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International Conference on Sustainable Transport

28.09. - 29.09.2024. | SVETI MARTIN, CROATIA

PROCEEDINGS

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PREFACE

The proceedings of the *International Conference on Sustainable Transport – SuTra 2024*, held under the joint organization of University North and the University of Rijeka, Faculty of Maritime Studies, Croatia, represent a valuable collection of scientific and professional contributions dedicated to one of the most pressing issues of our time – the sustainability of transport systems.

As globalization continues to accelerate, the demand for efficient movement of goods and people is growing exponentially. However, this growth must be aligned with the principles of environmental protection, energy efficiency, and long-term socio-economic viability. The SUTRA 2024 conference provided a multidisciplinary platform for researchers, practitioners, policymakers, and industry representatives to exchange knowledge, experiences, and innovative ideas aimed at reducing the environmental impact of transportation.

With a wide range of topics encompassing maritime, rail, road, air transport, and inland waterways, the contributions in this volume reflect the complexity and interconnectivity of transport systems and their relationship with the environment. The conference emphasized the importance of an integrated, interdisciplinary approach to solving transport challenges, recognizing that collaboration between academia, industry, and public institutions is essential to achieve sustainable mobility.

We would like to express our sincere gratitude to all authors, reviewers, and participants whose engagement made SUTRA 2024 a success. We hope that the insights and findings presented in this book of proceedings will inspire further research and contribute to the advancement of sustainable transport practices.

Editors

CONTENTS

Enhancing Active Transportation: Supporting Safe and Sustainable Cycling and Walking in Croatian Elementary Schools

Julijan Jurak, Mario Ćosić, Matija Sikirić, Sandro Tokić, Luka Vidan, Mario Klisura

University of Zagreb, Faculty of Transport and Traffic Sciences, Croatia

ABSTRACT

This research evaluates the initiatives that support sustainable cycling and walking among elementary school pupils from four Croatian cities. The study employed a mixed-methods design involving data collection with children, parents, teachers, and local officials. The data collection covered intervention outcomes, safety conditions, environmental awareness levels, and infrastructure and traffic patterns in areas within and around schools. The findings show that workshops, better infrastructure, and initiatives significantly increase children's potential for walking or cycling. Zagreb and Split have greater opportunities for active transportation but face challenges of traffic density and safety. The cities of Varaždin and Slavonski Brod show considerable involvement from the community and opportunities for flexible solutions. Significant challenges involve maintaining infrastructure, responding to parental concerns regarding safety, and integrating active transportation courses into educational programs. The research provides policymakers, urban planners, and educators, emphasizing the need to integrate infrastructure development, supportive policy frameworks, and community engagement to foster a culture of active transportation in Croatian cities.

Keywords: Urban Mobility; Road Safety; Infrastructure Improvement; Community Engagement.

1. INTRODUCTION

Traffic accidents remain the leading cause of death for young people aged 10 to 25, both globally and in Croatia. The most vulnerable groups are children, young people, cyclists, moped riders, motorcyclists, and pedestrians. The research activities were part of the project "Increasing the safety of children in school zones through the education of children, teachers, parents, and other road users", which is co-financed by the National Road Safety Programme and is included in the activity 7.3 – Safe driving. The main goal of the research is to halve the number of accidents caused by careless driving by 2030. The implementation of the project is based on the education, on the proposal of infrastructure measures, and on the development of new technologies and tools that can improve traffic safety in the environment of elementary schools. The Elementary School Sesvetski Kraljevec (the City of Zagreb) was chosen as the pilot project. After its completion, the project was implemented in other elementary schools in three other cities in the Republic of Croatia. The present research assesses programs that encourage pupils in elementary schools in four Croatian cities: Zagreb, Varaždin, Split, and Slavonski Brod (**Figure 1**) to walk and cycle in an environmentally friendly way. A variety of methods were used in the study, such as survey data and personal meetings with children, parents, educators, and local government representatives [1-2].

Figure 1. Geographical distribution of four Croatian cities.

In addition to observational research and GIS mapping used to analyse infrastructure and traffic patterns in and around school areas across four cities, data collection included pre- and post-intervention evaluations assessing changes in students' travel behaviours, perceived safety, and environmental awareness. The preliminary results indicate that neighbourhood projects, instructional workshops, and enhancements to infrastructure (such as bike lanes and pedestrian crossings) greatly boost children's chances of walking or cycling to school.

Significant challenges involve maintaining infrastructure, responding to parental concerns regarding safety, and integrating active transportation courses into educational programs [3-5]. A geospatial visualization of traffic accidents between 2021 and 2023 was developed using QGIS, based on official data provided by the Ministry of Internal Affairs. The spatial distribution of accident density is shown by using the Quadratic Kernel Density method. Heat maps highlight areas with an increased concentration of pedestrian and cyclist traffic accidents, with significant differences in their locations.

Different accident densities are shown in different colours, with light shades of yellow indicating areas with lower density, and dark shades of red indicating areas with higher density. The most intense dark red colour shows the centre of the hotspot, i.e. locations with six or more recorded traffic accidents.

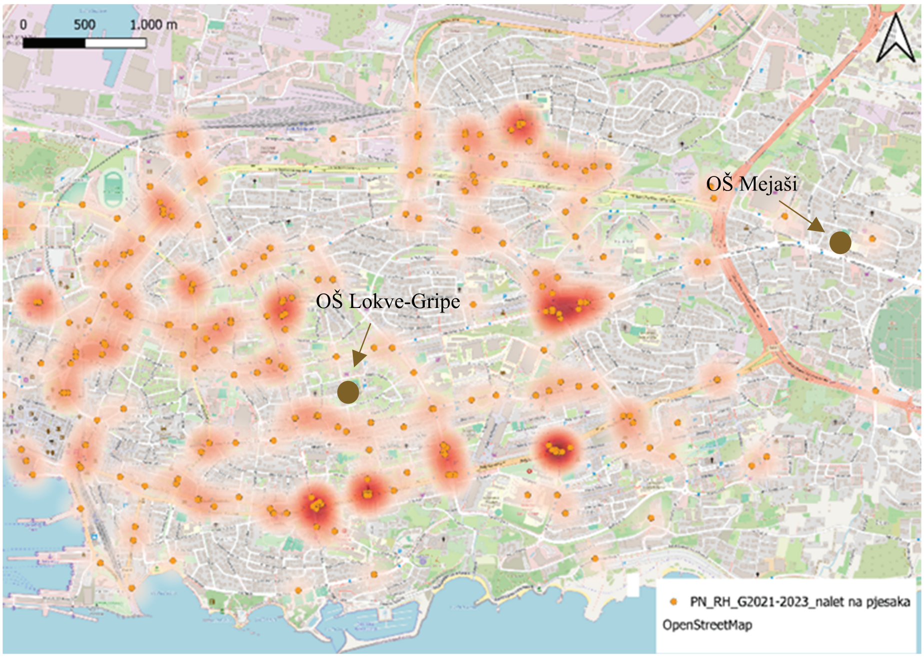

Figure 2. Geographical location of two elementary schools in the city of Split.

As shown in **Figure 2** for the city of Split, two elementary schools were selected in each city, based primarily on the density of traffic accidents in the surrounding area. This research offers actionable insights for policymakers, urban planners, and educators, emphasizing the importance of integrating infrastructure development, supportive policy frameworks, and community engagement to foster active transportation practices and enhance urban sustainability in Croatian cities.

2. LITERATURE OVERVIEW

Active transportation, including cycling and walking, plays a critical role in fostering sustainable and healthier urban environments. The presented research offers insights into strategies, impacts, and barriers associated with promoting safe and sustainable active transportation, with particular emphasis on the role of safety measures in encouraging cycling and walking. For example, investments in protected bike lanes and improved pedestrian crossings were shown to significantly increase usage and reduce accidents [1].

Safety is particularly crucial for vulnerable populations such as children and the elderly. Urban planning plays an important role in enabling active transportation. Strategies such as mixed-use zoning, higher density development, and integrated public transit systems create an environment conducive to walking and cycling. Dedicated cycling tracks and pedestrian-friendly streets were highlighted as essential infrastructure investments [3].

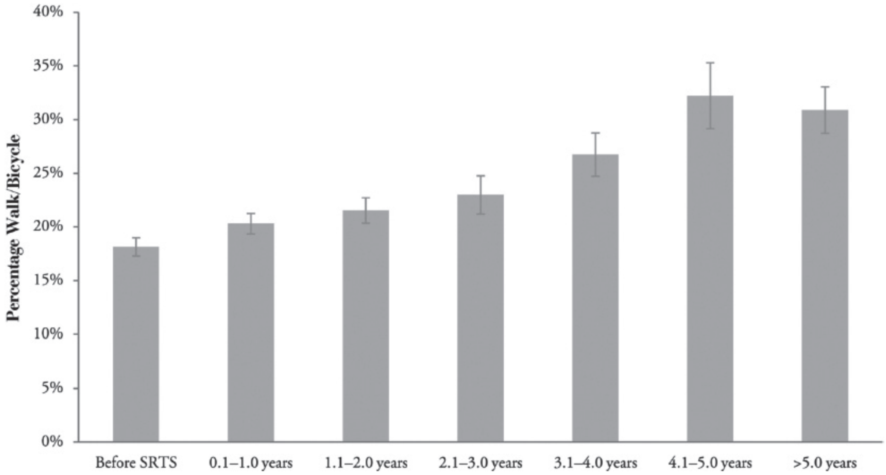

Figure 3. Average rates of walking and cycling to school by the length of participation in the Safe Routes to School program. [2]

With technological advances providing an 18% relative growth in active transport and educational initiatives adding a further 25% increase over five years, the Safe Routes to School (SRTS) program has proven to be successful in encouraging children to walk and cycle (**Figure 4**). Despite these achievements, future SRTS programs may be constrained by federal funding decreases under MAP-21. To preserve progress, the report advises planners to incorporate SRTS into capital improvement plans, subdivision regulations, and local policies. The outcomes highlight the importance of SRTS in encouraging active travel, despite being constrained by self-selection biases and wide intervention categories. [2]

Table 1. Characteristics of the Total Sample and Subsample with Parent-Reported Usual Travel Mode Data, and Prevalence of Walking to School by Individual and Environmental Characteristics. [5]

Characteristic	Total (n=1480) (%)	Sub-sample (n=1132) (%)	Walks <6 trips/week (%)	Walks ≥ 6 trips/week (%)	p-value	Model 1 Single factor model[b]	Model 2 Adjusted model[d]	95% CI
Overall (%)	100	100	71.8	28.2				
Gender (%)								
Male	48.7	47.4	75.6	24.4	0.007	1.00	1.00	
Female	51.3	52.6	68.4	31.6		1.43	1.43	1.11-1.84
Year level (%)								
5	26.5	27.4	71.9	28.1	0.998	1.00	1.00	
6	35.9	35.4	71.8	28.2		1.01	1.07	0.72-1.58
7	37.6	37.2	71.7	28.3		1.01	1.04	0.67-1.61
Maternal education (%)								
Less than Secondary	24.2	28.6	75.9	24.1	0.167	1.00	1.00	
Secondary/trade/diploma	45.3	50.9	70.8	29.2		1.30	1.20	0.82-1.74
Bachelor degree or higher	14.1	14.9	66.9	33.1		1.56	1.61	0.99-2.62
No response	16.5	5.6	73.0	27.0		1.17	0.93	0.44-1.99
Weight status[a] (%)								
Acceptable weight	75.9	76.3	71.3	28.7	0.514	1.00	1.00	
Overweight or obese	24.1	23.7	73.6	26.4		0.89	0.89	0.60-1.33
Refused						0.99	1.01	0.62-1.64
SES of school (%)								
Low	27.3	25.7	68.4	31.6	0.094	1.00	1.00	
Medium	34.8	36.4	75.5	24.5		0.70	0.85	0.54-1.33
High	37.9	37.9	70.6	29.4		0.90	0.72	0.48-1.06
Walkability of school neighborhood (%)								
Low	53.6	54.2	75.2	24.8	0.005	1.00	1.00	
High	46.4	45.8	67.8	32.2		1.45	0.94	0.65-1.35
Distance (mean km [SD])	1.69 (0.07)	1.80 (0.08)	2.25 (0.96)	0.66 (0.75)	<0.001	0.14[c]	0.14	0.08-0.24

[a] 299 students did not participate in the anthropometric measurements.
[b] Adjusted for clustering only.
[c] Adjusted for distance (km)^2 and clustering only.
[d] Adjusted for clustering and individual-level demographic characteristics, SES of school, school walkability, distance (km) and distance (km)^2.

The research emphasizes why infrastructure and street design affect children's active school commuting. While a strong connection paired with high traffic discourages walking, schools situated in locations with high street connectivity, but low traffic levels encourage it (**Figure 4**). The results highlight the importance of urban planning in creating school neighbourhoods that are walkable, with accessible sidewalks, safe crossings, and reduced traffic. To avoid locations on busy roadways, wider planning ought to consider school location policies, social objectives, and public health considerations. For children who are at risk of exposure, attention to community safety and socioeconomic inequalities is essential [5].

Behavioural studies reveal that convenience, perceived safety, and social norms strongly influence individuals' choices to adopt active transportation [3]. Public awareness campaigns and community engagement initiatives are effective in addressing behavioural barriers. Active transportation contributes to reduced greenhouse gas emissions, and it improves public health by encouraging physical activity. Quantitative assessments demonstrate lower air pollution levels and better health outcomes in communities with higher rates of walking and cycling [1]. Studies collectively recommend multi-faceted policies combining infrastructure development, educational programs, and regulatory measures. For instance, reduced speed zones in urban areas and incentives for bicycle use were cited as impactful interventions.

3. METHODOLOGY

To capture an accurate picture of traffic flow and density in the vicinity of each elementary school included in the project, traffic counters were installed in both directions, depending on the traffic volume and technical characteristics of each road, as shown in **Figure 4**. The number of vehicles during all day, the speed of every vehicle, and the length of the vehicle were measured and classified into a specific category by vehicle length:

- motorcycles, bicycles and e-scooters → from 0.5 m to 1.6 m
- personal motorized vehicles → from 1.7 m to 7.0 m
- light-duty vehicles → from 7.1 m to 13.0 m
- heavy-duty vehicles and buses → from 13.1 m to 25.5 m

Figure 4. Installation of traffic radar meters.

Education in schools was delivered using Mentimeter, an interactive presentation tool that requires active participation. Children from 5th to 8th grade engaged with the content, which focused on providing useful information about traffic rules and road safety during visits to participating schools (**Figure 5**).

The presentation was divided into two parts. In the first part, children answered general questions, such as their favourite school subject and current grade level, as well as questions related to traffic. Children's travel habits, the distance between their homes and school, as well as their perception of traffic safety, were detected. At the end of the first part, a test quiz was held to familiarize children with the functioning of the presentation and quiz.

Figure 5. Presentation by using the tool Mentimeter.

Figure 6. Road safety training ground for children by using bicycles and electric scooters.

The second part of the presentation consisted of two segments. The first segment was theoretical, and children were introduced to the safe ways of using bicycles and electric scooters, stopping distances at different speeds of driving, the importance of using retroreflective materials in low visibility conditions (especially at night), and the road safety regulation related to bicycles and electric scooters (**Figure 6**). The second segment was a competitive quiz in which the children's understanding of the knowledge presented in the previous part was checked. Children used their smartphones to access the presentation by scanning a QR code and responded to the questions in real time. The quiz assessed not only the accuracy of responses but also the speed at which students answered. At the end of the quiz, the most successful children received gift packages.

4. RESULTS

Two types of traffic counters were used: radar traffic counters and magnetic traffic counters. Each type has its own advantages and disadvantages, but the accuracy of the data collected from both types of counters exceeded a high 95%. This part of research on the streets shows major challenges in enforcing speed limits and reducing road traffic congestion, particularly in areas with a large proportion of cargo vehicles. Maximum recorded speeds of 172 km/h in zones with a 40 km/h limit indicate severe violations of traffic laws. On most streets examined, the 85th percentile speed exceeds the posted speed limits, underscoring a significant safety concern for all road users, particularly children.

Some roads have high daily traffic volumes, while others have twice as much traffic in the west compared to the east. Streets with lower traffic volumes show higher compliance with speed limits, although violations remain frequent. Findings emphasize the need for rapid infrastructure improvements, such as the establishment of traffic-calming zones and better speed control, especially in school zones. Other suggestions include optimizing routing for cargo vehicles and improving safety measures to promote prevention and reduce the possibility of traffic accidents. The results also provide a foundation for developing measures to improve transportation infrastructure and reduce hazards in the most congested areas.

Table 2. Descriptive statistics from traffic counter on the road near Đuro Pilar Elementary School in the City of Slavonski Brod.

Calculated speeds [V in km/h]

	Vmin	Vmax	Vavg	V15	V50	V85	Vexc %
Cross-section	7	134	53	45	53	62	98.1
istok	7	134	52	45	52	59	97.9
Outgoing	11	134	55	46	55	64	98.3

Descriptions

Vmin: Minimal velocity
Vmax: Maximal velocity
Vavg: Average velocity
V15: Critical velocity for the first 15% of vehicles
V50: Critical velocity for the first 50% of vehicles
V85: Critical velocity for the first 85% of vehicles
Vexc %: Speeding in %

The analysis of drone footage was conducted in the zones of three schools, including Davorin Trstenjak Elementary School, III Varaždin Elementary School, and August Harambašić Elementary School. The footage was recorded with the aim of collecting relevant data for assessing the safety of traffic routes, identifying critical points, and proposing possible improvements to increase the safety of children in school zones.

Figure 7. Risk of traffic accidents for road users after implementation of proposed improvement measures – Sesvetski Kraljevec elementary school.

The first step of the iRAP methodology [6] involves an inspection of the observed road network near elementary schools. This involves a visual inspection of road infrastructure elements. This is followed by the coding of attributes (road network elements) in the ViDA interface through five main attribute groups: road environment, road characteristics, intersections, traffic flow, facilities for vulnerable road users, land use, and observed speeds. The result of the coding is a quantitative value of the level of risk of traffic accidents for all road users for each 100-meter segment of the analysed section. The risk scale is expressed using a star rating system ranging from 1 to 5, where 1 star indicates the highest level of traffic risk and 5 stars represent the lowest. A road section rated with three or more stars is considered a relatively safe section.

5. DISCUSSION

To obtain precise data of traffic flows in the zone of each elementary school included in the project, radar and magnetic traffic counters were used. The accuracy of these measurements was high, reaching 95%. The collected data included key traffic parameters such as the maximum and minimum speed, average speed, and traffic flows during the day. Traffic counting was later used as the basis input for the iRAP methodology, which was used to analyse the safety characteristics of road infrastructure near the schools. This method also included visual inspection, which estimated the risk level for each 100-meter road segment. This assessment provided key insights into the safety of the analysed roads and enabled suggestions for infrastructure improvements. The results of traffic counts and traffic infrastructure analysis enabled a detailed evaluation of road safety near schools. Drone footage analysis identified critical points and proposed measures to enhance the safety of children in school zones. Based on all the collected data and the iRAP analysis, specific improvement measures were proposed, including the construction of safer pedestrian crossings, traffic flow optimization, and speed reduction in school zones. The recommendations aim to enhance safety and reduce risks for all road users, with particular emphasis on vulnerable groups such as children.

6. CONCLUSION

This research offers actionable insights for policymakers, urban planners, and educators, emphasizing the importance of integrating infrastructure development, supportive policy frameworks, and community engagement to foster active transportation practices and enhance urban sustainability in Croatian cities. With their larger infrastructures, Split and Zagreb offer more initial opportunities for active mobility, but they also have safety and congestion-related issues which must be addressed to support urban sustainability in Croatian cities. Varaždin and Slavonski Brod show considerable involvement by the community and an opportunity for flexible solutions. The detailed research reveals significant safety issues in school zones, primarily due to increased vehicle speeds and high traffic volumes, including the presence of large vehicles. Inadequately constructed pedestrian crossings, low visibility, and a lack of bicycle infrastructure are all major issues.

Maximum recorded speeds exceeded 100 km/h, often in zones with posted speed limits of 30 to 50 km/h, and a large proportion of vehicles were found to be in violation of speed regulations. Elevated crosswalks, improved signage, and traffic calming zones are among the recommended speed-reducing methods. Survey results indicate that parents and teachers strongly support enhanced enforcement of traffic regulations, increased traffic safety education, and improved infrastructure planning. The conclusions drawn from the collected data strongly support the promotion of non-motorized modes of transport for children's school travel, emphasizing the importance of developing safe environments and encouraging active mobility from the first grade onward. Efforts to promote secure routes for children, secured by infrastructure improvements and strict enforcement, are crucial for increasing safety and confidence in these neighbourhoods.

