiency than ordinary ones.

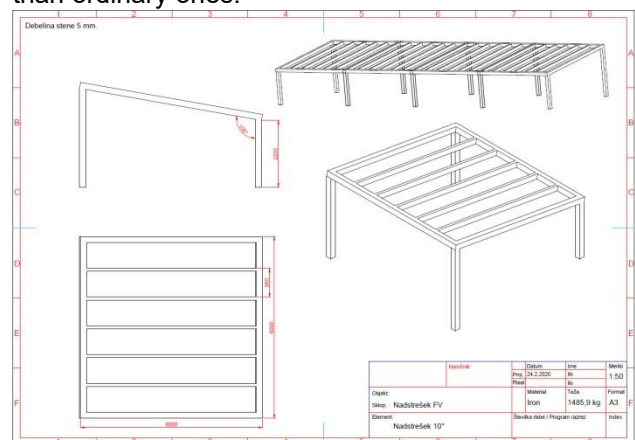


Figure 2: Modular design for PV on parking lots

2.1 PV system design using the PV*Sol program

The design of the photovoltaic system using the PV*Sol program involves several critical steps and considerations. The design process begins with the input of relevant data into the PV*Sol program. This includes information about solar radiation, climatic conditions, and specific characteristics of the site where the solar power system will be installed. The software utilizes data from the company Energetika Maribor and ARSO (Slovenian environmental agency) regarding annual solar radiation and climate conditions in the region. The PV*Sol program simulates the

expected energy production of the solar panels [7]. For instance, it was found that the annual energy production could reach approximately 189.164 kWh, with a significant portion contributing to the reduction of the company's electricity consumption. PV*Sol allows for a comparative analysis of different PV module types and configurations. This includes evaluating various installation methods and the performance of different photovoltaic (PV) modules, which helps in selecting the most efficient setup for the specific site conditions. The design also incorporates technical specifications for the selected modules and inverters. For example, the use of classic modules and bifacial modules, along with optimizers. Results of the expected energy production of the solar panels on hourly basis were exported into MS excel where we further processed the data.

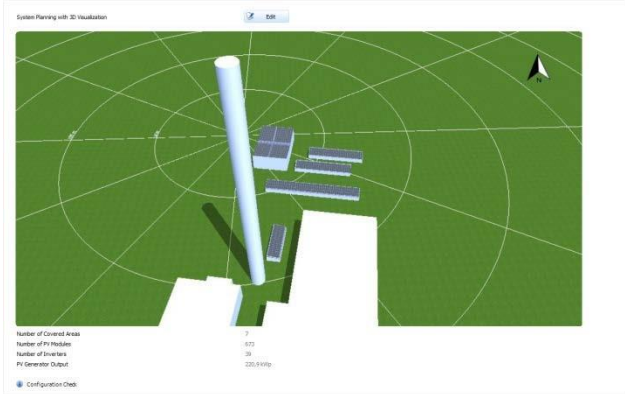


Figure 3: Planning in PV*Sol

In conclusion, the technical results of the optimal configuration for the PV system demonstrate a well-thought-out design that combines efficient module selection, strategic installation, advanced optimization technology, and robust inverter systems to achieve high performance and economic benefits. Desing uses high-efficiency PV modules (classis on rooftop and bifacial at parking lots). Each module is paired with Solar Edge power optimizer and utilized with three-phase Solar Edge inverters. Thus, considering the different possible module and layout variants, we looked for a variant where the yield of the solar power plant is as high as possible, while the excess energy produced remains low.

2.2 Economic viability and long -term sustainability

The economic viability of the photovoltaic (PV) project is assessed through various financial metrics and methodologies, as outlined in the provided contexts. Here are the key results:

- **Net Present Value (NPV):** The NPV is a critical measure used to evaluate the project's economic viability. It is calculated using a discount rate of 7.2% [1]. A positive NPV indicates that the project is expected to generate more cash than the costs incurred, making it a worthwhile investment. The methodology for calculating NPV considers the investment value, project returns over time, and the appropriate discount rate based on business conditions and risks.
- **Internal Rate of Return (IRR):** The project aims for the highest internal rate of return, which is a key indicator of profitability. The IRR is compared across different configurations to identify the most financially advantageous setup. The optimal configuration is expected to have the shortest payback period and the highest NPV after 25 years of operation, indicating strong economic performance.
- **Financing Structure:** The project financing is structured with 20% of the investment funded through equity and 80% through loans. This mix influences the expected return rates and the overall financial risk associated with the project. The desired return on investment is assessed based on this financing structure, which is crucial for determining the project's feasibility.
- **Electricity Pricing:** The price for electricity was set at 74,06 €/MWh in high tariff and 49,37 €/MWh in lower tariff (as in Table 1). A large share of electricity costs is also represented by the network fee, which is considered in the calculations. As a comparison, we have made calculations of the economic feasibility if all the electricity from the solar power plant were sold on the market. The reference price for electricity was set at 48.04 €/MWh [5].

In conclusion, the economic viability of the PV project is supported by a positive NPV, a favourable IRR, a wellstructured financing plan, operational support, and strategic pricing of electricity. These factors collectively indicate that the project is financially sound and likely to yield significant returns over its operational lifespan.

Table 5 Energy tariffs used

	Price without tax [€/kWh]
Energy higher tariff	0.07406
Energy lower tariff	0.04937

Network fee higher tariff	0.01146
Network fee lower tariff	0.00883
Energy Efficiency tax	0.0008
RES and CHP fee	1.84450
Market Operator fee	0.00013
Excise duty	0.00305

For the analysis, the losses due to shading and the consumption of the inverters were taken into account. For each variant, the compensated electricity based on

SE exploitation method / Layout variant	Payback period [years]		Internal rate of return [%]	
	Sale	Self-consumption	Sale	Self-consumption
Layout 1	10.98	10.82	6.11	8.15
Layout 2	10.63	10.35	6.59	8.94
Layout 3	10.56	9.96	6.67	9.63

the entire solar power plant is 169 kWp, with a module surface area of 921.9 m².

According to the PV*Sol simulation, the estimated annual electricity production would be 189,164 kWh. Out of this, 176,762 kWh would be directly offset against the company's annual electricity consumption. This would result in a cost savings of €14,801.47 (excluding VAT) in the first year of operation. **3.1 Key Findings**

4, 2, and 6. The least favourable option is Configuration 1, which utilizes all available space for the solar power plant but comes with the highest initial cost. With Configuration 5, the net present value of the project after 25 years is 16,641 €.

