TRANSPORT FOR TODAY'S SOCIETY

PROCEEDINGS OF TTS 2025

4th International Scientific Conference TRANSPORT FOR TODAY'S SOCIETY

Ohrid, North Macedonia
April 24-25, 2025

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Ohrid, North Macedonia, April 24-25, 2025

European Platform of
Transport Sciences

REPUBLIC OF NORTH MACEDONIA
MINISTRY OF EDUCATION AND SCIENCE

Republic of North Macedonia
Ministry of Transport

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"Transport for Today's Society"

University "St.Kliment Ohridski" - Bitola

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- VII ProSUMP Regional Conference
- Transport Community – Clean Bus and Clean Fleet meeting
- Study visit – examples of good practice of innovative mobility and street design in Ohrid

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Dear colleagues,

The Faculty of Technical Sciences at the University "St. Kliment Ohridski" – Bitola had the privilege of hosting the 4th International Transport for Today's Society (TTS2025) Conference, themed "Green Urban Transport Solutions." The event focused on forward-looking, environmentally sustainable approaches to smart urban mobility, addressing some of the most critical and complex challenges in today's transport systems.

The primary goal of the conference was to create a dynamic platform for integrating scientific research, policy-making, and practical implementation in the field of transport engineering. Particular emphasis was placed on energy efficiency, emission reduction, and intelligent mobility solutions.

The conference opened with a welcome speech by Dipl.-Ing. Sebastian Belz, Secretary General of the European Platform for Transport Sciences (EPTS), also delivered the keynote lecture titled "EPTS Foundation at a Glance."

The plenary program featured distinguished speakers:

- *Prof. Dr. Stane Božičnik from the University of Maribor, who presented "Market-Based Instruments for Transport CO_2 Emissions Management – From Theory to Practice".*
- *Prof. Dr. Elmar Fürst from the Institute for Transport and Logistics Management at WU Vienna, who presented a lecture on "Barrier-free Accessible Inclusive Cross-Border Public Transport".*

Both presentations offered valuable insights and emphasized forward-thinking strategies for fostering more sustainable and inclusive transport systems. A key highlight of the event was the participation of a representative from the Ministry of Environment and Spatial Planning of North Macedonia, who provided important perspectives on environmental policy and sustainable development.

The conference featured a rich compilation of 30 peer-reviewed scientific papers and a wide array of expert presentations, made possible through close collaboration with our esteemed co- organizers.

The scientific content of the conference was organized into three thematic sessions:

- *Session A: Intelligent and Sustainable Urban Mobility Solutions*
- *Session B: Enhancing Traffic Safety and Infrastructure Planning*
- *Session C: Environmental Challenges in Transport: Policy Framework and Logistical Strategies*

The active participation of students was particularly inspiring, as they presented original research and fresh perspectives. All student contributions were formally included in the official Conference Proceedings, recognizing their valuable role in advancing the field.

The success of TTS2025 reflects the collective commitment of researchers, professionals, students, academics, and institutional partners, as well as the dedication and hard work of the organizing team, to whom we extend our heartfelt appreciation.

Looking ahead to the next TTS Conference, we extend a warm invitation to join us once more in shaping the future of sustainable urban transport—collaboratively and with purpose.

On behalf of the Faculty of Technical Sciences, Bitola
Professor Dr. Verica Danchevska

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Session A:
Intelligent and Sustainable Urban Mobility Solutions

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Professional Paper

Applying the Artificial Neural Network Model to Predict the Use of Dockless Shared E-Scooters for Commuting Trips

Jelica Komarica[1], Draženko Glavić[2], Marina Milenković[3], Marija Malenkovska Todorova[4]

Abstract – **Traffic congestion from commuting trips caused by car users encouraged Belgrade inhabitants to express their views through an online survey, emphasizing their willingness to use the dockless shared e-scooter system if it were introduced. Applying the ANN model, key factors influencing the decision to use this sustainable transport mode were predicted.**

Keywords – **Dockless shared e-scooter, commuting trips, urban mobility, artificial neural network, prediction**

I. INTRODUCTION

During the past few years, in order to develop urban micro-mobility, e-scooters have appeared as one of the possible solutions. Due to their appearance, there was an expansion of the use of shared e-scooters by urban residents around the world [1], [2]. Although e-scooters may be privately owned, the surge in e-scooter use can be explained by the introduction of shared e-scooter systems in cities. Since their introduction in 2017, dockless shared e-scooter systems have spread to hundreds of cities around the world, and many new cities are preparing to welcome them to their streets [3]. Dockless ride sharing allows e-scooters to be left at the user's final destination, to be picked up by the next user, or picked up for charging. Dockless shared e-scooters are being touted as a solution to the last mile problem, a means of reducing traffic congestion, and an environmentally preferable mode of transportation [4].

The way they are used, as well as the strategies and policies of cities to promote e-scooters, differ between countries and even between cities. In many studies, safety when using e-scooters, infrastructure, as well as price are the three most common reasons for not using this type of transportation. Several countries, such as Germany, Australia and California, have fully regulated the use of e-scooters, while most countries are in transition or not all measures are being taken yet [1]. Just as the law varies, the price and policy of renting an e-scooter varies from country to country. Due to the increased level of motoring, Belgrade, the capital of Serbia, faces daily traffic congestion. One of the proposals for their reduction is increasingly reduced to sustainable solutions, and most often the use of micromobility vehicles. The advent of e-scooters caught many European legislators unprepared, with no regulations regarding use, driving or necessary measures related to the safety of both e-scooter users and other road users. This is also the case in Serbia, where a proposal to amend the law on the use of these vehicles was recently adopted, which has not yet entered into force. Bearing in mind the above, the main goal of this work is to determine the influencing parameters on decision-making regarding the choice of transportation during commuting, with the application of the predictive power of the neural network model. The focus is on the use of shared e-scooters through the hypothetical introduction of a dockless shared e-scooter system.

II. LITERATURE REVIEW

With the development of dockless shared e-scooter systems, there is more and more literature investigating the impact of using a dockless shared e-scooter on various factors such as travel behavior [4] and the impact on security [5]. Also, many authors have dealt with the influence of certain factors on the use of dockless shared e-scooters. Younes et al. [6] and Mehzabin Tuli et al. [7] concluded that warmer temperatures and better visibility were associated with a higher number of trips per hour. On the other hand, Mitra and Hess [3] found in their research conducted in Toronto and selected neighborhoods in Canada that 21% of respondents were willing to consider e-scooters for some of their current trips, and the majority would replace their existing walking (60%) and transit (55%) trips with shared e-scooters. Then, the results of the use of shared e-scooters in Vienna indicate that 75% of users of shared e-scooters would be men, and only 25% women [8] while in the city of Tricity in northern Poland, about 62% of e-scooter users would be men and 37% women [9]. In addition to the above, empirical data reveals that people are using shared e-scooters instead of cars at a significant rate, especially in many American cities - the rate of e-scooters for passenger car trips is between 25 – 40% in most cases [10]. Also, the study results of the introduction of dockless shared e-scooters in Paris (France) reduced walking, public transport, other shared mobility systems, passenger cars, and taxis by 35%, 27%, 9%, 4% and 6%, respectively [11].

It was mostly possible to see that the authors arrived at such knowledge with the help of conventional calculation methods. Although artificial neural networks (ANNs) have been proven to significantly reduce analysis time, cost, and complexity, numerous works have used their application for spatiotemporal micromobility vehicle service demand then classification of e-scooters and scooters, estimation of time and costs of service provision by e-scooters and similar. In this regard, the contribution of this paper is reflected in the application of the ANN model, which has so far proven to be very reliable, minimally deviating from traditional statistical analyses.

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III. Development of artificial neural network

The data analysis was carried out using the standard method of descriptive statistics and artificial neural network modeling, using IBM SPSS Statistics 21 software. A single-layer artificial neural network model was used to predict the decision-making on the choice of mode of transportation during commuting. Such models are developed to enable measurements that minimize error when predicting decision-making.

The architecture of the neural network model included three different layers. The input layer implies attribute values, in the form of neurons (nodes), which refer to independent variables. The hidden layer covers radially symmetric functions and unsupervised learning to describe hidden neurons. Finally, the output layer with the final values of the model classification, in the form of nodes, allows the calculation of the weighted sum from the output of the hidden layer and allows the calculation of the index class for the input pattern.

Neurons are connected by connections along which certain signals are sent. Depending on the input signals it received and the strength of the connections along which the signals traveled, each neuron sends an output signal of a certain strength. Input signals $(x_1, x_2, x_3, \dots x_n)$, which represent output signals from other neurons, are multiplied by the corresponding connection strengths $(w_1, w_2, w_3, \dots w_n)$. The output signal is equal to the weighted sum of the input signals. Within an artificial neural network, each neuron has a corresponding activation function, which is usually a non- linear, continuous, monotonically increasing, bounded, and differentiable logistic function. After the formation of the network architecture, the neurons of the ANN approach the training process. During the training process, datasets with authentic inputs and outputs are included as examples to train the model to predict the outputs. The neural network is trained by constantly adjusting the strength of connections between branches during training to detect the relationships that exist between input and output data. Finally, model formation is based on experimenting with different combinations of nodes in one hidden layer. During model development, in this paper, a training dataset of 80% and 20% testing was determined with randomly assigned values from the entire database. Considering that the neural network builds the model by learning from the potential correlation between the independent and dependent variables, it can justify the final results of the model, relating the predicted values to the existing values.

IV. Data description

The users' attitudes were collected using a questionnaire. The survey was conducted online over two months - from March to May 2021. An online questionnaire was sent to various companies and organizations of employed, unemployed, or retired people to ensure a representative sample. The attitudes of the respondents were analyzed in a) the existing state – without appropriate legislation, infrastructure, and common system of e-scooters; and (b) in a hypothetical situation that would include the definition of appropriate legislation, the construction of additional bicycle infrastructure and the introduction of a dockless shared system of e-scooters for 10 RSD/min + 20 RSD to start (unlocking the e-scooter). The price was defined based on the prices of this system in other cities, taking into account the economic indicators that were valid in local conditions, as well as the then-current price of public transportation in Belgrade. The value of €1 corresponds to 117 RSD.

In this paper, two approaches are combined: a revealed preference and a stated preference method. The first method analyzed the respondents' existing habits regarding the use of a certain mode of transportation for commuting, while the second approach was used to analyze user preferences regarding the use of a mode of transportation for a hypothetical situation. The data obtained by the stated preference method were used to predict respondents' responses using the ANN model.

A. Data preparation for model development

Data preparation for predicting the use of dockless shared e-scooters and other modes of transportation during commuting trips was performed to create datasets for a single – layer neural network model. The observed data related to the questions and answers of only those users who do not currently use e-scooters encourage a more sustainable way of commuting trips. During the creation of data sets, 13 attributes were defined, which are considered to be important in terms of evaluating the respondents' attitudes. The first 5 attributes refer to the socio-demographic characteristics of the respondents, then the next 2 attributes refer to the characteristics of the trip such as the current mode of transport used for commuting trips (trips for work/school/college) and the average mileage trips in one in the direction they go in the same direction. Finally, the remaining 6 attributes concern attitudes regarding the development of cycling infrastructure, but also regarding the safety of e-scooter users when moving. All 13 attributes were independent variables, i.e. input neurons within the input layer of the artificial neural network. The dependent variable was the choice of mode of transportation for commuting trips. The possible answers were "Dockless shared e-scooter" and "Other", and they represented two neurons in the output layer of the neural network.

B. Characteristic of the sample

The valid sample consists of 252 residents of Belgrade. Of the total number of respondents, 52.0% were women, while 48.0% were men. When it comes to the age structure of the respondents, most of them are between 19 and 25 years old (54.8%). The largest number of respondents belongs to the group of students (49.6%), followed by those who are in permanent employment (31.7%). Also, the largest number of respondents belongs to the group with a monthly income of less than €250 (50.4%) per month, followed by those with an income of €501 to €750 (18.3%). The average mileage traveled in one direction for commuting trips, in the most common case, is in the range of 5 km to 8 km (24.6%). Also, when traveling for the stated purpose, respondents most often choose a passenger car (55.2%), followed by public transport (35.3%). Other categories such as walking (5.6%), motorcycling (3.6%), and cycling (0.4%) are the least represented in commuting in the entire sample. However, only a small proportion of the total sample chooses to use the system of dockless shared e-scooters for commuting (28.2%). In comparison, the majority stick to the original decision or choose some of the modes of transportation that have been selected in the current situation (71.8%). Answers distributed in this way regarding the decision to choose a mode of transportation will be a real challenge for the neural network, considering the sample size.

V. Results and Discussion

For the network training process, a maximum time of 15 minutes is allotted, while the time dedicated to testing is automatically determined by the software. A manually created ANN model architecture with 13 neurons in the input layer, 7 neurons in the hidden layer, and 2 neurons in the output layer gave the best results. Different functions were used for different layers of the ANN network, i.e. in the hidden layer there is a hyperbolic tangent, and in the output layer Softmax functions. After determining the basic characteristics, the network was trained and then tested, after which its basic characteristics were determined. The values of the error functions indicate that the ANN network during testing has smaller error values of the sum of squares (21.54) compared to the error values during training (79.64), which indicates that the ANN model has smaller deviations of predicted values during testing, compared to the real ones. Taking into account the number of attributes and the size of the sample, the neural network model within the training phase gives very good results in predicting users who, for 10 RSD/min + 20 RSD for the start (unlocking the e-scooter), would opt dockless shared e-scooters or other vehicles. Also, with slightly worse predictive power, the ANN model during testing correctly predicted 82.7% of the answers of Belgrade residents, which is similar to the result during training (84.5%). Table 1 indicates the final prediction results, observed after both prediction phases.

TABLE I. Prediction of acceptability of dockless shared e-scooter

Sample	Estimated values	Estimated values: Shared e-scooter	Estimated values: Other	Correctly classified
Training	Shared e-scooter	37	22	62.7%
	Other	9	132	93.6%
	Overal	23.0%	77.0%	84.5%
Testing	Shared e-scooter	7	5	58.3%
	Other	4	36	90.0%
	Overal	21.2%	78.8%	82.7%

The results indicate that the model predicted worse the number of users who are willing to use dockless shared e-scooters for commuting and during the training and testing data (62.7% and 58.3% respectively), compared to those who would choose other modes of transport (93.6% and 90.0% respectively). This indicates a consequence of the sample size, and therefore a worse dependence on the attributes (independent variables) and the final answer of the respondents, which additionally had a negative impact on both training and data testing. In addition to the above, the IBM SPSS Statistics 21 software enables the presentation of the predicted pseudo-probability of the ANN model for two perceived classes of responses, i.e. decisions about the choice of mode of transportation when going to work in a box-plot diagram. As a rule, for each box plot in each different class, values above 0.5 can confirm correct predictions. In this regard, the box plot graph developed on the ANN model showed the predicted probability of the observed acceptability class. The first box plot on the left indicates the answer "Shared e-scooter", while the second box plot shows the probability of "Other" being classified as the answer "Shared e-scooter", even though it actually belonged to the answer "Other". The same logic guides the second box plot. Therefore, these results indicate that the ANN model better correctly classified the answers into the class "Other" compared to the class "Shared e-scooter" (see Fig. 1).

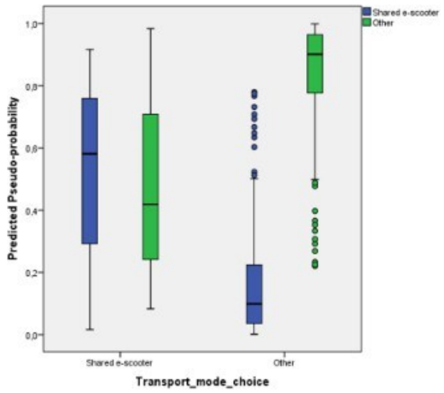

Fig. 1. Predicted pseudo-probability presented for responses

Based on the Mann–Whitney statistic, the ROC curve is one of the most important performances for defining the quality of a classification model. The value under the ROC curve can be described as the probability that a randomly selected user can be correctly rated or ranked if they are more likely to choose a particular mode of transportation. Its highest and best value can be 1.00. The measured area under the curve and the best score of 0.862 indicate a very good ability to classify users using the ANN model depending on the response.

Table 2 indicates the importance of assessing independent variables in the formed neural network model. The table includes all values of independent variables whose importance and normalized importance (NI) are ranked from highest to lowest. The focus is on the category of respondents who, for 10 RSD/min + 20 RSD for the start (unlocking the e-scooter), would use shared e-scooters for commuting trips.

TABLE II. Independent Variable Importance

Variables	Importance	Normalized Importance
Rating of topography terrain	0.115	100.0%
Age	0.108	93.8%
Current modal split	0.105	91.6%
Rating of safety e-scooter users on the bicycle path	0.105	91.5%
One-way mileage to work	0.096	83.2%
Rating of safety e-scooter users on the sidewalk	0.085	74.2%
Rating of safety e-scooter users on the road	0.071	61.4%
Rating of safety e-scooter users on the bicycle lane	0.069	60.0%

Variables	Importance	Normalized Importance
Rating of development cycling Infrastructure	0.058	50.7%
Income	0.051	44.0%
Gender	0.050	43.5%
Education	0.049	42.7%
Employment	0.038	33.4%

The conducted analysis indicates that the topography of the route's terrain when commuting trips has the greatest indication of all observed independent variables (NI = 100%). Namely, among respondents who rated the topography of the terrain as half flat/half hilly (18.3%) and flat terrain (6.0%), the largest percentage are ready to use shared e-scooters, looking at the entire sample. This result is expected, taking into account the driving conditions of the e-scooter, which involves standing, and in this sense, the mostly flat terrain can significantly contribute to comfort during driving. Other variables with the highest values were age (NI = 93.8%), followed by the current modal split to commuting trips (NI = 91.6%). This result is analogous to the responses of the respondents from the entire sample, which indicate that younger respondents in the age category of 19 to 25 years (15.9%) and mainly passenger car users (18.7%) are more willing to use shared e-scooters. This gives the impression that e-scooters are increasingly popular among young people, who are aware of the benefits of these vehicles, compared to passenger cars.

Compared to all other parameters, employment has the lowest indication of all observed independent variables (NI = 33.4%). Namely, although the opinions of the respondents indicate that students and employees are the most willing to use a dockless shared e-scooter (13.1% and 9.1%, respectively), they are not of decisive importance as to whether someone will use an e-scooter or other modes for commuting trips. Similarly, the other variables with the lowest values were education (NI = 42.7%), followed by gender (NI = 43.5%). So, even though these results are analogous to the responses of respondents who indicate that educated people with a university degree and younger respondents attending high school are more willing to use dockless shared e-scooters compared to others (8.3% and 11.1% respectively), their answers are not crucial. In this regard, although men are more willing to pay for the use of shared e-scooter services compared to women (14.3%), they are not of crucial importance for the model when predicting.