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The Essential Role of Crane Simulators in Port Safety and Efficiency

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ABSTRACT

The use of crane simulators in modern port operations is essential to ensure the safety, efficiency and operational readiness of crane operators, especially given the challenges of handling large vessels, unpredictable weather conditions and maintaining high safety standards. These advanced training tools provide a highly realistic environment where operators can learn and practise the skills required to handle different types of cranes such as ship-to-shore (STS), rubber-tyred gantry (RTG) and mobile harbour cranes in a risk-free environment. Simulators can replicate complex scenarios, such as limited distances between ship and shore, sudden storms, high winds and poor visibility, allowing operators to hone their skills in dealing with real port operations. They are essential for training emergency procedures such as emergency stops and unexpected vessel movements. This is crucial to prevent accidents that have occurred in the ports of the northern Adriatic, such as cranes breaking down or ships breaking apart. Well-trained personnel prepared for any handling scenario can improve operational efficiency, reduce loading and unloading times and handle different types of cargo, from standard containers to dangerous goods. The article introduces a sustainable approach to developing the crane simulator based on the serviced cabin of the port crane and presents the benefits of the simulator classroom as a learning environment where teachers, students and observers work together to acquire the required knowledge. As part of the project "UL for a Sustainable Development – ULTRA", the new didactic resource will serve as a tool for the simulation, modelling and analysis of cargo handling processes and systems in intermodal transport.

Keywords: Crane Simulator; Learning Environment; Digitization in Higher Education; ULTRA project.

1. INTRODUCTION

Many accidents have occurred in recent years when container ships collided with port infrastructure, causing cranes to collapse. The latest such incident took place in Turkey at the Port of Kocaeli, where a 368-meter container ship struck a port crane while docking, leading to a domino-like collapse of three ship-to-shore (STS) cranes. The estimated damage exceeded 50 million dollars [1]. Similar accidents have been reported in ports such as Port Said (Egypt), Kaohsiung (Taiwan), Antwerp (Belgium), and Jebel Ali (United Arab Emirates). The common thread in these incidents is the collision of a container ship with a crane, resulting in its collapse. These collisions are often caused by navigational errors, primarily due to human error [2]. Unfortunately, most crane-related accidents in ports are not limited to ship collisions. Many incidents arise directly from crane operation itself, including damage to ships or injuries to port workers. These are frequently attributed to the inexperience of crane operators or challenging external conditions, such as strong winds. Windy conditions in particular pose a significant hazard during the loading and unloading of vessels, as they can destabilize cargo, affect crane movements, and increase the risk of accidents. Ensuring safe port crane operations in such environments remains one of the most significant challenges for ports worldwide.

Training crane operators is critical for minimizing these risks and preventing operational errors. The goal of training is to equip personnel with the knowledge and skills necessary for the safe and efficient handling of cargo during loading and unloading operations [3]. Training programmes cover a wide range of topics, including the use of lifting equipment, communication signals, and safety protocols for crane operations. Trainees also learn how to operate various crane types, handle container spreaders (including twin lift, dual hoist, and tandem lift techniques), identify and mitigate risks, and conduct pre-use inspections. Practical lessons include manoeuvring the crane, positioning and moving containers, and handling ship structures and hatch covers.

Given the complexity of crane operations and the need for safety, training on actual cranes can be risky and costly. This is where crane simulators come in. Numerous crane simulator providers offer highly realistic environments where operators can practice their skills in a risk-free setting. These simulators provide real-time feedback and detailed performance reports, enabling continuous improvement [4],[5]. Economically, simulators provide a cost-effective alternative to live training, reduce wear and tear on equipment, and help avoid accidents and operational downtime. Environmentally, they support sustainability by reducing emissions and energy consumption associated with real-time crane use [6]. Modern simulators are also designed to address the evolving challenges of maritime logistics, such as handling larger vessels and incorporating the latest technological advances. By integrating realistic scenarios, including adverse weather conditions like strong winds, these tools ensure that operators are better prepared for real-world challenges. Simulators are thus essential for improving the safety, efficiency, and environmental impact of port operations, especially in regions frequently affected by storms and severe weather conditions.

At the Faculty of Maritime Studies and Transport, we are fully aware of these challenges, which is why we have applied for the ULTRA funding call to secure resources for the development of a dedicated crane simulator. This simulator is based on a real crane cabin donated by the Port of Koper. The process of building the simulator and preparing the first training scenarios for crane operators has already begun.

2. INNOVATIVE APPROACHES TO CRANE OPERATOR TRAINING: A CASE STUDY IN SUSTAINABLE PRACTICES

Advanced simulation technologies, including virtual reality and cabin-based systems, are being increasingly integrated into crane operations to improve training, enhance safety, and promote sustainability in the maritime industry. This case study delves into these innovations and their real-world impact.

There are two main approaches to simulator training on the market: virtual reality (VR) crane simulators and cabin-based crane simulators. The primary difference between these two methods lies in the user experience, setup, and intended application. In a VR crane simulator, users are fully immersed in a virtual environment using VR headsets, providing a high level of immersion. This setup offers a 360-degree view, allowing users to experience the crane's surroundings as though they were physically present inside the crane. Operators interact with virtual controls and gain a realistic sense of spatial awareness. The system typically includes VR headsets, motion controllers, and sometimes additional sensors for hand tracking. Since the environment is entirely digital, VR simulators require less physical space and fewer hardware components. This makes them ideal for early-stage training, where users can safely and efficiently learn the basics of crane operation in a controlled, immersive setting. Additionally, the flexibility of a virtual environment is particularly beneficial in scenarios where space or budget is limited [7]. In contrast, the cabin-based crane simulator replicates the physical cabin of an actual crane. It allows users to train in a realistic mock-up, equipped with physical controls, screens, and in some cases, motion platforms that simulate the movements of a crane. While the environment is displayed on monitors rather than providing a full 360-degree perspective like VR, this setup offers a highly realistic and tactile experience, closely mimicking the operator's perspective from a real crane cabin. Cabin-based simulators are more complex and require a dedicated physical space, including control desks, seating, and possibly a motion platform. Due to the more intricate hardware setup, this approach is better suited for advanced training, where the goal is to familiarize operators with the actual physical controls and the environment of a crane. This type of simulator is ideal for preparing operators to handle real-life scenarios and develop the muscle memory required for crane operation.

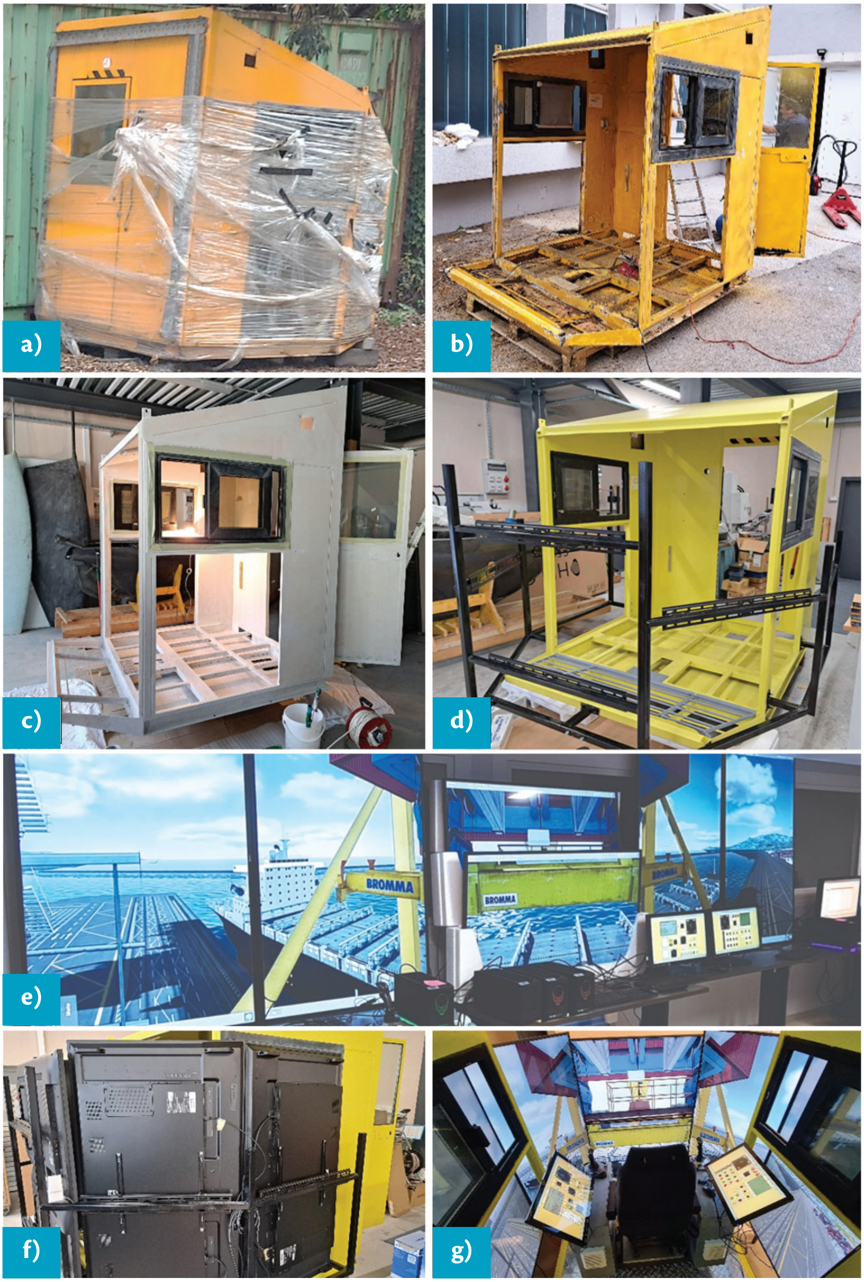

Figure 1. Crane Cabin Reparation and Modification Process: a) Dismantled crane cabin donated by the Port of Koper; b) Removal of glass surfaces and initial treatment of rusted metal; c) Protection and painting of metal components; d) Installation of supporting consoles for the large screen; e) Software setup and hardware calibration in the laboratory; f) Cabling and mounting of the large screen; g) Final appearance of the crane simulator.

As part of the "UL for Sustainable Development – ULTRA" project, the Faculty of Maritime Studies and Transport is enhancing its rail and air transport courses by incorporating modern digital solutions and fostering collaboration with other faculties, research institutes, and industry partners. This initiative includes the introduction of specialized modules and hands-on training opportunities, aimed at boosting students' employability in the transport and logistics sectors.

Simultaneously, the Faculty is developing a didactic cabin-based crane simulation environment specifically for intermodal transport training. This innovative simulator will support both cutting-edge training and sustainability efforts in maritime logistics. It will be an invaluable tool for simulating, modelling, and analysing cargo-handling processes in intermodal transport, helping to prepare future crane operators for the challenges of modern port operations while promoting environmentally responsible practices.

The development of this simulation environment involves the refurbishment of a decommissioned port crane cabin, generously donated by the Port of Koper in Slovenia. In the initial phase, the cabin was dismantled into individual parts, with the seat and controls carefully removed. The cabin frame was then adapted and customized. Realistic controls, seating, and monitors were reinstalled to enhance the simulation experience, ensuring a highly realistic environment for trainees (**Figure 1**). The simulator is powered by TCS 5000 TechSim software, developed by Wärtsilä, which provides an accurate representation of crane operation from the cabin. The system allows both trainees and instructors to observe and analyse cargo-handling operations, offering valuable insights into performance and areas for improvement.

2.1. Crane models supported by the simulator

The TCS 5000 TechSim STS Konecranes crane model is a high-fidelity crane simulator designed for training and testing in port and terminal operations. It simulates the operation of ship-to-shore (STS) cranes used in container handling [8]. The simulator replicates the dynamics, control systems and operating scenarios of a real crane, allowing operators to gain experience in a safe and controlled environment. Key features include realistic motion and visual environments, operator skill assessments and a range of customizable training modules to improve efficiency and safety in container handling (**Figure 2**).

Figure 2. STS Konecranes Crane. [8]

Figure 3. RTG Konecranes Crane. [9]

The TechSim/TCS 5000 RTG Konecranes Crane Model is a full-scale crane simulator designed for training operators of Konecranes Rubber-Tyred Gantry (RTG) cranes [9]. It accurately replicates the behaviour and control systems of real RTG models and provides realistic container handling scenarios. The simulator is able to replicate key functions such as precise lifting of loads, trolley movements and gantry travel. It includes advanced features such as realistic physics, environmental conditions and error simulations, allowing participants to gain hands-on experience and improve their skills in a safe, controlled environment (Figure 3).

3. COMPREHENSIVE UTILIZATION OF FULL MISSION CRANE SIMULATORS: CURRENT CAPABILITIES AND FUTURE POTENTIAL

The crane operator simulator training program is meticulously designed to develop expertise progressively, beginning with fundamental operations and advancing to complex container handling and specialized scenarios [8]. The initial phase of the program focuses on familiarizing operators with basic crane controls, including movements of the hoist, trolley, and crane bridge, both individually and in combination. As operators become proficient with these basics, they progress to handling individual containers. Here, they learn to operate spreaders effectively and adhere to crucial safety protocols. With growing experience, participants move on to more advanced tasks, such as aligning and stacking containers, and accurately placing them on trailers. The training program encompasses comprehensive exercises for loading and unloading vessels, including specific tasks for working in the holds and on deck. A key component of the training involves preparing operators for challenging conditions, such as high winds, poor visibility, and equipment malfunctions, ensuring they are adept at managing these scenarios. The program culminates in a rigorous assessment designed to verify that operators are fully equipped for real-world operations. Monitoring and evaluation of participants' performance play a critical role in this process. Instructors use a dedicated console at their workstation to observe participants' interactions with the simulator in real time. The console provides detailed feedback on control inputs, such as joystick movements. The "Trends" window, for instance, graphically displays the lifting and lowering speeds of the spreader, enabling instructors to detect subtle issues like uneven acceleration or irregular movements that may indicate a lack of control precision [8] (Figure 4).

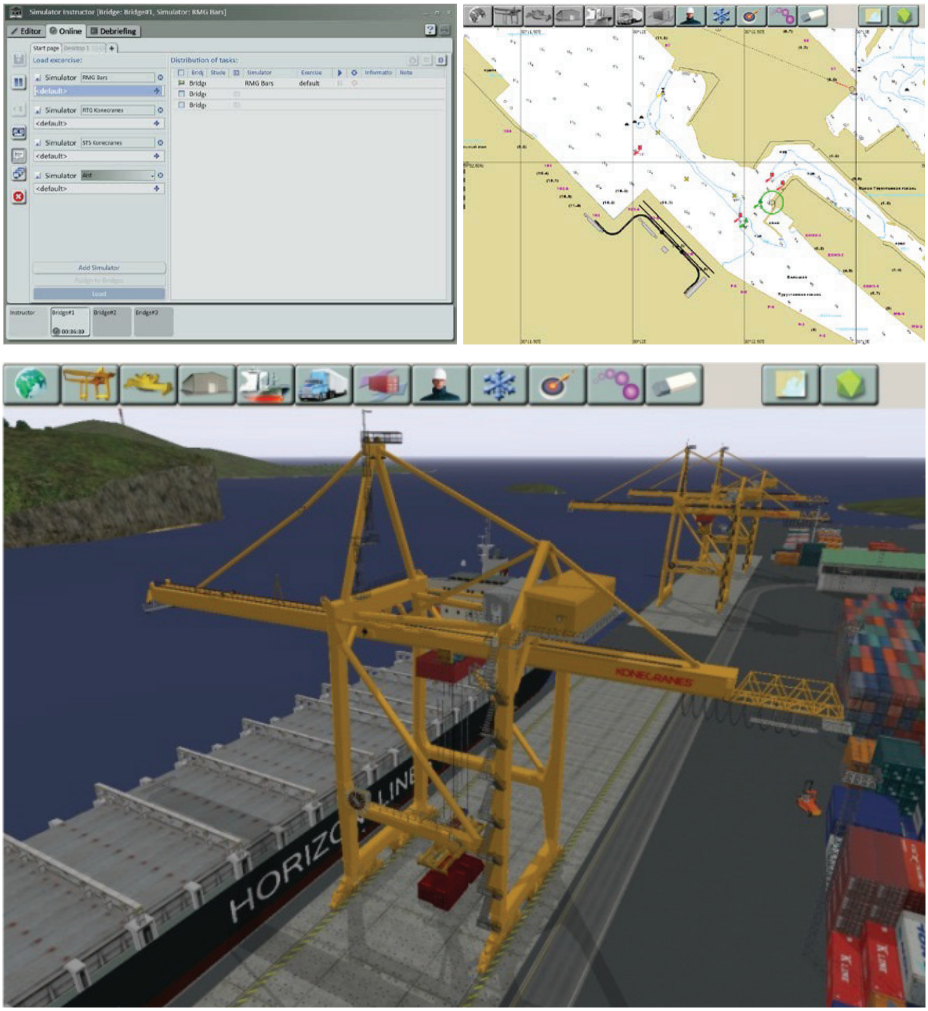

Figure 4. Instructor console. [8]

To enhance the learning experience, instructors can leverage feedback to encourage participants to repeat exercises, allowing them to practice and correct mistakes. This iterative process of practice, feedback, and repetition helps participants refine their control skills, leading to smoother and more consistent performance. The integrated 3D view within the simulator facilitates visual tracking of progress and provides real-time insights into critical metrics, such as speed and positioning. This continuous cycle of improvement aids participants in developing the precision required for effective and safe crane operation. Additionally, the simulator software supports comprehensive performance assessment by evaluating participants against predefined criteria established by the instructor. This system ensures objective and consistent assessments, aligning with the guidelines set out in the instructor's scenario plan. This structured approach allows for clear measurement of progress and identification of areas needing improvement.

Beyond their educational applications, crane simulators play a vital role in advanced simulation and research. The instructor interface allows for precise monitoring and documentation of each operation, including detailed tracking of changes to control consoles and joysticks over time. This data can be analysed using machine learning techniques to enhance the automation of operational and emergency systems. Moreover, simulators provide a controlled environment for testing various external forces, such as wind, which can impact crane performance and stability [10]. They enable the development of more efficient cargo handling techniques, the evaluation of existing methods [11] and comprehensive risk assessments [12]. In the context of operator performance, simulators are invaluable for mental workload analysis [13] and fatigue assessment. The use of biometric devices during these assessments yields more reliable data as participants remain seated, ensuring consistent and accurate measurements [14].

4. CONCLUSION

The use of crane simulators makes an important contribution to improving training efficiency, operational safety and overall performance in port operations. By allowing operators to experience realistic scenarios in a risk-free environment, simulators help to shorten the learning curve, support the safe handling of complex tasks and provide opportunities for performance evaluation and feedback. Our work to date shows that simulation-based training has great potential to improve both individual competences and systemic safety standards. It enables consistent engagement with rare but critical situations and promotes faster decision making and better situational awareness.

Future work will aim to improve our understanding of the cognitive load of crane operators by incorporating advanced biometric tools. In particular, we plan to use eye-tracking glasses to monitor pupil dilation and track eye movements. This technology will provide real-time insight into where crane operators are focusing their attention, which is critical to understanding the cognitive demands placed on them during different tasks. By analysing these attention patterns, we can better assess how crane operators deal with complex operations and potential distractions. In addition to eye tracking, the integration of facial expression monitoring software allows us to analyse emotional reactions in more detail. This allows us to correlate the observed emotional states with stress levels and overall mental workload. Such detailed analysis will help us to understand how emotional and cognitive factors influence operator performance under different conditions.

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Quality Control of Concessionaire Operations: Case Study of Croatia

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ABSTRACT

A concession is a permit to perform an activity requiring special approval, granted by a public authority. It allows an entity to economically utilize goods, perform works, or provide services. The European Concessions Directive defines concessions as "contracts for pecuniary interest", and Croatia's Concessions Act aligns with this definition. While financial supervision of concessionaires is well regulated in Croatia, the monitoring of service quality – especially in public-interest activities such as port operations and maritime transport – remains insufficiently developed. This paper uses a normative legal analysis to examine the concession grantor's responsibilities and explore mechanisms for supervising concessionaire performance quality. Focusing on Croatia as a case study within the broader EU legal context, it identifies key regulatory gaps and proposes a set of structured monitoring measures to improve oversight and public service delivery.

Keywords: concessions; concessionaire supervision; Concessions Directive; Concessions Act.