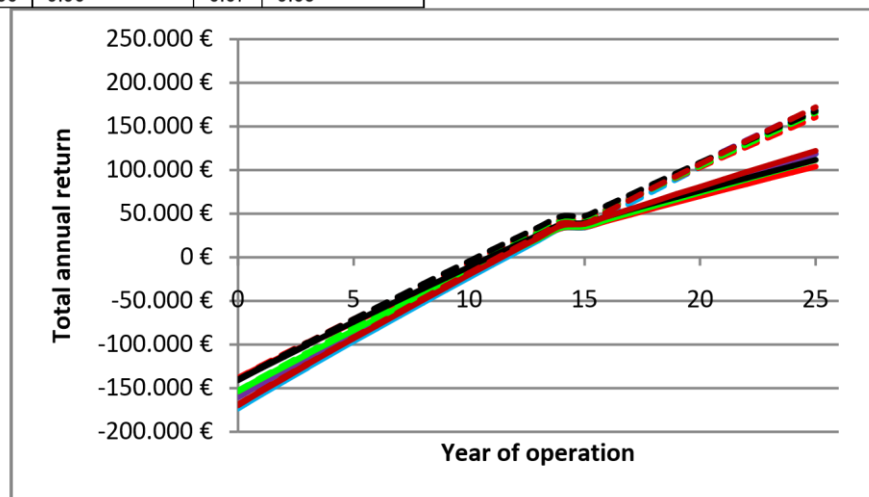


Figure 51: Total annual return of configurations

15-minute measurements of consumption and production was calculated. The 2.5 % efficiency loss due to degradation of the modules is considered. This assumes a linear decline in module efficiency to 80.7% of nominal power in the 25th year of operation [8], [9]. Maintenance costs were estimated as 0.35 % of investment per year. The calculation also considers the costs of replacing inverters after 15 years of operation.

3 RESULTS

The study evaluates six different PV system configurations, each with varying initial investment costs, expected energy yields, and operational efficiencies. The primary cost considerations include:

- **Capital expenditure (CAPEX):** Initial investment required for purchasing PV panels, inverters, and installation.
- **Operational expenditure (OPEX):** Recurring maintenance costs estimated at 0.35% of the initial investment per year.
- **Revenue from electricity sales or selfconsumption savings:** Modelled over a 25-year period.

The most optimal option was found to be Variant 5, which requires 384 photovoltaic modules. The supporting structure consists of 22 carports, each measuring 6 x 6 meters. The total installed capacity of

1. Net Present Value (NPV)

The NPV calculations indicate that self-consumption models outperform pure electricity sales, given the current market conditions and feed-in tariffs.

2. Internal Rate of Return (IRR)

The IRR for self-consumption models is higher than for grid sales, due to better cost savings and energy independence. **3. Payback Period**
The shortest payback period is around 9.81 years for option 5, while other configurations take between 10 to 11 years to break even. After this period, the systems generate pure profit, making them a lucrative long-term investment.

Results of comparison of different variants can be seen in Table 2.

Table 2 Comparison of different variants by payback period and internal rate of return

Layout 4	10.72	10.31	6.47	9.00
Layout 5	10.32	9.81	7.02	9.92
Layout 6	10.79	10.64	6.41	8.48

3.2 Challenges and Limitations

While the financial analysis is promising, the study highlights some potential risks and limitations, including:

- **Degradation of PV panels:** Efficiency decreases over time, impacting long-term revenue generation.
- **Grid constraints:** Regulatory restrictions on energy export and possible changes in feed-in tariffs can affect profitability.
- **Capital cost fluctuations:** Market variability in PV module prices and installation costs can impact investment decisions.

The investment cost analysis demonstrates that selfconsumption is the optimal financial strategy for PV system deployment. System configuration 5 emerges as the most profitable, with the highest IRR and shortest payback period. Future research should explore the impact of battery storage and dynamic pricing models to further improve financial performance.

4 CONCLUSIONS

6 different installation variants were analysed with

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power plants sized between 162 kW and 202 kW. The analysis presented system Configuration 5 with 169 kW of output power as the most optimal setup for implementing a photovoltaic (PV) power plant at Energetika Maribor. The annual electricity production with such a solar power plant would amount to 189,164 kWh, of which 176,762 kWh or 93% could be used for self-supply. The remaining energy is represented by surpluses delivered to the network. On an annual basis, this means a reduction in the cost

Figure 3 shows that the total return on investment for selfconsumption transitions from a negative to a positive value between the 11th and 12th year, while for electricity sales, this occurs around the 13th year of operation. Over their lifetime, all investments would pay off and recover the initial capital. The highest total return after 25 years of operation would be achieved with Configuration 6, amounting to 172,027 €, while Configuration 5 has the shortest payback period of 9.81 years. The diagrams clearly show a drop in revenue in the 15th year, corresponding to the replacement of inverters and the change in electricity purchase prices after the expiration of operational support. While the differences between individual configurations are minor, the method of electricity utilization (self-consumption vs. sales) has a significant impact on financial outcomes. The most profitable photovoltaic power plant setup is selfconsumption with Configuration 5, followed by Configurations 3, The figure 4 illustrates the difference between the two approaches to utilizing the solar power plant. It is evident that, in this case, selling electricity is not a viable option, as selfconsumption proves to be more beneficial given the current discount rate and electricity sale conditions. According to the net present value method, an investment is acceptable if the difference between revenues and expenses remains positive at the end of the period. However, in the case of electricity sales, this is not the case. The internal rate of return (IRR) for a solar power plant intended for electricity sales ranges from 6.11 % for Configuration 1 to 7.02 % for Configuration 5.

of electricity of 14,801 € at the existing electricity purchase price.