VI. Conclusion

To use a shared e-scooter system, users have to pay a certain fee which usually includes a fixed part to unlock the scooter and a part that depends on the duration of the ride. In this work, that fee meant 10 RSD/min plus the unlocking fee (20 RSD). By applying the ANN model, in addition to the predictive assessment, an analysis of the influencing variable on the decision-making on the choice of transportation was also performed. The main results of this research are as follows:

– In a hypothetical situation that includes built cycling infrastructure, defined legislation, and the implementation of dockless shared e-scooters, with a defined fee, 28.2% of respondents would switch to the use of a dockless shared e-scooter system during commuting trips;
– The ANN model predicted the choice of transportation mode with high accuracy and precision, with 82.4% of respondents' responses correctly classified, observing the test sample;
– The ANN model indicates that the topography of the terrain of the route has the greatest importance (100%), followed by age (93.8%), and the current modal split (91.6%) on the choice of mode of transportation during commuting trips.

The results of this work can help decision-makers in defining an adequate transport policy that would ensure the successful implementation of the dockless shared e-scooter system and increase its acceptance by the general public. The direction of future research should be aimed at increasing the sample to determine with greater accuracy and precision the influence of each independent variable and thus enable adequate decision-making.

References

[1] D. Glavić, A. Trpković, M. Milenković, and S. Jevremović, “The E-Scooter Potential to Change Urban Mobility—Belgrade Case Study,” Sustainability 2021, Vol. 13, Page 5948, vol. 13, no. 11, p. 5948, May 2021, doi: 10.3390/SU13115948.

[2] J. Komarica, “The impact of micromobility on environmental pollution,” Journal of Road and Traffic Engineering, vol. 69, no. 1, pp. 45–52, Apr. 2023, doi: https://doi.org/10.31075/PIS.69.01.06.

[3] R. Mitra and P. M. Hess, “Who are the potential users of shared e-scooters? An examination of socio-demographic, attitudinal and environmental factors,” Travel Behav Soc, vol. 23, pp. 100–107, Apr. 2021, doi: 10.1016/J.TBS.2020.12.004.

[4] D. Glavić, M. Milenković, A. Trifunović, I. Jokanović, and J. Komarica, “Influence of Dockless Shared E-Scooters on Urban Mobility: WTP and Modal Shift,” Sustainability 2023, Vol. 15, Page 9570, vol. 15, no. 12, p. 9570, Jun. 2023, doi: 10.3390/SU15129570.

[5] J. P. Allem and A. Majmundar, “Are electric scooters promoted on social media with safety in mind? A case study on Bird’s Instagram,” Prev Med Rep, vol. 13, pp. 62–63, Mar. 2019, doi: 10.1016/J.PMEDR.2018.11.013.

[6] H. Younes, Z. Zou, J. Wu, and G. Baiocchi, “Comparing the Temporal Determinants of Dockless Scooter-share and Station-based Bike-share in Washington, D.C.,” Transp Res Part A Policy Pract, vol. 134, pp. 308–320, Apr. 2020, doi: 10.1016/J.TRA.2020.02.021.

[7] F. Mehzabin Tuli, S. Mitra, and M. B. Crews, “Factors influencing the usage of shared E-scooters in Chicago,” Transp Res Part A Policy Pract, vol. 154, pp. 164–185, Dec. 2021, doi: 10.1016/J.TRA.2021.10.008.

[8] B. Laa and U. Leth, “Survey of E-scooter users in Vienna: Who they are and how they ride,” J Transp Geogr, vol. 89, p. 102874, Dec. 2020, doi: 10.1016/J.JTRANGEO.2020.102874.

[9] T. Bieliński and A. Ważna, “Electric Scooter Sharing and Bike Sharing User Behaviour and Characteristics,” Sustainability 2020, Vol. 12, Page 9640, vol. 12, no. 22, p. 9640, Nov. 2020, doi: 10.3390/SU12229640.

[10] K. Wang, X. Qian, D. T. Fitch, Y. Lee, J. Malik, and G. Circella, “What travel modes do shared e-scooters displace? A review of recent research findings,” Transp Rev, vol. 43, no. 1, pp. 5–31, Jan. 2023, doi: 10.1080/01441647.2021.2015639.

[11] Z. Christoforou, C. Gioldasis, A. de Bortoli, and R. Seidowsky, “Who is using e-scooters and how? Evidence from Paris,” Transp Res D Transp Environ, vol. 92, p. 102708, Mar. 2021, doi: 10.1016/J.TRD.2021.102708.

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Professional Paper

Exploring Pathways on How Artificial Intelligence is Shaping Safer, Smarter, Greener Cities

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Abstract – **Artificial intelligence is a driving force behind the transformation of smart cities, advancing traffic management, enhancing public transportation, and supporting environmental sustainability. This paper analyses its role in intelligent transportation systems, urban planning, and emission reduction initiatives, drawing on real-world examples from diverse global contexts. Our findings emphasise the critical importance of this technology in shaping urban environments that are safer, more efficient, and more sustainable through innovative, data-driven solutions.**

Keywords – **Artificial Intelligence, Smart Cities, ITS, Sustainability, Traffic Optimization**

I. INTRODUCTION

Urbanisation is progressing at an exceptionally fast pace, leading to a growing concentration of people in urban areas. This trend places increasing pressure on transport networks, public safety systems, environmental resources, and city governance. Traditional urban management approaches are becoming less effective in addressing modern challenges such as traffic congestion, pollution, and inefficient service delivery.

In this context, Artificial Intelligence (AI) is emerging as a powerful tool for urban innovation. Cities are increasingly adopting AI technologies to support smarter decision-making, automate key operations, and enable real-time monitoring. These capabilities are especially valuable in sectors like smart mobility, intelligent transportation systems (ITS), and environmental management [4].

This paper explores the diverse ways AI contributes to the development of smart cities. It focuses on how technologies such as traffic control algorithms, autonomous vehicles, and predictive urban planning tools are helping to create safer, more efficient, and more sustainable urban environments. In addition, it highlights how AI works in combination with other advanced technologies—such as the Internet of Things (IoT), big data analytics, and cloud computing—to transform urban transport and public services.

II. THE IMPACT OF ARTIFICIAL INTELLIGENCE ON URBAN LIVING

Artificial Intelligence is transforming urban planning by supporting data-driven approaches to infrastructure development and resource allocation. AI-powered tools use advanced analytics and simulation techniques to evaluate key urban factors such as population growth, traffic flow, and environmental impact. This enables planners and decision-makers to base their strategies on accurate data and predictive insights, leading to more efficient and sustainable urban development.

By analysing demographic, economic, and geospatial data, AI systems can predict patterns of urban growth, align infrastructure development with future needs, and improve the overall quality of life in cities. A notable example is Barcelona, where AI-driven systems have been used to manage extensive urban datasets, supporting sustainable city planning and development efforts [3].

AI-based urban planning uses predictive modelling to simulate development scenarios, evaluate the potential impacts of proposed infrastructure projects, and optimise the allocation of public resources. This approach contributes to the creation of urban environments that are more adaptable, resilient, and better equipped to meet future challenges.

Key benefits of AI in Urban Environments:

- Enhanced Traffic Efficiency: AI technologies improve traffic flow by predicting congestion, dynamically adjusting traffic signal timings, and providing real-time updates to commuters. According to McKinsey & Company, AI-driven traffic management systems can reduce travel times in urban areas by up to 20% [4].
- Improved Public Transportation: AI enhances the performance and reliability of public transport systems by optimising routes and schedules in response to real-time demand. This leads to reduced waiting times, increased punctuality, and greater overall user satisfaction [5].
- AI contributes to lower emissions by reducing vehicle idling, decreasing fuel consumption, and optimizing mobility patterns. These improvements support the development of cleaner, healthier, and more sustainable urban environments[6].

III. INTELLIGENT TRANSPORTATION SYSTEMS AND ARTIFICIAL INTELLIGENCE

The rapid pace of urban expansion, coupled with growing mobility demands, has placed significant strain on traditional transportation infrastructures. This has resulted in widespread issues such as persistent traffic congestion, higher rates of road accidents, and environmental degradation due to increased emissions. Traditional traffic management systems often struggle to process large volumes of dynamic data and are typically reactive rather than proactive. As a result, their ability

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to effectively address the complex challenges of urban mobility is significantly limited.

The integration of Information and Communication Technology (ICT) and the Internet of Things (IoT) into urban transport systems has enabled the development of Intelligent Transportation Systems (ITS), which enhance mobility through real-time data exchange, automation, and system-wide connectivity.

ITS represents a comprehensive framework that utilises real-time data collection, processing, and communication to enhance the efficiency, safety, and sustainability of transportation networks. These systems integrate diverse data sources—including sensors, GPS devices, surveillance cameras, and wireless communication networks—to enable a holistic and adaptive approach to traffic management and public transit operations [11].

Artificial Intelligence significantly enhances the functionality of ITS by enabling advanced data analytics, pattern recognition, and predictive modelling. AI algorithms support adaptive traffic signal control systems that dynamically adjust signal phases in response to real-time traffic conditions, thereby alleviating congestion and reducing vehicle idle times. In addition, AI-driven predictive maintenance models analyse sensor data to anticipate component failures in vehicles and infrastructure, allowing for timely interventions that minimise service disruptions and improve operational safety.

AI also facilitates intelligent routing solutions that leverage both real-time and predictive traffic data to optimise route planning for public and private transportation systems. This adaptive routing approach enhances operational efficiency while improving the user experience by reducing travel times and increasing reliability.

Furthermore, machine learning techniques are employed to analyse large-scale mobility datasets, enabling the identification of travel patterns, the detection of hazards, etc. These insights support proactive maintenance planning and more effective emergency response strategies**.**

IV. Case Studies on AI-Smart Transport

The following case studies show how cities around the world are using artificial intelligence to improve transportation systems, make mobility more efficient, and solve urban challenges with smart, data-based solutions.

- Poznań, Poland: The city has implemented a comprehensive ITS that incorporates AI algorithms for centralized traffic management. The system gathers and analyses data from a wide network of sensors and cameras, allowing for real-time traffic signal optimisation and rapid incident detection. Empirical evidence shows a notable decrease in travel times and operational costs, along with improved responsiveness to traffic disruptions. Nevertheless, the system's effectiveness relies heavily on the reliability and accuracy of sensor data, emphasising the importance of strong data quality assurance measures [7].
- Hangzhou, China: Alibaba Cloud's ET City Brain represents a highly advanced AI-powered ITS, integrating deep learning, video analytics, and big data processing to manage traffic flow, public safety, and city services in real time. The platform has achieved a 92% accuracy rate in incident detection, reduced average commute times by approximately three minutes, and improved emergency response efficiency by up to seven minutes. By combining historical data with real-time inputs, the system provides predictive capabilities that maintain operational effectiveness even when data is incomplete [8].
- Austin and New York, USA: Both cities have adopted AI-driven ITS frameworks that include loop detectors, semi-active traffic signal controls, and AI-based incident analysis tools. These technologies have contributed to reducing congestion during peak hours and improving overall road safety. Furthermore, the integration of smart fare systems and vehicle tracking technologies has enhanced the efficiency of public transportation and improved the passenger experience.
- Stavanger, Norway: Marking a significant milestone in autonomous public transportation, Karsan launched Europe's first full-sized autonomous bus, operating without a driver on a predefined urban route and powered by the flowride.ai platform. In parallel, a pilot program in Munich—combining technologies from MAN and Mobileye—is testing autonomous buses to reduce energy consumption by up to 50%. These initiatives demonstrate the environmental potential of integrating AI into public transit systems, highlighting advancements in both efficiency and sustainability [9]

These diverse case studies highlight the versatility and scalability of AI-enhanced ITS solutions. They demonstrate that, whether addressing traffic congestion, optimising public transit, or advancing autonomous mobility, AI technologies play a central role in the evolution of contemporary urban transportation networks.

AI presents a significant opportunity for the Western Balkan countries to modernise key sectors such as transportation, healthcare, agriculture, and public administration. Although the region is still in the early stages of AI adoption, several countries—such as Serbia, North Macedonia, and Albania—have begun developing national AI strategies and pilot projects aimed at digital transformation. One of the key challenges remains limited infrastructure and investment, alongside the need to strengthen research capacity and digital skills. However, with targeted policy support, regional cooperation, and international partnerships, the Western Balkans have the potential to leverage AI for economic growth, improved governance, and alignment with EU digital development goals. The Western Balkans face urban challenges comparable to those in other rapidly growing regions, including increasing traffic congestion, inefficient public transportation, and the need for more sustainable resource management.

In recent years, several cities across the region have started to adopt artificial intelligence (AI)-based technologies to modernise transport systems and enhance the quality of urban life [11].

- Skopje, North Macedonia: With support from the European Union and local startups, pilot projects have been launched in the Western Balkans to implement intelligent traffic lights that use AI to analyse real-time traffic flow. In addition, public transportation mobile applications powered by machine learning now provide estimated bus arrival times, significantly enhancing the user experience and increasing the efficiency of public transit systems [10].

- Zagreb, Croatia: As part of broader digital transformation efforts, AI algorithms are being utilised to optimise public transport routes by analysing traffic data and passenger behaviour patterns. Additionally, integrated smart parking platforms that use AI to predict available parking spaces have had a notable impact in reducing congestion, particularly in central urban areas.
- Novi Sad, Serbia: Integrated smart parking platforms that use AI to predict available parking spaces have had a notable impact in reducing congestion, particularly in central urban areas. For example, Novi Sad, Serbia, has implemented a pilot system within its smart city initiatives that monitors pollution and traffic through connected IoT sensors and AI-based analytics. This system enables predictive mobility management and early detection of traffic incidents, contributing to improved traffic flow and environmental monitoring.

However, to ensure long-term impact, increased investment is required in digital infrastructure, data processing capabilities, and regional cooperation, particularly in the areas of standardisation and regulatory alignment.

Beyond improving operational efficiency, AI-enabled ITS play a vital role in supporting urban sustainability and safety objectives. The emergence of autonomous vehicles (AVs) marks a significant transformation within ITS ecosystems. AI algorithms are fundamental to AV functionalities, including perception, decision-making, and navigation, enabling these vehicles to operate safely and effectively in complex urban environments. Autonomous public transport solutions—such as driverless buses—are already being piloted and deployed in various parts of the world, indicating a future in which AI not only enhances existing infrastructure but also reshapes urban mobility paradigms.

Complementing the rise of autonomous vehicles, emerging technologies such as drones for aerial traffic monitoring, connected vehicle-to-everything (V2X) communication, and blockchain-based data security protocols are increasingly being integrated into ITS architectures. These innovations broaden the capabilities of AI-enabled urban mobility by enhancing situational awareness, enabling secure data exchange, and introducing new methods of transportation management.

However, the deployment of AI-driven ITS also raises important governance and ethical challenges. Robust governance frameworks are essential to address concerns related to data privacy, algorithmic transparency, accountability, and cybersecurity. Building and maintaining public trust is critical to ensuring the widespread adoption and long-term success of these advanced systems.

Instead of a Conclusion

Artificial Intelligence serves as a transformative catalyst in the creation of safer, smarter, and more sustainable cities. Its integration into urban infrastructure not only enhances traffic management and public transport efficiency but also enables cities to adapt dynamically to the changing needs of their populations. By mitigating traffic congestion and optimising mobility patterns, AI contributes significantly to the reduction of greenhouse gas emissions and fuel consumption, key drivers of environmental sustainability in densely populated urban areas. These advancements support the alignment of economic development with ecological responsibility, ultimately fostering more liveable, resilient, and future-ready urban environments.

Despite these substantial benefits, several challenges remain. Limitations in data quality and a lack of interoperability among diverse sensor networks can hinder the overall performance of AI-enabled systems. Moreover, the complexity and high initial costs involved in integrating legacy infrastructure with advanced AI technologies pose significant obstacles, particularly for municipalities with constrained financial and technical resources. Addressing these issues is essential to ensure the inclusive and effective deployment of AI across urban environments.

Future efforts should prioritise enhancing the robustness of AI models to effectively handle incomplete or noisy data, as well as the development of scalable and modular ITS architectures that can adapt to diverse urban contexts. Additionally, exploring hybrid human–AI control frameworks—designed to balance automated efficiency with human oversight—will be vital for ensuring safety, accountability, and flexibility in dynamic urban environments. A critical emphasis on sustainable AI, particularly through improving computational efficiency and minimizing energy consumption, will be essential to ensure that technological innovation aligns with broader environmental and climate goals.

Maximising the potential of AI in urban systems requires interdisciplinary collaboration among urban planners, AI researchers, policymakers, and community stakeholders. In particular, the integration of AI within Intelligent Transportation Systems (ITS) exemplifies how technology can address complex mobility challenges while contributing to broader urban development goals. Ultimately, the synergy between artificial intelligence and green technology is reshaping the future of urban living. It marks the beginning of a new era of intelligent, adaptive, and environmentally conscious urban ecosystems where technology not only enhances quality of life and public health but also drives sustainable development for future generations.

References

[1] Wang, J., & Zhang, L. (2024). Artificial intelligence in intelligent transportation systems: A systematic review. Journal of Intelligent Manufacturing and Smart Energy, 6(1), 23–45. Emerald Publishing. https://www.emerald.com/insight/content/doi/10.1108/jimse-11-2024-0035/full/html

[2] Atlas of Urban Tech. (n.d.). Hangzhou City Brain. Retrieved from https://atlasofurbantech.org/cases/chn-hangzhou/

[3] Kartsakli, E., & Mateu, J. (2023). AI for sustainability in Barcelona. Urban AI. Retrieved from https://medium.com/urban-ai/ai-for-sustainability-in-barcelona-cc5135d252d0
[4] McKinsey & Company. (2017). Shared mobility: Sustainable cities, shared destinies. McKinsey & Company. Retrieved from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/shared-mobility-sustainable-cities-shared-destinie
[5] World Bank. (2017). India: Mysuru's SMART public bus transport for livable cities. Retrieved from https://www.worldbank.org/en/news/video/2017/03/17/india-mysuru-s-smart-public-bus-transport-for-livable-cities
[6] Barcelona Supercomputing Center. (2023). BSC develops pioneering artificial intelligence method to fight urban air pollution. BSC-CNS. Retrieved from https://www.bsc.es/news/bsc-news/bsc-develops-pioneering-artificial-intelligence-method-fight-urban-air-pollution
[7] Intelligent Transportation Society of America. (2024). ITS Technology Use Case Library. ITS America. Retrieved from https://itsa.org/wp-content/uploads/2024/05/Use-Case-Library-Final_DI-Week.pdf
[8] Zhang, J., Hua, X.-S., Huang, J., Shen, X., Chen, J., Zhou, Q., Fu, Z., & Zhao, Y. (2020). City brain: practice of large-scale artificial intelligence in the real world. Frontiers of Information Technology & Electronic Engineering, 21(4), 522–537. https://doi.org/10.1631/FITEE.1900493
[9] Sustainable Bus. (2024). Karsan's e-Atak Autonomous, green light to enter regular traffic in Norway.
[10] Koltovska Nechoska D, Nechkoska, Petrevska R, Bogdanoska, Jovanovska M., Ai-Based Traffic Control and Management Systems: A Synthesis of Macedonian Research Experiences, Transportation Research Procedia 83 (2025) 513–519, Published by ELSEVIER B.V. https://doi.org/10.1016/j.trpro.2025.03.020
[11] Koltovska Nechoska D., Renata Petrevska Nechkoska, Mimoza Bogdanoska Jovanovska, Addressing trans-regional issues in ITS from managerial and technical perspectives, UKLO, 2023. ISBN-13 978-9989-786-67-9, 2022

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Professional Paper

Shared Mobility Systems in Support of Public Mass Passenger Transportation

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Abstract – **The topic of this paper is to present the concept of shared mobility as an innovative approach within transportation, specifically as a support for public mass transportation. In today's urban and rural environments, issues related to traditional transportation models are growing, prompting the search for innovative, sustainable, and efficient mobility solutions. In this context, the concept of shared mobility continues to evolve as an innovative approach that changes the way we move within and outside cities. This paper will present the key aspects of shared mobility, showcasing its various forms and its impact on mobility.**

Keywords – **shared mobility, public transportation, sustainable traffic**

I. INTRODUCTION

In recent years, we have witnessed transformations in urban areas all over the world, where old or traditional models of transport are being replaced by innovative and sustainable approaches to mobility. At the center of these changes is the concept of shared mobility, which emphasizes the sharing of resources and services to offer efficient and sustainable mobility solutions within the city itself and to reduce current congestion and emissions caused by traffic. Shared mobility includes a large spectrum of different forms of shared use of means of transport, some of which are "carsharing", "ridesharing", "bikesharing". This approach brings numerous benefits, including reduced costs to users, reduced number of vehicles on the road, environmental benefits, and increased accessibility and flexibility of transportation. Also, those systems encourage innovation and technological progress in transportation. Overall, shared mobility represents a key step towards a more efficient, environmentally sustainable and affordable transport system, which contributes to the overall progress of society and the environment.