1. INTRODUCTION

The Republic of Croatia enacted the Concessions Act in 2017 [1] (hereinafter: CA), thereby harmonizing its legal framework on concessions with the European legal framework established by the Concessions Directive [2]. The Directive marked a significant shift in the legal theory of concessions. Contrary to the traditional definition, which considered a concession a special right granted by public authorities (typically concerning limited resources such as maritime or water resources), it is now simply defined as "a right acquired through a contract" [3].

Pursuant to the provisions of the CA, a concession grantor publishes a notice of intent to award a concession using a standardized form. Interested bidders must submit their offers within the deadline specified in the notice, after which the offers are opened, reviewed, and evaluated. The procedure closely resembles the public procurement process.

For the purposes of this paper, it is essential to emphasize that the CA prescribes two possible criteria for selecting the most favourable bid: 1. economically most advantageous offer from the perspective of the concession grantor, which includes factors related to the subject of the concession, such as quality (including technical achievements, aesthetic, innovative, functional, and environmental characteristics), operational and management costs, efficiency, servicing and technical support after delivery, delivery dates and completion deadlines, service prices for end users, and 2. the amount of the concession fee.

The criterion of the highest offered concession fee involves selecting the bid with the highest proposed concession fee. After the expert commission for concessions reviews and evaluates the bids, the concession grantor issues a decision on awarding the concession. The decision on awarding the concession constitutes an administrative act. For the sake of completeness, it should be noted that concessions upon request are also exceptionally possible [4].

However, issuing the concession award decision does not conclude the concession-granting procedure. Two legal acts emerge in the concession process: the concession award decision and the concession contract [5]. The concession contract, by its legal nature, is an administrative contract, thus falling within the domain of public law [6]. Administrative contracts were introduced into Croatian legislation by the General Administrative Procedure Act of 2009 [7]. The parties involved in concluding an administrative contract are always clearly defined — typically a public authority and a private person, or alternatively, a public legal entity and a private legal entity [8]. Unlike the concession award decision, which is in the form of an administrative resolution, the concession contract for complex concessions may encompass several hundred pages of text.

Concessions in Croatia are granted for various activities. The CA lists 23 such activities, and the phrase indicating they are granted "particularly" for the listed activities implies that additional activities may be specified by law. From Article 8 of the CA, we highlight only those related to transport and logistics, which will be examined in greater detail in this paper: concessions on maritime domain, for performing regular and coastal maritime and river transport services, for ports, for the construction and management of motorways and specific road infrastructure on state roads (such as bridges and tunnels), for providing public transport services, for airports, in the railway sector, and for cableway operations.

Concessions are often granted for public service activities such as operations on maritime domains, ports, and motorways. The concession grantor (which is always a public authority) assigns the right to perform these activities to a private entity (either a legal or natural person). Simultaneously, the public authority is obliged to ensure and monitor the proper performance of the concessioned activity. For example, if a concession is granted for a port open to public traffic (a seaport that any natural or legal person may use under equal conditions, in accordance with its intended purpose and within its available capacity) [9], the public authority is responsible for ensuring that the port fulfils its designated function. A similar obligation applies in the case of regular maritime transport services, where the public authority ultimately bears responsibility for maintaining connectivity between islands and the mainland.

The supervision of the concessionaire may be conducted from two perspectives. The first is monitoring the payment of concession fees, which is clearly and precisely regulated under current legislation. The second type of supervision concerns the quality of the concessioned activity's performance. Although the CA mandates this form of supervision, it does not elaborate on its implementation, and legal doctrine has not extensively addressed the issue.

Given that monitoring the quality of the concessionaire's work is essential for concessions involving public service provision, this paper considers it necessary to examine the obligations and possibilities of such supervision in greater detail. Furthermore, we will propose practical methods for conducting this supervision, focusing primarily on transport and logistics activities. We believe that, *cum grano salis*, these considerations could be applied to other types of concessions as well. It is worth noting that the Concessions Directive itself emphasizes this point in Recital 5: "States or public authorities should remain free to define and specify the characteristics of the services to be provided, including any conditions regarding the quality or price of the services, in accordance with Union law, in order to pursue their public policy objectives."

This paper adopts a normative legal analysis approach, focusing on the Croatian legal and institutional framework concerning concessions. The methodology includes a review of primary legal sources such as the CA, sector-specific legislation (e.g., the Maritime Domain and Seaports Act), and relevant European Union law, particularly the Concessions Directive. Secondary sources, including scholarly articles and government documents, are used to support interpretation and contextualization. The paper identifies normative gaps in quality control mechanisms and proposes institutional improvements through the formulation of monitoring measures based on legal reasoning, best practices, and policy analysis.

This paper contributes to the ongoing discussion on concession regulation by focusing on the underexplored issue of quality control in the Croatian context. While financial oversight of concessionaires is well regulated, legal and institutional mechanisms for monitoring service quality remain insufficiently developed. By identifying these normative gaps and proposing a structured set of monitoring measures, the paper offers a novel analytical framework that can serve as a basis for legal and policy reform.

2. CONCESSION POLICY

The issue of supervising the concessionaire's performance is addressed in Part Two of the CA, titled *Concession Policy*. It is important to note that the definition of concession policy, as provided by the CA, primarily pertains to the activities of the competent ministry. However, the same section of the Act also regulates provisions relevant to this article, particularly concerning the responsibilities and powers of the concession grantor.

2.1. Supervision of the obligation to pay the concession fee

The concession grantor undertakes all prescribed actions to ensure the proper execution of the concession contract and to protect the assets and interests of the Republic of Croatia. These actions include notifying and calling upon the concessionaire to settle overdue and unpaid concession fees, activating security instruments, and initiating enforced collection procedures. If the concession fee remains unpaid, the concession grantor must notify the ministry responsible for finance about the measures taken without delay.

The law comprehensively regulates the obligations of both the concession grantor and the concessionaire concerning the concession fee. It mandates that the concession grantor must submit the concession contract and any annexes to the ministry responsible for finance within ten days of their conclusion. The same applies to any modifications to the concession contract.

Additionally, the CA stipulates that, in supervising the performance of the concession contract, the concession grantor must: 1. continuously monitor performance, which includes overseeing the work of the concessionaire, subcontractors, and sub-concessionaires, ensuring that they fulfil their contractual obligations, including the regular payment of the concession fee. 2. take prescribed measures, i.e., the grantor must take all necessary actions to ensure the proper, complete, and timely collection of the concession fee and any accrued interest. 3. maintain accurate records, i.e., the concession grantor must ensure the correct and regular entry of data into the Concession Register. The ministry responsible for finance manages the Concession Register.

The CA equates unpaid concession fees with unpaid taxes. Consequently, if the concession grantor fails to collect the concession fee, even though there are available security instruments, it must promptly notify the ministry responsible for finance and submit all necessary documentation. The ministry will then collect the concession fee from the concessionaire according to the regulations governing the collection of taxes and other public charges. In summary, in cases of unpaid concession fees, the state has access to the same extensive collection mechanisms applicable to unpaid taxes.

Furthermore, the CA primarily regulates the supervision of concessionaires' financial obligations. For example, during the inspection process, inspectors are authorized to review documentation related to accounting, material, and financial operations. This review focuses specifically on the legality, purposefulness, and timeliness of the calculation and payment of concession fees.

2.2. Supervision of concessionaire activities

As previously mentioned, many activities performed under a concession arrangement constitute public service provision. By entering such a public contract, the public authority aims to fulfil a specific public interest, which can vary but fundamentally seeks to satisfy a particular public need [10].

For instance, in concessions involving mariculture (such as fish and shellfish farming), the concessionaire primarily bears the financial risk of business failure. In contrast, public services must be performed according to prescribed and agreed-upon rules. For example, an island must be connected to the mainland by a ship of the specified capacity, making the required number of daily dockings. Similarly, airports and seaports must function as public ports. The quality of services must be monitored. Moreover, if a concessionaire fails to fulfil its obligations under a public service concession on a maritime domain, the concession grantor must have the authority to revoke the concession [11].

The CA includes only a few provisions concerning the supervision of concessionaire activities. Among the previously mentioned obligations under concession policy is the requirement to "continuously monitor the concessionaire's operations and the fulfilment of obligations under the concession contract". Additionally, the CA stipulates that the annual report prepared by the concession grantor, which must be submitted to the ministry responsible for finance by 1 June of the current year for the previous year, must also include "actions taken concerning the concessionaire's activities".

An exceptionally important provision of the CA is that the concession grantor may unilaterally terminate the concession contract if the concessionaire "fails to perform works and/or provide services according to the quality standards for such works or services as stipulated in the concession contract, specific laws, and other applicable regulations governing the concession's subject matter". Thus, service quality is a valid reason for exercising one of the concession grantor's most critical powers: the unilateral termination of the concession contract. Given the severity of this measure, such termination must be adequately substantiated. In the event of a potential dispute before an administrative court [12], the concession grantor will have to provide clear and undeniable proof that the concessionaire failed to deliver services in accordance with the stipulated standards in the contract. Failure to do so could result in large-scale damage claims by the former concessionaire, ultimately borne by taxpayers.

As previously noted, one of the criteria for selecting the most favourable bid – in the case of the economically most advantageous offer – is service quality. According to the CA, this includes technical achievements, aesthetic, innovative, functional, and environmental characteristics. Moreover, the CA explicitly states that in the event of a concession contract transfer, such a transfer "must not reduce quality or disrupt the continuity of the concession contract's implementation".

From the beginning of the concession process – including the selection of the concessionaire, the performance of activities of public interest, the possibility of concession transfer, and the potential unilateral termination of the concession contract – the need for measuring service quality is repeatedly emphasized. However, no detailed guidelines are provided.

A similar situation exists in specific sectoral laws. For example, the comprehensive Maritime Domain and Seaports Act [13] of 2023, finally harmonized with the CA and the Concessions Directive [14], regulates supervision in only one article (Article 193), consisting of two paragraphs. The first paragraph states that "Supervision over the fulfillment of obligations assumed under the concession contract shall be conducted by the concession grantor". The second paragraph addresses the supervision of financial obligations, specifying that it is performed by the ministry responsible for finance. This regulation is notably sparse.

The CA does not specify how the concessionaire's performance should be monitored regarding service quality, nor do essential sector-specific regulations, such as the one governing concessions on maritime domains – a critically important natural resource in the Republic of Croatia [15]. The lack of clear guidelines on monitoring mechanisms leaves concession grantors without standardized procedures for ensuring compliance, quality, and efficiency. As a result, each concession grantor must independently establish their own monitoring measures. In the following sections, we propose recommendations for implementing effective monitoring procedures.

3. PROPOSED MONITORING MEASURES

3.1. Legal framework for quality monitoring

As previously noted, the concession grantor must supervise the quality of concession performance, which is particularly important for concessions involving public services. The first issue to address is the legal framework enabling such supervision of the concessionaire's activities. Although the CA does not explicitly prescribe this, an interpretative analysis of its provisions indicates that the concession grantor has the authority to regulate this matter explicitly.

Before initiating the concession award process, the concession grantor is required to prepare a feasibility study. This study must consider several factors, including public interest, environmental impact, nature conservation, cultural heritage protection, financial implications, and alignment with economic development, spatial, and concession award plans. Service quality falls within the scope of public interest when it comes to concessions providing public services.

Based on the feasibility study and concession valuation, the concession grantor prepares the bidding documentation. The CA mandates that the bidding documentation must include all necessary information enabling economic operators to submit requests to participate and/or offers. Notably, the documentation must also contain a draft concession contract to avoid future ambiguities and disputes.

The concession contract is a crucial component of the concession relationship. Implementing the concession award decision depends on concluding the concession contract [16]. Therefore, provisions on service quality monitoring must be incorporated directly into the draft concession contract, which forms an integral part of the bidding documentation. This ensures that the quality control mechanisms are clearly defined and legally binding from the outset of the concession agreement.

3.2. Quality monitoring procedures for concessionaire performance

Monitoring the quality of service delivery is inherently more complex than monitoring the quality of tangible products. As Kolanović observes, "A service is an intangible product whose value is defined by the market, that is, by the consumer – the user". Unlike physical products, services are produced and consumed simultaneously, making it impossible to assess their quality before they are offered to the market or delivered to the end user [17].

Unlike tangible goods, services possess specific characteristics that must be considered when developing a service quality monitoring model:

1. *Intangibility*: Services cannot be seen, touched, tested, or examined before purchase.
2. *Perishability*: Unused service capacity results in a lost service opportunity, as services cannot be stored for future use.

3. *Heterogeneity*: Service quality can vary depending on the service provider.
4. *Lack of ownership*: Consumers gain only access or use of the service; they pay for usage, access, or rental rather than ownership.
5. *Simultaneity of production and consumption*: Services are produced and consumed simultaneously, often requiring either the consumer or the service provider to be physically present [18].

Monitoring service quality requires a multi-dimensional approach. This includes evaluating services from the perspective of the organization providing the service, the stakeholders involved in its delivery, and the end users receiving it. For example, in the context of ports, which provide public services, the most significant challenge in determining service quality is the lack of a unified model or tools for measuring service quality and assessing user satisfaction. Establishing a standardized assessment framework would enhance transparency, ensure accountability, and promote continuous improvement in service delivery [17].

Given this context, it is crucial not only to identify the problem but also to propose potential solutions. These recommendations could apply either to specific concession contracts or to future legislative amendments. We will outline a range of suggested measures and procedures for monitoring the performance quality of concessionaires providing public services. This proposal is neither final nor exhaustive but rather a starting point for developing a comprehensive quality monitoring framework.

Proposals for effective monitoring and improvement of concessionaire performance:

1. Conduct (inspections and audits)

a. *Regular inspections:* Establish a mandatory inspection schedule (quarterly, semi-annual, or annual) with clearly defined criteria, including checks on technical standards, safety measures, work procedures, deadlines, and other obligations (e.g., cargo unloading times, carrier timetables).

b. *Expert involvement:* Engage independent experts in specific areas (e.g., environment, transport, safety) to ensure objective evaluations. Special care should be taken to avoid conflicts of interest, which can be challenging in smaller countries like Croatia.

2. Monitor (Key Performance Indicators – KPIs) [19]

a. *KPI definition:* Develop specific and measurable KPIs such as response time to breakdowns or complaints, number of services provided in accordance with standards, and others.

b. *Benchmarking:* Compare KPIs with best practices at the EU or international level to encourage innovation and improvements.

3. Utilize (feedback collection)

a. *User surveys:* Conduct regular surveys among service users to gather information on satisfaction, service quality, and potential issues.

b. *Transparent complaint channels*: Provide accessible channels (online forms, hotlines) for submitting complaints with clear deadlines for resolution.

c. *Workshops and meetings:* Organize regular meetings with stakeholders (concessionaires, users, regulatory bodies) to discuss changes and solutions.

4. Require (periodic reports)

a. *Standardized reporting forms:* Develop standardized reporting templates covering technical, operational, and financial aspects.

b. *Digital registry:* Implement mandatory submission of reports through a digital system to streamline data processing and analysis.

c. *Quality reports:* Include dedicated sections in reports addressing quality measures and any identified deviations.

The proposed measures outlined above are general and should be adapted to specific concessions. For instance, when public services are offered to citizens, the legal framework for consumer protection must be incorporated [20].

Additionally, in the provision of public services, the concession grantor must consider whether the provided service is one where users have the legal right to lodge complaints under the General Administrative Procedure Act (GAPA) [7]. Since 2009, GAPA has recognized users' rights to file complaints concerning the conduct of public service providers. This applies to both economic activities, such as utility services or water resource management, and non-economic activities, often still referred to – albeit imprecisely and with outdated terminology – as "social services" [21]. It is important to emphasize that the legal regulation of complaints also has its shortcomings, requiring further procedural elaboration in practice [22]. However, the complaint process underscores the responsibility of public authorities for the provision of public services, even when these services are transferred to a private legal entity through a concession [23].

In some concession-based services, such as public transportation in regular coastal maritime traffic, numerous specific conditions have already been regulated through by-laws. These include additional technical requirements that must be met by vessels providing public transport services [24]. These considerations demonstrate that while the proposed quality monitoring measures provide a foundational framework, their implementation must be tailored to the specific characteristics, legal obligations, and operational context of each concession. We provide a few more examples. If the service is provided to end users – natural persons – the Consumer Rights Directive [25] should be considered. For protected areas in Croatia, the Guidelines for

Management Planning of Protected Areas and/or Ecological Network Sites [26] may be relevant, along with management plans such as Croatia's National Plan for the Management of Railway Infrastructure and Service Facilities and the Development of Rail Transport Services until 2030 [27].

In order to support the implementation of these monitoring measures, international standards such as ISO 9001 (Quality Management), ISO 14001 (Environmental Management), ISO 55001 (Asset Management), ISO 10002 (Customer Satisfaction), ISO 31000 (Risk Management), and ISO 19011 (Auditing Management Systems) can serve as valuable frameworks for ensuring consistency, accountability, and continuous improvement. An overview of the proposed measures is presented in **Table 1**.

Table 1. Overview of Proposed Quality Monitoring Measures in Concession Performance

Monitoring Area	Proposed Measure	Purpose	Related ISO Standards
Inspections and audits	Regular scheduled inspections by independent experts	Ensure compliance with contractual and safety standards	ISO 9001, ISO 55001, ISO 19011
Key Performance Indicators (KPIs)	Definition and monitoring of KPIs (e.g., response times, punctuality)	Enable objective performance assessment and benchmarking	ISO 9001, ISO 31000
User feedback	Surveys, complaint mechanisms, stakeholder meetings	Incorporate end-user experience into service improvement	ISO 10002
Reporting requirements	Standardized templates, digital submission, quality reports	Ensure transparency and allow systematic analysis	ISO 9001, ISO 14001

4. DISCUSSION AND CONCLUSION

This paper has examined the current Croatian legal framework for concession quality control, with an emphasis on public services such as port operations and maritime transport. The analysis shows that while the legal foundation for concession award and financial supervision is well developed, the legal instruments for monitoring performance quality remain underdefined and fragmented across different legal sources.

The proposed quality monitoring measures – including regular inspections, KPIs, structured user feedback, and standardized reporting – are based on normative analysis of existing legal obligations and general administrative principles. These recommendations aim to provide a structured model for concession grantors to ensure better oversight and service consistency.

However, it should be noted that these conclusions are based on legal and policy analysis and not on empirical data. Further research could include case studies and stakeholder interviews to validate the effectiveness and feasibility of the proposed framework. Improved regulatory clarity, together with practical implementation tools, could contribute to enhanced accountability and public service delivery within concession-based operations in Croatia.

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Predicting Profit-Loss using an Amalgamated Baseline Long Short-Term Memory Network with Self-Aligned Criminal Search for Fulfilment Cost Challenges

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A B S T R A C T

The paper introduces an amalgamated baseline long short-term memory with a self-aligned criminal search optimization algorithm model to forecast profit or loss in product fulfilment, aligning with the critical management goal of optimizing costs. The model undergoes training with a substantial dataset, validation for optimality, and subsequent testing with smaller datasets, providing an optimal solution for predicting and conducting comparative analysis to ensure profitable fulfilment execution. From a business analytics and management standpoint, the predictive analysis outlined in this paper offers valuable insights for creating dashboards and integrated performance metrics, thereby enhancing overall organizational efficiency.

Keywords: Machine Learning; Logistics; Supply Chain Management; Transportation; Simulation.

1. INTRODUCTION

Since the onset of the pandemic, logistics costs have surged, primarily driven by rising freight expenses and challenges in ensuring successful deliveries. It is crucial to accurately predict whether shipping products will result in a global profit or loss, offering significant benefits to entrepreneurs and organizations engaged in worldwide product sales. Efficiently managing the shipping of products poses considerable challenges in consistently maintaining optimal logistics. These challenges directly influence the overall profit and loss in product fulfilment. Knowing whether a shipment will result in profit or loss would greatly benefit the organization. Therefore, there is a crucial need for a model that analyses past data and predicts the outcome of product fulfilment by forecasting the overall incurred costs.

To predict profit or loss effectively, a new model is introduced: the amalgamated baseline long short-term memory with self-aligned criminal search optimization algorithm model. This model aligns with the critical management goal of achieving an optimal product fulfilment cost. The process involves training the model with a substantial dataset, validating its optimality, and testing the smaller datasets. The model offers an optimal solution for predicting and performing comparative analysis, contributing to the successful execution of profitable fulfilment. From a business analytics or management perspective, the predictive analysis presented in this paper can be utilized to create dashboards and integrated performance metrics, ultimately enhancing the organization's overall efficiency.