This conclusion is based on a comprehensive

evaluation of financial, technical, and environmental factors, with an emphasis on self-consumption over energy sales. The key findings highlight that:

- **System Configuration 5 achieves the highest internal rate of return (IRR)** and the shortest payback period, making it the most financially viable option.
- **Self-consumption proves to be the most beneficial model**, as selling electricity to the grid does not yield

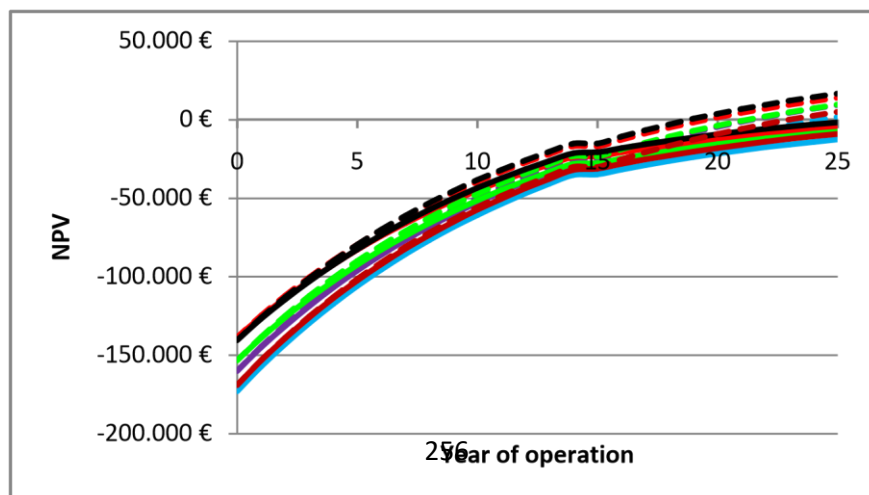


Figure 52: Net present value of configurations

significant returns under current market conditions.

- **The combination of classic modules on warehouse rooftops and bifacial modules on parking lots** ensures high efficiency and improved energy yield.
- **The optimal tilt angle of 20°** on rooftops further enhances performance of the system.

Additionally, environmental benefits were also considered. The reduction of CO₂ emissions by 91 tons annually underscores the sustainability of the project, aligning with Slovenia's renewable energy objectives.

In conclusion, the study confirms that investing in a solar power plant with a focus on self-consumption is the most economically and environmentally sound decision. Future optimizations could explore the integration of battery storage solutions to enhance energy independence and further improve financial returns.

The assessment of economic viability through methods such as Net Present Value (NPV) and Internal Rate of Return (IRR) provides valuable insights into the financial performance of projects, particularly in the renewable energy sector. However, these methods come with certain limitations that must be acknowledged:

- **Sensitivity to Assumptions:** Both NPV and IRR calculations are highly sensitive to the assumptions made regarding discount rates, cash flow projections, and the lifespan of the project. A slight change in these assumptions can lead to significantly different outcomes, which may misrepresent the project's true economic viability.
- **Complexity in Multi-Variant Scenarios:** When comparing multiple investment options or configurations, the complexity increases, making it challenging to derive clear conclusions.
- **Market Fluctuations:** The methods assume stable market conditions, which may not hold true in realworld scenarios. Fluctuations in energy prices, interest rates, and inflation can significantly affect the projected cash flows and, consequently, the viability assessment.

Despite these limitations, the methods for assessing economic viability are widely applicable in various areas:

- **Renewable Energy Projects:** The methodologies are particularly relevant for evaluating investments in renewable energy sources, such as solar and wind power, where long-term cash flows and initial capital investments are critical considerations.
- **Infrastructure Development:** These financial metrics can be applied to large-scale infrastructure projects, helping stakeholders understand the potential returns and risks

associated with significant capital expenditures.

- **Investment Decision-Making:** Investors and financial analysts utilize these methods to make informed decisions regarding capital allocation, ensuring that resources are directed towards projects with the highest expected returns.

In conclusion, while the methods for assessing economic viability provide essential insights into project feasibility, it is crucial to recognize their limitations and consider a broader range of factors when making investment decisions. Their application in renewable energy and infrastructure development highlights their importance in guiding financial strategies in these sectors.

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Leadership in Smart Cities: Emotional Intelligence as a Driver of Smart City Ecosystem Transformation

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Abstract: This paper aims to examine the role of organizational leaders in the process of transforming urban areas into smart cities with a detailed analysis of the key challenges they face. The introduction of the smart city concept requires the modernization of leadership styles, organizational strategies, and resources as well as increased agility and adaptability to new internal and external business conditions. Current research indicates that emotional intelligence plays a key role in the efficient and effective management of these changes. Therefore, the aim of this research is to examine the impact of emotional intelligence on the leadership and economic performance of organizations in Serbia. Quantitative analysis showed that emotional intelligence significantly contributes to the quality of leadership. Additionally, it was found that it acts as a moderating factor in the relationship between leadership and economic performance of organizations. Research findings indicate a positive correlation between a higher level of emotional intelligence among leaders and improved economic results of the organizations. The obtained results show that the development of emotional intelligence in leaders is a key factor for successfully managing processes within the Smart City ecosystem. Furthermore, the findings of this research provide important guidelines for the strategic selection and development of leaders who will lead organizations in smart cities in Serbia.

Keywords: Leadership, Smart Cities, Emotional Intelligence, Economic Performance, Smart City Ecosystem

1 INTRODUCTION

In the digital age cities are changing their trajectories by following the "smart" revolution aimed at managing, providing, supporting, and ensuring proper planning for cities and their participants (Marchesani et al., 2023). Although the concept of a "smart city" is widely used for various purposes and from different perspectives, the literature still does not provide a precise definition (Sancino, Hudson, 2020). Despite this, "smart cities" and "intelligent cities" can respond to the challenges of urbanization (Albert, 2019). Smart cities leverage ICT to address urban challenges through an intelligent use of technology. Over time, the focus has shifted from being purely technology driven to emphasizing citizen engagement, resilience, and sustainable development (Sancino, Hudson, 2020).

Through examples of initiatives involving collaboration among different organizations and sectors (Bakici, 2012) as well as through the transformation of the world based on the successful implementation of the 17 United Nations Sustainable Development Goals (Agenda 2030, 2015) we are witnessing a fairer and more sustainable development path for every city (Boykova et al., 2016). In smart cities, innovative solutions are created through mutual collaboration for better integration of urban spaces (Jacques et al., 2024) while achieving sustainable development goals (Makkonen et al., 2024). Smart Cities are hubs for innovation and economic development with unmatched solution exchange and development. Organizational effectiveness hinges on its people: employees, shareholders, suppliers, customers and more. Firms boost customer satisfaction through regular feedback and enhance

employee motivation via training, recognition, and competitive pay. Effective communication drives sound decision-making and keeps everyone aligned with organizational goals, as the ultimate goal of a smart city is sustainability (Manoharan et al., 2023).