II. SHARED MOBILITY AND ITS MODALITIES

Shared mobility is an innovative concept of services that allow users to share vehicles or instead own or using them exclusively privately. The very idea of shared mobility is to optimize the use of resources. Instead of each person owning their own vehicle that is unused most of the time, sharing systems allows the same vehicles to be used by several people, which simultaneously reduces the need for personal vehicles, increases the efficiency of use, and reduces traffic that burdens existing roads and parking lots. The reduction in the number of vehicles on the roads results in less congestion and a reduced need to build additional infrastructure. Ultimately, shared mobility has the potential to transform the traditional model of mobility in a way that is more economically sustainable, efficient and environmentally friendly. [1]

Some shared mobility concepts are described below.

1. **Carsharing** - is a car rental model in which people rent vehicles for short periods, usually by the hour. This type of service is attractive for users who rarely use vehicles, as well as for those who occasionally want to access a different type of vehicle than the one they use every day. [2]

Fig. 1. Car sharing system on Leipzig, Germany
Photo: P.Brlek

2. **Ridesharing** - is a transport service where several people share one vehicle to travel on a similar or the same route. This usually involves using a mobile app to connect drivers with passengers going in the same direction. A synonym for "ridesharing" is "carpooling". As a mode of travel, it is based on an agreement between two or more neighbors, friends, relatives or acquaintances that they will take turns driving to work or on a daily, weekly or monthly basis. All participants contribute to the fuel costs and other costs of the driver's car, resulting in a reduction in the number of vehicles on the road and traffic congestion.[3] An example of "carpooling" itself is the BlaBlaCar platform.
3. **Ridehailing** - the type of transportation which is most often included under "Ridesharing", but unlike that here Transportation Network Companies (TNCs), like Uber, Lyft, or Via, provide transportation for one or more people through applications and function similarly to taxis, and the service is charged according to a precisely determined tariff.

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4. **Bikesharing** - The bike sharing system is very similar to car sharing models. Users can access bikes for use when needed. Bike-sharing stations are usually self-contained, concentrated in urban areas and offer access from one station to another, i.e. bikes can be returned to any station. Such an approach is called "Station-based bikes". The principle of "Dockless bikesharing" refers to bicycle sharing with a single station that allows users to rent a bicycle and return it to any place within a predefined operational area, that is, to certain zones where bicycles can be freely parked.[4] Individual accesses offer various locations to pick up and return bikes. Most operators cover maintenance, storage and parking costs. Generally, rides of less than 30 minutes are included in the membership fee. Users join the bike sharing system on an annual, monthly and daily basis.
5. **Scooter sharing systems** - Electric scooters, are an increasingly popular means of transport in urban areas around the world. These scooters are powered by an electric motor that enables users to travel faster and more comfortably than with classic scooters. Their simple use, practicality and ecological aspect make them attractive alternatives for short trips in the city [5]. E-scooters are typically "dockless", meaning that they do not have a fixed home location and are dropped off and picked up from certain locations in the service area. They also provide convenient mode of transport for last-mile mobility in urban areas
6. **Mopeds** - play an important role in shared micro-mobility as a practical and agile means of transport over short distances in urban areas.

Fig. 2. Bike sharing system on Krk island, Croatia
Photo: P.Brlek

Mobility management is an important challenge for urban areas. Planners and policy makers are faced with financial constraints but also with conflicting requirements, such as maintaining a high quality of life while simultaneously creating an attractive environment for businesses, and limiting traffic in sensitive areas, such as the strict center of the city or the old city core, without these restrictions hindering the free movement of goods and people.- [6]

To turn the restrictions that exist in city traffic to the benefit of business entities, but also citizens, the mobility management plan must be clear, concrete and networked. Shared mobility offers the possibility of connecting several types of transport, and this is one of its most significant advantages, and it remains for local authorities to determine in which ways they will manage it to make it even smarter and more sustainable.

III. Analysis of Shared Mobility Systems in European Cities

According to data from the European market, shared mobility systems are growing year by year. These were systems that grew even during the Covid 19 pandemic, unlike other transport systems whose profits and the number of users fell by large percentages in those years. The data on revenue and the number of users of the shared mobility system at the European level are presented below.

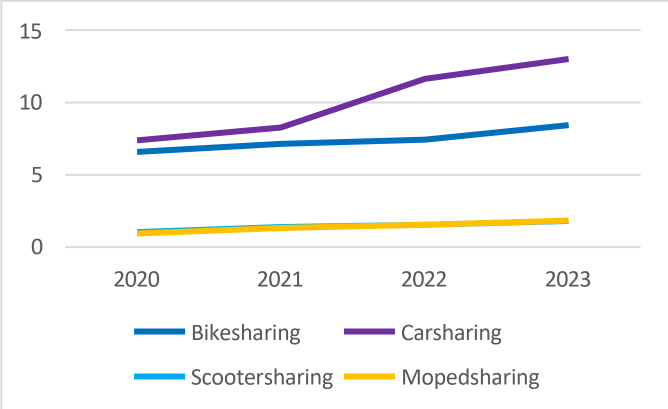

Fig. 4. Revenue of shared mobility systems in billion €
Source: [7]

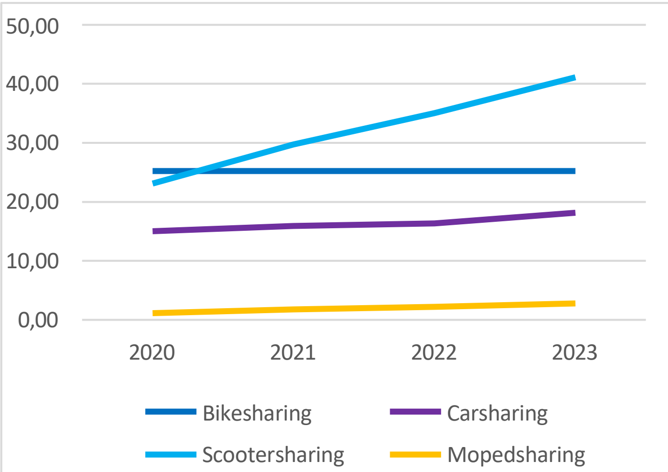

Fig. 5. Users of shared mobility systems in millions
Source: [7]

Figure 5 shows the movement of users of certain shared mobility systems. The biggest growth occurred in scooter sharing, where the number of users grew by almost 100%, that is, from 23.10 million users in 2020 to 41.10 million users in 2023. Other systems recorded a much smaller growth in the observed period.

The analysis of shared mobility systems in European cities explores various aspects of such systems. Researchers are studying the impact of these systems on reducing traffic congestion, improving air quality, encouraging sustainable forms of transportation, and overall contributing to the sustainability of cities. The analysis includes factors such as usage, financial viability, safety and traffic planning.

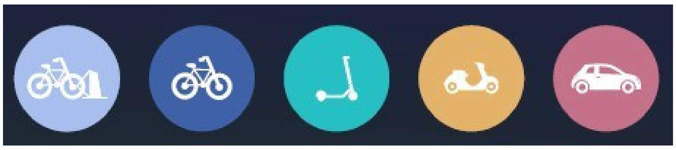

Fig. 4. Analyzed sharing systems
Source: [8]

Traffic safety is a complex issue that requires a wide range of approaches and cannot be achieved by police measures and actions alone. An interdisciplinary approach that includes the participation of different sectors of society is essential to achieve measurable results in improving traffic safety. As a key element of the overall safety of society, traffic safety also belongs to the area of national interest. Maintaining traffic safety has a great impact on society as a whole and requires the active participation of the wider social community, including educational institutions, technical experts, public services, technological innovators and citizens. Through the joint effort and cooperation of all relevant stakeholders, we can ensure measurable results and improve traffic safety as a key element of national interest.

Table I
PRESENTATION OF THE INCREASE IN THE NUMBER OF SHARED MOBILITY VEHICLES AND THE NUMBER OF TRIPS

	Number of shared mobility vehicles (in thousands)	Number of trips (in millions)
2020	450	245
2021	645	405
2022	870	545
2023	930	600

Source: [8]

Table 1 shows the increase in the number of shared mobility vehicles and their use expressed in the number of trips during the four-year period starting from 2020 to 2023 on the 115 cities observed in the EU. During 2020 and 2021, a significantly lower number of shared vehicles and number of trips than in 2023 is visible, which can be attributed to the COVID-19 pandemic. The situation of shared mobility has undergone significant changes. In some cities, the services of shared bikes, electric scooters and shared cars have been temporarily suspended due to reduced use and the need for social distancing. On the other hand, in other cities, these services have seen an increase in popularity as many prefer to choose individual forms of transport to reduce contact with others. Some cities have even expanded their bike lanes to encourage people to use bicycles as an alternative and safer mode of transportation during the pandemic. [9] In this way, the pandemic has affected shared mobility by encouraging service providers and users to adjust their habits and priorities towards greater safety and health protection, while at the same time cities have promoted sustainable and safe forms of transport in response to the emerging situation.

Of the observed cities, the majority (91) have at least one bicycle sharing system, while the least (35) have a moped sharing system. However, some cities have more than ten different sharing vehicle systems and are thus more acceptable to people with sustainable travel habits.

According to the data presented, the number of vehicles and rides increases from year to year, but not all systems are well received. Thus, due to the ban on the use of scooters in Paris, scooter operators had to turn to dockless bikes. For this reason, the reduction of scooter fleets in some other cities in 2023. the number of dockless bikes increased by 50%. Despite various regulations reducing the number of vehicles in larger cities, the rest of the fleet is transferred to smaller cities, which thus get the opportunity to get to know sustainable forms of transport. In this way, scooter fleets generally do not shrink. Mopeds are mostly used in Spain and Italy, and the attempt to open the market in Eastern Europe ended badly due to vandalism and theft, so in 2023 the moped fleet was generally reduced by almost 30%. Carsharing is most prevalent in large German cities, and in the observed year, the fleet increased by 25% while the number of rides increased by almost 40%. [8]

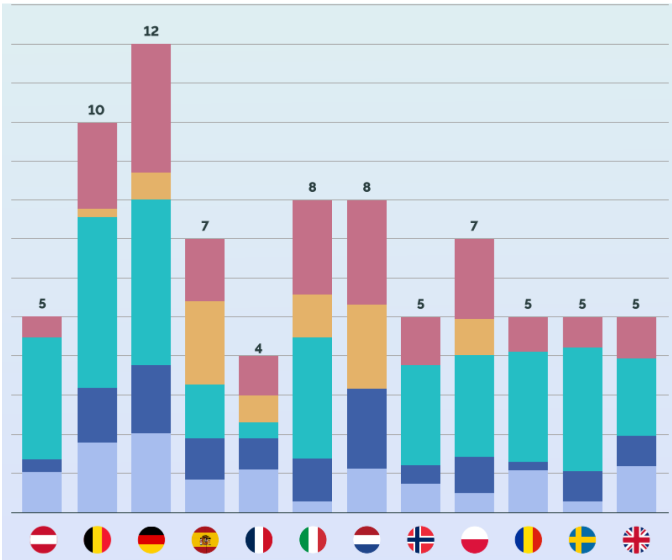

Fig. 2. Average number of services per city in 2023
Source: [8]

IV. CONCLUSION

Shared mobility is changing the traditional mode of transportation because it has the potential to create a shift towards social, environmental and economic efficiency using technology. The new situation has put pressure on conventional transport companies (bus operators, taxi companies, etc.) to improve and modernize their services in order not to lose their customers, as well as on local authorities to ensure proper regulation, licensing and taxation. Shared mobility and micromobility hubs, along with traditional public transport terminals, form modern passenger and freight transport systems and encourage residents to use sustainable forms of transport.

In recent years, there has been a lot of controversy regarding the regulation of technologies and services related to shared mobility modes, especially in relation to transportation network companies that offer ride-hailing or ride-sharing services. Such problems arise from the increasing time gap between the development of innovations and regulatory responses, which puts pressure on policy makers and local authorities to find a balance between governance, regulation and control that allows innovations in urban mobility to be integrated into transport systems.

On the other hand, transport users are increasingly demanding in terms of reliability, flexibility, availability, comfort and cost of their transport choices. In addition, environmental issues are becoming increasingly important among the urban population, and the arrival of innovative mobility solutions can satisfy these aspirations. The current transport sector must be resilient in order to develop the ability to adapt to new circumstances, adopt new technologies and find ways to meet the current and future needs of its customers. Then shared mobility services can be considered a challenge, but also an opportunity to change urban life in an unprecedented way.

Even though ride-on-demand services are the shared mobility modality that generates the most media attention, this does not mean that other shared modes are unimportant. On the contrary, in large urban centers there is room for many mobility options, which can act as complements rather than competitors, improving the transport offer and expanding the range of user choice.

By expanding the range of shared systems and combining it with MaaS to tourist destinations, it is possible to significantly increase the use of these forms of mobility. [10] As for future research, it would be interesting to develop some indicators to assess the effectiveness of shared modes of transportation in reducing traffic congestion and air pollution levels. Additionally, stated preference experiments could provide valuable insights into how shared mobility services can complement traditional public transport. These experiments would help identify the attractiveness of different shared mobility options for users, ultimately contributing to more effective and sustainable transport planning. [11] Also, a survey of shared mobility users can be conducted to find spatio-temporal patterns of shared trips/rides, travel behavior patterns, and how integration of shared modes with traditional transportation options can be achieved.

References

[1] C.A Soares Machado, N. P. M de Salles Hue, F. Tobal Berssaneti, J. Alberto Quintanhilha, An Overview of Shared Mobility, 2018. p. 1-21

[2] Shaheen, S.; Cohen, A.; Martin, E.U.S. Department of Transportation's Mobility on Demand Initiative: Moving the Economy with Innovation and Understanding; Transportation Research Circular: Washington, DC, USA, 2018.

[3] Hahn, Robert, and Robert Metcalfe. "The ridesharing revolution: Economic survey and synthesis." *More equal by design: economic design responses to inequality* 4 (2017).

[4] Brlek, P., Krpan, Lj., Cvitković, I., Maršanić, R.: The public bicycle system as an indicator of successful sustainable mobility in cities – 38. Meeting on transport systems with international participation "Automation in traffic", Osijek, 2018

[5] Milas, Nikola. "Izmjene Zakona o sigurnosti prometa na cestama u 2022. godini s posebnim osvrtom na nove kategorije vozila – električni romobili." *Policija i sigurnost*, vol. 31, br. 3/2022, 2022, str. 397-413. https://hrcak.srce.hr/285053.

[6] European court of auditors (2020), Special Report: Sustainable Urban Mobility in the EU: No substantial improvement is possible without Member States' commitment, https://op.europa.eu/webpub/eca/special-reports/urban-mobility-6-2020/en/index.html

[7] Shared Mobility: market data & analysis, Market insights report, Statista, 2024, https://www.statista.com/study/40459/mobility-services-report/

[8] European Shared Mobility, Annual Review 2023, Fluctuo, 2024

[9] Brlek, P., Cvitković, I, Martinčević, I., Kos, G.: Economic Aspects of the Covid-19 pandemic on external transport costs, 61st International Scientific Conference on Economic and Social Development – "Corporate social responsibility in the context of the development of entrepreneurship and small businesses", Varaždin, 2020

[10] Martinčević, I.; Brlek, P., Domjan Kačarević, N.: Mobility as a Service (MaaS) as a Sustainability Concept for Tourist Destinations. Sustainability, 14 (2022), 12; 7512, 20 doi:10.3390/su14127512

[11] Kožul, N., Novačko, L., Babojelić, K.: Assessing preferences for the introduction of a new tram line on University of Zagreb campus using stated preference experiment – Road and Railn Infrastructure VIII, Proceedings of the Conference CETRA 2024, 2024 p 901-907, doi:10.5592/CO/CETRA.2024.1585

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Professional Paper

Concept of an Integrated Timetable in the Area of the City of Varaždin, Croatia

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Abstract – **The city of Varaždin is the regional center of Varaždin County with its administrative, economic, educational, health, administrative and other important facilities. One of the first steps in creating a quality public transport system is the implementation of an integrated passenger transport system, which, in addition to the quality of travel, accessibility of destinations and frequency of departures, opens up new mobility options, which contributes to a better standard of living for residents.**

Keywords – **Public transport, City line network, Modal split, Portfolio of transport tickets, Economic sustainability**

I. INTRODUCTION

The city of Varaždin, as the regional center of Varaždin County, is located in the north of the Republic of Croatia and serves as an administrative, economic, educational, healthcare, and administrative hub for over 43,000 residents across a total of 10 settlements. Public urban transport by city buses in the area is currently operated under a municipal transport contract. However, this system is not attractive to a large number of passengers due to inadequate route planning, a non-integrated timetable, long travel times, and insufficient quality travel information. Therefore, one of the key elements of quality urban development is the creation of a sustainable transportation system for the city and the region, based on the principles of sustainable mobility. In this development, a well-structured public transport system is essential, which in the future should become the dominant mode of transportation for residents. This paper focuses on urban bus public transport, considering its quality and long-term development, as well as assessing the economic and other elements of its long-term sustainability. Given these considerations, it is necessary not only to optimize the existing public transport system by defining an optimal network of urban and suburban bus lines within the city but also to establish a modern public transport system that is attractive to users, offers quality and comfort in travel, and at the same time is climate-neutral with minimal environmental impact.