2. LITERATURE REVIEW

Jackson *et al* [1] utilize the GPT-3 Codex to automatically generate simulation models for logistics systems from natural language descriptions, showcasing the successful creation of functional simulations for queuing and inventory management systems. The refined language model simplifies the development process, offering a technological foundation for effective human-AI collaboration in building simulation models for logistics systems. Hasan *et al.* [2] investigate the intermodal freight diversion from road to inland water transport (IWT) in Bangladesh for domestic transportation through ports. They identify cost, time, reliability, flexibility, and environmental factors as significant barriers and recommend operational, organizational, fiscal, and regulatory measures to facilitate the modal shift. Comparative analysis along the Dhaka-Chittagong trade corridor reveals that, despite longer transit times, IWT offers lower total logistics costs than road transport, and further infrastructure improvements could enhance its competitiveness, making it an attractive option for reducing transport costs and time.

Takeyasu *et al.* [3] explore optimization in sea and air transport by formulating mathematical models considering transportation costs, warehouse stock fees, and reduced costs for volume discounts. The expanded objective function, incorporating a "multi-step tournament selection method", aims to minimize expenses under specified constraints, enhancing decision-making in international logistics by applying genetic algorithms. The research demonstrates practical advancements by incorporating volume discounts and expanding constraints, contributing to more effective decision-making in global logistics management. Engblom *et al.* [4] investigate the self-reported logistics costs of manufacturing and trading companies in Finland, comprising six components: transport, warehousing, inventory carrying, logistics administration, transport packaging, and indirect costs. Analysing panel data from 241 companies in 2005 and 2008, the study utilizes various methods, including GLMM and principal component analysis, revealing that logistics costs, influenced by factors such as time, employees, turnover, industry, and internationalization, tend to be lower in larger companies with caution advised when interpreting changes in costs over time due to the influence of background variables.

3. NOVELTY

In this study, we have developed a machine-learning model, the novel amalgamated baseline long short-term memory network with a self-aligned criminal search algorithm *ALSTM-SCSOA*, to address cost management challenges in predicting profit or loss for product fulfilment problems. Utilizing a dataset comprising consignor-to-consignee details and other factors affecting overall fulfilment costs, the model enables the prediction of whether a shipment will result in profit or loss. Acting as an initial assessment tool for consignors, it helps determine the viability of product fulfilment from warehouse to consumer before actual shipment, enhancing decision-making in the fulfilment process.

4. DATA HANDLING AND PREPROCESSING

The dataset from Kaggle [5], provided by Sai Charan Komati, aligns with our machine-learning model goals. The model optimizes training weights to forecast shipment outcomes by ensuring seamless integration and error-free pre-processing. The data handling and pre-processing workflow, outlined in **Figure 1**, involves collection, cleaning, selection, scaling, and segmentation into training and testing sets.

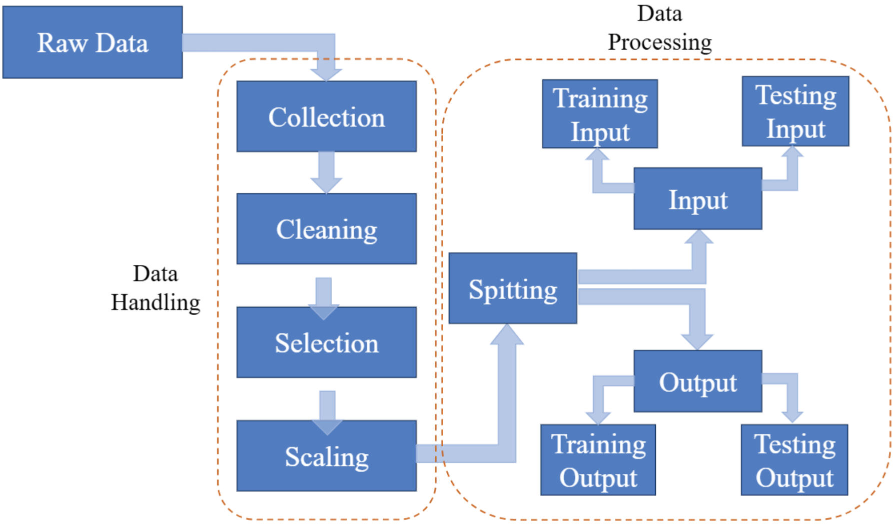


Figure 1. Data handling and pre-processing workflow.

4.1. Data handling

The dataset comprises 53 features and 180 thousand rows, but only 15 essential features are selected for each iteration due to its size. These critical features include Category ID, Customer City, Customer Country, Customer Segment, Customer State, Latitude, Longitude, Market, Order City, Order Country, Order Item Total, Order Region, Order State, Shipping Mode, and Order Profit Per Order. These features play a pivotal role in determining the flow of the product fulfilment process from consignor to consignee. The original dataset consists of 180,520 rows, removing duplicate and null data, resulting in 180,510 rows. Eliminating these duplicate null entries is crucial to uphold dataset integrity and prevent NAN output during subsequent mathematical computations in the objective functions. This step guarantees that the data is optimal for the successive stages of data handling in addressing our specific problem.

As mentioned, the 15 features must be transformed into numeric values, excluding zeros. Among these features, five – Category ID, Longitude, Latitude, Order Item Total, and Order Profit Per Order – are already numeric, while the remaining ten are alphanumeric. To address this, the alphanumeric features are converted into numeric values by assigning unique numbers to each specific alphanumeric value. This numerical representation through conversion or scaling ensures compatibility with machine algorithms and optimization processes. The datasets undergo additional scrutiny to identify zero values. Mathematical calculations may yield a NAN result in zero values, so these instances are replaced with 0.0001 to maintain a numerical value. Additionally, the "Order Profit per Order" values are scaled to fall within the range of -100 to 100. This scaling prevents significant deviations in the range, reducing the impact of outlier values on output weights. Following these steps, the dataset is refined to 148,639 rows and 15 columns, making it suitable for pre-processing.

4.2. Data pre-processing

The obtained dataset requires numerical organization tailored to our specific requirements. To enhance the understanding of the dataset, fourteen collective features are grouped as the input dataset (x^t), while the column representing Order Profit per Order in dollars is singled out as the output dataset (y^t). Subsequently, the input and output datasets are divided into training and testing datasets in an 80:20 ratio. Consequently, x^t is split into two datasets: x^t_{train} containing 118,911 rows and 14 columns, and x^t_{test} with 29,728 rows and 14 columns. Similarly, y^t is divided into y^t_{train} comprising 118,911 rows and one column, and y^t_{test} with 29,728 rows and one column, respectively.

5. ALSTM-SCOA FOR FORCASTING PRODUCT FULFILMENT COST

The proposed model integrates a novel amalgamated baseline long short memory network (*ALSTM*) as a machine learning approach and a self-aligned criminal search optimization algorithm (*SCSOA*) as an optimization technique for addressing the product fulfilment cost problem. The classical *LSTM*, introduced by Hochreiter *et al.* [6] as shown in **Figure 2**, employs a gradient-based method, distributing constant error updates throughout the network.

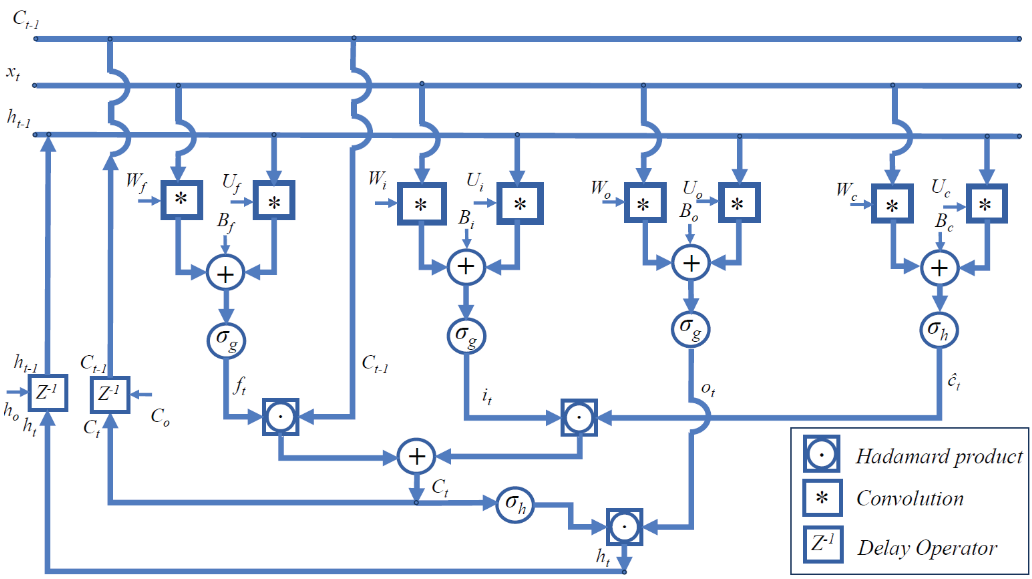


Figure 2. Diagram of classical LSTM.

LSTM primarily comprises three gates and a cell candidate for update: the forget gate (f_t), the input gate (i_t), and the output gate (o_t), while ($\hat{c}_t$) represents the cell candidate for update. The forget, input, and output gates are computed using sigmoid functions $\sigma_g(x)$, denoted as $\frac{1}{1-e^{-x}}$, while the cell candidate employs the hyperbolic tangent function ($\sigma_h(x)$ represented by $tanh(x)$). The following equations define the output of these four gates.

$$f_t = \sigma_g(f_k|_{m\times n}); \quad f_k|_{m\times n} = W_f|_{1\times n} \circledast x_t|_{m\times n} + U_f|_{1\times 1} \circledast h_{t-1}|_{1\times n} + b_f|_{1\times n} \tag{1}$$

$$i_t = \sigma_g(i_k|_{m\times n}); \quad i_k|_{m\times n} = W_i|_{1\times n} \circledast x_t|_{m\times n} + U_i|_{1\times 1} \circledast h_{t-1}|_{1\times n} + b_i|_{1\times n} \tag{2}$$

$$o_t = \sigma_g(o_k|_{m\times n}); \quad o_k|_{m\times n} = W_o|_{1\times n} \circledast x_t|_{m\times n} + U_o|_{1\times 1} \circledast h_{t-1}|_{1\times n} + b_o|_{1\times n} \tag{3}$$

$$\hat{c}_t = \sigma_g(c_k|_{m\times n}); \quad c_k|_{m\times n} = W_c|_{1\times n} \circledast x_t|_{m\times n} + U_c|_{1\times 1} \circledast h_{t-1}|_{1\times n} + b_c|_{1\times n} \tag{4}$$

where W_f, Wi, W_o, W_c and U_f, U_i, U_o, U_c represent the respective input weights. Additionally, b_f, b_i, b_o, b_c denote the input bias, and $\circledast$ represents the convolution steps. The input dataset is denoted by x_t, while h_{t-1} represents the output of the previous iteration. For the first iteration, h_{t-1} is initialized with a random value within the range $[-h, h]$. From the above, we can calculate the long-term memory C_t and its final output h_t, denoted by the below equations.

$$C_t = f_t \odot C_{t-1} + i_t \odot \hat{c}_t \tag{5}$$

$$h_t = o_t \odot \sigma_h(C_t) \tag{6}$$

The \$CSOA\$ algorithm, as introduced by Srivastava *et al.* [7], is inspired by police investigative procedures outlined in their paper. In the British model, which is applicable across Commonwealth jurisdictions, the responsibility for criminal investigations lies with the Detective Chief Inspector (*DCI*). The Detective Inspector (*DI*) is tasked with official fieldwork, while the Confidential Informant (*CI*) gathers unofficial information. Communication exclusively flows from subordinates, i.e., from *DI* and *CI* to *DCI*, with no information exchange between *DI* and *CI*. One may review the algorithm details from [7]. The self-aligned weight introduced by Zhang *et al.* [8] is also introduced $w(t) = \frac{(w_{mx}-w_{mn})}{N}\times$, where w_{mx}=0.9, w_{mn}=0.01, N is the maximum number of iterations, and t is the number of current iterations.

Table 1. Notations in the criminal search optimization algorithms

Name	Description
I^t	The current information available to *DCI*
I^{t+1}	The updated information about the prime suspect
a^t	A random number between -1 and 1
t	The stage of the investigation or iteration
w	The self-aligned weight
DI^t	The current information available to *DI*
DI^{t+1}	The updated information available to *DI*
DI_I^t	The information collected by *DI* from the lead suspect, calculated as the difference between I^t and DI^t
DI_a^t	Information collected by *DI* from their previous best information, calculated as the difference between DI^{t-1}_a and DI^t
DI_r^t	The information collected from a random fellow *DI*, calculated as the difference between DI^t_r and DI^t
r_1, r_2, r_3	Randomly generated between 0 and 1
b	Weight ranging between 0 and 1
CI^t	The current information available to the *CI* about the suspect
CI^{t+1}	The updated information available to *CI*
CI_a^t	The previous best information collected by the *CI*, calculated as $[CI^{t-1} - CI^t]$
CI_{DI}^t	Information collected by the *CI* from the *DI* through *DCI*

The update rules are as follows, with the notation as shown in **Table 1**:

$$I^{t+1} = I^t + I^t \times a^t \tag{7}$$

$$DI^{t+1} = w \times DI^t + r_1 \times DI_I^t + b \times r_2 \times DI_a^t + (1-b) \times r_3 \times DI_r^t \tag{8}$$

$$CI^{t+1} = w \times CI^t + r_1 \times CI_a^t + r_2 \times CI_{DI}^t. \tag{9}$$

6. SIMULATION

The proposed model was implemented using the LabVIEW©2019 platform, and all simulations were conducted on a personal computer equipped with an Intel (R) Core (TM) i3-1115G4 and 36.0 GB of memory. The model's primary goal is to optimize the *ALSTM* model using *SCSOA* to achieve the most optimal error. Three error calculation methods – mean square error (*MSE*), integral absolute error (*IAE*), and normalized root mean square error (*NRMSE*) – are utilized to assess and compare errors. The model workflow encompasses training, testing the *ALSTM-SCSOA* model, and amalgamating the baseline for testing results. In the training phase, the iterative process involves refining the error from the *ALSTM* network by incorporating training datasets and utilizing the *SCSOA* updating mechanism. This iterative approach aims to determine the optimal weight W_{opt}. Subsequently, using the derived optimal weight, the model undergoes testing to predict whether the product fulfilment will result in profit or loss.

Before initiating the training and testing phases, it is necessary to initialize W_{int}, a weight matrix of 4×(n+1) that includes W_f, W_i, W_o, W_c, U_f, U_i, U_o, U_c as input weights, and *b*, *a* Bias matrix of 6×n comprising b_f, b_i, b_o, b_c, c_o, and h_o. The values are randomly initialized within the [0,100] range, and since the number of input features is 14, n=14, the matrices *W* and *b* can be represented as follows.

$$W|_{4\times(n+1)} = \begin{bmatrix} W_f|_{1\times n} & U_f|_{1\times 1} \\ W_i|_{1\times n} & U_f|_{1\times 1} \\ W_o|_{1\times n} & U_o|_{1\times 1} \\ W_{\hat{c}}|_{1\times n} & U_{\hat{c}}|_{1\times 1} \end{bmatrix}_{4\times(n+1)} \tag{10}$$

$$b|_{6\times n} = \begin{bmatrix} b_f|_{1\times n} \\ b_i|_{1\times n} \\ b_o|_{1\times n} \\ b_{\hat{c}}|_{1\times n} \\ c_o|_{1\times n} \\ h_o|_{1\times n} \end{bmatrix}_{6\times n} \tag{11}$$

6.1. Training

In the initial iteration, the training phase begins using the initially set matrices, specifically *W* and *b*. Utilizing these initialized weight matrices in conjunction with the input, the *ALSTM* network calculates the output *y*. The obtained output *y* is then compared with the desired training output dataset, represented as y_d, to compute the training error e_{train}. In the subsequent step, the *SCSOA* updating process is employed to adjust the weight, optimizing it for that specific iteration. This iterative process is repeated, utilizing the updated weight instead of the initial weight, until the training error e_{train} approaches zero, determining the best optimal weight, denoted as W_{opt} for the testing phase. **Figure 3** on the left side illustrates the systematic diagram for training the *ALSTM-SCSOA* model.

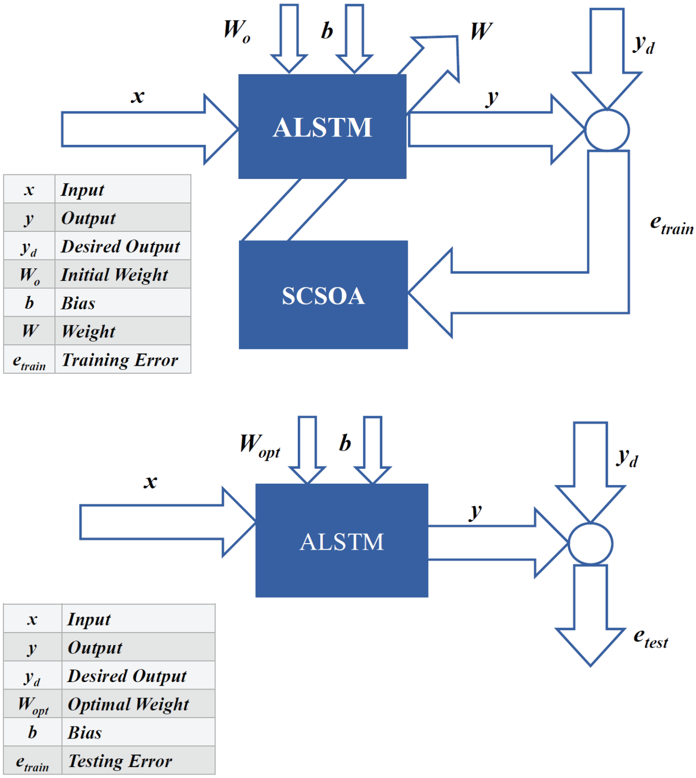


Figure 3. Training and testing of ALSTM.

6.2. Testing

Utilizing the training dataset in conjunction with the optimal weight matrices W_{opt} and *b*, a similar analysis is conducted using the *ALSTM* network to determine the optimal delivery time as the predicted output. This expected output is compared with the actual production, resulting in the e_{test} error calculation. The two outputs – specifically, the prediction of the optimal *y* and the comparison with y_d – contribute to addressing and resolving e_{train} for subsequent comparative analysis related to the continuous food delivery problem. Figure 3 right side depicts the systematic diagram for training the *ALSTM-SCSOA* model.

6.3. Amalgamation of baseline

The deviation in the predicted outcomes during testing is attributed to the extensive datasets and their variability. To address this issue, a baseline factor *bl* is introduced, calculated as $\frac{\mathrm{Max_{act}} - \mathrm{Min_{act}}}{2}$, where Max_{act} is the maximum and Min_{act} is the minimum value of the actual output. This baseline factor helps fine-tune the predicted results, aligning them more closely with the actual datasets.

7. ANALYSIS OF RESULTS AND COMPARISON

The calculation of errors in both the training and testing phases involves three specific error metrics: mean square error (*MSE*), integral absolute error (*IAE*), and normalized root mean square error (*NRMSE*), as indicated in **Table 2**. These error standards assess e_{train} and e_{test}. By utilizing this diverse set of error metrics, datasets from testing undergo additional comparative analysis, addressing challenges in product fulfilment cost problems. **Figure 4** presents a comparative analysis, showcasing the performance of the *ALSTM-SCSOA* model in terms of three error types – *MSE*, *IAE*, and *NRMSE* – through a convergence plot of e_{train} for optimality.

Table 2. Calculation of three types of errors

Sl no.	Types of error	*Formulae*
1	*MSE*	$\frac{1}{n} \times \sum_{i}^{n} (y_d - y)^2$
2	*IAE*	$\frac{1}{n} \times \sum_{i}^{n} (y_d - y)$
3	*RMSE*	$\sqrt{\frac{1}{n} \times \sum_{i}^{n} (y_d - y)^2}$
4	*NRMSE*	$\frac{RMSE}{(Max_{rmse} - Min_{rmse})}$

The initial error metric is the mean square error, denoted as e_{mse}. It is calculated using the standard formula from **Table 2**, where *i* signifies the iteration count and *n* represents the total number of iterations. Based on subsequent comparative analysis, the model is configured for *100* iterations, indicating no significant reduction in system error beyond the 100^{th} iteration. Similarly, the error metrics, including integral absolute error (e_{iae}) and normalized root mean square error (e_{nrmse}), are denoted by specific symbols. The visual representation of actual vs. predicted outcomes for these three errors is illustrated in **Figure 4**.