For a smart city to function as a sustainable system while simultaneously achieving its broader goals, it is essential to assess how ready a city is to implement projects or programs (Pries-Heje & Cranefield, 2018) in line with the needs of modern leadership (Gurick, Felger, 2022). According to the McCleskey's research (2012), the knowledge is fundamental to develop leadership skills and encompasses core cognitive abilities, including analytical, practical, social, emotional, and contextual intelligence. Leadership effectiveness lies in the ability to understand the impact of leadership style on teams and organizations. Leadership style should be a result of one's attitude, personality, experience and emotional intelligence (Kochieyl et al., 224). A smart city leadership is underexplored both empirically and theoretically. Understanding emerging leadership styles in smart cities is crucial for shaping successful policies and practices as it depends on technology's role in 21st century life. While smart governance is recognized as key, there is a notable lack of research that examines how leadership is actually exercised in these environments (Sancino, Hudson, 2020). Understanding leadership in a smart community is key to creating a harmonious society that respects diverse needs and goals. Smart cities

open the path to social and emotional intelligence, promote intercultural understanding as successful leadership requires a complex combination of skills and behaviors (Gurick, Felger, 2022). Smart cities are complex ecosystems that use technology to address issues of urbanization, security, and sustainability, creating ecosystems that improve the quality of life and stimulate economic activity. A crucial role in this process is played by organizations, businesses, and a highly skilled workforce that enables the development and realization of sustainable ecosystems. Therefore, developing various competencies including emotional intelligence and leadership is key (Fitsilis, Kokkinaki, 2021). Therefore, the exploration of emotional intelligence is

indispensable for the essence of organizational behavior in the future (Ashkanasy et al., 2005).

2 LEADERSHIP AND EMOCIONAL INTELLIGENCE

The concept of leadership has existed since the very beginnings of human history. As humans developed collective life and organizational structures the need for leadership and management arose. In modern society, leadership is a key factor in the successful functioning of organizations and achieving their goals. Research shows that leadership is not a fixed category but a dynamic process that constantly adapts to changes in the business environment enabling organizations to effectively fulfill their mission and vision (Kiyak et al., 2020). The quality of leadership comes naturally to some while others acquire and develop these skills through work and active engagement supported by ethical and spiritual characteristics that are indispensable (Budur et al., 2019). The leader of the future, aside from knowledge and intelligence, stands out by his/her ability to apply their own emotional intelligence (McCleskey, 2014). Leading in a smart community requires a complex combination of leadership skills and all levels of intelligence: individual, emotional, and social. Exceptional leadership involves understanding and representing the needs of the ecosystem of a smart city's public and private entities, while organizational leadership in smart city settings aligns individual needs and creates solutions that enhance the overall progress of the organization (Gurick, Felger, 2022).

Dulewicz and Higgs (2003) highlight that academia and top management in companies increasingly recognize the key role of emotional intelligence in effective leadership. Modern research emphasizes its significance in professional advancement and research processes, while elements of emotional intelligence are increasingly integrated into tools for assessing leadership competencies and styles. Additionally, organizational culture plays a significant role in the development and application of these constructs in practice. Emotional intelligence (EI) is considered to be twice as important as IQ. Research indicates that EI forms the foundation for essential skills across various jobs. It involves the ability to recognize emotions, use them to support thinking, understand emotional meanings, and manage emotions effectively to foster personal and intellectual growth (Mayer et al., 2004). Research shows that Emotional intelligence may serve as a key factor for success in the workplace. Core competencies such as recognizing, understanding and managing emotions in oneself and others, are considered essential in most definitions of emotional intelligence (Schutte et al., 2014). Emotional intelligence refers to an individual's ability to recognize and manage their own emotions as well as the emotions of others, both individually and within groups. In a smart city development enhancing

emotional intelligence helps individuals develop skills to improve work performance, making self-awareness crucial. As a transversal skill, EI aids in understanding personal emotions, translating intentions into actions, and making informed decisions (Fitsilis, Kokkinaki, 2021). Emotional intelligence competencies, like self-awareness and self-control, are learned abilities that help recognize, understand, and use emotions effectively, leading to superior work performance. Most of above mentioned abilities demonstrated an impact on job outcomes. These include but are not limited to; new business creation and employment satisfaction which are the core goals of development efforts (Boyatzis, 2008). This is particularly significant for leaders in organizations within Smart Cities. For example, the implementation of smart cities differs: in Asian regions, a technological, "top-down" approach is effective when building cities from the ground up. In contrast, European cities with their rich historical and cultural heritage and diverse social contexts would adopt a more complex, "bottom-up" approach. This method involves multiple stages, considering the interests of various stakeholders, and emphasizes developing human capital and fostering interdisciplinary collaboration to drive qualitative changes in the urban environment and society (Boykova et al., 2016). Gerli et al. (2022) explore how psychological factors such as emotions, attitudes, beliefs, and information-seeking influence skill development in the context of technology acceptance. The study explains how the interaction of cognitive and emotional elements shapes decisions regarding the adoption and use of smart technologies. The authors highlight that increasing digital skills does not guarantee automatic technology adoption and emphasize the importance of creating initiatives that ease this process. It is crucial for leaders in European countries to recognize this issue and accelerate the smart city implementation process through proper initiatives, and emotional intelligence is key both for recognizing and finding solutions that employees will accept without resistance. Organizations should prioritize emotional intelligence in hiring, alongside other technical skills and business expertise (Goleman, 2001).

Effective leadership is crucial during periods of change, particularly in the transformation of cities into smart cities, which brings significant organizational shifts. Research by Palmer et al. (2001) identifies a strong correlation between emotional intelligence and various aspects of transformational leadership, highlighting its role as a key factor in leadership effectiveness. Emotional intelligence enables leaders to observe, interpret, and respond to subordinates more effectively, shaping their workplace experiences. Furthermore, it is recognized as a strong predictor of leadership success (Kerr et al., 2006). Studies also confirm a positive relationship between emotional intelligence and transformational leadership (Leban &

Zulauf, 2004). Leaders with high emotional intelligence are more inclined to adopt a transformational leadership style, as they possess the ability to inspire and motivate their followers (Barling et al., 2000).