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The aim of this paper is to demonstrate how a high-quality public transport system can be established at the regional level, grounded in efficient route planning and the implementation of an integrated and synchronized timetable, which allows for seamless transfers between lines and significantly improves accessibility across the entire region. The scope of the study focuses on the city of Varaždin, for which a new public transport system has been proposed, and all necessary research has been conducted to facilitate its development. The methods used in this study include data analysis and synthesis, generalization, compilation, surveying, statistical analysis, observation and counting methods.

II. EXTERNAL TRANSPORT COSTS AND THE ADVANTAGES OF USING PUBLIC TRANSPORT SYSTEMS

It is well known that transportation generates a certain amount of external costs, which are not only paid by transport operators or users but also burden other sources, most often local, regional, national, and federal budgets. [1] According to the Handbook on External Costs by the European Commission, the total external costs of transport in EU countries amounted to €841.1 billion in 2016, which represents 5,7% of the total gross national product of the entire EU. [2] Consequently, transport has a significant devastating impact on human health, climate change, and environmental quality. However, public passenger transport generates significantly lower levels of harmful effects compared to private cars while delivering the same transport efficiency. Regarding space usage, particularly in urban areas, all sustainable modes mainly walking, cycling, and public transport offer substantial advantages over individual car travel.

External transport costs include expenses related to traffic accidents, air pollution, climate change, noise damage, congestion and delays, processes for the production and distribution of propulsion energy, destruction of nature and landscapes, water and soil pollution, biodiversity losses, and other similar costs. [3] The average external cost of transport in the EU for one passenger kilometer when using a private car is 12,6 eurocents. In contrast, the cost for urban and suburban buses within the EU averages 3,8 eurocents per passenger kilometer. [2] Thus, a well developed public transport system, through its operation and reliability, provides citizens and consequently the economy with a great number of direct and indirect positive effects that can be quantified. [4] Transport marginalization, which leads to social exclusion, has consequences that also affect an individual's success in education and professional careers. [5]

A statistically significant correlation has been observed between transport marginalization and students' academic performance, with results also indicating its impact on how they spend their free time. This means that they are deprived of certain educational opportunities, particularly extracurricular activities, which results in partial or complete social exclusion from specific experiences and life opportunities. [5]

III. ANALYSIS OF THE EXISTING MUNICIPAL PUBLIC BUS TRANSPORT SYSTEM

According to data from 2021, the total population density of the city of Varaždin is 731 inhabitants/km², while with the surrounding settlements, it reaches 1,269 inhabitants/km². This indicates that public passenger transport is feasible in the area. Additional feasibility is provided by the gravitational pull of residents from the neighboring Međimurje County, which has a density of 144,38 inhabitants/km². Entrepreneurs in the city employ a total of 5,269 workers, excluding those employed in the public sector, who commute daily to and from work. Other demand generators include educational, recreational, and tourist facilities. Tourism, as an important sector in Varaždin County, requires mobility within the destination, where public transport can offer a sustainable solution. An analysis of the existing municipal public transport network in Varaždin was conducted in January 2024 and characterized as a commuting network with numerous inadequately routed lines, resulting in low travel attractiveness. The lack of attractiveness stems from the fact that some routes are designed in a way that certain destinations can be reached faster on foot, while others follow a circular route in one direction or have a partially circular section. This design allows for quick one-way travel between certain stops, but return trips require completing the full loop, making travel times two to three times longer than walking the same distance.

Commuter public transport operates mainly during peak hours, connecting dispersed locations (settlements) within a region to central hubs (main destinations). In contrast, a regular public transport system consists of a large number of well-routed, interconnected lines, allowing for transfers throughout the day and significantly improving accessibility and connectivity compared to a commuter-based system. [6] A comparison with the current network in Varaždin indicates that the city's bus lines are predominantly commuter-based, with inadequate routing. Further analysis of connections at key nodes revealed that transfers between most lines in the system are not possible. Even when transfers are feasible for one-way travel, they become impractical in the opposite direction, as waiting times at key nodes often exceed 30 minutes, making the system unattractive. These issues, along with poor routing, significantly reduce the overall accessibility of the transport system. The analysis of existing timetables also revealed irregular frequencies and a very limited number of departures per route. This leaves large parts of the evening without service, making it difficult for residents to return home from work, participate in recreational and cultural activities, and further reducing the system's attractiveness. Additionally, timetable analysis identified long and impractical bus stop names, often containing full addresses.

Furthermore, bus stop names differ for trips in opposite directions, making navigation within the system more difficult for users. A comparison was also made between traffic count data from the Croatian Roads Traffic Count Report (2022) and the Evaluation of the Sustainable Urban Mobility Plan of the City of Varaždin (2023). The latter study conducted traffic counts at key intersections in Varaždin on Tuesday, January 10, 2023. It analyzed the flow of personal vehicles, light and heavy freight vehicles, buses, motorcycles, bicycles, and pedestrians over six hours in three distinct time periods. The analysis concluded that the total number of vehicles has increased despite a decrease in the population both in the city and across the county.

Key findings from the Evaluation of the Sustainable Urban Mobility Plan of the City of Varaždin (2023) include that the most congested routes leading into the city center are Zagrebačka and Optujska streets, with increased traffic compared to 2017; that traffic congestion has also intensified in the city's first ring road, particularly in Augusta Cesarca Street; that the highest pedestrian numbers were recorded near major trip generators such as schools, universities, hospitals, and similar locations; that the percentage of cyclists was very low, likely due to winter weather conditions and the lack of cycling infrastructure; that the modal share of car traffic was as high as 83%, while public transport use accounted for less than 1%. Despite high mobility levels on city streets and entry points, a significant number of potential public transport users exist, provided that an adequate transport system is offered.

At the main bus station in Varaždin, a passenger count was conducted to analyze travel flows into and out of the city, which significantly impact overall traffic patterns. This analysis covered departures and arrivals in county bus services, as well as some inter-county routes. In 2022, the municipal public transport system recorded 75,802 passengers. In 2023, there was an 11,76% increase, with 84,714 passengers using the system.

A survey was conducted to assess potential transport demand, including two questions about public transport preferences. Question 38: "If a public transport system existed in your area, where a single ticket could be used for trains and buses (both county and city services), with synchronized timetables allowing for easy transfers, a well-developed network covering a large area, affordable fares, and departures every hour or more frequently from early morning until midnight, would you change your travel habits and use public transport?" 53% of respondents answered "Yes", while another 32% answered "Maybe". Follow-up question: "To what extent would you use such a public transport system as described in the previous question?" 73% of respondents stated that they would use such a system as much as or more than their personal car, or would even switch entirely to public transport. These responses clearly indicate that a significant portion of Varaždin residents have both the desire and the need for a modern public transport system with high availability and frequent services. Therefore, it is necessary to design public transport networks that offer frequent departures, seamless transfers, and full accessibility throughout the day.

IV. PROPOSAL FOR A NEW OPERATIONAL CONCEPT

The new proposal for the municipal urban bus transport network has been designed to ensure maximum possible accessibility, covering the entire county. The developed proposal is supported by survey results from the broader Varaždin area and aligns with the strategic objectives of the Sustainable Urban Mobility Plan of the City of Varaždin (2018) and the Master Plan for Integrated Passenger Transport (2017). The new network of lines is based on the principle of an integrated clock-face timetable, meaning that the departure intervals in the same direction are set to a constant value (time interval), depending on transport demand levels, vehicle capacity, and similar factors.

The integrated clock-face timetable is characterized by structured, identical planned time intervals for subsequent services. Services are periodic, with a precisely determined and equal time gap between them. Theoretically, the time intervals do not have to be the same for different services, but to fully utilize the systematic benefits of periodic scheduling, intervals are usually equal or integer multiples of a base time period. The period or time interval can take any value, and for regular and consecutive public transport services, it reflects either the total travel time on a route or an integer portion of it. Where possible, departures can be scheduled at round-number intervals, such as every 60 minutes. In this case, passengers only need to remember the departure minute, for example, 12 if trains from City X depart at 7:12, 8:12, 9:12, etc. [7]

The application of an integrated clock-face timetable enables easy transfers for passengers at key transport hubs (provided that all necessary infrastructure conditions are met), while connections between different lines and modes allow users to continue their journey to their final destination. If combined with a Transit-Oriented Development (TOD) approach, integrating walking-public transport-walking travel options, the system ensures high regional accessibility and significantly enhances the attractiveness of public transport. The time of departure and arrival of trains at the final hub stations at regular time intervals is called tact running time. The specific scheduling interval depends on transport needs, and the number of passengers on a given route.

A clock-face timetable aims to synchronize all lines at a single hub so that they depart at approximately the same time. This means that railway traffic should be organized so that all trains from different directions serve key railway hubs around the same time. At these railway hubs, trains from all directions converge at regular intervals, offering passengers multiple options for onward travel immediately upon arrival. This is illustrated in Figure 1. A clock-face timetable increases the speed of travel within the network, reducing waiting times for transfers.

Another example of transfers between two feeder lines and a mainline is shown in Figure 2, demonstrating the advantages of an integrated clock-face timetable, which allows seamless transfers between all lines meeting at a given hub.

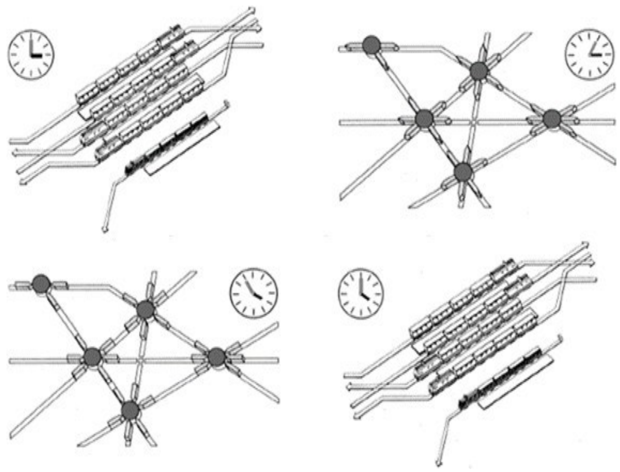

Figure 1. Diagram of the functioning of an integrated clock-face timetable, where synchronized arrivals at hubs, transfers between all trains, and connections between all trains at all hubs are enabled. Source: [8]

Due to the implementation of an integrated clock-face timetable, all transfers between all lines can be repeated at regular time intervals. The diagram also presents key questions that a public transport user must have answered to obtain essential information for their journey.

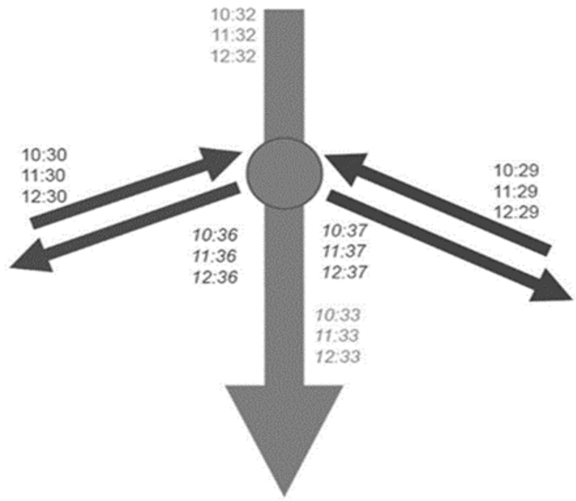

Figure 2. Example of an integrated clock-face timetable at a hub where three lines meet, allowing transfers between all three lines. Source: Original work

Such a system enables the continuous repetition of times throughout the day when all vehicles from all lines passing through a hub actually arrive at the hub. This ensures that passengers can transfer from any line to any other line. By enabling transfers at key hubs through the application of a clock-face timetable, passengers can reach any destination (station or stop) within the system.

Therefore, the integrated clock-face timetable system ensures complete spatial and temporal accessibility across the entire region where it is implemented.

A. Graphical Representation of the New Transport System

The foundation of the proposed system consists of urban municipal passenger transport lines. According to the Road Transport Act (2022), public passenger transport by road is defined as a service provided using M1 category vehicles with a capacity of seven + one or eight + one passenger seats, provided they are equipped with a tachograph in compliance with Regulation (EU) No. 165/2014 of the European Parliament and Council (February 4, 2014) concerning tachographs in road transport, repealing Council Regulation (EEC) No. 3821/85 on tachographs in road transport, and amending Regulation (EC) No. 561/2006 on the harmonization of certain social legislation relating to road transport. Additionally, M2 or M3 category vehicles may be used on certain routes, following a pre-determined timetable, pricing structure, and General Transport Conditions. This service is considered a public economic service and a public good provided in the public interest by the Republic of Croatia to meet public transport needs.

A municipal public transport system is proposed, which, according to the Road Transport Act (2022), refers to public road transport within a single local government unit. Such services may operate non-stop across neighboring local government units if required by the road network and are conducted under a public service contract in accordance with Regulation (EC) 1370/2007 and the Municipal Economy Act. In Varaždin, the Department of Construction and Municipal Affairs is the responsible local authority overseeing this service.

In the city of Varaždin, the core of public transport should be a network of urban municipal public transport lines with regular and frequent departures at consistent intervals throughout most of the day. The potential for regular passenger transport has been proposed in two variants: optimal and minimal and both utilizing the same network layout but differing in the number of departures. The proposed new transport network is illustrated in Figure 3.

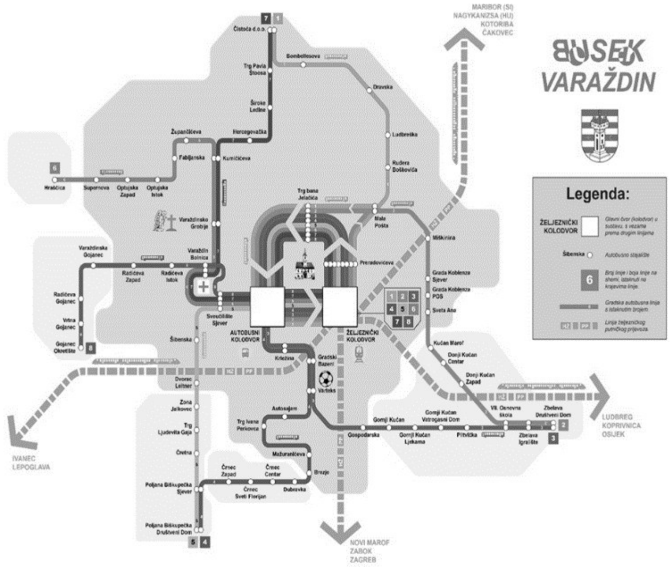

Figure 3. Proposed network of urban municipal public transport lines in Varaždin
Source: Original work

This network is designed as a radial network, meaning it extends outward radially from a central key hub toward the periphery and endpoints. The routing has been planned to maintain efficient travel times between stops and endpoints while ensuring comprehensive coverage of urban neighborhoods. The vast majority of households, institutions, and workplaces are within a 10-minute walking distance of a bus stop in the system.

This network variant has been designed to be operational in a short timeframe with minimal infrastructure adjustments, requiring only minor modifications to some bus stops. No major roadwork or intersection modifications are necessary. Additionally, the network is structured to facilitate an integrated clock-face timetable.

All bus lines converge at a single central hub, the former City Bus Terminal, which, in the new system, is renamed the Railway Station. The planned timetable for both variants has been structured so that each departure allows seamless transfers between all lines, facilitating smooth onward and return journeys. Bus stop names have been simplified and improved, unlike the previous network, which had 20 stops with departures in only one direction, significantly limiting return trip options. This issue has been completely resolved in the new system.

In the new proposed network, routing has been significantly improved and there are no circular routes. Scheduled travel times are designed to be achievable even during peak traffic congestion. The network also highlights a segment of the railway system, showcasing the potential for integrated passenger transport, which could be enhanced through a joint fare agreement with the railway operator.

B. Timetables and Proposed Vehicles

The optimal proposed timetable includes a total of 19 round trips per day. Departure frequency is every 60 minutes, ensuring a consistent service standard throughout the day while allowing for transfers between all lines at the key hub during each departure. According to survey results, where over 77% of citizens stated they would use a quality public transport system as much as or more than a private car, or even exclusively use public transport, it is evident that there is a demand for high-quality public transport.

Traffic counts at key intersections in Varaždin showed that during peak hours, over a six-hour measurement period, the total number of vehicles on the main corridors of the city's peripheral areas was 55,972 in both directions. With an average car occupancy of 1,2 passengers per vehicle, this represents 67,166 trips in both directions within the same time frame. Even with a modal shift of just 1%, this would amount to 671 trips. Combined with the existing approximately 400 passengers per weekday in the current public transport system, this brings the total to nearly 1,100 daily trips, enough to fully occupy almost 14 suburban buses of 12 meters in length. Based on these data, for the first phase of improving municipal public transport in Varaždin, it is optimal to select a fleet of low-floor city buses with at least two wide double doors and a capacity of 75 to 85 passengers (both seated and standing).

In later phases, when passenger numbers increase, it may be necessary to introduce higher-capacity vehicles, such as M3+ category articulated buses, 18 meters in length, with a capacity of approximately 130 passengers.

According to Figure 3, each of the 8 routes requires one vehicle to maintain the daily schedule. This means that 8 vehicles are required to operate the full timetable, with a recommendation for two additional backup vehicles, bringing the total to 10 vehicles in the proposed public transport system. Fleet management should involve rotating active and reserve vehicles to ensure that all buses accumulate an equal number of kilometers annually.

C. Economic Framework for the Proposed System

Total costs for each route have been calculated based on the assumption that most lines operate on a clock-face timetable with departures every 60 minutes. The Ministry of the Sea, Transport, and Infrastructure of the Republic of Croatia co-finances the costs of county passenger transport up to 75% of reported expenses per month or year, provided that the operations are governed by a public service contract, in accordance with EU Regulation 1370/2007. It is expected that a similar funding model will be applied in the future for municipal public transport, provided that it operates under public service contracts and is integrated with railway and county transport services. The long-term goal is to establish integrated passenger transport systems across Croatian regions, also governed and regulated through public service contracts in line with EU Regulation 1370/2007.

The cost per bus/day calculation is based on total vehicle operating costs, including driver salaries. The average daily cost per bus is derived from the Study "Minimum accessibility standards in public passenger transport in road transport in the Republic of Croatia", which states that M3 category buses operating at least 360 days per year and covering over 600 km per day had an average daily cost of €499,42 (excluding VAT). Adjusted for vehicle purchases without depreciation costs, the cost per bus/day amounts to €429,50. This serves as a baseline for realistic cost calculations.