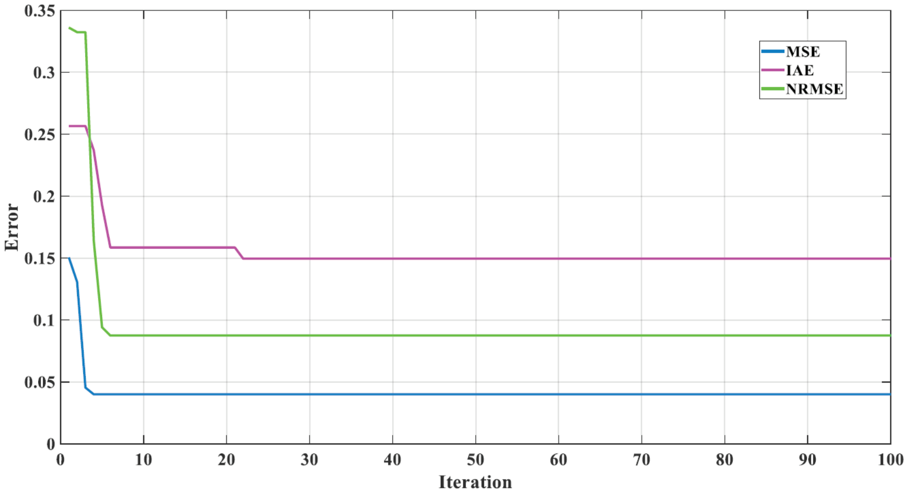
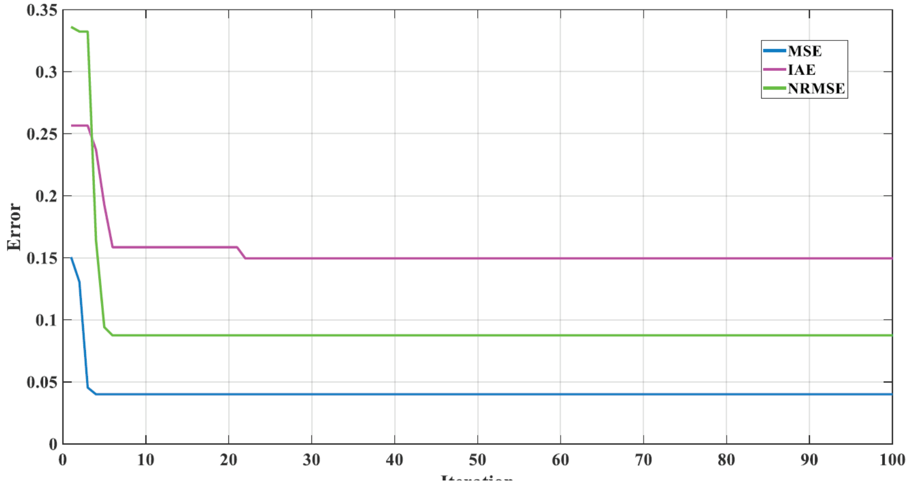


Figure 4. Convergence of error for MSE, IAE and NRMSE.

The forecasting model can predict a profit or loss in the product fulfilment cost processes before the consignor hands it over to the freight forwarder. This allows the consignor to anticipate the likelihood of order fulfilment, providing the advantage of planning and organizing orders according to their preferences. As depicted in **Figure 5**, the proposed model effectively predicts profit or loss in product fulfilment, highlighting its importance in incorporating real-time data for estimating outcomes in live service scenarios.



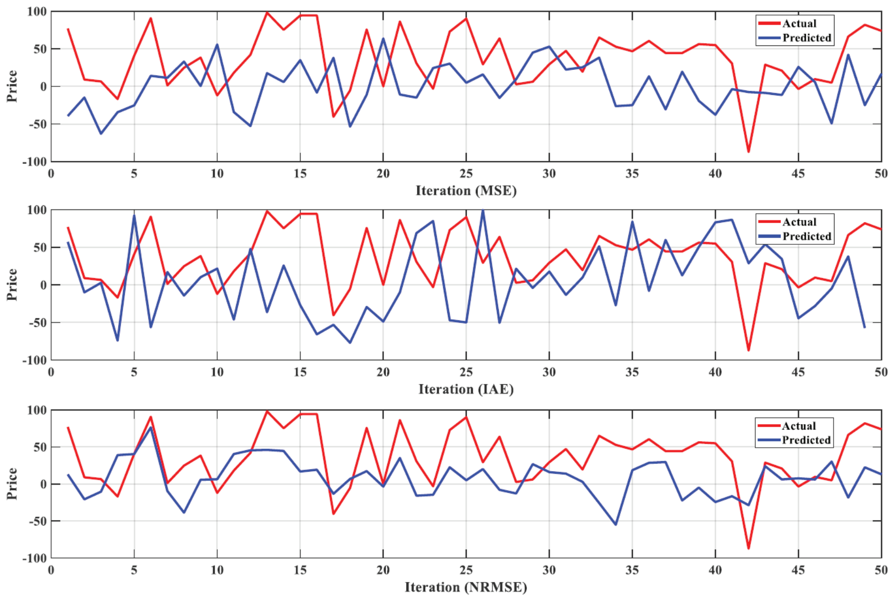


Figure 5. Actual vs prediction for MSE, IAE and NRMSE.

8. CONCLUSION

The paper addresses the challenges of predicting profit or loss for product fulfilment costs. Our innovative approach integrates a novel *ALSTM* network model with *SCSOA* for error optimization. A thorough analysis of three error metrics highlights the superiority of *NRMSE*-based error calculation within the proposed *ALSTM-SCSOA* model. However, it is crucial to acknowledge the limitations arising from the absence of diverse multi-bucket order datasets, which restricts a comprehensive evaluation of our approach to a single-bucket or one iteration per assessment across various constraints and bottlenecks. Another limitation is the singular focus of the data on a solitary objective, neglecting the consideration of multi-objectives such as time and cost. The cost may increase in specific iterations for less time, emphasizing the need for a multi-objective approach encompassing time and cost considerations. Future research endeavours should prioritize obtaining and analysing additional datasets to assess the adaptability of our method across a range of product fulfilment scenarios. Consequently, upcoming studies could explore the development of a novel *ALSTM-SCSOA* network tailored for multi-buckets and multi-objective prediction and comparison.

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Optimal Solution to the Location Problem by Determining the Number and Locations of Source Nodes Using the Solver Tool in the Military Domain

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ABSTRACT

The aim of this paper is to explore the role of modern logistics infrastructure in optimizing location problems within a military organization. The focus is on determining the optimal number and placement of source nodes (military storage facilities) and on planning the transport of homogeneous cargo units (e.g., pallets), with the ultimate goal of achieving organizational sustainability. The research analyses how to meet the demand of destination points within a military logistics network while minimizing costs and respecting the capacity limits of each source. The results demonstrate that efficient selection of source locations and distribution quantities significantly enhances the effectiveness and sustainability of logistics support.

Keywords: Information Tool; Optimal Solution; Expense Reduction; Source Nodes.

1. INTRODUCTION

This paper addresses the analysis of the facility location problem in the context of logistical support within a military organization, with the aim of optimizing the number and distribution of source nodes and the organization of transport for homogeneous cargo units (e.g., pallets). The main goal is to contribute to the sustainability of military logistics through efficient resource use and cost reduction.

Logistics within a military organization represents a functional domain that encompasses the organization, planning, and execution of material support and provisioning [1]. Despite the absence of a unified logistics organization, all components implement a single integrated logistics process [2]. The movement of forces and materials requires reliable transport infrastructure, mobility, and a traffic management system – especially in the context of operational needs [3], [4].

In today's economic environment, where time is a crucial factor, optimization of logistics processes becomes a necessity. Particular emphasis is placed on the rationalization of military material transport, given its key role both in peacetime and wartime conditions. The transport system must ensure deployment and continuous supply of forces in the field [5].

With the development of military logistics, new elements have emerged, such as integrated resource management, logistics engineering, and lifecycle planning of military equipment [6]. Logistics engineering in particular aims to ensure the design and production of military equipment that supports logistics operations throughout its entire life cycle [7]. Experiences from the U.S. military – such as the use of containers and pallets – have also been integrated into civilian logistics systems [8], [9]. Today, it is evident that transport is a fundamental element of any logistics support, as affirmed by General Hodges' statement: "*War is a test of will and logistics*" [10].

2. MATERIALS AND METHODS

By applying exact methods, it is possible to obtain an optimal solution to the location problem, which is described by a mathematical model of the transportation problem. A location problem involves determining the transport schedule for a specific transport substrate – homogeneous cargo units such as pallets, boxes or cartons from *n* sources where the substrate is located in *m* destinations where demand must be met, using the criteria of the lowest transport costs or the shortest transport time along available transport routes. For example, the transport problem can be solved using the graphical method or the simplex method (linear programming). However, if these methods require an unacceptably long computation time, heuristic algorithms such as ant colony, simulated hardening and others, can be employed instead. While these methods do not guarantee optimal solutions, they can provide acceptable and practical results within the given constraints [11]. However, as in the specific problem of optimizing the location problem of logistic support, it is necessary to apply current practical knowledge and skills on examples of three basic logistic problems, the optimization of the mathematical model of linear programming will be presented using the *MS Excel* program tool *Solver*, which is part of the standard *MS Office* software package. The knowledge and skills acquired through its application can serve as a basis for further study of models and methods for solving logistical problems using more sophisticated software tools. The vast majority of logistics problems that arise in the planning and management of logistics processes can be reduced to optimization problems. It is through the application of transport models that the functioning of the transport network as a whole can be optimized in this sense [12]. To obtain an optimal solution to the location problem, it is necessary to connect source hubs (military storage complexes) with destination hubs (barracks) via transport routes so that the demand is fully met while minimizing transportation costs for the military organization [11],[13],[14]. This type of problem typically involves multiple feasible solutions, from which the one that yields the best outcome, according to one or more predefined criteria, must be selected. Naturally, the set restrictions must be respected [13].

2.1. Location problem

The location problem is the problem of determining the number and locations of source nodes and the schedule of transport of a certain substrate (homogeneous cargo units such as pallets, cartons, boxes...) from *n* sources, where the substrate is located, to *m* destinations, whose demand for the substrate should be met using available transport routes according to the criterion of the lowest costs. In addition to transport costs, the costs here also refer to infrastructure costs (source nodes: MSC) from which transport flows are generated. Location problems differ from transport problems in that the number and locations of source nodes are not known, but need to be determined, and infrastructure costs are also considered [7], [11]. In order to satisfy the demand of the destination, the number and locations of the source nodes (military storage complex – MSC) represent the choice of locations in the transport network from which goods can be transported, considering that each location (node in the transport network) has its own demand as a destination. Furthermore, a source can simultaneously fulfil the demand of both its specific location and other locations, to the extent permitted by its capacity [7]. The transport schedule determines the source (i.e., the locations of the MSCs), the amount of substrate to be transported, the destination, and the transport route. In the basic location problem, the following parameters are given: the capacities and costs of MSCs, the demand at each destination, the available transport routes (i.e., the connections between source and destination), and the unit transport costs (lengths of transport routes). The basic form of the location problem can easily be further complicated by introducing additional factors, such as source capacity, the capacity of transport means, the throughput of transport routes and/or time windows at the source or destination [11]. By approximating the system with a linear programming model, the location problem can be reduced to an optimization problem. In the location model, constant (transport schedule) and binary (number and locations of source nodes) variables are used. In this sense, certain elements of the location problem are represented by the corresponding elements of the model, as follows [7]:

- The objective function representing the total costs of supplying the destination to be minimized (infrastructure costs and transport costs).
- The number and locations of source nodes and the transport schedule are represented by decision variables. In other words, these are the amounts of substrate that are transported from a specific source to a specific destination along a transport route that connects a specific source with a specific destination.
- Restrictions represent conditions that must be met: demand must be met, MSC capacities cannot be exceeded, transport can only take place on available transport routes.
- The input data include given dimensions of the transport network: possible locations and capacities of sources, demand of destinations, infrastructure costs and unit transport costs.

The location model defines both the number and location of sources, as well as the distribution of goods flows within the transport network. At the same time, it is essential to consider how to determine the number and locations of sources and which destinations they should supply, as well as how to quantitatively determine the distribution of transport and which transport routes should be selected. The answers to these questions determine the infrastructural and substructural solution of the transport network in a given case. In order to optimize the overall functioning of the transport network, it is necessary to apply the mentioned location models [7], [11].

3. RESULTS

3.1. Location Problem – Solution Methods for the Given Optimization Problem

As an example of solving the location problem in the military organization, we will take the initial elements: from eight military storage complexes MSC (**Table 1**), 14 barracks should be supplied with material and technical means (material and technical means – MTS). Other input data, such as mutual distances between MSCs and barracks expressed in tons per kilometre (ton kilometre – tkm), MSC demand (expressed in tons) and barracks capacity (expressed in tons), are given in **Table 1**, which shows the input data used for the location problem with a binary location decision variable added.

Assuming that one wants to limit the number of active MSCs from which certain goods are delivered to the barracks, it is necessary to modify the solvability with the given expressions (1), (2) and (3):

$$K_{max} = \sum_{i=1}^{n} l_i \cdot k_i \tag{1}$$

whereby:

$$\sum_{i=1}^{n} l_i \leq a \tag{2}$$

$$P = \sum_{j=1}^{m} p_j \tag{3}$$

where:

l_i = binary location decision variable (1,0) where the values are interpreted:

1 = MSC at location *i* is active; *0* = MSC at location *i* is not active

n = total number of MSC locations

a = the default maximum number of active MSCs (*a* is a given number less than *n*)

k_i = MSC capacity at location *i*

K_{max} = the total number of barracks to be supplied

P_j = barracks demand *j*

P = total demand of all barracks

The problem is solvable if criterion (4) is met:

$$P \leq K_{max} \tag{4}$$

The mathematical model described by expression (5) also needs to be modified:

$$minF = \sum_{i=1}^{n} \sum_{j=1}^{m} d_{ij} \quad \text{(objective function)} \tag{5}$$

With the restrictions (conditions) given by the mathematical expressions (6), (7), (15):

$$\sum_{i=1}^{n} q_{ij} = p_j \quad \text{for each } j = 1, \dots, m \text{ (demand met in every barrack)} \tag{6}$$

Table 1. Input data of the location problem.

MSC / Barrack	Distances (km)													
	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V. Peratovica	14. Slunj
1. Velika Buna	424	249	313	27	38	188	295	238	225	241	521	255	151	120
2. Sv. Rok	192	26	74	229	273	397	63	447	464	32	289	464	360	103
3. Knin	86	88	10	302	346	470	95	520	537	105	192	537	433	166
4. Slunj	289	78	165	107	94	274	160	325	341	94	386	341	237	10
5. Daruvar	535	360	424	129	104	68	406	96	168	325	632	168	32	231
6. Trbounje	77	110	26	363	407	531	93	581	598	127	205	598	494	188
7. Varaždin Breg	489	315	378	83	131	230	361	280	297	280	586	297	113	185
8. Križevci	475	300	364	68	117	216	346	170	283	266	572	283	80	171
Requests (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17

Table 2. Optimal solution of the location problem of the transport network.

MSC / Barrack	Transport schedule (t)																
	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V. Peratovica	14. Slunj	Active MSC	Delivery from MSC (t)	Location capacity
1. Velika Buna	0	0	0	**40**	**12**	0	0	0	0	0	0	0	0	0	1	52	300
2. Sv. Rok	0	**10**	0	0	0	0	**8**	0	0	**12**	0	0	0	0	1	30	300
3. Knin	**20**	0	**13**	0	0	0	0	0	0	0	**7**	0	0	0	1	40	200
4. Slunj	0	0	0	0	0	0	0	0	0	0	0	0	0	**17**	1	17	100
5. Daruvar	0	0	0	0	0	**14**	0	**50**	**18**	0	0	**12**	**5**	0	1	99	100
6. Trbounje	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Varaždin Breg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Križevci	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Delivery in barrack (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17	5		
Total tkm: 17.000											**Maksimum number active MSC (Imax) =**				**5**	**(arbitrarily assigned)**	

$$\sum_{j=1}^{m} q_{ij} \leq k_i \cdot l_i \text{ for each } i = 1, \dots, n \text{ (supply from MSC limited by its capacity)} \quad (7)$$

$$\sum_{i=1}^{n} l_i \leq l_{max}, \; l_i \in \{0,1\} \quad (8)$$

Where:

d_{ij} = distance from MSC *i* to the barracks *j*

q_{ij} = decision variable (quantity of supplied goods) barracks *j* from MSC at location *i*

l_i = binary location decision variable, where the values are interpreted as follows:

I = MSC at location *i* is active; *0* = MSC at location *i* is not active

m = the total number of barracks to be supplied

n = total number of MSC locations

k_i = monthly MSC capacity at location *i*

p_j = monthly demand in the barracks *j*

3.2. The optimal solution to the location problem

The optimal solution to the location problem is obtained by optimizing the mathematical problem. This problem includes elements for determining the number and location of source nodes, as well as the connections between source nodes (MSCs) and destination nodes (barracks) via transport routes. A key factor for achieving the optimal solution to the given location problem is determining the quantity of goods to be transported from each source to each destination in a way that fully meets the destination's demand, minimizes costs and does not exceed the source's capacity [7]. The optimal transport schedule, with the default maximum number of active MSC = 14, obtained by optimizing the mathematical model with the *Solver* software tool is shown in **Table 2**.

The optimal number and locations of MSCs and the monthly transport schedule that meets the set constraints with the least cost of supplying the barracks was obtained by optimizing the mathematical model using the MS Excel program tool *Solver*, as follows in **Figure 1**.

Figure 1. Graphic representation of the optimal solution to the location problem.

The MSC "Borik" in Velika Buna supplies the barracks in Zagreb (40 t) and Petrinja (12 t), transporting a total of 52 tons of logistics packages, which is less than its full capacity. The capacity is not fully utilized.

The MSC "Sveti Rok" in Sveti Rok supplies the barracks in Udbina (10 t), Zemunik (8 t) and Gospić (12 t), transporting a total of 30 tons, which is less than its capacity. The capacity is not fully utilized.

The MSC "Golubić" in Knin supplies the barracks in Split (20 t), Knin (13 t) and Ploče (7 t), which makes a total of 40 tons of logistics packages out of a full capacity of 300 tons. The capacity is not fully utilized.

The MSC "Debela Glava" in Slunj supplies the barracks in Slunj with 17 tons of logistics packages. The capacity is not fully utilized.

The MSC "Hrvatski Ždral" in Doljani (Daruvar) supplies the barracks in Požega (14 t), Našice (50 t), Đakovo (18 t), the training ground in Đakovo (12 t) and the training ground in Velika Peratovica (5 t). The total amount of transported logistics packages is 99 tons.

Military storage complexes supply the barracks indicated by the arrows on the map in **Figure 1**.

The total minimum monthly cost of supplying the barracks at the level of the entire transport network is €116,800, shown in **Table 4.**

Table 3. Optimal solution of the transport network

	Distance (km)														
MSC / Barrack	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V. Peratovica	14. Slunj	Capacity of MSC
1. Velika Buna	11	7	8	2	2	6	8	7	8	6	17	7	6	5	1
2. Sv. Rok	6	2	5	6	8	11	5	12	13	2	8	13	11	5	1
3. Knin	5	5	2	8	9	12	5	16	15	5	6	15	12	6	1
4. Slunj	4	5	6	5	5	8	6	8	9	5	11	10	7	2	1
5. Daruvar	8	11	13	5	5	5	11	5	6	8	19	6	2	7	1
6. Trbounje	5	5	2	11	11	17	5	18	18	5	6	18	15	6	0
7. Varaždin Breg	15	8	11	5	6	6	9	8	6	8	18	8	6	6	0
8. Križevci	15	8	11	5	5	6	9	6	6	8	18	8	5	6	0
Demand (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17	

Table 4. Optimal solution of the total monthly cost of the transport network

	Transport schedule (t)																
MSC / Barrack	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V. Peratovica	14. Slunj	Active MSC	Delivery from MSC (t)	Location capacity
1. Velika Buna	0	0	0	**40**	**12**	0	0	0	0	0	0	0	0	0	1	52	300
2. Sv. Rok	0	**10**	0	0	0	0	**8**	0	0	**12**	0	0	0	0	1	30	300
3. Knin	**20**	0	**0**	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0
4. Slunj	0	0	0	0	0	0	0	0	0	0	0	0	0	**17**	1	37	100
5. Daruvar	0	0	0	0	0	**14**	0	**50**	**18**	0	0	**12**	**5**	0	1	99	100
6. Trbounje	0	0	**13**	0	0	0	0	0	0	0	**7**	0	0	0	1	20	200
7. Varaždin Breg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Križevci	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Delivery in barrack (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17	5		
Total monthly transportation cost: 116.800 €											**Maksimum number active MSC (Imax) =**				**5**	**(arbitrarily assigned)**	

4. DISCUSSION

Since transport costs can account for up to 50% of total logistics costs, improving transport efficiency has a significant impact on increasing the overall performance of the logistics network. Given the importance of transport within logistics, it is consistently treated as a critical factor. As a result, numerous mathematical methods have been developed that focus specifically on transport and location problems. Although even modern mathematical methods still do not allow the calculation of optimal solutions to extremely complex logistics problems, which is their drawback, they are still used and improved on a daily basis. In addition, problems arise even with their application in solving transport and location problems because they require adequate professional knowledge and skills in modern technologies and scientific research methodologies, which means that they can only be used successfully, efficiently and rationally by professional competent experts. In particular, mathematical methods can be implemented in programming tools and thus enable experimentation with planned ideas, in a relatively more profitable way and without unwanted consequences. It is a quick and simple way of reaching the expected results, which can later be easily checked and evaluated, and based on this, conclusions can be made about whether something is effective and profitable for application in the real world. Undoubtedly, in the near future, artificial intelligence will play a major role in the planning of military operations, as well as in solving such transport and location problems, reducing costs and increasing overall efficiency. It will certainly reshape the overall planning and management of both military and civilian traffic.