Numerous studies have highlighted the significant impact of emotional intelligence on employee performance, yet there is a notable gap in research on its effect on economic performance, emphasizing the need for further exploration of this relationship. The findings suggest that understanding emotional intelligence and its influence on performance can enhance organizational value, as employees adopt best practices and contribute more effectively to success. Additionally, emotional intelligence is a key predictor of job and organizational performance, particularly when fostered through individual performance, including taskrelated and contextual factors (Baporikar, 2020). This is particularly relevant for leaders in smart cities, where effective leadership is crucial for urban transformation.

Emotional intelligence significantly influences employee performance by improving emotional regulation, interpersonal skills, and response to workplace challenges, thereby enhancing productivity and organizational effectiveness (Sharmin et al., 2024). The results demonstrate that emotional intelligence

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impacts both individual and organizational outcomes. Given its importance for personal and organizational success, integrating emotional intelligence into organizational practices is essential for fostering a high-performance work environment (Goleman, 2001). Research indicates that emotional intelligence is not crucial for transactional leaders but contributes to improved communication and team management (Harms & Crede, 2010). The influence of emotional intelligence on communication has been confirmed in organizations in Serbia, as studies show a statistically significant impact of emotional intelligence on communication satisfaction within organizations in Serbia (Nikolić et al., 2014).

For all the above reasons, this paper aims to highlight the significance of emotional intelligence especially its impact on leaders in smart cities. Additionally, the paper points to the significance of emotional intelligence among leaders within organizations in Serbia. The results of the research should provide important guidelines for the strategic

selection and development of leaders who will guide organizations in smart cities in Serbia.

3 METHODOLOGY

The research was conducted whitened organizations in Serbia and involved 256 participants. Responses were measured using a Likert scale. Transformational leadership behavior was assessed using the Transformational Leadership Behavior Inventory (TLI). TLI evaluates four dimensions: Core transformational leader behavior, High performance expectations, Supportive leader behavior, and Intellectual stimulation (Podsakoff et al., 1990; MacKenzie et al., 2001). These four dimensions were combined into a single construct representing transformational leadership. In this study, transformational leadership behavior was measured using two dimensions: contingent reward behavior and contingent punishment behavior (MacKenzie et al., 2001). Furthermore, transformational leadership behavior was also analyzed as a single construct.

Financial performance was measured through a questionnaire encompassing seven indicators: Productivity, Profitability, Market share, Sales growth, Competitive status, Asset growth, and Salaries (Terek et al., 2016; Vukonjanski et al., 2016; Nikolić et al., 2015). In this study, these indicators are analyzed as a

single dimension.

Emotional intelligence was measured using a questionnaire that assesses five dimensions: selfawareness, managing emotions, selfmotivation, Empathy, and Social skills (Weisinger, 1998). For the purposes of this paper, emotional intelligence is analyzed as a single construct.

4 RESULTS

This study analyzes the impact of emotional intelligence; however, the directions of its influence has not been examined. The primary objective is to determine whether emotional intelligence affects leadership in organizations in Serbia and to assess how this impact affects their economic performance. Descriptive statistics are presented in Table 1, which includes the dimension names, their corresponding abbreviations, minimum and maximum values, standard deviation, and Cronbach's alpha coefficient.

Dimensions	Short name	Min	Max	Mean	Std. Deviation	Cronbach's Alpha
Core transformational leader behavior	L1	1.00	7.00	4.5283	1.78188	.912
	L2	1.00	7.00	5.4702	1.49075	
High performance expectations	L3	1.00	7.00	3.5770	1.58519	.891
Supportive leader behavior						.891
Intellectual stimulation	L4	1.00	7.00	4.1362	1.80259	.912

Contingent reward behavior	L5	1.00	7.00	4.2154	1.85478	.8
	L6	1.00	7.00	5.1429	1.73433	.8
Contingent punishment behavior	TF	1.29	7.00	4.3463	1.25849	.8
	TS	1.00	7.00	4.6129	1.38274	.8
Transformational Leadership						.8
Transactional Leadership						.8
Emotional intelligence	EI	1.00	5.00	3.9184	.58759	.9
Financial performance	FP	1.00	5.00	3.4547	.85090	.8

Table 1 Descriptive Statistics

The correlation analysis examining the influence of emotional intelligence on leadership in organizations in Serbia is presented in Table 2.

Table 2 The impact of EI on leadership in Serbia

	L1	L2	L3	L4	L5	L6	TF	TS
EI	.303**	.328**	.134*	.227**	.191**	.170*	.316**	.237**

** . Correlation is significant at the 0.01 level (2-tailed). * . Correlation is significant at the 0.05 level

To assess the impact of emotional intelligence, the overall sample was divided into two groups based on emotional intelligence levels: high and low. The effect of leadership on (2-tailed).

economic performance in organizations in Serbia was analyzed within these sub-samples, and the results are presented in Table 3.

EI_HL		L1	L2	L3	L4	L5	L6	TF	TS
FP	L	.308**	.262**	.041	.185	.168	.122	.282**	.202*
	H	.370**	.428**	.352**	.434**	.409**	.125	.494**	.370**

Table 3 The impact of leadership on economic performance in subsamples of low and high EI

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**Correlation is significant at the 0.01 level (2-tailed).

*.Coreelation is significant at the 0.05 level (2-tailed).

5 DISCUSSION

Emotional intelligence impacts all aspects of leadership in organizations in Serbia. The most significant impact of emotional intelligence is on High performance expectations behavior which can contribute to increased trust in employees and their abilities in the workplace. Additionally, emotional intelligence has a slightly stronger influence on

transformational leadership behavior than on transactional leadership in organizations in Serbia. Transformational leadership has an additive effect even on transactional leadership. The effect of transformational leadership drives followers to achieve more than what is usually expected of them (Northouse, 2018).

In the high emotional intelligence subsample, all aspects of leadership have a statistically significant impact on economic performance except for Contingent punishment behavior. According to Podsakoff et al. (1982), a leader's use of contingent negative

reinforcement involves responding to an employee's poor performance with actions like reprimands and expressions of disapproval. Considering the relatively low impact of emotional intelligence on Contingent punishment behavior in the global sample this relationship should be further examined.

In the low emotional intelligence subsample, both transformational and transactional leadership impact economic performance as well as Core transformational leader behavior and High performance expectations. In this study, Supportive leader behavior, Intellectual stimulation, Contingent reward behavior, and Contingent punishment behavior do not have an impact on economic performance in the low emotional intelligence subsample.