The cost per kilometer method is based on a fixed price per kilometer traveled. The most recent cost proposal from the Ministry and transport associations was €1.81 per kilometer for M3 buses. Since fixed costs make up about two-thirds of total operating costs, while variable costs account for one-third, costs do not increase linearly with the number of kilometers traveled but gradually decrease, following a logarithmic growth pattern. However, fixed cost per kilometer calculations are not fully accurate, as the average per-kilometer cost decreases with increased total mileage. According to the 2023 inflation calculator from Croatia's Central Bureau of Statistics, inflation from September 2018 to October 2023 was 25,9%. It is recommended that all cost estimates be adjusted for inflation, and that the state budget allocation for public transport be increased accordingly to match rising operational costs. In conclusion, funding for the public transport system is proposed from the following sources: state budget of the Republic of Croatia, local government budget, revenue from ticket sales or other revenue streams.

D. Proposal for a Fare System and Ticketing Portfolio

The fare zone structure has been defined to include a single unified zone within the city of Varaždin. The attractiveness of the public transport system depends on its financial affordability, making it particularly important that seasonal, monthly, and annual tickets remain reasonably priced. It is proposed that public transport tickets be available for purchase at: bus station ticket offices, public administration offices, tourist information centers, bus drivers and retail stores. In addition to paper tickets, it is strongly recommended to develop smart cards for public transport and to introduce the possibility of purchasing tickets online via a website or mobile application. The optimal revenue model from ticket sales is presented in Table 1.

Table 1.
Estimated annual revenue from public transport ticket sales for the proposed fare system in municipal public transport in Varaždin (optimal scenario)

	Tickets sold		**Revenues**	
Type of transport ticket	**Monthly**	**Per year**	**Monthly**	**Per year**
Unit	300	3000	270,00 €	2.700,00 €
Daily	1000	10000	1.800,00 €	18.000,00 €
Weekly	200	2000	1.180,00 €	11.800,00 €
Monthly	1000	10000	14.900,00 €	149.000,00 €
Annual		250	0,00 €	37.000,00 €
			Total:	**218.500,00 €**

Source: Original work

The revenue estimate is primarily based on the optimal timetable variant. If the network is not integrated, timetables are not harmonized, and the proposed fare structure is not applied, the projected revenues will not be achieved under any scenario. Any costs not covered by ticket sales are supplemented by public administration, specifically the City of Varaždin. For its investment, the city gains multiple benefits from public transport, including urban development improvements that often far outweigh the costs. Implementing the proposed measures can lead to the predicted revenues, along with additional actions such as:

- Promotional campaigns encouraging public transport use via various media channels (TV, print, flyers, posters, email promotions, social media, etc.);
- Printed and online information resources on using the system, planning trips, and selecting the appropriate ticket type;
- Educational campaigns targeting youth, students, retirees, and employees, highlighting the advantages of public transport and teaching how to plan and use the system efficiently;
- Educational and awareness campaigns for young children on safe public transport usage;
- Public forums and events promoting public transport through media coverage.

V. CONCLUSION

One of the first steps in creating a high-quality future public transport system in northern Croatia, which should ultimately be an integrated passenger transport system, is the establishment of a well-structured and long-term sustainable municipal urban public transport system. Such a system must ensure travel quality, destination accessibility, frequent departures, and comprehensive travel information, while also minimizing environmental impact.

The legal framework allows cities and municipalities to organize public transport within their administrative boundaries. This can be managed independently by a single local authority or jointly by multiple municipalities. Currently, Varaždin's municipal public transport system accounts for fewer than 90,000 trips annually. The modal share of public transport is just 0,86% of total passenger kilometers, compared to 83,35% for private cars. Each day, over 67,000 car trips are made between the city and the surrounding region, indicating significant potential for a high-quality public transport system to capture a portion of these trips. A more efficient public transport system would bring many benefits to the city and region:

- Lower pollution and reduced climate impact due to fewer car trips;
- Improved road safety by reducing traffic accidents;
- Reduced congestion in the city;
- Higher social inclusion by offering accessible travel options.

Survey results indicate that nearly 54% of citizens would use a high-quality public transport system with frequent departures every 60 minutes and comprehensive coverage of key destinations. The current system's limitations stem from only 8 departures per day per route on 5 lines and inefficient routing leading to longer-than-necessary trips. To address these issues, a new network of 8 lines has been proposed, with more logical route planning along key corridors, ensuring public transport is faster than walking but also an improved timetable with 19 return trips per day, allowing departures every 60 minutes throughout the day.

Final conclusion is that public transport improvements in Varaždin are essential for achieving the city and region's transport, economic, environmental, and social sustainability goals. Economic sustainability is ensured through potential modal shifts, increasing public transport usage, fostering social inclusion, and enhancing overall quality of life.

REFERENCES

[1] Klečina, A., (2020), Sustainable mobility measures in spatial planning implementation documents - the example of the municipality of Trnovec Bartolovečki, Koprivnica: University of North, Master's thesis

[2] Handbook on the external costs of transport (2019), Brussels: European Commission, Directorate-General for Mobility and Transport

[3] Huib, E., Schroten, A., Matthijs, O., Sutter, D., Schreyer, C., Zandonella, R., Maibach, M., Doll, C. (2011), External costs of Transport in Europe, Update Study for 2008, Delft: CE Delft, Infras, Fraunhofer ISI

[4] Petar, S., Klečina, A., Kaniški, I., Grgurević, D., (2019)., Integrated passenger transport as a measure for increasing service quality, Pula: Proceedings, 20th International Symposium on Quality, Quality – Yesterday, Today, Tomorrow, 20-22. 3. 2019.

[5] Gašparović, S. (2014), The impact of traffic marginalization on the everyday life of the secondary school population of the city of Zagreb, Zagreb: University of Zagreb, Faculty of Science, Department of Geography, doctoral thesis (dissertation)

[6] Vuchic, V. (2007), Urban transit systems and technology, Hoboken, NJ: Wiley & Sons

[7] Tzieropoulos, P. et al (2008), Quality of cadence, in Diagnostic, Feedback on the implementation of the 2008 cadence in Rhone Alpes, EPFL-LITEP, Lausanne (restricted diffusion)

[8] Georges, R. (2007), Development of the ITF Beginnings – Present – Future, Railway Technology Colloquium

OTHER USED LITERATURE

Booth, D., Hanmer, L. and Lovell E. (2000), Poverty and Tansport, A Report Prepared for the World Bank in Collaboration with DFID. Overseas Development Institute, London, UK

Botma, H., Papendrecht, H. (1991), Traffic operation of bycicle traffic, Freeway operations, highway capacity, and traffic flow, Transportation Research Record, Issue Number: 1320, Publisher: Transportation Research Board, ISSN: 0361-1981, p. 65-72

Currie, G., Richardson, T., Smyth, P. et al. (2009) Investigating links between transport disadvantage, social exclusion and well-being in Melbourne–preliminary results. Transport Policy 16(3): 97–105

Feigon S., Murphy, C. (2016), Shared mobility and the transformation of public transit, Transportation Research Board, Transit Cooperative Research Program Research Report

Grava, S., (2004), Urban transportation systems, Choices for communities, New York, McGraw-Hill

Hine, J., (2009), Transport and Social Exclusion. Elsevier, Newtownabbey, UK

Klečina, A., (2018), Framework for developing a marketing plan for integrated passenger transport in the area of the future North Traffic Administration, Koprivnica: University of North, final thesis

Lucas, K., Mattioli, G., Verlinghieri, E., i Guzman, A. (2016), Transport poverty and its adverse social consequences, Proceedings of the Institution of Civil Engineers, Transport 169 December 2016 Issue TR6, P. 353–365

Lucas, K. and Markovich, J. (2011) International perspectives, In New Perspectives and Methods in Transport and Social Exclusion Research (Currie G (ed.)). Emerald, Bingley, UK, pp. 223–239

Martens, K., (2013), Role of the bicycle in the limitation of transport poverty in the Netherlands. Transportation Research Record 2387: 20–

Martens, K. and Bastiaanssen, J. (2014), An index to measure accessibility poverty risk. Proceedings of Colloquium Vervoersplanologisch Speurwerk, Eindhoven, the Netherlands

Mock, A.; Thill, J.-C., (2015) Placement of Rapid Transit Park-and-Ride Facilities. Transp. Res. Rec. J. Transp. Res. Board 2015, 2534, 109–115.

Mohideen N. (1996), Stability analysis of cyclic timetables for a highly interconnected rail network, PhD Thesis N° 1435, EPFL, Lausanne

Ortega, J., Tóth, J., Péter, T., (2021), Planning a Park and Ride System: A Literature Review, Future Transp. 2021, 1(1), 82-98; https://doi.org/10.3390/futuretransp1010006

Parkhurst, G., (2000) Influence of bus-based park and ride facilities on users' car traffic. Transp. Policy 2000.

Parkhurst, G., Meek, S., (2012), The Effectiveness of Park-and-Ride as a Policy Measure for More Sustainable Mobility. In Transport and Sustainability; Emerald Group Publishing Limited: Bingley, UK, 2014; pp. 185–211.

Road Transport Act (2022)

Scheiner, J., (2008), Accessibility, spatial context and location preferences: is there evidence for accessibility poverty? In How to Define and Measure Access and Need Satisfaction (Becker U, Böhmer J and Gerike R (eds)). Transport Series of Dresden Institute for Transportation and Environment (DIVU), Dresden, Germany, pp. 193–225

Schwieterman, J. P., Livingston, M. ,Van Der Slot, S. (2018), Partners in transit: A review of partnerships between transportation network companies and public agencies in the United states. Tech. rep., Chaddick Institute for Metropolitan Development, Depaul University, Policy Series

Study "Minimum accessibility standards in public passenger transport in road transport in the territory of the Republic of Croatia" (2018), Zagreb, Ministry of the Sea, Transport and Infrastructure of the Republic of Croatia

Sustainable Urban Mobility Plan of the City of Varaždin (2018) and the Master Plan for Integrated Passenger Transport (2017).

White, P., Public transport, its planning, management and operation (2009), fifth edition, London and New York, Routledge

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Professional Paper

Accelerating Moving Walkways – Characteristics and SWOT Analysis

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Abstract – **This paper studied the subsystem for specialised passenger transport, such as accelerating moving walkways. A SWOT analysis has shown that this subsystem can be easily integrated into the environment, to ensure the transport of more people with less environmental impact. However, budgetary constraints, safety regulations and the development of new technologies may limit its use.**

Keywords – **accelerating moving walkways, public passenger transport, SWOT analysis**

I. Introduction

The current world population of 7.6 billion is expected to reach 8.6 billion by 2030, 9.8 billion by 2050 and 11.2 billion by 2100, according to a new United Nations report [1]. Urbanization is set to continue and growth is concentrated mainly in large cities [2-3]. Currently, more than 50% of the world's population lives in cities, and by the middle of the 21st century, it will be 66% [4]. This will require the adoption of new technologies for more efficient use of resources in all sectors, including transport systems, to meet the growing demand for the movement of people, but also to reduce congestion and pollution. International goals and guidelines for sustainable urban development are a response to global trends and challenges related to urbanization. Various mobility options such as car sharing [5], bike sharing [6], on-demand transport and ride-hailing [7] are now increasingly available in many urban areas.

Metro and other capacitive public transport subsystems also require a serious approach to the design of escalators and moving walkways due to the large number of passengers arriving at the stops. Escalators are used to transport people between floors and are the most efficient means of moving large numbers of people around a building [8]. Moving walkways also facilitate the movement of pedestrians and were first used at exhibitions such as the Universal Exposition in Paris in 1900 [9]. Today they are most commonly found in transport hubs such as airports or railway stations [10]. In several cases, these systems have also been installed in hilly urban areas to facilitate access to elevated areas, for example, Medellín in Colombia and Perugia in Italy. Contrary to previous assumptions, moving walkways are not being used as a means of transport in urban centres. The prevalence of private and public transport continues to predominate, with pedestrian mobility occupying a subordinate position. The integration of a moving walkway system could potentially enhance pedestrian mobility and promote a transition towards more sustainable transportation options. The system is fully electric and has low energy consumption and noise levels [11].

In order to realise the use of moving walkways as a mode of transport, it is necessary to consider their limitations, possibilities and technological developments necessary for the success of this system. Such research necessitates multidisciplinary approaches. The design of a moving walkway network should be informed by a range of transport and practical considerations, including speed, cost and passenger demand. Furthermore, it is important to consider the influence that such a network could have on individual mobility and the environment. This comprehensive approach facilitates the analysis of the system's characteristics and performance.

This paper sets out to explore the characteristics of specialised means of public passenger transport, with a particular focus on accelerating moving walkways. A SWOT analysis was conducted to identify the strengths and weaknesses of these systems, as well as to determine the external opportunities and threats that they face.

II. Moving Walkways

During the 1960s and 1970s, the advent of environmental awareness, the oil crisis, and the long-term consequences of car-centric urbanism served to fuel the need for alternative modes of mobility that would serve to reduce dependence on the automobile. During this period, a range of innovative options for the future were explored with the aim of providing greater satisfaction and convenience to users. It was hypothesised that individuals would continue to utilise automobiles until more viable alternatives became accessible. Consequently, numerous systems for facilitating personal transportation were evaluated, with the moving walkway emerging as a particularly promising scheme.

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Scarinci et al. 2017 [11] claim that this system garnered increasing attention as a potential solution to urban congestion and pollution, in addition to promoting sustainable urban mobility. The integration of moving walkways within urban design aims to enhance the mobility of pedestrians while offering a novel perspective of the cityscape. While these systems do not inherently increase the speed of pedestrian movement, they do offer an alternative perspective of the city. In addition, the concept of faster walkways has been contemplated, with the intention of complementing existing transportation modes.

Conventional moving walkways are characterised by a number of disadvantages that limit their wider application. The most common type of moving walkway utilises a series of interconnected metal pallets mounted on rollers. The concealed service space of these moving walkways is typically about 1 m deep at the ends of the aisles, which imposes special requirements on the building or supporting structure that may prove difficult or expensive to achieve, as the floor space may not be readily accessible. Conventional moving walkways are also distinguished by their elevated degree of mechanical complexity. This complexity can result in mechanical failures, frequent servicing, and mechanical noise. Conventional moving walkways are constrained to traversing solely horizontal and linear pathways, thus hindering their adaptability to inclined, curved, or spiral configurations [12].

In an effort to overcome the slow speed disadvantage of conventional moving walkways, variable speed moving walkways have been developed as a solution. These moving walkways enable individuals to enter at a speed that is slightly below their normal walking pace, subsequently travel at a higher velocity, and finally disembark at a speed that is marginally below their normal walking pace. This configuration is advantageous in reducing the probability of injury to individuals who might suffer a fall due to a sudden change in speed when entering or exiting the moving walkway. The accelerating moving walkway (AMW) provides a higher maximum speed than traditional moving walkways, thereby minimising passenger travel time.

III. ACCELERATING MOVING WALKWAYS

The first prototypes of accelerating moving walkways were constructed between the 1970s and 1980s, and since then, they have attracted increasing attention from researchers in terms of transportation [13], technological aspects of the system [14], design [15], and integration of the system with urban infrastructure [16].

Accelerometers have been shown to be competitive in the field due to their capacity, speed, energy consumption, safety and ability to integrate into the urban environment. However, they are not suitable for independent wheelchair users or other passengers with reduced mobility [17].

The AMW system is characterised by its capacity for straightforward integration into the environment, a feat facilitated by its minimal installation requirements [18]. The accelerating moving walkway was developed as a solution to achieve higher maximum speeds in comparison to traditional moving walkways that move at a constant speed. The system has been designed to ensure that the entry and exit speeds are equivalent to those of conventional moving walkways, thereby facilitating safe boarding and alighting of passengers. However, it has also been configured to offer a higher speed in the middle section. The system has been shown to reach speeds of 12-15 km/h, which is competitive with city buses as a discontinuous system that takes into account walking times, waiting for the vehicle, and stopping at stops [19].

The AMW system has been shown to have a higher maximum capacity than bus lanes or buses in mixed traffic. In the context of accelerating moving walkways with a tread width of 1 m, the practical capacity of the AMW system exceeds that of buses in mixed traffic. The operational costs of AMW are lower than those of other transportation systems because they are less complex to operate (fewer personnel are required) and maintain (simpler technology). The low energy consumption of the AMW system is also a contributing factor to its cost-effectiveness [17].

The AMW system is characterised by enhanced safety due to its segregation from the transportation system in mixed traffic, thereby mitigating the risk of human error [20]. Furthermore, these systems generate less noise, a crucial consideration when operating within confined spaces. Furthermore, these systems generate less ground vibrations that have the potential to disrupt the environment when compared with other transportation systems.

Based on many years of experience, the basic requirements for an ideal accelerating moving walkway system to meet today's needs can be listed [21]:

- The entry and exit speeds of the system are consistent with those of conventional low-speed moving walkways and escalators. It is recommended that these speeds be no greater than approximately 3.2 km/h,
- The system in the higher speed section should move at a speed of about 16 km/h,
- It is essential that acceptable levels of acceleration and deceleration are in place for passenger comfort and safety,
- It is advisable to include a movable guardrail, i.e. handrails on the side, for added safety and convenience.

3.1. Specific application of AMW in cities

The Paris Metro (Gateway)

A "Gateway" is defined as a device used for entering or exiting a public transport system, such as the Paris Metro. A single lane of the accelerating moving walkway was opened in 2002 in a Paris Métro station (Fig 1.), connecting the underground station to the railway station. During the testing phase preceding its opening to the public, the initial maximum speed was set at 10.8 km/h. However, this was reduced to 9 km/h due to safety concerns, and the initial speed was also reduced proportionally from 2.7 km/h to 2.2 km/h. The primary issues were observed to occur in the acceleration and deceleration zones. Initially, the acceleration was fixed at 0.43 m/s^2; however, owing to numerous issues related to feelings of imbalance or even falls, a value of 0.28 m/s^2 was selected. The acceleration and deceleration sections were measured at approximately 10 metres in length, with a width of 1.2 metres and a length of 185 metres. The capacity of the lane was estimated to be approximately 7,000 passengers per hour. The system was subject to repeated mechanical failures and was ultimately removed [22].

Fig. 1. Accelerating moving walkways in a Paris metro station [23]


Fig. 2. Turbo-lane at Toronto Airport, Canada [24]

Toronto Airport (Turbo-lane)

A notable illustration of a successful implementation of an accelerating moving walkway can be observed at the Toronto Airport in Canada, which was installed in 2007 between Terminals 1 and 2 (Fig 2.). The technology of this AMW system is based on sliding pallets. The entry speed of 2.34 km/h corresponds to the standard speed for conventional moving walkways. The maximum velocity recorded in the central section is 7.2 km/h, which is three times the velocity recorded at the point of entry. The length of the moving walkway is 270 metres, with one AMW unit constructed for each direction. This configuration enables individuals to traverse the entire distance within a mere 140 seconds. The acceleration and deceleration zones, i.e. the transition between the low and high-speed zones, are 13 metres each. The AMW attains its maximum velocity within approximately 10 seconds. This corresponds to an acceleration of 0.14 m/s^2. The width of the moving walkway is 1.2 m, which is the most common width used for current moving walkways. This width facilitates the formation of two columns of passengers. The system's hourly capacity is approximately 7,000 passengers. The utilisation of sliding metal pallets in this system has been demonstrated to be a safer alternative to the installation in Paris [25].