5. CONCLUSION

Mathematical methods and software tools based on them are used to solve optimization problems, primarily to minimize costs. Any organization that wants to improve its efficiency and consequently expects to improve some crucial issues related to logistics transport processes and determining the number and location of source nodes, will primarily focus on problem optimization. Consequently, positive effects can also be observed through a better design of the transport network and an improved schedule for the transport of logistics packages, which does not mean that the working abilities of network users will decrease. Quite the opposite, their degree of utilization increases with a significant reduction in "empty kilometres". In conclusion, the results obtained in this study offer optimal solutions aimed at improving service quality and reducing transport costs, an ongoing priority for military organizations, particularly with regard to cost-efficiency. The findings confirm that transport plays a very important role in logistics processes. Motivated precisely by this and the aforementioned opportunities offered by mathematical methods, this study explored the cost-effectiveness of optimizing the location problem of logistic support. The results are more than satisfactory. Based on the collected and analysed data, the obtained results outperform the existing state of the transport network in all segments. This was ultimately the goal of the study: to optimize the location problem of logistic support in a real-world scenario using mathematical methods and the *SOLVER* software tool. Professional personnel within the hierarchical structure of the military organization are responsible for determining the final configuration of the transport network for logistical support when optimizing the location problem. In the near future, artificial intelligence will play a major role in the planning of military operations, as well as in solving such transport and location problems, reducing costs and increasing overall efficiency. It will undoubtedly reshape the overall planning and management of both military and civilian transport.

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Is City Management Smart Management?

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A B S T R A C T

The concept of a smart city represents an urban environment that provides its residents with a high-quality and comfortable life. Cities that invest in improving and maintaining their competitive position can be considered smart, with the key to success lying in the cooperation between authorities and citizens. Managing smart cities is a complex and intricate process; therefore, it is crucial to implement measures and maturity assessments to further enhance cities and maintain competitiveness. Continuous evaluation and analysis of indicators demonstrate how sustainable and smart a city is. The research focuses on evaluating the maturity of city management in Northern Croatia by determining the maturity level of cities. The methodology for assessing city management maturity includes 19 indicators covering various areas. Each indicator is assigned a level from 1 to 5, and the results are analysed using the SMOP equation (Surface Measure of Overall Performance). Six cities in Northern Croatia were selected for the study: Krapina, Varaždin, Čakovec, Koprivnica, Križevci, and Đurđevac. Indicators analysed include areas such as the economy, education, energy, environment and climate change, finance, governance, health, housing, social conditions, recreation, security, solid waste, sports and culture, telecommunications, transport, urban/local agriculture and food security, urban planning, wastewater, and water. Maturity assessment is conducted for each city and indicator, and results are compared using charts to demonstrate city sustainability. The aim is to compare the maturity levels of the selected cities and thereby assess which dimensions cities need to improve their management in order to enhance economic, ecological, and social dimensions to achieve sustainability and competitiveness.

Keywords: Competitiveness; Cooperation; Quality of Life; Smart Cities; Sustainability; Technology.

1. INTRODUCTION

Smart cities represent a modern approach to managing urban environments, using advanced information and communication technologies to integrate different city systems [1]. The main goal of these technologies is to optimize resources and improve the quality of life of citizens [2]. This concept covers a wide range of areas, including energy efficiency, mobility, waste management, safety, health, education and citizen participation. Each of these aspects requires a high degree of coordination and strategic planning, which poses new challenges for the city administration.

The maturity of smart city management refers to the ability of city administrations to effectively implement, manage and maintain complex technologies that enable the smart functioning of all urban systems [3]. Measuring the maturity of management is essential for assessing the current state of the smart city and identifying areas that require further development. In this paper, the maturity of smart city management is assessed using the ISO 37120:2018 standard, an international standard that defines the indicators of sustainability and quality of life in cities.

Croatia, as a developing country, faces numerous challenges in the implementation of smart solutions, especially at the regional level. It is important to understand how different cities within the country are progressing differently in this area. The example of Northern Croatia, which includes the cities of Krapina, Varaždin, Čakovec, Koprivica, Križevci and Đurđevac, provides an ideal context for this analysis, given the differences in size, resources and technological infrastructure of these cities.

Assessing the level of maturity of city governance plays a key role, where it is important that cities continuously work to improve their economic, environmental and social dimensions. By recognizing the significance of this rating, cities can achieve greater sustainability and competitiveness compared to other cities.

2. SMART CITIES

In a world of rapid urbanization, the concept of smart cities is emerging as a more advanced approach to urban life by providing sustainable, efficient, and technologically advanced solutions. A city is referred to as "smart" when traditional institutions and services are improved through the use of digital technologies that ultimately benefit residents.

State-of-the-art technologies enable efficient management of basic resources (e.g. water, energy), thus ensuring the mobility and safety of city residents. By reducing environmental pollution and promoting social equality, urban spaces are created that are not only highly technologically advanced, but also socially responsible. Therefore, the idea behind smart cities is to improve the quality of life in the living and working environment through innovative solutions that bring qualitative changes to the everyday lives of residents, businesses and visitors.

2.1. IMD Smart City Index

Every year, IMD develops the Smart Cities Index, which evaluates residents' attitudes towards technological capabilities and structures in their cities. The 2024 edition of SCI examines 142 cities around the world, gathering insights from 120 residents in each area. The overall score for each city was derived from the perception collected over the last three years, using a 3:2:1 weighting system for the years 2024, 2023 and 2021 [4]. The index looks for two components of public perception: structure, which refers to the existing infrastructure in cities, and the technology pillar, which outlines the technological advantages and services available to residents. Five key domains are assessed at each level: safety and health, mobility, activities, opportunities and governance. Cities are classified into four categories based on the associated HDI (Global Data Lab) score.

City	Smart City Rank 2024	Smart City Rating 2024	Structure 2024	Technology 2024	Smart City Rank 2023	Change
Zurich	1	AAA	AAA	AA	1	—
Oslo	2	AA	AA	A	2	—
Canberra	3	AA	AAA	A	3	—
Geneva	4	AAA	AAA	AA	9	+5▲
Singapore	5	A	A	A	7	+2▲
Copenhagen	6	AA	AA	A	4	-2▼
Lausanne	7	AA	AA	A	5	-2▼
London	8	A	BBB	AA	6	-2▼
Helsinki	9	AA	AA	A	8	-1▼
Abu Dhabi	10	BB	BB	BB	13	+3▲

Figure 1. Smart City Index 2024. [4]

Cities within each HDI group are given a 'rating scale' ranging from AAA to D, which is determined by the score of the perception of a particular city in relation to the results of all other cities in the same group. The rating scale for group 1 (highest HDI quartile) is AAA–AA–A–BBB–BB; for group 2 (second HDI quartile), the scale is A–BBB–BB–B–CCC; for group 3 (third HDI quartile), the scale is BB–B–CCC–CC–C; and finally, group 4 (lowest HDI quartile) has a rating scale of CCC–CC–C–D [5]. The ranking is then displayed in two different formats: the overall position (1 to 142) and the score for each degree and the overall score.

2.2. Smart cities in Croatia

As technology advances, Croatian cities are increasingly embracing the idea of smart cities to improve the lives of their citizens and become more accessible, efficient, and sustainable. Croatian smart cities are adapting urban planning and services through innovation and digitalization.

The leading Croatian examples of smart cities are Split, Zagreb, Rijeka and Osijek [6]. These cities have adopted initiatives such as ride-sharing services, smart parking apps, and smart mobility, which includes electric bicycles and buses. Some cities have implemented smart public lighting that uses sensors to change the intensity of light based on environmental conditions, thereby reducing energy consumption and promoting sustainability.

However, according to the latest IMD Smart City Index for 2024, the city of Zagreb ranks 102nd out of a total of 142 evaluated cities [4]. Comparing Zagreb with many other cities around the world, this positioning shows that, despite its great potential, there is still room for progress in the development of smart city solutions and infrastructure.

2.3. Smart cities – Success stories in Zürich

The latest IMD Smart City Index for 2024 lists Zurich as the leading city in terms of smart cities [4]. This high score shows that Zurich is a leader in the implementation of innovative solutions and technologies that significantly affect the quality of life of citizens, increase the efficiency of city services and contribute to the sustainability of urban environments.

The strategy of the Zurich Smart City promises to unite politics, economy, science, culture and society for the benefit of all, with the intention to provide equal opportunities and a superior quality of life for all, as well as a networking strategy for the benefit of all. The smart city of Zurich involves the entire population in its efforts. This includes all residents, employees, or visitors to the city of Zurich.

The City of Zurich uses digital technology to improve the quality of the environment and achieve the society's 2000-watt goals, with a focus on resource conservation and sustainable development. It also promises innovation and provides favourable conditions for entrepreneurs through a modern and reliable digital infrastructure [7].

3. THE MATURITY LEVEL ASSESSMENT OF SMART CITY MANAGEMENT

A city is a complex system that requires careful and comprehensive management, with a continuous analysis of the current situation. Assessing the level of maturity of city governance plays a key role in ensuring that cities improve their economic, environmental and social aspects. By recognising the importance of the maturity assessment, cities can achieve greater sustainability and competitiveness compared to others. By using the management maturity assessment, cities gain insight into key indicators that allow them to have a detailed overview of all relevant areas.

Through the assessment of the maturity of smart cities, cities can also analyse their current state and set goals in terms of defining the desired state, as well as the desired values of individual indicators on the basis of which they will be able to define their management models [8].

Before starting the maturity assessment, it is necessary to identify needs, collect relevant data, check their correctness and completeness, and assess the maturity of individual areas and the overall maturity of the city. Once the overall maturity is determined, an analysis is carried out and recommendations for further improvement are made through the assessment of the maturity of smart cities, cities can also analyse their current state and set goals in terms of defining the desired state, as well as the desired values of individual indicators on the basis of which they will be able to define their management models.

3.1. Indicators for assessing the maturity of smart city management

The ISO international organization has issued a set of standards ISO 37100 – Sustainable Cities and Communities, which provide cities with a framework for achieving the Sustainable Development Goals [9]. This study used 19 indicators defined by the ISO 37120:2018 standard, a standard that defines a set of indicators to measure the efficiency of city services and quality of life. The standard covers the following categories of indicators: economy, education, energy, environment and climate change, finance, governance, health, housing, population and social conditions, recreation, safety, solid waste, sport and culture, telecommunications, transport, urban/local agriculture and food safety, urban planning, wastewater and water supply. Each of these indicators consists of supporting elements and represents key areas of the city that require careful management.

The indicator for the economy area consists of the following elements [10]:

- Unemployment
- Estimated value of commercial and industrial real estate as a percentage of the total estimated value of all real estate
- Percentage of persons in permanent employment
- Youth unemployment rate
- Number of enterprises per 100,000 inhabitants
- Number of new patents per 100,000 inhabitants per year
- Annual number of visits (overnight stays) per 100,000 inhabitants
- Commercial air connectivity (number of non-stop commercial air destinations)
- Percentage of service contracts for city services that contain an open data policy
- Survival rate of new businesses per 100,000 inhabitants
- Percentage of the workforce employed in occupations in the information and communication technology (ICT) sector

- Percentage of the workforce employed in occupations in the education and R&D sectors.

The indicator for the field of education consists of the following elements [10]:

- Percentage of school-age female population enrolled in school
- Percentage of pupils completing primary education: survival rate
- Percentage of students completing secondary education: survival rate
- Student-teacher ratio in primary education
- Percentage of school-age population enrolled in school
- Number of higher education diplomas per 100,000 inhabitants
- Percentage of urban population with professional knowledge of more than one language
- Number of available computers, laptops, tablets or other digital learning devices per 100,000 inhabitants.
- Number of science, technology, engineering and mathematics (STEM) higher education degrees per 100,000 inhabitants.

The indicator for the energy domain consists of the following elements [10]:

- Total final energy consumption per capita (GJ/year)
- Percentage of total final use derived from renewable energy sources
- Percentage of urban population with authorized electricity service (residential)
- Number of connections for gas distribution services per 100,000 inhabitants (residential)
- Final energy consumption of public buildings per year (GJ/m)
- Electricity consumption of public street lighting per kilometre of illuminated street (kWh/year)
- Average annual hours of electrical service interruption per household
- Percentage of electricity and heat produced by wastewater treatment, solid waste and other liquid waste and other waste heat resources, as a share in the total energy mix of the city for a given year
- Electricity and heat (GJ) produced from wastewater treatment per capita per year
- Electricity and heat (GJ) produced from solid waste
- Electricity and heat (GJ) produced from solid waste or other liquid waste per capita per year
- Percentage of urban electricity produced using decentralised electricity generation systems

- Storage capacity of the city energy network per total city energy consumption
- The percentage of street lighting controlled by the light effect control system
- Percentage of street lighting that has been renovated and newly installed
- Percentage of public buildings in need of renovation
- Number of electric vehicle charging stations per registered electric vehicle
- Percentage of buildings in the city with smart energy meters.

The Environment and Climate Change Indicator consist of the following elements [10]:

- Concentration of fine particles (PM2.5)
- Particulate matter concentration (PM10)
- Greenhouse gas emissions measured in tonnes per capita
- Percentage of areas designated for nature conservation
- Concentration of NO_2 (nitrogen dioxide)
- Concentration of SO_2 (sulphur dioxide)
- Concentration of O_3 (ozone)
- Noise pollution
- Percentage change in the number of native species
- Percentage of buildings built or renovated in the last 5 years in accordance with green building principles
- Number of remote real-time air quality monitoring stations per square kilometre (km^2)
- Percentage of public buildings equipped to monitor indoor air quality.

The indicator for the area of finance consists of the following elements [10]:

- Debt coverage ratio (debt servicing costs as a percentage of the city's own income)
- Capital expenditure as a percentage of total expenditure
- Income from own sources as a percentage of total revenues
- Tax collected as a percentage of the calculated tax
- Annual amount of revenue collected from the sharing economy as a percentage of income from own sources
- Percentage of payments to the city that are paid electronically based on electronic invoices)
- Greenhouse gas emissions measured in tonnes per capita.

The indicator for the control area consists of the following elements [10]:

- Women as a percentage of the total number of elected to city services
- Number of convictions for corruption and/or bribery by city officials per 100,000 inhabitants
- Number of registered voters as a percentage of the population of voting age
- Voter participation in the last municipal elections (in percentage of registered voters)
- Annual number of online visits to the municipal open data portal per 100,000 inhabitants
- Percentage of city services available and requestable online
- Average response time to inquiries through the city's system for non-urgent inquiries (days)
- Average downtime of the city's IT infrastructure.

The health indicator consists of the following elements [10]:

- Average lifespan
- Number of hospital beds per 100,000 inhabitants
- Number of doctors per 100,000 inhabitants
- Mortality rate under five years per 1000 live births
- Number of medical and midwifery staff per 100,000 inhabitants
- Suicide rate per 100,000 inhabitants
- Percentage of urban population with an online unique health record available to healthcare providers
- Annual number of remote medical examinations per 100,000 inhabitants
- Percentage of urban population with access to real-time public warning systems for air and water quality advice.

The indicator for the residential area consists of the following elements [10]:

- The percentage of the population living in inadequate housing
- Percentage of the population living in affordable (cheaper) housing
- Number of homeless people per 100,000 inhabitants
- Percentage of households that exist without registered legal ownership
- Percentage of households with smart energy meters
- Percentage of households with smart water meters.

The indicator for the area of population and social conditions consists of the following elements [10]:

- Percentage of population living below the international poverty line
- Percentage of urban population living below the national poverty line
- The Gini coefficient of inequality
- Percentage of public buildings accessible to people with disabilities
- Percentage of the municipal budget allocated for the provision of aids, devices and assistive technologies to citizens with special needs
- Percentage of marked pedestrian crossings equipped with accessible pedestrian signage
- Percentage of the municipal budget allocated to provide programmes designed to bridge digital change.

The indicator for the recreation area consists of the following elements [10]:

- Square meters of public indoor recreation space per capita
- Square meters of public outdoor recreation space per capita
- Percentage of public recreation services that can be booked online.

The indicator for the safety area consists of the following elements [10]:

- Number of firefighters per 100,000 inhabitants
- Number of fires killed per 100,000 inhabitants
- Number of deaths caused by natural hazards per 100,000 inhabitants
- Number of police officers per 100,000 inhabitants
- Number of homicides per 100,000 inhabitants
- Number of volunteer and part-time firefighters per 100,000 inhabitants
- Response time for emergency services from the first call
- Crimes against property per 100,000 inhabitants
- Number of deaths caused by industrial accidents per 100,000 inhabitants
- Number of violent crimes against women per 100,000 inhabitants
- Percentage of the city area covered by digital surveillance cameras.

The indicator for the solid waste area consists of the following elements [10]:

- Percentage of urban population with regular solid waste collection (residential)
- Total collected municipal solid waste per capita
- Percentage of urban solid waste that is recycled
- The percentage of urban solid waste that is disposed of in a sanitary landfill

- Percentage of urban solid waste treated in waste-to-energy plants
- Percentage of urban solid waste that is biologically treated and used as compost or biogas
- The percentage of urban solid waste that is disposed of in an open landfill
- Percentage of urban solid waste that is disposed of in other ways
- Generation of hazardous waste per capita
- Percentage of urban hazardous waste that is recycled
- Percentage of waste disposal centres (containers) equipped with a telemeter
- Percentage of the urban population that has door-to-door garbage collection with individual monitoring of household waste
- Percentage of the total amount of waste in the city used for energy production
- Percentage of the total amount of plastic waste recycled in the city
- Percentage of public trash cans that are public trash cans with sensors
- Percentage of urban electrical and electronic waste that is recycled.

The indicator for the field of sport and culture consists of the following elements [10]:

- Number of cultural institutions and sports facilities per 100,000 inhabitants
- Percentage of the municipal budget allocated to cultural and sports facilities
- Annual number of cultural events per 100,000 inhabitants
- Number of online reservations of cultural facilities per 100,000 inhabitants
- Percentage of urban cultural records that have been digitized
- Number of book titles and e-books of public libraries per 100,000 inhabitants
- Percentage of the urban population who are active users of public libraries.

The indicator for the field of telecommunications consists of the following elements [10]:

- Number of internet connections per 100,000 inhabitants
- Number of mobile connections per 100,000 inhabitants
- Percentage of urban population with access to sufficiently fast broadband internet
- Percentage of metropolitan area under white zone/dead centre/not covered by telecom network
- Percentage of the metropolitan area covered by the municipal internet connection.

The indicator for the transport area consists of the following elements [10]:

- Kilometres of public transport per 100,000 inhabitants
- Annual number of trips by public transport per capita
- Percentage of passengers using a mode of travel other than a personal vehicle
- Kilometres of cycle paths per 100,000 inhabitants
- Transport deaths per 100,000 inhabitants
- Percentage of the population living within 0.5 km of public transport that runs at least every 20 minutes during peak periods
- Average commuting time
- Percentage of city streets and roads covered by online traffic alerts and real-time information
- Number of users of sharing economy transport per 100,000 inhabitants
- Percentage of vehicles registered in the city that are low-emission vehicles
- Number of bicycles available through municipal bike-sharing services per 100,000 inhabitants
- Percentage of public transport lines equipped with a publicly available real-time system
- Percentage of urban public transport services covered by the single payment system
- Percentage of public parking spaces equipped with e-payment systems
- Percentage of public parking spaces equipped with a real-time availability system
- Percentage of traffic lights that are intelligent/smart
- City area mapped with real-time interactive street maps as a percentage of the total city area
- Percentage of vehicles registered in the city that are autonomous vehicles
- Percentage of public transport routes with municipal secured and/or managed internet connectivity for commuters
- Percentage of roads that are compliant with autonomous driving systems
- Percentage of the city's bus fleet that is power-driven.