6 CONCLUSION

Enhancing emotional intelligence is crucial for leaders driving smart city initiatives. Higher levels of emotional intelligence among leaders will provides the self-awareness, selfregulation, and interpersonal skills necessary to navigate complex, people-centered urban transformations and lead organizations effectively in this specific environment. This is particularly important in the diverse European context and in regions such as Serbia, where the successful integration of smart technologies requires not only technical expertise but also the ability to engage, motivate, and align a broad range of stakeholders. By fostering emotionally intelligent leadership, smart cities can promote innovative, inclusive, and sustainable organizational practices, contributing to the development of urban environments that effectively address the evolving challenges of the smart city ecosystem.

Research findings indicate that emotional intelligence significantly influences all aspects of leadership in organizations in Serbia particularly through behaviors characterized by high performance expectations that reinforce trust in employees. Transformational leadership demonstrates a stronger impact in environments with high emotional intelligence. Conversely, in organizations with low emotional intelligence, only specific leadership practices affect economic performance, while behaviors such as providing support, intellectual stimulation, and contingent punishment exhibit no significant effect.

These results undermine the importance of cultivating emotional intelligence among leaders in Serbia. As research shows, these urban environments require agile and adaptive leadership and emotionally intelligent leaders are proven to be better equipped to navigate rapid technological advancements and engage diverse stakeholders. Leaders with increased emotional capacity are more likely to establish a strong foundation for fostering financial growth and sustainable development in smart cities.

A limitation of this study is that the obtained results are specific to enterprises in Serbia and stem from

research that did not directly examine the development of smart cities in the country. According to the study by Prigoda et al. (2022), none of the major cities in Serbia are fully prepared for the urbanization process, despite governmental efforts toward the digitalization of urban areas and the inclusion of citizens in decision-making processes, recognizing the positive impact of smart city development on the national economy. This research explores advancements in the application of geographic information systems, the functioning of municipal services, and eGovernment, as well as specific solutions already implemented. Several cities in Serbia have been identified as progressing toward becoming smart cities, including Niš, Kruševac, Pančevo, Zrenjanin, Novi Sad, and Belgrade (Prigoda et al., 2022). Given these findings, future research on smart city development should be conducted in cities in Serbia that are on the path to becoming smart cities. Additionally, the recommendation for organizations is to consider emotional intelligence as a factor in the selection of leaders in enterprises operating within these evolving smart city environments.

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Person detection and re-identification in open-world settings of retail stores and public spaces

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Abstract: Practical applications of computer vision in smart cities usually assume system integration and operation in challenging open-world environments. In the case of person re-identification task the main goal is to retrieve information whether the specific person has appeared in another place at a different time instance of the same video, or over multiple camera feeds. This typically assumes collecting raw data from video surveillance cameras in different places and under varying illumination conditions. In the considered open-world setting it also requires detection and localization of the person inside the analyzed video frame before the main re-identification step. With multi-person and multi-camera setups the system complexity becomes higher, requiring sophisticated tracking solutions and re-identification models. In this work we will discuss existing challenges in system design architectures, consider possible solutions based on different computer vision techniques, and describe applications of such systems in retail stores and public spaces for improved marketing analytics. In order to analyse sensitivity of person re-identification task under different open-world environments, a performance of one close to real-time solution will be demonstrated over several video captures and live camera feeds. Finally, based on conducted experiments we will indicate further research directions and possible system improvements. **Keywords:** person re-identification; computer vision; retail stores; public spaces; marketing analytics;

1 INTRODUCTION

Modern computer vision techniques are solving complex technical challenges posed by applications in open-world settings. This refers to scenarios in which the system must overcome uncontrolled and difficult to predict characteristics of the operating environment. This is also the case with person detection [1] and person re-identification [2] tasks, which have traditionally been researched in the context of autonomous vehicles [3], robotics [4], human-machine interfaces [5], crowd analysis [6], and most commonly security applications [7]. The concept of smart cities [8] and the integration of such vision systems [9]–[11] into complex decision-making frameworks [12]–[14] have introduced the need for efficient and robust solutions, with the ability to make necessary trade-offs between operational costs and system performance on a case-by-case basis. The common goal is providing necessary insights into persons' behaviour based on the ability to detect and possibly re-identify the same person at different points in time and space [15]. Such applications also raise the questions of ethical and privacy nature, which is a significant line of current research [16], [17]. Nevertheless, integration of behaviour analysis systems in retail stores and public spaces is gaining momentum [18] and is expected to have significant impact on insightful business operations and space management.

Approaching potential customers based on research analysis of their behaviour can be considered a key ingredient for designing successful marketing strategies and campaigns. It is also manifestation of the general trend of tailored campaigns and data-driven

decisions emerging across different modalities of interaction with retail shoppers and public space users. In other words, persons' movement patterns and time spent in different parts of a store or elsewhere directly answer the questions: "How do consumers shop?", or "How people engage in public space?". Data driven insights into these questions are foundations for comprehensive understanding of their behaviour. Thus, behavioural constructs in different conceptual frameworks, like e.g. emotional regulation consumption or compensatory consumption [19], can be better related with the motivational and emotional aspects of the shopping process and public infrastructure engagement. It is also the kind of data that cannot be obtained from point-of-sale [20] or simple visitor statistics [21]. Therefore, spatial analysis of human behavior can be considered one of the complementary technologies for achieving optimal decisions and reducing the cost of adapting to individual needs of customers or users. In this paper, we provide a brief overview of methods and approaches for addressing design challenges for person detection and person reidentification in open-world environments and describe their use in retail sector and public spaces. We also present a demonstration of one cost efficient, close to real-time solution based on OAK-D lite [22] embedded vision platform [23] and discuss advantages and limitations of such hardware implementation and baseline algorithmic approach.

The rest of the paper is organized as follows. In Section II we break down the landscape of existing methods for person detection and person re-identification tasks and provide a structured overview of research directions that have been established by

pursuing different solution architectures under the assumptions of specific imaging modalities, identification scenarios, robustness requirements and model learning strategies. In Section III we go into implementation details of developed low-cost solution and indicate advantages and limitations of the adopted fast prototyping system design approach. Section IV presents conducted experiments and discusses their implications for possible applications in retail marketing analytics and public space management. Finally, in Section V we indicate directions for future research and possible system improvements.