IV. SWOT Analysis

The following text presents the results of a SWOT analysis for accelerating moving walkways. This analysis highlights their own strengths and weaknesses as well as in combination with external opportunities and threats in order to properly analyze the possibility of implementing a AMW system.

Strengths:

• Efficiency in moving people: Accelerators can move large groups of people faster than standard moving walkways, reducing waiting times and getting more people through more quickly.

• Energy efficiency: Modern technologies allow walkways to use energy more efficiently, especially with features such as automatic deceleration when there are no users.

• Reducing congestion: They help to reduce overcrowding at metro stations and other busy transportation areas by making it quicker for people to move around.

• Improving accessibility: For people who find it hard to move around or those with a lot of luggage, special lanes make it easier and faster to get around.

Weaknesses:

• High installation and maintenance costs: It can be expensive to set up and look after moving walkways. This is because they use complicated technology and need to be serviced regularly.

• Safety risks: Faster moving walkways can be more dangerous, especially at the start and finish points.

• Limited application: They are not suitable for all situations or locations, especially where there is not enough space for longer moving walkways.

Opportunities:

• Technological advancements: better and more efficient technologies can reduce costs and make the lanes safer and more efficient.

• More people living in cities: As cities grow, people need better ways to get around, which will increase demand for these systems.

• Integration with other types of transport: If we can link these lanes with other public transport, like metros and bus lines, it can make the whole transport system better.

Threats:

• Regulatory constraints and safety standards: Strict safety rules can limit how the lanes are designed and how fast they can be built, affecting how well they work.

• Alternative technologies: Other technologies, such as self-driving cars and better bus rapid transit (BRT) and metro systems, can mean that moving walkways are not needed.

• Economic conditions: If there is a recession or budget problems, this can affect decisions about investing in new infrastructure, including moving walkways.

V. Conclusion

Moving walkways have been conceptualised as a potential mode of transportation since the 19th century; however, they are not currently employed as a primary means of urban transportation. Nevertheless, they are receiving increasing attention as a potential solution to the problems of congestion and pollution in urban areas.

The SWOT analysis demonstrated that AMW represent a promising form of transport for central city areas, encouraging spontaneity and continuity in movement, in contrast to contemporary public transport systems. The moving walkways system is distinguished by its ability to utilise limited spatial resources while maintaining high operational capacity. Moreover, the system is sustainable due to its minimal energy consumption. Consequently, the integration of AMW into a future urban transport system, in an environment devoid of private vehicles, is a conceivable prospect. In such a scenario, pedestrians would assume a pivotal role as the primary mobility actors.

Moreover, the AMW system facilitates the efficient conveyance of large numbers of passengers at a relatively low cost. When taking into account walking time, waiting for the vehicle, and staying at stations/stops, the total travel time is competitive with discontinuous transport systems. The system's integration into the environment is seamless, and its environmental impact is minimal due to its energy-efficient design.

The most significant environmental factors that have the potential to impact the efficiency and necessity of a AMW system are budgetary constraints, the emergence of novel and advanced existing technologies, and rigorous safety regulations.

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REFERENCES

[1] United Nations, Department of Economic and Social Affairs. https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html
[2] D. D. Parrish, Z. Tong, "Clean air for megacities". Science, vol. 326, no. 5953, pp. 674–675, 2009.
[3] H. Taubenböck, et al., "Monitoring urbanization in mega cities from space", Remote Sensing of Environment, vol. 117, pp. 162–176, 2012.
[4] UN-Habitat, World Cities Report 2016
[5] V. Roblek, M. Meško, I. Podbregar, "Impact of car sharing on urban sustainability", Sustainability, vol. 13, no. 2, p. 905, 2021.
[6] A. Tripodi, L. Persia, "Impact of bike sharing system in an urban area. Advances in Transportation Studies", vol. 36, pp. 143-156, 2015.
[7] M. Gilibert, I. Ribas, C. Rosen, A. Siebeneich, "On-demand shared ride-hailing for commuting purposes: comparison of Barcelona and Hanover case studies". Transportation Research Procedia, vol. 47, pp. 323-330, 2020.
[8] KONE Corporation. Escalators and Autowalks Planning Guide. https://www.kone.us/images/kone-escalator-autowalk-planning-guide_tcm25-18783.pdf
[9] I. Asimov, *Caves of Steel,* New York, Random House Publishing Group, 1954.
[10] R. Scarinci, F. Bahrami, A. Ourednik, M. Bierlaire, "An exploration of moving walkways as a transport system in urban centers". European Journal of Transport and Infrastructure Research, vol. 17, pp. 191–206, 2017.
[11] R. Scarinci, F. Bahrami, A. Ourednik, M. Bierlaire, An exploration of moving walkways as a transport system in urban centers. EJTIR 17(2), pp. 191−206, 2017.
[12] D. Rockwood, D. Garmire, A new transportation system for efficient and sustainable cities: Development of a next generation variable speed moving walkway. Sustainable Cities and Society 14 pp. 209–214, 2015.
[13] Kusumaningtyas, I., Lodewijks, G., 2013. On the application of accelerating moving walkways to support passenger processes in Amsterdam Airport Schiphol. Transportation Planning and Technology 36, 617–635.
[14] Ikizawa, K., Nagai, H., ichiro Aoe, S., Sato, T., Okuno, R., Yanagisawa, T., 2001. Development of an accelerating walkway. NKK Technical Review 84, 66–70
[15] Abe, Y., Beniya, Y., Masuda, H., 2001. Accelerating Moving Walkway"ACCEL-LINER". Bridges 10, 55.
[16] Rockwood, D., Garmire, D., 2015. A new transportation system for efficient and sustainable cities: Development of a next generation variable speed moving walkway. Sustainable Cities and Society 14, 209–214
[17] Kusumaningtyas, I., Lodewijks, G., 2008. Accelerating Moving Walkway: A review of the characteristics and potential application. Transportation research part A: policy and practice 42, 591–609.
[18] Turner, D.L. (1998), "Escalators and moving walks", in G.R. Strakosch (ed.), The Vertical Transportation Handbook,3rd ed., John Wiley and Sons, New York, 219–244.
[19] Kusumaningtyas, I., 2009. Mind Your Step: Exploring aspects in the application of long accelerating moving walkways. Ph.D. thesis. Delft University of Technology. Mechanical, Maritime and Materials Engineering. Marine and Transport Technology.
[20] Brand, C., Preston, J., 2003. Which technology for urban public transport? in: Proceedings of the Institution of Civil Engineers-Transport, pp. 201–210.
[21] J. K. Todd, Dunlop s-type speedaway: a high-speed passenger conveyor, 2020.
[22] Gautier, F., 2000. Gateway: the high-speed walkway, in: Rail Transit Conference, 2000.
[23] https://en.m.wikipedia.org/wiki/File:Parisian_high-speed_walkway.jpg
[24] https://nymag.com/speed/2016/12/10-mph-moving-sidewalks-could-make-crosstown-buses-obsolete.html
[25] Gonzalez Alemany, M., Soffritti, M., Behrend, M., Eisele, T., 2007. TurboTrack: making long distances shorter. ThyssenKrupp techforum, 68–75.

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Professional Paper

Trolleybus Network as a Linear Charger for Electric Battery Buses

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Abstract – **Electric buses are becoming increasingly popular in public transport. One of the challenges associated with this is the increasing need for batteries. When purchasing electric buses, cities and transport companies are in many cases guided by the desire to achieve results as quickly as possible. Therefore, buses with large traction batteries are often purchased, allowing for a significant range and minimizing infrastructure costs. However, such an approach may prove to be wrong in the long term when considering the costs of replacing the traction batteries during the vehicle's lifetime. In addition, an important factor is also the increasing need for batteries related to electromobility and the limited raw material resources. For this reason, the authors of this article have proposed a method for charging electric buses that allows a significant reduction in battery capacity while maintaining high traffic flexibility. The article presents a hybrid in-motion charging method for charging electric buses based on the use of the overhead line of trolleybuses as a linear charger. This solution was developed based on the authors' extensive professional experience, e.g. during the introduction of trolleybuses with an additional battery power source in Gdynia (Poland). The presented hybrid charging method is an extension of the Gepard project implemented in Gdynia (Poland). The experience gained from the implementation of the CAR - Creating Automotive Renewal project, in the framework of which a fast charging station for trolleybuses was developed, were used.**

Keywords – **Camera ready paper, Proceedings of papers, TTS.**

I. Introduction

In the dynamic charging system (In Motion Charging - IMC), part of the route is covered with a trolleybus traction network (OHL - overhead line), which allows for the charging of traction batteries during movement. The vehicles cover the rest of the route, i.e. the part in which there is no contact line, using traction battery power. This allows for the charging of the vehicle without stop-ping, increasing the flexibility and functionality of the system. In addition, covering a section of the route with a traction network reduces the length of the route to be travelled in battery mode, which in turn allows for a reduction in the capacity of the traction batteries [1-4].

Modern technical solutions significantly increase the attractiveness of the trolleybus network for IMC charging. One of them are semi-automatic trolleybus current collectors, which allow for quick connection of the vehicle to the trolleybus OHL [5-6].

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II. Gepard project Gdynia

In Gdynia (Poland), as part of the Gepard program (supported by National Fund for Environmental Protection and Water Management) bus line 170 was electrified. This electrification was combined with the modification of the route (the route in the central part of the city was extended) and the change of its number to 32. Line 32 has a lengths of cca. 10 km one-way, of which 4 km is under the trolleybus OHL catenary and 6 km are driven in battery mode (Fig. 12) [7].

Due to the specificity of line 32, it was decided to introduce dedicated vehicles with special electrical equipment to serve it – Trolleybus 2.0. In classic trolleybuses, due to the need to provide electric shock protection, all electrical equipment operating at 600 V (traction converter, traction motor, on-board converter, or traction batteries) must be equipped with two-stage insulation from the vehicle body. This requires the implementation of an electrical installation dedicated to trolleybus solutions. In the case of line 32, however, most of the route takes place in battery mode. For this reason, it was decided to use an unusual technical solution that would combine the features of a trolleybus and an electric bus under commercial name Trolleybus 2.0 (Fig. 2).

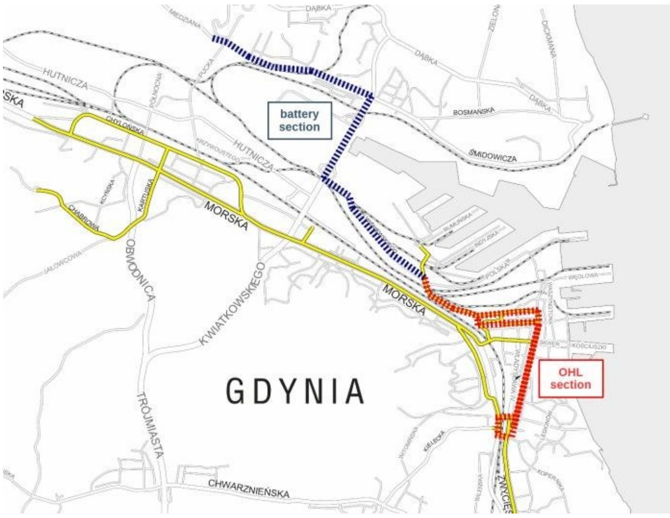

Fig. 1. The scheme of 32 route, yellow lines: existing trolleybus OHL network [7]

It consisted in the maximum unification of the vehicle with a classic electric bus, i.e. the use of a standard electric bus installation with standard, single-stage insulation and a traction battery as the main power source. The battery is charged from the trolleybus catenary by means of an input DC-DC converter (charger) with a power of 150 kW (during standstill, the current received from the catenary is limited to 160A).

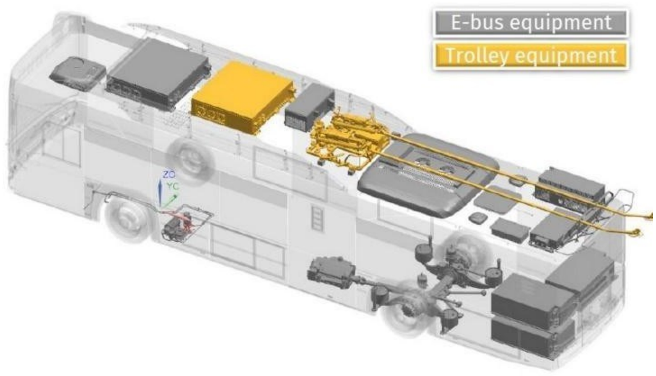

Fig. 2. Trolleybus 2.0 vehicle © Solaris Bus & Coach [7]

For the Gepard project, the traction batteries are charged in two stages. When SoC drops below 90%, the batteries are charged with the full power of the converter. When state of charge (SoC) is above 90%, the charging power is reduced mainly due to the need to balance the cells (equalize their voltages). Fig. 3 shows the driving distance when powered from the catenary, at which the input converter works with full power (fast charging). It can be noticed that even in unfavorable weather conditions, the batteries SoC is at 90% after only 10-15 minutes of driving, i.e. after 3–3.5 kilometers. Currently, about 40% of the route of line 32 is covered with catenary, but based on experience obtained from operation (Fig. 3) it can be estimated that the length of the network can be reduced half, i.e. having a catenary coverage of 20-25%.

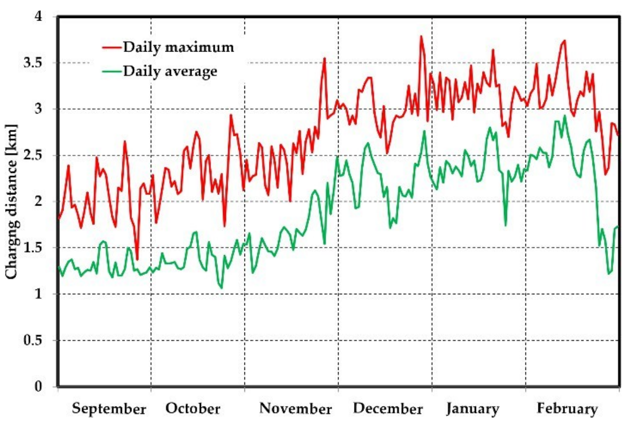

Fig. 3. Length of OHL (Charging distance) at which the charging converter works with full power (fast charging) [7]

III. Hybrid Charging: CAR Project - Range Extender for Trolleybuses

The energy consumption of an electric vehicle varies much more than that of ICE vehicle, mainly due to the influence of external (weather) conditions. Hence, during winter the interior heating needs to consume high amount of electric energy. This issue is illustrated in Figure 4, which shows the histogram of energy consumption of the Gdynia trolleybus during a one year period. However, as you can see, high energy consumption occurs very rarely.

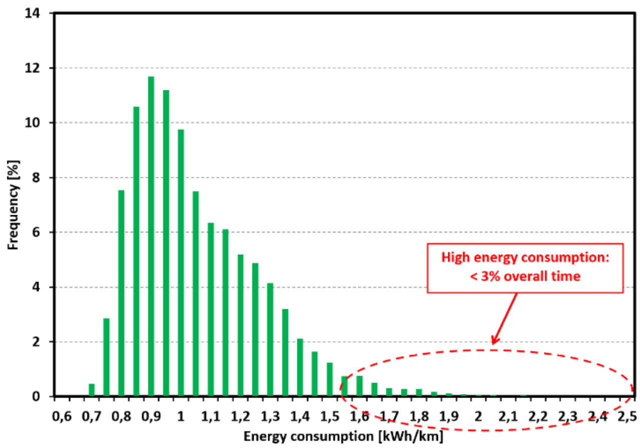

Fig. 4. Histogram of annual energy consumption of electric bus [7]

This concept allows reduction of the costs of building a traction OHL network. In case of low temperatures, when due to high energy consumption charging from the network is insufficient, the missing energy would be supplied from a fast charging station (Fig. 5). Such a hybrid charging system for electric buses based on the trolleybus OHL and an additional fast charging station will be named as IMC hybrid.

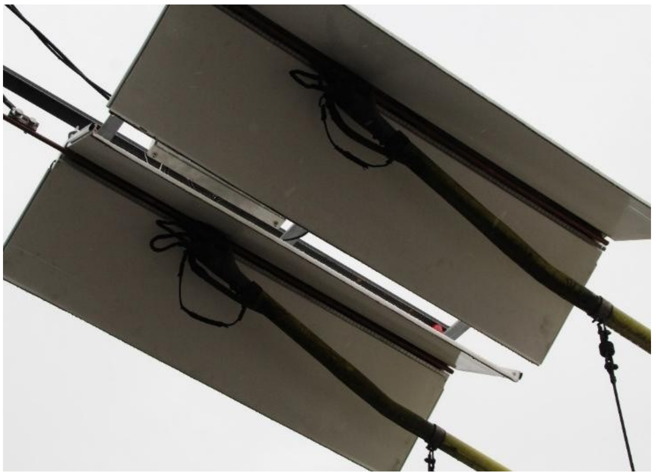

Fig. 5. Fast charging connection point for trolleybuses designed by AREX company (Gdynia) – CAR project

Another solution to the problem is introducing fast charging stations for trolleybuses, which use trolleybus current collectors to draw a power of 150–350 kW (Fig. 5). This was the aim of CAR project (Creating Automotive Renewal). Compared to classic electric buses, this solution has a significant advantage: charging can start immediately after connecting the receivers (no synchronization charging station-vehicle is required). The impact of the trolleybus catenary on the appearance of the public space can also be minimized. Thanks to the use of aesthetic poles and load-bearing elements, the trolleybus OHL can be aesthetically integrated into surroundings.

The stationary charging plays only additional role. Hence, it is possible to reduce the power demand from the power grid by using of SES (Storage Energy System). This is important due to the fact that fast charging stations for electric buses require a sufficiently high power supply. The peak power consumed by the charging station can be significantly reduced by using a stationary battery energy storage system. This solution is known in electric car charging stations under the name Grid Booster. Such a device was also built in Gdynia as part of the CAR project by AREX company (Fig. 6). The energy of installed batteries is 65 kWh. Limiting the peak power allows you to reduce the costs of purchasing eclectic energy, as well as to simplify the execution of the power connection. It is also possible to power the charging station with low voltage (400 V AC) instead of high voltage (15 kV AC or more), which greatly simplifies the connection process [14–16].

Fig. 6. Fast charging station with storage energy system designed by AREX company (Gdynia) – CAR project

IV. Conception of Dynamic Charging System in Skopje

Republic of North Macedonia has a Public Transport Company Skopje (Javno soobrakajno pretprijatie Skopje) that maneuvers over 50 urban and 50 suburban bus lines which makes it the largest passenger carrier in the country. The company has a park that is mostly double decker Yutong Chinese buses as well as LAZ models from Ukraine which are in number way lower than Yutong. Consequently many time the City of Skopje tried to plan a tram transport but without a successes. With global warming and the problem with emission that the whole world is dealing with the most reasonable solution as well as a cheaper solution to the emission problem is the form of dynamic charged electric busses. Moreover there are few boulevards the city has that are crowded during the rush hour but the most crowded with high intensity of traffic during the whole day is Boulevard Partizanski Odredi. This boulevard has 14 bus lines at all hours that connect the heart of the city with all parts urban and suburban. Electric charged buses in the IMC system is a possibility for this boulevard since there are multiple lines to operate with if we take into consideration a construction of an overhead contact line along the boulevard. This infrastructure that would be build can be used by many vehicles while reducing the unit cost (per vehicle or per transport work) for construction as well as maintenance. Moreover the suggested route for the trolleybus network for charging vehicles in the IMC system is shown in Fig. 7. Also in table II we list existing bus lines that use dynamic charging. Needless to say the mention trolleybus overhead traction line is 3.5 km long.