The indicator for urban/local agriculture and food security consists of the following elements [10]:

- Total urban agricultural area per 100,000 inhabitants
- The amount of food produced locally as a percentage of the total food supplied in the city
- Percentage of undernourished urban population

- Percentage of the urban population with overweight or obesity – body mass index (BMI)
- Annual percentage of the municipal budget spent on urban agriculture initiatives
- Annual total municipal food waste collected sent to a composting processing plant per capita
- Percentage of urban land area covered by the online food supplier mapping system.

The indicator for the area of urban planning consists of the following elements:

- Green area (ha) per 100,000 inhabitants
- Area of informal settlements as a percentage of city area
- Ratio of jobs to places of residence
- Close to basic services
- Annual number of citizens involved in the planning process per 100,000 inhabitants
- Percentage of building permits submitted via the electronic submission system
- Average time for issuing a building permit (days)
- Percentage of urban population living in medium to high population density.

The indicator for the wastewater area consists of the following elements [10]:

- Percentage of the urban population served by wastewater disposal
- Percentage of urban wastewater that is treated centrally
- Percentage of population with access to improved sanitation
- Wastewater treatment compliance rate
- Percentage of treated wastewater that is reused
- Percentage of biosolids reused (dry matter weight)
- Energy obtained from wastewater as a percentage of the city's total energy consumption
- Percentage of the total amount of wastewater in the city that is used for energy production
- Percentage of wastewater pipeline network monitored by a sensor system to monitor real-time data.

The indicator for the water area consists of the following elements [10]:

- Percentage of urban population with drinking water supply service
- Percentage of urban population with sustainable access to an improved water source
- Total household water consumption per capita (litres/day)

- Drinking water quality compliance rate
- Total water consumption per capita
- Average annual hours of water supply interruption per household
- Percentage of water loss (not counting water)
- Percentage of drinking water monitored by a real-time water quality monitoring station
- Number of real-time water quality monitoring stations per 100,000 inhabitants
- Percentage of the city's water supply network monitored by a smart water supply system
- Percentage of buildings in the city with smart water meters.

3.2. Assessment of the maturity of the indicator

When assessing the maturity of an indicator, it is necessary to define a maturity scale, which makes it possible to assess the maturity of the indicator. A table for assessing the maturity of indicators is presented below.

Table 1. Table for the assessment of indicator maturity. [8]

Level	Explanation
Level 1	The city recognizes the importance of measuring indicators but currently does not have a developed management plan or a responsible monitoring service. It is in the planning phase of the basic information system for managing indicators in the future.
Level 2	The city recognizes the importance of indicators and has already measured some of them but does not have a plan for further management. It plans to start activities for further measurement and management of indicators and is looking for innovative IT solutions that will facilitate management and decision-making.
Level 3	The city recognizes the importance of indicators, and the desired values are measured and defined. Although there is a plan for further management of indicators, activities have not started yet. All collected data and plans are available to citizens through information systems.
Level 4	The city recognizes the importance of indicators and regularly conducts measurements to compare with the previous situation and set new goals. An indicator management plan has been developed and is continuously implemented, and all data are integrated and available to citizens through information systems.
Level 5	The city continuously measures the indicators according to the established plan, and the collected results are systematically analysed and used to make informed decisions. This approach allows the city to effectively monitor and adapt strategies, ensuring better resource management and achieving the set goals.

3.3. Methodology

The maturity assessment process begins with the assessment of each indicator, whereby the level of management for each of them is determined. The levels are assigned based on the table described above. Once all indicators have been assigned the appropriate levels, the Surface Measure of Overall Performance (SMOP) is calculated using the equation for the area (OFP). This equation involves multiplying the indicators according to the following formula: SMOP = $((P_1P_2) + (P_2P_3) + (P_3P_4) + (P_4P_5) + (P_5P_6) + \ldots + (P_nP_1)) \times \sin(360/n)/2$, where the values P_1 to P_n represent the maturity levels of individual indicators, and *n* denotes the total number of indicators.

After calculating the SMOP, $SMOP_{max}$ is determined by assuming that all indicators are at the highest level (level 5). Finally, the overall maturity level is obtained using the formula: Total level = $SMOP/SMOP_{max}$. Based on the resulting overall maturity level, the corresponding maturity category of the observed city is identified. The levels range from 1 to 5, with level 1 ranging from 0.00 to 0.32; level 2 from 0.33 to 0.49; level 3 from 0.5 to 0.66; level 4 from 0.67 to 0.82; and level 5 from 0.83 to 1.00, which is shown in the table below.

Table 2. Maturity level of the city. [8]

Level	Value
Level 1	0-0.32
Level 2	0.33-0.49
Level 3	0.50-0.66
Level 4	0.67-0.82
Level 5	0.83-100

4. THE MATURITY LEVEL ASSESSMENT OF NORTHEN CITIES IN CROATIA

The maturity level assessment of the city management in Northern Croatia is presented through a series of indicators that measure the efficiency of different sectors in the cities of Krapina, Varaždin, Čakovec, Koprivnica, Križevci and Đurđevac. Each indicator is a key element of urban development. By using these indicators, it is possible to compare the maturity of management and identify areas that require additional attention and improvement. The table below provides an overview of the maturity level assessment of smart city management in Northern Croatia [11].

Table 3. Comparative review of the management maturity level assessment in the cities

Indicators \ Cities	Krapina	Varaždin	Čakovec	Koprivnica	Križevci	Đurđevac
The field of economy	0.21	0.51	0.37	0.38	0.28	0.18
The field of education	0.28	0.22	0.37	0.34	0.34	0.31
The field of energy	0.34	0.34	0.40	0.85	0.26	0.19
The field of environment and climate change	0.36	0.35	0.38	0.70	0.37	0.24
The field of finance	0.45	0.70	0.49	0.41	0.48	0.52
Management area	0.25	0.23	0.32	0.20	0.21	0.23
The field of health	0.20	0.50	0.59	0.21	0.31	0.23
Residential area	0.19	0.19	0.25	0.35	0.21	0.18
Area of population and social conditions	0.21	0.18	0.33	0.38	0.23	0.20
Recreation area	0.32	0.38	0.32	0.20	0.62	0.25
Security area	0.26	0.30	0.22	0.22	0.20	0.21
Solid waste area	0.32	0.22	0.38	0.52	0.28	0.25
Sports and culture area	0.54	0.71	0.63	0.59	0.64	0.61
Telecommunications area	0.29	0.59	0.19	0.45	0.19	0.34
Transport area	0.18	0.34	0.22	0.23	0.19	0.17
Urban/local agriculture and food security area	0.22	0.25	0.26	0.23	0.17	0.21
Urban planning area	0.20	0.33	0.29	0.17	0.17	0.22
Wastewater area	0.28	0.51	0.28	0.61	0.21	0.20
Water area	0.18	0.18	0.18	0.20	0.18	0.18

Cities in northern Croatia show different levels of maturity in key sectors. They reach the highest levels of maturity in the areas of energy, recreation and sport, while there is more room for improvement in the management and security sectors.

Koprivnica achieves the highest level of maturity in the field of energy, with an indicator score of 0.85. This result positions Koprivnica among the leading cities in energy efficiency, which can be attributed to the successful implementation of energy optimization measures and the integration of renewable energy sources. Such data indicate a high level of technological development and infrastructural adaptation of the city, which supports sustainable and optimal consumption of energy resources.

Apart from Koprivnica, other cities in the north of Croatia show high levels of maturity in specific sectors. Varaždin achieves significant results in the field of recreation, which indicates an extremely developed sports infrastructure and extensive programs for citizens. Čakovec, on the other hand, shows high maturity in the sports and culture sector, which suggests that the city offers a rich cultural life and a variety of sports activities, with numerous events and programs that engage citizens and encourage their active participation in the community.

This analysis indicates differences in maturity levels among cities in northern Croatia in different sectors. The maturity level assessment allows cities to identify key areas for improvement and develop strategies aimed at greater sustainability and improving the quality of life for their citizens.

These data provide basis for improving the development strategies of cities, especially in sectors where low results have been achieved, thus increasing the overall maturity and efficiency of the system.

5. CONCLUSION

Cities are complex and dynamic systems in which it is crucial to ensure that all information and segments are interconnected in order to improve the quality of life of residents. Every city must strive for continuous improvement through regular analysis of key elements important for its development and the well-being of its population. The assessment of the level of maturity of cities provides a clear insight into the areas where cities are performing well and identifies those areas that require further improvement. This process is not only a tool for measurement, but also an incentive for continuous improvement, which leads to better development of cities and an increase in their competitiveness compared to others.

In order for cities to attract and retain population, it is important that they become as sustainable as possible, offering citizens a better, calmer and more economically affordable way of life. In the long run, such an approach not only improves living conditions, but also reduces operating costs, making cities more desirable places to live.

If we compare these results with the IMD Smart City Index, it becomes clear that cities in Northern Croatia are still in the early stages of smart city development. While there are some positive developments, especially in specific areas, most cities still have a long way to go towards achieving end-to-end smart solutions that integrate technology and sustainability at a more advanced level. A lot of work and further investment in smart solutions are necessary to increase the competitiveness of these cities and improve the quality of life of residents.

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UNIVERSITY NORTH

The Key Role of Electromobility in the Future of Sustainable Transport

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A B S T R A C T

Electromobility is the concept of using an "electric powertrain" to transport people and goods to support sustainable development [1]. Electric vehicles (EVs) are promising technologies for achieving a sustainable transport sector in the future due to their very low to zero carbon emissions, low noise, high efficiency, and flexibility in grid operation and integration [2]. In many regions, there is a lack of progress with electricity decarbonization, significantly limiting EVs' potential emission and air quality benefits [3]. For research on the mentioned topic, a survey was used as the most common data collection method from respondents, with direct insight into participants' attitudes toward the transport system and those who generate transport demand. Survey data from 2021, when approximately 600 participants took part in the survey, were used, which are compared with the data obtained from the survey implemented in 2024. By comparing the surveys, it is concluded that individuals who use private cars daily do not favour electric vehicles but are considering buying the same. When it comes to price, they are initially more expensive, but the government offers the possibility of incentives and subsidies to encourage citizens to buy. In addition, the cost of filling is significantly lower than the cost of fuel, affecting the overall cost of maintenance, which most survey respondents agreed with.

Keywords: Electric Cars; Infrastructure; Batteries; Environmental Impact; Electricity.

1. INTRODUCTION

The discovery and development of rechargeable batteries led to significant advances in the development of electric vehicles. A key moment in the history of electric cars occurred in 1859 when the French physicist Gaston Planté invented the lead-acid battery, which significantly increased the practicality of electric cars. Planté's invention laid the foundation for the further development of electric vehicles. In 1881, Camille Alphonse Faure, also a Frenchman, significantly improved the capacity of the lead-acid battery by adding a lead-sulphate mixture to the lead plates, which increased the battery's capacity and efficiency. This improvement opened the door to the industrial production of batteries, which ensured broader application in various industries, including the development of electric vehicles.

In the same year, the Frenchman Gustav Trouvé used the discovery of the rechargeable battery to power his DC-motor tricycle, which he presented at the Paris Exhibition of 1881. This event marked one of the first public demonstrations of an electric vehicle. A few years later, Thomas Parker introduced his electric vehicle in England, which showed that England and France were the leading forces in developing electric cars. While France and England led the development of electric vehicles, the United States joined this innovation only at the end of the 19th century. Despite the delay, Planté and Faure's battery technology development created the basis for advancing electric vehicles worldwide [4].

By the beginning of the 20th century, electric vehicles alone made up the majority of cars on the roads in the United States. Between 1935 and 1960, their development stagnated because, at that time, the price of oil was high, which made internal combustion cars less profitable. Only the discovery of large oil deposits in Texas caused fuel prices to fall, favouring the development of classic cars. The main problem with electric vehicles was their autonomy: the distance they could travel without recharging. Gasoline/diesel cars could travel much longer distances, while electric cars had a limited range, making them less suitable for travel. In the 1920s, road infrastructure improved, making long-distance travel easier and faster, but electric cars could not keep up with the pace due to the limitations of their batteries. At the same time, other large oil deposits were discovered worldwide, mainly in the United States, further reducing fuel costs. At the same time, cars with internal combustion engines became more affordable and reliable thanks to mass production, making them the primary means of transportation.

Although batteries in electric vehicles experienced significant improvements between 1910 and 1925 – their capacity increased by 35%, their lifespan by 300%, their range by 230%, and maintenance costs reduced by 65% – they were not developed enough to compete with gasoline-powered cars [5]. Today, although modernized and more sophisticated, the batteries used in electric vehicles rely heavily on the fundamental principles established by Gaston Planté. His contribution and Faure's improvements were crucial to the industrialization and popularization of electric vehicles, laying the foundation for their further development and ubiquity in today's world. Sustainability and energy saving have become key goals of modern society and given that transportation consumes between 40 and 60% of the total amount of fossil fuels, electric cars are considered the solution of the future.

The use of electric vehicles is increasingly present in public transport worldwide, and Croatia is no exception. In the late 19th and early 20th centuries, electric trams became essential to urban transport in Croatian cities such as Rijeka, Zagreb, and Osijek. Also, the gradual electrification of the railway network began on the Rijeka-Šapjane route, which enabled more efficient and environmentally friendly transport. Today, Croatia has a railway network of 2,617 kilometres, 980 kilometres of which are electrified, representing a significant, but still insufficient, contribution to the modernization of the railway system [6].

2. TECHNICAL CHARACTERISTICS AND INFRASTRUCTURE OF ELECTRIC VEHICLES

Electric cars are powered by electric motors, using energy stored in batteries, without relying on other sources, such as internal combustion engines, which are present in hybrid vehicles. Compared to conventional cars, electric vehicles do not produce exhaust gases and have significantly less energy loss, thus achieving greater efficiency and reducing negative environmental impact.

One of the key differences between electric and conventional cars is the almost silent operation of electric vehicles, with some noise coming from the sound systems installed for safety. The structure of electric motors is significantly more straightforward than internal combustion engines, which allows them to operate for a more extended period and reduces the need for frequent maintenance. Some models of electric vehicles use electric motors located directly on the wheels, which achieves greater power and improved performance. In contrast, others use a central electric motor connected to the wheels via a transmission system. Airflow often achieves cooling, while water systems are used for temperature regulation in exceptional cases [7]. A key part of an electric vehicle is the control unit, also known as the controller, which manages the energy flow between the battery and the motor and converts direct current to alternating current, allowing precise power control. Because electric motors can provide sufficient power even at low speeds, most electric cars do not use a mechanical transmission. However, some manufacturers are considering installing transmission systems for future models due to the reduced torque at higher speeds.

One of the biggest challenges in developing electric cars is its battery system and capacity. The goal is to create smaller, lighter batteries, reducing the vehicle's overall weight and thus increasing energy efficiency. At the same time, efforts are being made to increase battery capacity so that vehicles can travel longer distances on a single charge, with the possibility of fast charging, a long operating life, and as low as possible production costs. Lithium-ion and lithium-polymer batteries are most commonly used, but further research and development are necessary to meet the increasingly stringent market requirements [7]. A sophisticated charging and discharging control system manages the battery's operation to ensure stability and maintain the optimal operating temperature. Fast charging stations are increasingly present throughout Europe, and there is also the possibility of charging batteries at home, where, depending on the capacity, it takes up to eight hours to reach maximum capacity.

The term battery for electric vehicles was mentioned in the 19th century when scientist Michael Faraday demonstrated using lead fluoride and silver sulphide as solid electrolytes. In the 20th century, the development of batteries was linked to laboratory experiments. At the end of the 20th century, personal electronics became increasingly important, and the demand for smaller, more powerful batteries that lasted longer than previous ones grew. Today, the battery market is worth around 23 billion euros per year. A battery is an electrochemical storage of electrical energy. The structural elements of a battery are the anode, the electrode as a separator, and the cathode. The chemical reactions themselves release electrons. Between the anode and the cathode is an electrolyte that prevents the direct passage of electrons to the cathode and directs them around an electrical circuit to which the consumer is connected or something similar to an electric motor. During charging, the process is reversed. There can be over a hundred individual cells in a battery, while for a typical 12 V battery, this number is 6. The characteristics of the battery itself are measured by density, power, and energy. Battery density depends on how long the battery can last before it is discharged; power density represents the speed at which it can deliver that energy. World-renowned battery manufacturers announce that in the future, they will strive to increase battery capacity and expect a range of up to 350 km on a single charge. Some types of batteries are lead-acid batteries, nickel-metal hydride batteries (NiMH batteries), and lithium-ion batteries (Li-ion batteries) [8].

Lithium-ion batteries are the most efficient due to their high energy density (about 250 Wh/kg), long life, and fast charging, making them ideal for electric vehicles. NiMH batteries, which are used in hybrid vehicles, have a lower energy density (about 80 Wh/kg) and a higher capacity loss with frequent discharge.

Although the oldest technology, lead-acid batteries, have a low energy density and short life and are used mainly in secondary vehicle systems due to their better efficiency, greater autonomy, and faster charging, lithium-ion batteries are currently the best choice for electric vehicles. Battery cooling is one of the factors that affect battery performance. In addition to driving style, temperature also affects charging time and vehicle safety. Low temperatures can lead to lack of power and energy and even prevent the vehicle from starting. In high-temperature conditions, the battery must be cooled, which is achieved by air or water cooling. The goal of the cooling system is to regulate temperature variations. Air systems are cheaper and more straightforward, while liquid cooling systems take up less space and allow for more powerful battery use. Air systems are less efficient at maintaining temperature due to their low heat exchange capacity than liquid cooling systems. If the temperature threshold is exceeded, the result is accelerated battery "aging" and premature battery failure. Electric vehicle manufacturers aim to ensure that the battery has a lifespan of approximately 8-10 years.

Batteries that have reached the end of life cannot be used anymore and must be recycled for several reasons. The most important reason is environmental protection. Batteries contain many materials and components, some of which are dangerous to the environment and people. Throwing batteries away or improper disposal can lead to the leakage of hazardous substances into water and soil, which pollutes the environment and nature, endangers animals and people, and can cause fires. Recycling reduces the accumulation of waste in landfills. The production of new batteries requires large amounts of raw materials, which may cause shortages and potential price increases in the future. Recycling old batteries provides secondary raw materials for making new batteries [9]. Battery recycling as a technological process consists of the following stages:

- collection of worn-out or discarded batteries in appropriate and designated locations
- if necessary, disassembly from electronic devices in warehouses or recycling yards
- safe transportation to the recycling facility
- sorting process of different types of batteries
- shredding using various procedures and machines
- separation of different raw materials using appropriate methods [10].

A user driving an electric vehicle must deposit the waste battery or accumulator in special containers to collect this waste. The seller must set up such containers for separate collection in his business premises, collect this type of waste regardless of the manufacturer, and then hand over the collected waste batteries to an authorized collector, who takes them over free of charge. An authorized collector of waste batteries and accumulators must hand over such waste to an authorized person for treatment and/or recycling or to export it from the Republic of Croatia with a special permit from the Ministry of Environmental Protection. A recycler is a "legal or natural person with a permit to perform the activity of treatment and recycling of waste batteries and accumulators, is a concession holder and has a contract with the Fund for Environmental Protection and Energy Efficiency" [10].

Charging stations are classified into three categories, depending on the type of electricity used and the charging speed, and their number is constantly increasing: in shopping mall parking lots, garages, gas stations, private parking lots, and city streets. More and more companies are installing electric charging stations so their employees can charge their cars during working hours. A standard charger charges the battery up to 100% in 3 hours at 22 kW charging stations. The vehicle can also be charged wirelessly; it is enough to park it above the "electric pad", and the charging process starts automatically. Only the charging of the electric car battery is charged, which is why the use of electric cars is increasing [11].

The battery charger has a built-in device that converts alternating current (AC) into direct current (DC), which is needed to charge the battery of an electric vehicle. A battery charger is not required when direct current is supplied directly to the battery, but its function is to monitor the charging process. As more public charging stations are equipped with communication modules and management software installed, a charging spot can be reserved, and it is easy to see which charger is available. Electric cars use energy much more efficiently than cars with conventional engines, and charging vehicles is their "pain" point because it takes longer than refuelling and generates energy losses. Losses are affected by the length and thickness of the charging cable, as well as temperature and charging power. During the transfer of electrical energy, heating occurs, which means that part of electrical energy is converted into heat. Maintaining the temperature significantly affects the level of loss because an increase in battery temperature increases loss. When using fast chargers of 400-500VAC/100-125A power, it is necessary to cool the charging cables due to high power [11].