2 RELATED WORK

Person detection [1], [10], [11], alongside face detection [24], [25], is probably one of the most studied object detection tasks in the literature [26]. Similarly, person re-identification (ReID) [2], alongside face recognition [27], is one of the longstanding recognition problems in vision [28], [29]. Its goal is to retrieve information whether the specific person has already appeared in video or over multiple camera feeds in the past. In such case, re-identification is considered as successful if we can correctly assign person's identity with some of the identities already present in the gallery, or create a new identity entry in the case of novel person in the scene. Described working scenario corresponds to the open-set ReID task, which is different from the closed-set setting in which it is assumed that the query object already exists in the gallery. These two problems, detection and re-identification, can be approached either traditionally, i.e. separately [30], [31], in a sequential manner, or jointly, i.e. in an end-to-end manner [32], [33], which is a characteristic of more recent ReID approaches. In the following we provide a brief overview of methods utilized in these two specific tasks of interest.

2.1 Detection task

In general, besides the problem of defining object categories [34], object detection approaches solve two fundamental problems in vision: localization and classification of object instances inside the scene. Consequently, binary classification of persons in the image can be formulated as a two stage: localization and detection problem, or as a single stage, i.e. one step regression task [26]. As there are numerous approaches for person detection, their applicability depends on the cost-performance trade-off put in front of system designer. The role of the detector in the broader context of the system in which it operates is also important. In this sense, the choice of an adequate working point on the detector's receiver operating characteristic (ROC) is also a matter of compromise and the requirements set regarding the subsequent processing of generated information. Thus, precision and recall, or the relationship between detector's sensitivity (hit rate) and specificity (false positives rate)

play a crucial role in the design choice of accompanying or downstream processing elements that are relying on detector's decisions. However, in some cases, greedy approaches in which the possibility of a miss is avoided by increasing the sensitivity of the detector, despite a higher number of false alarms, are also justified if it is possible to adequately use such results. Such techniques may include the use of detection or confidence scores in the case of still images, spatial filtering based on the temporal history of the object's locations in the case of video signal, or additional side information obtained from other sources. In the given context of public spaces monitoring and retail analytics, it is interesting to note that usual detection paradigm can be modified in order to overcome some of the difficulties posed by the application scenario. Thus, a new object detection paradigm called Locount is proposed in [35], with the goal of localizing groups of objects of interest and estimating number of instances within the group. It is similar to the type of problems considered in [6], which indicates that the task of person detection is still of active research interest. This is especially true in the case of openworld environments, where adaptation and resilience to various aggravating circumstances such as illumination variation, image noise, presence of occlusions, and variations in scale or resolution of persons in the video are often needed. It is achieved through advanced learning techniques, data augmentation, or combining of different signal modalities.

2.2 Re-identification task

According to [36], image-based person re-identification methods can be broadly grouped by: 1) signal modality (e.g. visible, infrared [37], thermal [38], or cross-modal [39]); 2) learning approaches (e.g. whether the recognition is based on metric learning [40], [41] or more complex deep ReID architectures and learning frameworks [31], [42]); and 3) how generalization across multiple domains, i.e. cross-domain ReID is addressed [43]. Video-based person ReID methods [44]–[46] that exploit temporal information in the learning process are also seen as a separate line of research, with a similar division of methods with respect to the above-mentioned properties. Other aspects in relation to which ReID solutions are considered include different types of challenges where standard methods exhibit certain weaknesses, leading to classes of special, specific methods that effectively overcome the limitations of standard solutions. Thus, the main characteristics of effective ReID solutions are invariance to different variations of the input signal and robust hierarchical feature representations that lead to accurate identity matching.

Resolution mismatch [47], when a low resolution query image is matched against the high resolution gallery samples, is a common example of ReID problem that is affected by the scale of the object and image acquisition setup. Opposite situations of high

resolution query images are also common, giving rise to resolution independent features [48] and multiscale pyramid representations [45].

The most common person ReID goal is a short-term identification, where it is assumed that the pedestrian's clothing remains unchanged over time. While such assumptions are fully justified in the case of described retail application scenarios, a more general solution would be the invariance of ReID to changes in person's clothing [49] and appearance [50], when captured during different activities. Thus, a step forward ideal long-term or lifelong person ReID would be invariance to clothchanging, which could be regarded as more applicable in realworld scenarios. In [51] authors claim that the most reliable discriminative characteristic for above-mentioned invariance is unclothed body shape, i.e. effective representation of the 3D shape and texture of the human body. It is closely related to other biometric identification methods based on human gait recognition [4], [52], which are complementary to classical image- or video-based ReID [53].

Significant class of adaptation methods also includes occluded person ReID [54]–[57]. A common strategy is to steer ReID toward decisions based on features that comprehend or do not take into account the hidden part of the person. Such examples include learning the dynamic prototype mask [54], feature attention mask [58], saliency-guided patch transfer [56], using multiple views of the same person [55], or relying on part based representations [59] and fine-grained image analysis [60], see e.g. [61], [62]. There have also been attempts to partition feature space [63], while the standard learning strategy for person ReID has been the triplet loss framework [64], [65] and its extensions [66]. Alternatives include various deep metric learning approaches [40] and ranking optimization at inference stage [42].

2 PROPOSED PERSON ReID IMPLEMENTATION

In order to analyze the sensitivity of person re-identification task under open-world setting of retail stores and public spaces we have implemented one cost efficient, close to real-time solution. It is based on OAK-D lite [23] device and pre-trained person detection and person ReID models made using OpenVINO [67] hardware acceleration deep learning framework. The corresponding camera device is shown in Fig. 1 and its main characteristics are summarized in Table I.

Table 1 Main characteristics of OAK-D lite platform

Feature	Specification
Processor	Intel Movidius Myriad X VPU
Cameras	1x 13 MP RGB (IMX214, rolling shutter) 2x 0.31 MP mono (OV7251, global shutter)
Stereo baseline	75 mm

AI performance	4 TOPS (1.4 TOPS for AI)
Video output	Up to 4K@30fps (H.264/H.265/MJPEG)
Depth perception	Stereo, 300,000-point, 200+ FPS
Connectivity	USB 3.1 Gen1 Type-C
Dimensions	(WxHxD), 91 mm x 28 mm x 17.5 mm
Weight	61 g
Variants	Fixed-focus / Auto-focus (RGB cam)
Mounting	1/4"-20 tripod, VESA (7.5 cm, M4)

As can be seen from Table I, it is a versatile and heterogeneous computing platform. It is suitable for applications in different vision tasks that require real time stream processing and advantages of using embedded hardware implementation, such as high level of integration, small form factor, modular design, low power consumption and relatively low cost, taking into account that the device integrates both imaging devices and signal processor. Besides providing the options of choosing between the global and rolling shutter, on board cameras are also designed to be geometrically precisely aligned in a linear arrangement to facilitate calibration and accurate distance measurements. Nevertheless, in the given experiments we have relied only on the main high resolution RGB camera and multiple stream processing by frame grabbing from created camera source in the constructed processing graph.