TABLE I

JSP BUS ROUTE PREDESTINATED BY IMC OPERATION

Bus route	*Route length [km]*	*Length of route under OHL [km]*	*Covering of route by OHL*
2	13,5	3,5	0,26
2A	14,6	3,5	0,24
4	9,1	3,5	0,38
12	14	3,5	0,25
15	10	2,5	0,25
21	12,5	3,5	0,28
22	12	3,5	0,29
22A	11	3,5	0,32
26	8	2,5	0,31

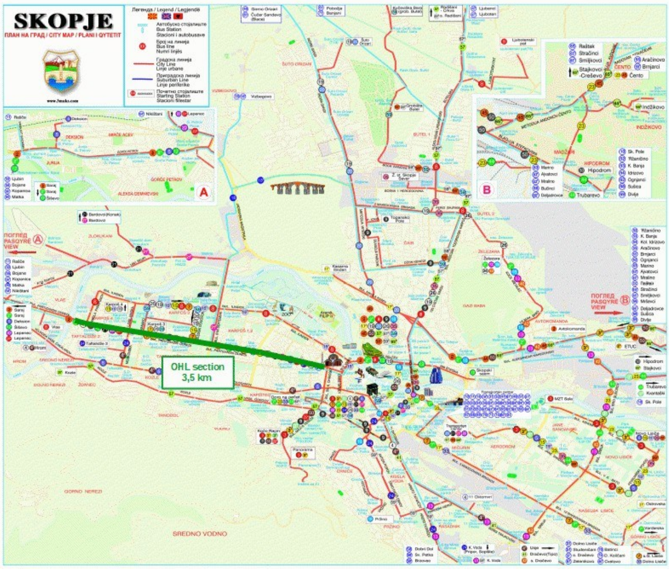

FIG. 7. THE IDEA OF IMC SYSTEM IN SKOPJE, BASED ON WWW.JSP.COM.MK

V. Conclusion

Trolleybuses are often considered an outdated means of transport. However, this is far from the truth. Modern technological solutions significantly increase the attractiveness of trolleybus transport, especially with the autonomy provided by batteries. Such solutions allow for the optimization of infrastructure costs while minimizing batteries. This is particularly important at a time when demand for batteries is increasing and sources of raw materials are very limited.

The use of OHL infrastructure for dynamic charging allows reducing the capacity of traction batteries. This is especially important in terms of long-term running costs, as lower battery capacity brings lower replacement cost.

The integrating OHL infrastructure for dynamic charging lowers long-term battery costs and enables sustainable urban transit solutions. IMC-based hybrid charging is a cost-effective and environmentally friendly alternative to conventional electric bus charging methods. In Motion Charging (IMC), which allows electric buses to charge while in motion using a trolleybus overhead line (OHL), can be a breakthrough solution for sustainable public transport. Its main advantage is reducing battery capacity, which lowers both purchase and operational costs. By charging while driving, buses do not require long stops at charging stations, which increases their availability and operational efficiency.

Skopje is a city that undoubtedly needs effective public transport. An electric BRT system seems to be the optimal solution. Using linear structure of the bus routes in the Karposh district is due to the use of the IMC system which makes it potential by using a separate bus lane that has and overhead contact line (Fig. 7). Unlike building a tram system this way is much cheaper solution. Rather than building a standard electric bus charger stationary this is more flexible solution while traction network will be used by many buses making it justifiable building the needed infrastructure. What is extremely important, such a charging corridor, apart from powering electric buses, can also be used for other purposes, e.g. to power charging stations for electric cars.

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REFERENCES

[1] M. Bartłomiejczyk, Dynamic charging of electric buses. De Gruyter Poland, Warsaw, 2018.

[2] E. Lenz, "Electric bus with IMC from Kiepe Electric: Reliable, simple and more cost effective", Fachmagazin V+T Verkehr und Technik, editions 8 + 9, 2017

[3] M. Bartłomiejczyk,, "Practical application of in motion charging: Trolleybuses service on bus lines", In: 18th International Scientific Conference on Electric Power Engineering, 17-19.5.2017, Kouty nad Desnou, Czech Republic, 2017

[4] M. Wolański, "Economic Efficiency of Trolleybus Transport". In: Wołek M., Wyszomirski O.: "The Trolleybus as an Urban Means of Transport in the Light of the Trolley Project", Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk, 2013

[5] Bartłomiejczyk, M.; Połom, M. Sustainable Use of the Catenary by Trolleybuses with Auxiliary Power Sources on the Example of Gdynia. Infrastructures 2021, 6, 61. https://doi.org/10.3390/infrastructures604006

[6] Bartłomiejczyk, M.; Połom, M. Possibilities for Developing Electromobility by Using Autonomously Powered Trolleybuses Based on the Example of Gdynia. Energies 2021, 14, 2971. https://doi.org/10.3390/en14102971

[7] M. Bartłomiejczyk, L. Jarzebowicz, S. Mirchevski and M. Połom, "Advancing Urban Transit: Gepard and CAR projects - Innovations in Trolleybus Technology," 2024 Zooming Innovation in Consumer Technologies Conference (ZINC), Novi Sad, Serbia, 2024, pp. 31-35, doi: 10.1109/ZINC61849.2024.10579108

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Professional Paper

The Use of Electric Bicycles in the Function of Sustainable Development

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Abstract: **Due to the existence of environmental problems, people must become aware of the need to reduce the use of fossil fuels and the possibility of using alternative energy to power vehicles. In the field of transportation, there are options for using vehicles powered by alternative energy, one of which is the use of electric bicycles.The paper addresses the topic of using electric bicycles as an alternative mode of transportation to passenger cars, as well as examples of good practice.**

Keywords: **electric bicycle, transport, ecology**

I. Introduction

Fast-paced lifestyles, the rush to get to work on time, excessive traffic, and environmental pollution have forced citizens to look for alternatives in the use of transportation. Many have replaced driving cars with the use of electric bicycles.

The presence of various environmental problems has shifted human focus from the use of fossil fuels to energy conservation. This has also influenced the presence of various modes of transport that are more environmentally friendly and energy efficient [1]. The electric bicycle has now developed not only as a sports tool, but has also been transformed into a means of transportation.

The use of electric bicycles in densely populated residential areas helps reduce air pollution, which is currently on the rise, with motor vehicle emissions contributing the most [2].

Today, many types of electric bicycles are available around the world, from those with only a small engine to those with more powerful engines that are closer to the functionality and style of a motorcycle [1].

II. Development of the Electric Bicycle and Its Impact on the Environment

An electric bicycle is produced from a combination of a bicycle as a means of transport to which an electric component has been added as a driving force. By using a qualitative descriptive method, more detailed knowledge about the impact of using an electric bicycle on the environment is expected.

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A. Types of electric bicycles

There are two types of electric bicycles. The first ones use pedals, meaning their shape is not much different from a regular bicycle, so they can be ridden either with pedals or with an electric motor. The second type is those that do not use pedals, so their physical form is like an automatic motor system, and the driving force comes from an electric motor [10].

n their application, electric bicycles and electric motors have the same characteristics, they are powered by batteries. The use of batteries in electric bicycles aims to allow cyclists not to get tired while pedaling and to reach the desired place in a shorter time compared to using an ordinary bicycle [8].

B. Electric bicycles function

Electric bikes are introduced as an option to current two-wheel drive models. They are presented as a result of the development of bicycles that are powered by electricity without removing the basic riding components from the bicycle [4].

The function of an electric bicycle is not much different from the function of a classic bicycle. Even if a battery is used, electric bicycles still use human power to pedal and do not replace the user's function of the bicycle [1].

C. The working principle of an electric bicycle

The principle of operation of an electric bicycle is a simple start from a stationary state to movement. Electric bicycles are known to use a source of electricity from a battery that is already charged with electricity to power the motor [6]. During operation, the electric bicycle needs to regulate the power that will enter the electric motor so that it can move without pedaling [4].

Simply put, the movement of an electric bicycle is the result of changing the electrical energy, which originates from the battery, into the energy used to drive the dynamo that produces the rotation [9].

Currently, it is known that much progress has been made in terms of the conversion of energy production related to means of transportation. The development of alternative means of transport does not only affect the transfer of technology, it can be connected to a better life [7]. In this case, it aims to provide health to the community, since it is known that many environmental issues are related to the pollution produced by the exhaust gases of vehicles as a means of transportation [11]. The electric bicycle is the result of the development of a means of transportation that is based on zero emission of exhaust gases, its existence can minimize the impact on the environment [5].

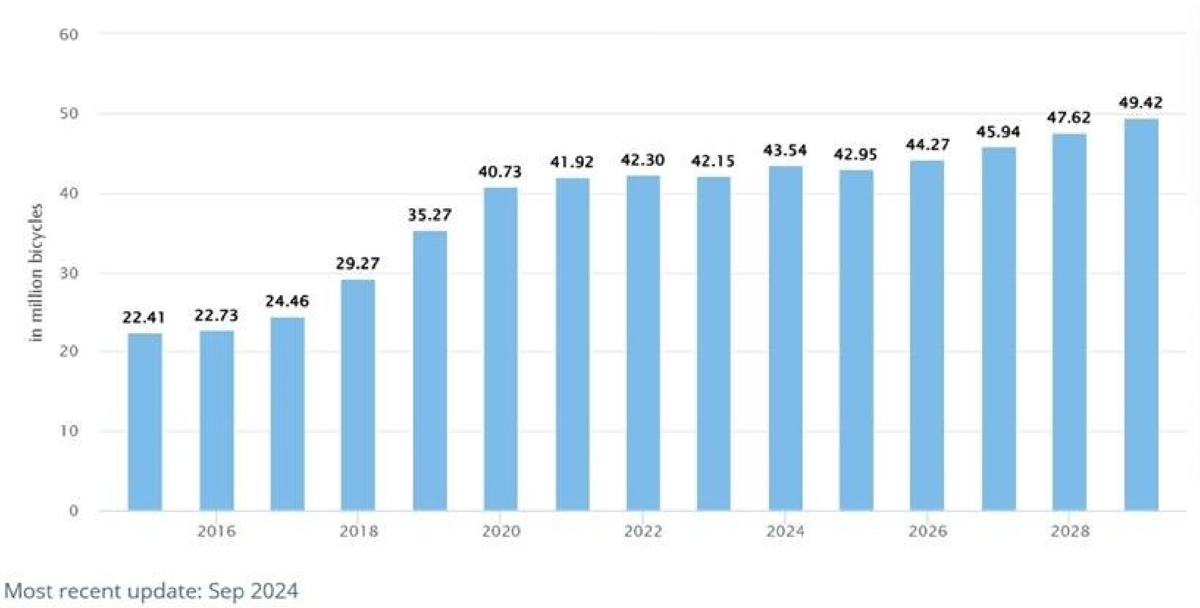


Fig. 1. Number of electric bicycles expressed in millions [18]

The use of electric bicycles at this time has started to reach people who use electric bicycles as a means of transportation. This can be seen from the use of electric bicycles for activities such as commuting [13]. In this form, electric bicycles, which are motorized, will be able to use traffic lanes, so it can produce the risk of a traffic accident [14].

Waste batteries can be the next focus, it is known that it is one of the wastes that cannot be recycled, and in certain cases it can pollute the environment if they are not disposed of properly [2].

D. Parking for electric bicycles

When it comes to parking solutions, there are a few key differences between electric bike racks and regular bike racks. One of the most obvious differences is the size and weight of the bikes. Electric bicycles are usually larger and heavier than ordinary bicycles, which means that more space is needed for parking [17].

In addition, some facilities will choose to provide charging for electric bikes. Charging stations must be located where the charging infrastructure can be connected to electricity and may require even greater row spacing [17].

Cost is an important factor to consider when planning and installing electric bike parking. Due to the unique needs of electric bikes, parking solutions electric bike racks are generally more expensive than regular bike racks. Despite the higher price, there are several cost-effective electric bike parking solutions on the market, with some companies offering a modular design that allows you to pay only for the features you currently need. For example, some manufacturers offer charging stations as an add-on that can be easily installed later, which can help reduce initial costs [17].

Different parking solutions are available in the market to suit different locations. Some racks are designed to fit one or two e-bikes in tight spaces but do not allow for charging, while others may include multiple rows [17].

Another important issue is the required level of security. Electric bikes are generally more expensive than regular bikes, making them a more attractive target for theft. Therefore, e-bike parking facilities must provide a higher level of security, such as locking mechanisms that secure both the frame and the front wheel, or advanced access control systems that use cards or mobile apps to lock and unlock the bikes. Bike lockers are one option that provides additional space and safety for electric bikes [17].

III. Electric bicycles around the world

The electric bicycle market within the bicycle market worldwide is experiencing minimal growth, influenced by factors such as limited infrastructure and high costs. However, with growing environmental concerns and the trend towards green transportation, the market is expected to see an increase in demand in the coming years [18].

Unit sales in the electric bicycle market are expected to reach 49.42 million bicycles by 2029. Data on the number of electric bicycles expressed in millions of bicycles are shown in Fig. 1 [18].

A. Subsidy for electric bicycle - Spain

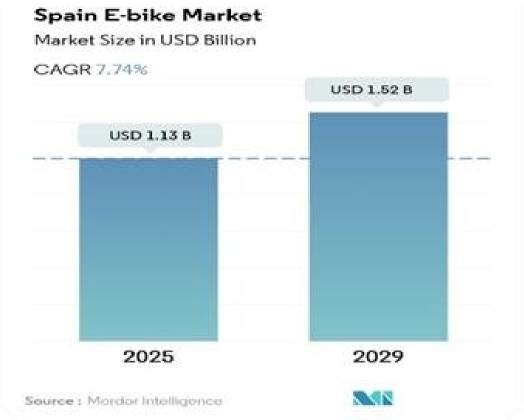
In Europe, the market is driven by the growing awareness of environmental sustainability and the availability of government subsidies for the purchase of electric bicycles. These factors have led to a higher rate of adoption of electric bicycles in European countries compared to other regions [15].

The Spanish government has for the first time launched subsidies for the purchase of electric bicycles as a way to improve air quality.

Spain is a country that traditionally subsidizes the purchase of cars. But something is changing - for the first time, the Spanish government has approved aid for the purchase of electric bicycles. This means that the government recognizes the importance of this vehicle as a means of transportation in cities to improve air quality, and we can assume that it will bring a boost to the important bicycle industry in this country [15].

Subsidies for the purchase of more efficient vehicles, such as electric bicycles, range up to 30%, making them more accessible to the general public.

Statistical data indicate changes where the number and value of sales of electric bicycles increases from year to year by 7.74%. The market, which is estimated at 1.13 billion dollars in 2025, is expected to reach 1.52 billion dollars in 2029, as shown in Fig. 2 [19].



Study Period	2017 - 2029
Base Year For Estimation	2024
Forecast Data Period	2025 - 2029
Market Size (2025)	USD 1.13 Billion
Market Size (2029)	USD 1.52 Billion

Figure 2. Value of the electric bicycle market in Spain [19]

B. Innovative recycling scheme – France

After intense advocacy by French ECF member FUB, lawmakers approved a new measure that will provide owners of old, polluting cars with a grant of up to €2,500 to purchase electric bicycles when recycling their vehicles [16].

MPs in the National Assembly of France have voted to introduce a new measure to include electric and cargo bikes in the national car scrapping scheme. The Parliament adopted an amendment to the draft climate law that aims to reduce greenhouse emissions by 40% in 2030 compared to 1990 levels [16].

Olivier Schneider, president of FUB, said that "it was recognized for the first time that the solution is not to make cars greener, but to simply reduce their number" [16].

France has already had positive experiences with similar measures in the past:

- In 2017, a general subsidy for the purchase of electric bicycles almost doubled the number of sales, acting as an important catalyst for market adoption. A survey of subsidy recipients also found that 61% of trips made by e-bike replaced conventional fuel vehicle trips.
- In 2020, as part of mobility measures related to the COVID-19 pandemic, the French government introduced a €50 subsidy for bicycle repairs.

The positive reception of these measures is reflected in the bicycle market statistics. According to Union Sport and Cycle, more than 510,000 electric bicycles were sold in 2020, a growth of 29% compared to 2019. This growth was also accompanied by a 21% increase in the average price per electric bicycle, bringing the average total figure to around 2,100 euros. Electric bicycles now represent a whopping 56% of market value [16].

At the moment, sales of electric bicycles in France continue to grow, and it is estimated that one in five bicycles sold is electric [16].

By introducing this scheme, France follows other countries such as Lithuania or Finland, which have introduced similar incentives, but with lower premium amounts of 1,000 euros [16].

C. The value of electric bicycles

The worldwide electric bicycle market revenue is forecast to reach $37.01 billion by 2025, with revenue showing a CAGR of 4.48%, leading to a projected market size of $44.10 billion by 2029, shown in Fig. 3 [18].

In the global electric bicycle market, China is a dominant force, driving innovation and setting trends for the industry.

China has become a leader in electric bike adoption, with millions of electric bikes on the streets and efficient rental systems in major cities such as Beijing and Shanghai.

In China, the electric bicycle market has experienced significant growth due to the country's high population density and traffic congestion in urban areas. The government has also implemented policies to promote the use of electric vehicles, including bicycles, as a solution to air pollution [18].

Looking from an international perspective, it is evident that in 2025 the largest income will be achieved by China ($11,560 billion), and after China, the largest income will be achieved by: Germany ($6,606 billion), the USA ($2,173 billion), France ($1,825 billion) and Austria ($1,466 billion) [18].

D. Prognosis

Various forecasting techniques are used in the forecasts. The choice of forecasting technique is based on the behavior of the relevant market. The main drivers are GDP, consumer spending per capita and population. The scenario analysis is based on a Monte Carlo simulation approach that generates a range of possible outcomes. By running a number of simulated scenarios, the model provides an estimate of the distribution of the results, allowing the analysis of likely ranges and confidence intervals around the forecast [18].