3. DEVELOPMENT OF ELECTROMOBILITY IN THE REPUBLIC OF CROATIA

At the end of 2018, the implementation of the Easte project was completed, with a total value of €5.05 million. This project ensured the procurement of installations, commissioning of 27 multi-standard rapid charging stations, procurement, installation and commissioning of ICT solutions for charging station management, billing system, establishment of roaming platform with 11 countries, building a respectable competitive advantage, localization of EU best practices, etc. [12]. At that time, BigEVdata and NEXT-E were projects implemented in the Republic of Croatia, both financed from the European Union funds. The goals of the mentioned projects included the implementation and development of electromobility through integrating electric vehicles and the associated infrastructure. The projects were also linked to activities related to: supporting national e-mobility plans and EV deployment strategies in the region, developing sustainable vehicle charging solutions, assessment involving renewable energy, introducing innovative business processes and consumer packages to reduce oil dependency, reducing CO_2 emissions in Europe, establishing cooperation with policymakers to ensure the implementation of lessons learned with the aim of introducing a pan-cohesive electric vehicle charging infrastructure, presenting the best strategies and approaches for the use of infrastructure and services, all with the aim of presenting pan-cohesion plan and guidelines for the widespread use of electric vehicles [12].

According to data from March 2020, only 730 fully electric vehicles were registered in Croatia, while in Norway, there were as many as 215,000, which is a big difference and means that the number of electric vehicles is completely negligible compared to most EU countries. Regarding hybrid vehicles, according to data from the same period, 5,899 vehicles were registered in the Republic of Croatia, and 207,000 in Norway. In relation to motor vehicles, hybrid and electric vehicles then accounted for 0.38%, a negligible percentage compared to the total number of vehicles [12].

The European Union has set a target of one million charging points for electric vehicles by 2025 in its strategic document "European Green Deal". Croatia is currently lagging in the availability of publicly accessible charging infrastructure, with around 400 publicly accessible charging points per 9,000 inhabitants. At the same time, the EU average is one publicly accessible charging point per 2,000 inhabitants. At the end of 2022, Croatia recorded 950 active charging points for electric cars. In a broader sense, the charging infrastructure for electric vehicles represents a distribution network, while in a narrower sense, it includes the equipment for powering electric cars and charging stations.

Croatia has been encouraging citizens to use electric vehicles more for the past decade, spending significant money on them. There is a considerable number of charging stations for electric vehicles throughout Croatia. However, there is also a substantial problem in many residential areas with no electric charging stations, meaning residents cannot plug their cars into a home outlet. Most parking spaces lack the necessary infrastructure to install chargers [13]. For new buildings and buildings undergoing significant renovation, whose purpose does not include residential, with more than ten parking spaces, at least one charging point and duct infrastructure, i.e., pipes for electrical cables, shall be installed at least once for every five parking spaces, to enable the installation of charging points for electric vehicles at a later stage. Article 21.c of the Construction Act states: "For new buildings and buildings undergoing significant renovation, with more than ten parking spaces, when the building is for residential purposes or other purposes of which one is residential, duct infrastructure, i.e., pipes for electrical cables, shall be installed for each parking space to enable the installation of charging points for electric vehicles at a later stage". It can be read from the Act that new residential buildings will need to have a recessed installation for chargers on each parking space located in the building or immediately adjacent to the building, and all other buildings will have to have an installation on one of each parking space, which will enable greater electromobility of residential settlements.

The Environmental Protection and Energy Efficiency Fund has been implementing co-financing programs to purchase energy-efficient vehicles since 2014. Over the past 10 years, around €63.6 million in grants have been invested in purchasing around 12,000 such vehicles, which ultimately significantly impacted the number of registered electric cars in Croatia [14].

According to the European Union strategy proposal, Croatia should apply low-CO_2-emitting fuels by 2030, including electric and hybrid vehicles, natural gas and biogas vehicles, liquefied petroleum gas, hydrogen, and biofuels. The Environmental Protection and Energy Efficiency Fund is also tasked with accelerating the transformation of Croatia's transport system towards energy efficiency. The Low-Carbon Development Strategy predicts that by 2050, as much as 35% of the vehicle fleet in Croatia should be electric. In 2019, the Environmental Protection and Energy Efficiency Fund published a public call for co-financing the purchase of electric cars for citizens. The subsidies were awarded on a first-come, first-served basis, with only a limited number of people eligible for the incentives, depending on how quickly they applied. Citizens could receive up to 40% of the grant for the purchase of a new electric vehicle, namely €10,620 for electric cars, €5,310 for plug-in hybrids (with CO_2 emissions below 50 g/km), €2,655 for electric scooters and motorcycles, and €665 for electric bicycles [14].

In 2021, the "fastest finger" application system was abolished, and applications were carried out through car dealerships. The vehicle seller applied several steps. First, manufacturers, importers, and vehicle representatives had to report their points of sale and available models of environmentally friendly vehicles to the Fund. After that, the Fund published a Public Call for citizens and companies, and sellers submitted applications for co-financing. That year, the Fund provided €13.94 million for co-financing energy-efficient vehicles – €11.95 million for individuals and legal entities and €1.99 million for the public sector. Citizens could receive an incentive for one new vehicle, while companies could purchase more, but with a maximum incentive of €53,090. Purchased vehicles had to be owned for at least two years. Co-financing amounted to up to 40% of the vehicle's value, and the maximum amount depended on the category. The public call was published on 2 June 2021, and applications began on 10 June. All funds were reserved in less than eight hours, so the competition was temporarily closed. Croatia's best-selling electric vehicle model 2021 was the Renault Twingo Electric (over 400 vehicles ordered), followed by the Dacia Spring and Tesla Model 3. In addition to the Fund for Environmental Protection and Energy Efficiency, a national association for e-mobility also operates in Croatia [14].

The association aims to promote electric vehicles and advocate for changes to laws and regulations to facilitate their purchase and use. The association has proposed abolishing VAT on purchasing electric vehicles, allowing continuous yearly purchases without state co-financing. The association has also established a working group to install 100,000 chargers in public lighting poles across Croatia to improve the infrastructure for electric vehicles [14]. A new co-financing program for energy-efficient vehicles is planned for 2025, but exclusively for legal entities. This program, worth €21 million, will be financed from European Union funds through the National Recovery and Resilience Plan, and its publication is expected in the first half of the year. In addition, 32 million euros will be allocated to co-finance the installation of electric charging stations. However, co-financing the purchase of electric vehicles for individuals in 2025 is not planned. Although it is not currently scheduled, the possibility of launching a tender has been left open in case the necessary funds are secured.

4. RESEARCH RESULTS AND SURVEY ANALYSIS

Two surveys were conducted in 2021 and 2024 as part of the study on drivers' attitudes towards electromobility. The aim was to collect data on drivers' perceptions of electric vehicles, their willingness to purchase them, and their environmental awareness. Both surveys covered different age groups and respondents' interests to obtain the broadest possible insight. According to the General Data Protection Regulation (GDPR) and Croatian national legislation, our research does not require formal ethical approval as it involves the collection of anonymous survey responses without personal or sensitive data. In addition, the study does not include vulnerable groups, medical or psychological interventions, or any procedures that could pose a risk to participants. Therefore, by institutional and national ethical guidelines, formal ethical committee approval is not required for this type of research. The 2021 survey, conducted via Microsoft Forms, comprised 25 questions and included 616 respondents. It focused on personal characteristics, vehicle usage habits, and attitudes toward electric cars. The results were analysed and graphically presented using Microsoft Excel. In 2024, the survey included 481 respondents with 19 questions of similar content. Respondents provided information on car use and their willingness to switch to electric vehicles. The results were also processed and graphically presented. By comparing these surveys, it is possible to monitor changes in driver attitudes and observe trends in the development of the electric car market.

In the 2021 survey, out of 616 respondents, 39% were male, while 61% were female. In comparison, in the 2024 survey, which included 481 respondents, 66.8% were female, while 33.2% were male. Also, in the 2021 survey, by age group, 5% of respondents were under 18, while the largest share of respondents was in the 18-30 age group, accounting for 45% of all the respondents. The 31-50 age group comprised 43%, while 6% of respondents were over 50. The 2024 survey recorded a decrease in the share of respondents under 18 to 3.3%. The most significant number of respondents belonged to the 18-25 age group, with 34.9%, while 19.2% were aged 26-35. The 36-45 age group comprised 21.9% of respondents, and 20.7% were over 46. These data show a significant increase in the proportion of women among respondents over three years, while the proportion of men has decreased proportionally. They also show that the proportion of younger respondents has reduced, while in the 2024 survey, respondents in older age groups (36 and older) are more represented compared to 2021. In the 2021 survey, when asked how many personal cars their household owns, 45% of respondents (277) responded that they owned two cars for personal use, while 18% indicated that they owned three vehicles. In the 2024 survey, the most significant number of respondents, 35.8%, also revealed that they owned two cars, but the proportion of those who owned only one car has increased to 27.6%.

The proportion of households with three vehicles has risen to 24.8%, while 12.8% of respondents own four or more cars. These data show that in 2024, the number of households with more cars increased, while the share of those with one car also increased significantly compared to 2021. The results are shown in **Figure 1**.

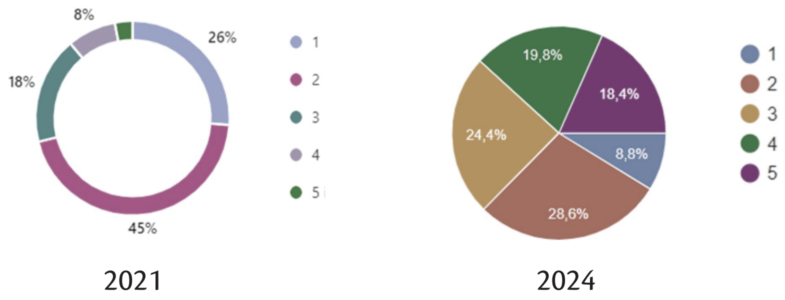

Figure 1. Comparison of data from 2021/2024 concerning the number of cars owned by respondents. (Source: author)

Regarding how often respondents use their car and how many kilometres they drive per day, in 2021, 63% of respondents used their vehicle several times a day, while 13% used it once a day or several times a week. Most respondents, 40%, drove between 20 and 50 kilometres per day, while 31% drove up to 20 kilometres. About 14% of respondents drove between 50 and 80 kilometres, while only 6% drove more than 100 km daily. In 2024, 69.9% of respondents used their vehicle daily, and 13.6% used it once a day or several times a week. The most significant number, 38%, drove between 20 and 50 kilometres, while 29.4% drove up to 20 kilometres. This data confirms that most respondents continue to use their vehicle daily and drive up to 50 kilometres, indicating a constant need for a car. The comparison shows a slight increase in the frequency of vehicle use, with similar daily distances, confirming the critical role of personal transportation in respondents' lives. The results are shown in **Figure 2**.

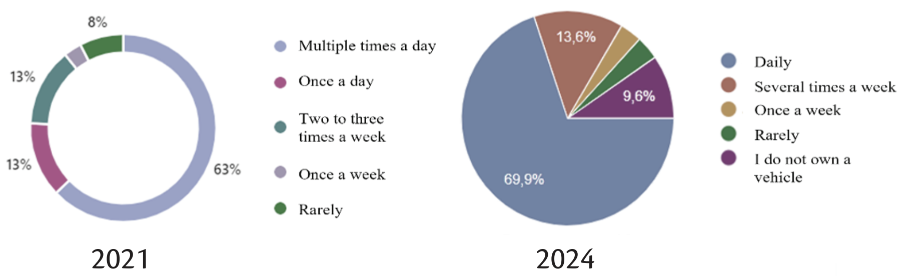

Figure 2. Comparison of data from 2021/2024 on respondents' use of personal cars. (Source: author)

When asked what type of vehicle respondents currently use, in the 2021 survey, out of a total of 616 respondents, 35% used a gasoline vehicle, while 62% drove a diesel vehicle. Only 1% of respondents used gas, hybrid, or electric vehicles. Out of 481 respondents from 2024, 57.6% used a diesel vehicle, while 36.9% used a gasoline vehicle. 2.3% of respondents used gas and hybrid vehicles, while only 0.7% drove an electric vehicle. Results are presented in **Figure 3**.

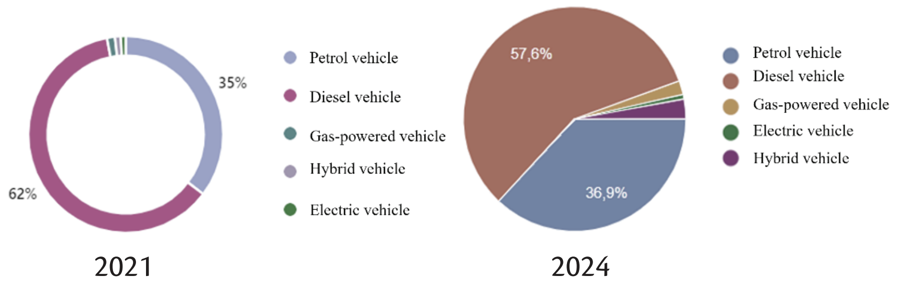

Figure 3. Comparison of data from 2021/2024 about the type of vehicle that respondents currently use. (Source: author)

The data shows a slight increase in the use of gas and hybrid vehicles. In contrast, electric vehicles still make up a small percentage, indicating a slower adoption of environmentally friendly options. The share of diesel and gasoline vehicles has also decreased, but ecologically friendly vehicles are still in the minority.

In 2021, only 11% of 616 respondents had experience with electric cars, while 89% did not. By 2024, this share has increased to 18.8%, but 81.2% of respondents still had no experience with electric vehicles. The lack of test vehicles in car dealerships and insufficient education of the population also contribute to the low share of experience with electric cars, as opportunities to test and drive were often limited to various events or immediately before concluding a purchase contract. Results are presented in **Figure 4**.

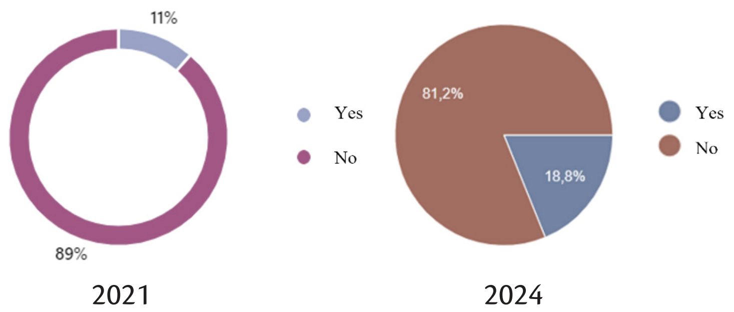

Figure 4. Comparison of 2021/2024 data about experiences with electric cars. (Source: author)

In 2021, out of 616 respondents, 256 respondents, or 21% to be precise, identified the range of electric cars as the biggest problem. This problem includes the rapid reduction in range due to air conditioning, the impact of low temperatures, the time required for charging, and the lifespan of the battery. In 2024, out of 481 respondents, 40.4% believed that the most critical problem was the high price of electric cars. The second biggest problem, according to 22.3% of respondents, related to the safety and reliability of these vehicles, which can be seen in **Figure 5**.

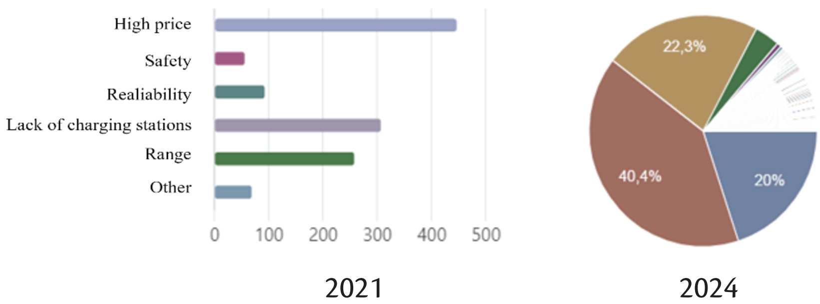

Figure 5. Comparison of data from 2021/2024 about the most significant problems of electric cars. (Source: author)

This shift in perception of electric car issues suggests that new challenges and concerns have emerged, focusing on cost and safety. Earlier concerns, such as range and charging time, are still present but less pronounced. **Figure 6** shows that in 2021, 95% of respondents believed that electric vehicles were too expensive and that the state did not provide sufficient support, while only 5% believed that the incentives were inadequate. By 2024, this share decreased slightly to 89.2%, and 10.8% of respondents believed the incentives were sufficient. Although attitudes are changing slightly, most still believe that electric vehicles are expensive and that the government should increase incentives. In 2021, 47% of respondents advocated the reduction of VAT, 48% its complete abolition, and only 5% saw no need for change. In 2024, 50.4% of respondents supported the reduction of VAT, 34.2% its abolition, while 15.4% believed that the current incentives were sufficient. The data indicate a clear view of the majority that additional measures are necessary for greater accessibility of electric vehicles.

Despite the high price of electric cars, some drivers are willing to pay more than 50% more to drive one. At the same time, an equal number of respondents believe they should not allocate more financial resources than conventional vehicles.

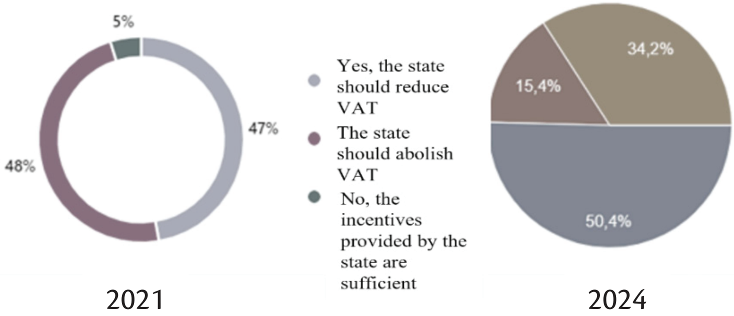

Figure 6. Comparison of 2021/2024 data about VAT reduction on electric vehicles. (Source: author)

According to data from 2021 and 2024, respondents' opinions on harmful emissions and environmental protection are divided. A smaller proportion of respondents indicated that these issues were not important to them, while a significant proportion of respondents, approximately 45%, considered them crucial. Conventional vehicles require regular maintenance and servicing after a certain number of kilometres, often resulting in significant financial costs, especially when performed at authorized service centres. In contrast, owners of electric vehicles are largely spared these expenses. According to the above, the price and lower maintenance costs of vehicles are significant factors for the majority of survey respondents.

New technologies, advanced systems, top-notch design, quiet engine operation, and comfort are some of the characteristics of electric vehicles on which respondents from 2021 and 2024 had to express their opinions. Based on this, it can be concluded that the above is very important to many current and future owners, over 90%.

5. CONCLUSION

Electric vehicles are increasingly present around us today, but they still have a long way to go before they can be compared to conventional vehicles. Electric vehicles do not have the same capabilities as traditional vehicles, as they are limited in charging time and range and relatively expensive compared to internal combustion vehicles. Electric vehicles make up a small part of the vehicle fleet. The infrastructure for charging electric vehicles in cities and on suburban roads cannot meet the large number of electric vehicles that could appear in the future. The biggest problem that could arise is disposing of worn-out batteries, which are very expensive. Driving electric vehicles provides pleasure and superb comfort. To achieve the growth trend of electromobility, it is essential to encourage and introduce electromobility into all branches of economy, activities, and transport sector so that its use becomes as simple as possible and not too expensive and difficult to access (not all cities are equally developed, nor is the infrastructure for implementation). In addition to incentives, educating people in daily contact with vehicles and experts responsible for maintenance and introducing innovations is essential. To generate interest, it is imperative to emphasize, present, and promote such a way of preserving the environment, sustainability, and creating new opportunities. For this study, a survey of drivers on electromobility was conducted to obtain the necessary data on their attitudes toward electric cars. The surveys provided feedback on the respondents' opinions on purchasing environmentally friendly, cost-effective vehicles and their attitudes and general views on electric cars. The survey was conducted during 2021 and 2024. Over 3 years, attitudes have not changed significantly, nor has the awareness on ecological vehicles been raised, which may be a consequence of excessively high prices, but also of the fact that the state does not provide enough incentives for the purchase of electric cars, which ultimately boils down to a significant lack of interest in a sustainable mode of transport.

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