Figure 1 Embedded vision platform used in experiments

OAK-D Lite platform integrates multiple specialized processing units and sensors that collaboratively handle different computational tasks, optimizing performance and efficiency. Thus, Movidius Myriad X Vision Processing Unit (VPU) integrates several system components two of which are of main interest for implemented person ReID. First one is Image Signal Processor (ISP), on-chip hardware accelerator responsible for different camera pipeline functions and highthroughput image pre-processing tasks such as denoising and color correction. The second one is Neural Compute Engine (NCE), neural network hardware accelerator, which enables efficient deployment of trained deep learning models or any other computational graphs that are possible to define in supported ONNX [68] or OpenVINO [67] network exchange formats. Its advantage is small power consumption, which is especially suitable for edge

processing and deployment in environments that require continuous system operation. Note that although the main processing (person detection and person ReID) was done on embedded platform, experimental setup also required a host device (CPU) for higher-level program control and application logic (visualization, communication and I/O interface).

For software implementation, besides the device drivers and other utilities provided by Luxonis corporation under the MIT license in official DepthAI code repository [69], we have used OpenCV [70] and Python programming language. We note that there are also C++ device interfaces and code implementations, available in [71]. The main algorithmic solution was taken from OpenVINO repository and consists of the pre-trained person detection model, available in [72], and person ReID model available from [73]. As a starting point for developing additional functionalities we have utilized demonstration script in [74], from which the provided code implementation was made: <https://github.com/brkljac/personReID>. Possible alternative for baseline implementation could also be some general purpose ReID toolbox [75].

4 EXPERIMENTAL RESULTS AND DISCUSSION

The experiments included visual analysis of system performance in various operating environments. We have analyzed ability of system to cope with person ReID task in outdoor and indoor space, under different illumination and in the presence of varying number and dynamics of people. General conclusions is that in all considered scenarios system managed to achieve close to real time operation, but never more than ≈ 12 frames per second (fps). On the other hand, under certain difficult conditions, the fps dropped even to ≈ 4 fps. This included low-light conditions, but mainly the presence of very dynamic background noise in the scene. For example, in an outdoor scene where a significant portion of the background was covered by leaves, in the presence of wind, the background dynamics were very pronounced and caused additional slowdown. However, even in such cases the final ReID result was quite good and without any false detections in the described background area. The most challenging ReID were cases where the same person changed orientation towards the camera while walking or when entering and exiting the scene. This led to the creation of multiple identities for the same person, which is a common problem with person ReID. During experiments in an indoor retail space, it was found that certain object arrangements cause false person detection and initialize a correct but false person ReID in subsequent frames. This indicates that person detection module could be subject to further improvements in terms of robustness.

Most of the situations described above are illustrated in Fig. 2 and Fig. 3, while the corresponding video files are available in the given code repository, Section III.

The observed variability in people's appearance could be overcome by model training on datasets like [76], [77], which contain a sufficiently diverse range of appearances (positions of the person relative to the camera, changes in illumination and

different human activities). Another research direction are more frequent ReID model updates through better use of historical appearances and without re-indexing of images in the gallery [78].

5 CONCLUSIONS

In this paper, we analyzed solutions for person ReID from a technical and application perspective. Conducted experiments revealed the need for improvement of the existing baseline solutions in order to make them fully applicable as analytic tools in the considered retail stores and public spaces. They also revealed the need to combine signal modalities in order to filter and improve existing ReID in indoor space. Therefore, perceptual features like



Figure 2 (a) succesful ReID, but with low fps rate due to dynamic background noise; (b) succesful ReID under low light conditions, but with identity loss after change of person's orientation at the end of sequence; (c) retail store application.



Figure 3 (a) crowded indoor space: succesful ReID, but with low fps; (b)~false person detection, but with correct ReID; (c)~low light operation.

image depth [79], sound or other sensing devices [80] could bring complementary side information. As already mentioned, [6], [35], crowded scenes and cluttered object detection sometimes require alternative formulations of standard vision tasks.

On the side of possible applications, further analysis of the data collected by ReID systems could reveal a more complex behavior patterns [81], [82], i.e. go beyond simple statistics like time spent in different

parts of a retail store. On the other hand, unsupervised representation learning [83] seems to be the key

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for described challenges and increasing the robustness of ReID. Nevertheless, existing person ReID solutions are already at the level that makes them applicable in the given context.

Acknowledgements

The authors would like to especially thank the conference organizers for their patience and support throughout the manuscript preparation process. This research was partially supported by the Science Fund of the Republic of Serbia, project "Multimodal multilingual human-machine speech communication - AI SPEAK", grant no. 7449; and by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (contract no. 451-03-137/2025-03/200156); and by the Faculty of Technical Sciences, University of Novi Sad, through the project "Scientific and artistic research work of researchers in teaching and associate positions at the Faculty of Technical Sciences, University of Novi Sad 2025" (no. 0150/295).

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711.4:005.591.6(082)

INTERNATIONAL Scientific and Professional Conference “ALFATECH“ Smart Cities and modern technologies (2025 ; Beograd)

Proceedings of International Scientific and Professional Conference “ALFATECH“ Smart Cities and modern technologies, Belgrade, February 28 th 2025 / [editor in chief Milan Gligorićević] ; [organizer Faculty of Information Technologies, ALFA BK University, Belgrade, Serbia [and] Faculty of Mathematics and Computer Science, ALFA BK University, Serbia [and] Faculty of Technical Sciences in

Čačak, University of Kragujevac, Čačak, Serbia]. - Belgrade : Alfa BK University, 2025 (Kraljevo : Glamur). - 270 str. : ilustr. ; 29 cm

Tiraž 250. - Bibliografija uz svaki rad.

ISBN 978-86-6461-093-3

1. Gligorićević, Milan, 1966- [glavni urednik]

a) Градови -- Интернет ствари -- Зборници b) Информациона технологија -- Зборници v) Урбанистичко планирање -- Технолошки развој -- Зборници

ISBN:978-86-6461-093-3



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