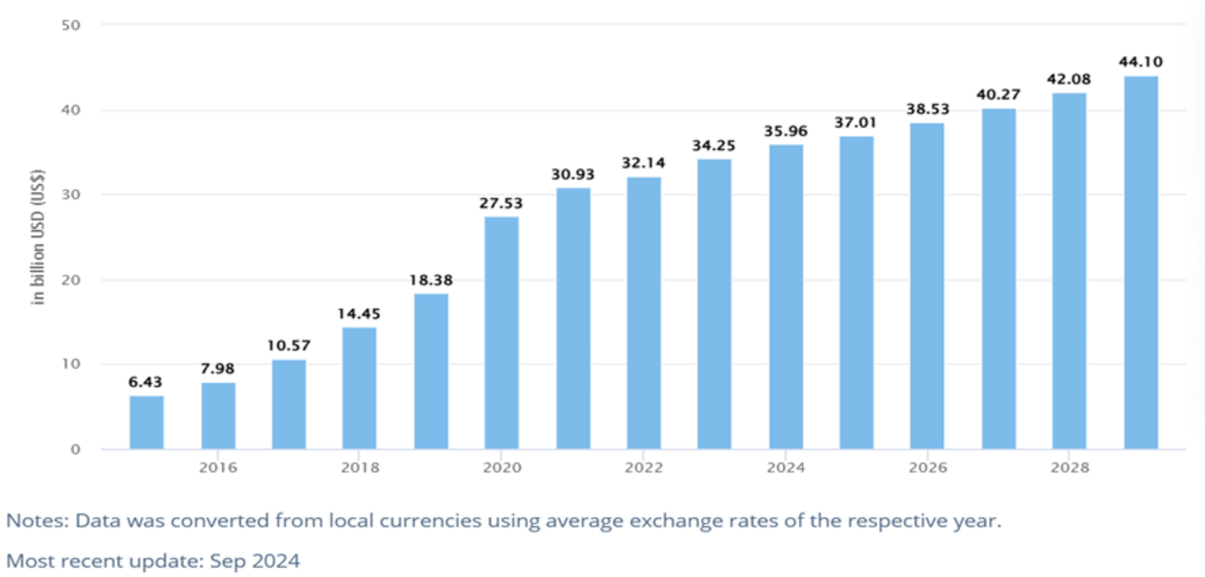


Fig. 3. Value of electric bicycles in billions of dollars [18]

IV. Conclusion

As the demand for sustainable transportation options continues to grow, electric bicycles are becoming increasingly popular among consumers. This trend is particularly pronounced in urban areas, where individuals try to avoid traffic jams. This shift towards greener and healthier modes of transport is indicative of a larger cultural shift towards sustainability and well-being.

The growth of the electric bicycle market within the bicycle market is also influenced by macroeconomic factors such as technological advancements, government regulations, and investment in sustainable transportation infrastructure. Countries with supportive regulatory frameworks and significant investments in green transportation experience higher market growth compared to regions with regulatory barriers and limited funding [18].

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References

[1] M James C 1977 Pedal power in work, leisure, and transportation. Pennsylvania: Rodale Press
[2] Dill J and Rose G 2012 Electric bikes and transportation policy: Insights from early adopters Transp. Res. Rec vol 2314 no 1 1–6.
[3] Johnson M and Geoff R 2015 Extending life on the bike: electric bike use by older Australians J. Transp. Heal. vol 2 no 2 276–283
[4] Matey S, Prajapati D R, Shinde K, Mhaske A, and Prabhu A 2017 Design and fabrication of electric bike Hand vol 27 no 250 40.
[5] Ramadhan A and Sihombing J P 2018 Kajian ergonomi desain sepeda fixed gear (fixie) Prod. J. Desain Prod. (Pengetahuan dan Peranc. Produk) vol 3 no 1 8–21 Feb. 2018.
[6] Sharma Y, Banker P, Raikwar Y, Chauhan Y and Sharma M 2018 R&D on Electric Bike IRJET vol 5 no 2 610–614.
[7] Wei L, Xin F, An K, and Ye Y 2013 Comparison study on travel characteristics between two kinds of electric bike Procedia-Social Behav. Sci. vol 96 1603–1610.
[8] M Hatwar N, Bisen A, Dodke H, Junghare A and Khanapurkar 2013 Design approach for electric bikes using battery and super capacitor for performance improvement in 16th International IEEE Conference on Intelligent Transportation Systems 1959–1964.
[9] Gabor R, Kowol M, Kołodziej J and Mynarek P 2018 Steady State Analysis of Switched Reluctance Motor with Modified Geometry of the Stator Designed for an Electric Bike in International Symposium on Electrical Machines (SME) 1–5.
[10] Lin C-H, Liu H-W, and Wang C-M 2010 Design and implementation of a bi-directional power converter for electric bike with charging feature in 5th IEEE Conference on Industrial Electronics and Applications.
[11] Niki H and Murakami T 2005 An approach to self stabilization of bicycle motion by handle controller in Transactions on Industry Applications 125.8 779–785.
[12] Jordehi A R 2019 Optimisation of demand response in electric power systems, a review Renew. Sustain. energy Rev. vol 103 308–319.
[13] Lugo A E 2018 Bicycle/Race: Transportation, Culture, & Resistance Portland: Microcosm Publishing.
[14] Schleinitz K, Petzoldt T and Gehlert T 2018 Risk compensation? The relationship between helmet use and cycling speed under naturalistic conditions J. Safety Res. vol 67 165–171.
[15] https://ecf.com/news-and-events/news/spain-subsidises-purchase-electric-bicycles
[16] https://ecf.com/news-and-events/news/electric-bikes-replace-polluting-cars-france-introduces-innovative-scrappage
[17] https://www.reliance-foundry.com/blog/electric-bikes
[18] https://www.statista.com/outlook/mmo/bicycles/electric-bicycles/worldwide#unit-sal
[19] https://www.mordorintelligence.com/industry-reports/spain-e-bike-market

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Professional Paper

Advantages and Disadvantages of Electrical Vehicles

Slobodan Mircevski[1], Mile Spirovski[2], Daniela Koltovska Nechoska[3]

Abstract – **Electric vehicles are electric motor drives, which are driven by an electric motor powered by the electrical energy stored in an accumulator or battery. The advantages of these vehicles compared to conventional vehicles with an internal combustion engine (ICE) mainly relate to lower air pollution in cities, independence (or rather, lower dependence, due to battery power) from fossil fuels, greater profitability over a longer period, etc. The energy needs of humanity are divided into 3 (three) large groups: electricity, transport and heating.**

Keywords – **internal combustion engine (ICE), Electrical vehicles, Baterry charger, Electricity sources.**

I. INTRODUCTION

The development of electric vehicle technology in the past decades and the expected disappearance of fossil fuels herald an increasing use of electric vehicles. According to Bloomberg estimates, in 2035 half of all vehicles sold worldwide will be electric. Electric vehicles have numerous environmental advantages, but it is necessary to pay attention to the origin of electricity, i.e. how it is created. From information still 2019, 84.3% of the energy consumed comes from fossil fuels. It is clear that almost all energy for transport is drawn from fossil fuels, primarily oil and its derivatives. According to Our world in data, 2019, 63.3% of the electricity produced is based on fossil fuels. Road transport is responsible for 22% of total CO2 emissions, a record 40% of NOx and 12% of particulate matter (PM10 and PM2.5). Some countries are developing energy systems that pollute less or do not pollute the environment at all, thanks to renewable energy sources. This paper presents a comparative analysis of air pollution from vehicles with ICE and electric vehicles. However, electric vehicles are still not widely available, i.e. their use is lagging behind forecasts. It is estimated that in 2020, 6.8 million electric vehicles were in use worldwide, of which 3 million (44%) began to be used that year, [1], [2]. It should not be overlooked that in parallel with the development of electric vehicles, ICE are also being improved and the production of cheaper fossil fuel vehicles is increasing. This situation slows down the growth of the number of electric vehicles. However, it is still predicted that electric vehicles will become dominant in the near future. At this point, it is assumed that about 63% of residents of developed countries are interested in switching to an electric car (Union of Concerned Scientists, 2019). The main reasons why interest is not greater are the high price of electric cars, the small distance (km) they can travel on a single charge, and the long battery charging time (h).

This paper will examine the main problems with electric vehicles. The impact of electric vehicles on the environment will be shown, by comparing them with conventional ICE. Different vehicle models and different countries are compared. The impact of direct and indirect effects is examined using the Climobile App application of the Luxembourg Institute of Science and Technology.

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II. MAIN PROBLEMS IN THE DEVELOPMENT OF ELECTRIC VEHICLES

A. High initial cost

It is estimated that in the United States the price of electric cars should be around $36,000 (Castrol, 2020) to increase their sales. The prices of the 3 best-selling electric cars are in that range: 1. Tesla Model 3 - $38,000, 2. Chevy Wolt - around $32,500, 3. Nissan Leaf - around $32,500. The Automotive Engineering magazine writes that the cost of purchasing an electric car in the United States is on average about $12,000 higher than that of conventional cars. Taking into account operating and maintenance costs, an electric car is certainly a more profitable investment. However, the initial difference is still too large for a larger number of buyers to opt for an electric vehicle. Greater sales of electric vehicles would cause more mass production, and thus a reduction in their price. This leads to the "chicken and egg" problem, where it is not yet possible to reduce the price to increase sales, and sales are not growing due to the high price. The majority of owners own new electric vehicles. With the increase in the number of vehicles, the number of used vehicles on the market is also growing. In the coming years, an increase in the number of used vehicles can be expected, and with it the purchase of an electric car at a lower price. The most expensive part of an electric vehicle is the battery. Leading companies have been successfully fighting this problem in recent years and have succeeded in significantly reducing the price of the most expensive component. In 2013, the average battery of a Tesla car cost $ 668 / kWh, which means that it was worth 2/3 of the total price of the car. By 2020, the price of the battery had fallen to $ 137 / kWh, and today it is estimated to be around $ 100 / kWh.

B. The problem of charging electric cars

Electric car manufacturers have found through research that buyers want to charge their car batteries from 0-100% in 31 minutes (Castrol, 2020). This poses a real challenge for manufacturers, considering that some models still do not have fast charging capabilities. For example, Chevrolet will only launch a fast-charging model in 2021, which charges the battery only up to 38% in 31 minutes. Nissan has a model with better performance, so it charges the battery up to 62% in the same time. The Tesla Model 3 has the best charging, up to 83% in ideal conditions, with the fastest supercharger model. However, this only allows for a range of 315 km. In colder weather, the charging time increases and the range decreases.

For the mass use of electric cars, it is necessary to provide widely available fast chargers that would meet the demands of drivers. Charging the battery at home is a serious problem. The Tesla Model 3 has a 50 kWh battery, which requires a powerful inverter for fast charging, which is practically impossible at home. There is a 7.7 kW rectifier, a relatively inexpensive device with a standard connection to a home installation, but with it the battery can be charged from 0-100% in about 10 hours. If this charging method is compared to refueling at existing stations for vehicles with ICE, it is clear that electric cars do not seem attractive for long distances. In order for electric cars to become more competitive, an adequate solution must be found for charging their batteries. A 250 kW inverter, which would charge the battery in about 30 minutes, is available on the market and costs about $ 57,000. It is impossible to expect individual users to accept such an expensive solution, let alone the significantly lower costs for the accompanying equipment that electric cars require. For the mass use of electric vehicles, a large number of widely available fast chargers are needed. States are not yet interested in such investments, and it must be noted that this is related to the development of electrical sources and the network. Electric car manufacturers are trying to help solve this problem, but they cannot do it alone. Tesla has provided its customers with a station with 6-8 fast chargers with a power of 120-150 kW, but it costs about $ 250,000. The closest equivalent of a Volkswagen station for the American market would cost about $ 350,000 (Electrify America, 2020). The properties of the batteries themselves are an additional problem when charging them. In lithium-ion batteries, the charging speed is not constant, as in all batteries, but depends on the degree of charge of the battery. At the beginning, 0-20%, the charging speed is much higher than at the end 80-100%. The charging speed does not depend directly on the power of the station, but on how much electricity the battery can accept. These battery properties show that it is more useful to charge it from 0-50% and drive it until it is empty, than to charge it from 0-100% and drive it until it is empty. A higher power of the charger does not mean a faster charging of the battery, especially at the beginning, so the charging times do not vary significantly for 150-250 kW chargers. Therefore, the number of fast chargers is more important than their power, but it is also a significant problem considering the cost of fast chargers. The average US resident lives 4 minutes from a liquid fueling station, and 30 minutes from a Tesla fast charger station. In order to achieve fast chargers within 5 minutes of the user, in addition to the existing 1000, another 30000 fast charger stations need to be built, which would cost about 8 billion dollars (Tesla, Inc., 2017). This leads to a situation in which sales of electric vehicles do not grow due to an insufficient number of fast charger stations, and the number of stations does not increase due to insufficient sales of electric vehicles, which is another "chicken and egg" problem.

In addition to the above, there is also a struggle in the market between different manufacturers of electric vehicles, which results in incompatible chargers for different vehicles. Tesla chargers have their own connector, and can also use the J1772 connector. With a special accessory, they can also use the CHAdeMo charger connector. There is also a 4th (fourth) type of CCS connector, with which Tesla cars are not compatible. The total number of chargers in the US could be sufficient if the problems of different chargers were overcome, but the struggle of different manufacturers for a monopoly leads to additional complications for users. In the EU this problem does not exist, because the CCS model is the standard.

C. The problem of energy storage

If we compare the energy potentials of liquid fossil fuels used to power conventional vehicles and the battery in which electricity is stored to power electric cars, a clear difference is noticeable, to the detriment of the battery. Existing technologies for storing energy in batteries are not efficient enough. Batteries are too large in volume and too heavy in relation to the stored energy and cannot compete with liquid fossil fuels.

For example, 1 gallon (3.78 l) of gasoline has an energy content of 33.7 kWh (8.9 kWh/l), according to the US Environmental Protection Agency. In a 2018 study that included 8 different manufacturers of lithium-ion batteries [1], [3], it was determined that the best existing battery cell used in cars stores 684 Wh/l, i.e. 13 times less than gasoline. If we take into account the supporting structure, cables and the battery cooling system, it becomes clear that liquid fossil fuels are superior in this aspect compared to batteries.

An even bigger problem for electric car manufacturers is the mass of the battery. Using the previous data, it is easy to conclude that 1 gallon of gasoline has a mass of approximately 2.7 kg with an energy density of 12.48 kWh/kg. The most efficient battery has an energy density of only 240 Wh/kg, which is 51.67 times less than gasoline, considering only the battery cell, without additional necessary equipment.

D. Car range (Distance traveled on a single battery charge)

In 2018, electric vehicle manufacturers, through a survey of users, came to the conclusion that at least 470 km should be traveled on a single charge. The Chevrolet car traveled 417 km, the Tesla Model 3 traveled 381 km, while the Nissan traveled 240 km. For short-distance driving, electric car users would have no problem. So, with a home battery charge in about 10 hours, at least 240 km could be covered. When it comes to driving longer distances, traveling with an electric car requires much more planning, taking into account the density of fast chargers. It is easy to conclude that 2 parameters are dominant for the range of the car: charging time and battery capacity. The forecast is that these parameters will improve, so the range of electric cars is expected to increase. But this will inevitably increase the price of electric cars. Today, some more expensive Tesla models exceed a range of 650 km.

III. ANALYSIS OF ELECTRIC CARS FROM AN ENVIRONMENTAL ASPECT

The benefits of using electric vehicles are often overestimated in terms of reducing pollution of the human environment. The general conclusion is that even in the most favorable scenario for the rapid introduction of electric cars, the effects of reducing emissions of greenhouse gases, i.e. improving air quality, will be minimal in the next decade. When considering the effects that vehicles have on the environment, it is necessary to include a large number of parameters, but also to fully analyze the environment for the alternative solution. The amount of pollutants that will be emitted is affected by the type of vehicle, its systems and parts, driving conditions, the type of terrain and road, driving speed, the age of the vehicle and its individual parts, the type of fuel, as well as other factors that are difficult to perceive and valorize in full. Currently, the effect of vehicles on the environment is seen almost exclusively through air pollution, but the impact on water pollution during the extraction of liquid fossil fuels is also significant, as is the pollution of the land due to the leaving (burying) of various substances that are inevitable during the production of vehicles, fuel fuels and other raw materials that are necessary for their use. When using electric vehicles, the greatest pollution is expected during the mining of lithium and other raw materials needed for batteries, as well as during the disposal of batteries after use.

We must remember that a large part of electricity is produced by burning fossil fuels, coal, fuel oil - oil and gas, which also causes negative effects on the environment, i.e. the source of pollution is moved from roads and streets and concentrated at the location of the power plant. It should be noted that not all fossil fuel power plants pollute equally. Coal-fired thermal power plants pollute the most, liquid fuel plants less, and gas-fired plants the least. Even with coal-fired power plants, there are differences, depending on age, country of production, technology. In our country, coal-fired power plants pollute the air more than those in the developed world.

Although renewable sources of electricity, hydroelectric power plants0, wind turbines and photovoltaic sources, are considered ecologically clean sources, they still have negative impacts on the environment. Hydropower plants cover the land with water and destroy especially low-growing forests, endanger animals and their habitats, pollute the water, prevent fish migration (in our country, the eel is disappearing), etc. Mini and micro power plants further destroy the ecosystem of rivers. Wind turbines and photovoltaic power plants often take away useful agricultural land, which should not be allowed as harmful, although it reduces investment due to the more favorable infrastructure in the plains. For such sources, hilly and mountainous terrain with infertile or less fertile soil should be used, although in current cases, there is a disturbance of the flora and especially the fauna in the environment.

In order to draw conclusions about the pollution caused by road traffic, this section analyzes the production of electricity and the exploitation of fossil fuels, as well as pollution during the production of vehicles.

A. Energy needs and electricity production in North Macedonia

North Macedonia is in the penultimate place in Europe in terms of energy consumption. Energy consumption per capita is more than 2 (two) times lower than the European average. In 2022, energy consumption per capita in our country was only 1.3 toe (1 toe = 1616 kg coal = 954 kg gasoline = 11.63 MWh), which is 58% below the European average, including 3200 kWh (44% below the European average). The country's energy needs for 2024 are estimated at 2750 ktoe, [10], [11], [12], [13]. Transport is the sector with the highest consumption at 35%. All liquid fossil fuels, as well as gas, are imported, as there are no domestic sources.

According to the 2021 census, North Macedonia has a population of 1,836,793, and the number of families is 559,418. They use 477,820 cars, 44,400 trucks, 6,300 tractors and 2,900 buses, [14]. Almost all vehicles (over 99%) are equipped with ICE. The railway is poorly developed, is in a major crisis and is rarely used. The use of gas in road transport is negligible. In 2018, 535,000 t of diesel and 120,000 t of gasoline were consumed. Assuming that the average energy value of liquid fossil fuels is 8.92 kWh/l, according to the fuel consumed in 2018, 5893 106 kWh were used in road traffic, [15],[16].

Electricity production in the country is mainly based on the use of lignite with a calorific value of 5500 kJ/kg. There are 3 (three) units x 225 MW = 675 MW in REK Bitola. In

Table.1. Average emissions of harmful gases from coal-fired power plants in the EU and the Western Balkans

Air pollutant	EU (t/MW)	Western Balkans (t/MW)
Sulfur dioxide SO2	4	82
PM particles	0.2	3.3
Nitrogen oxide NOx	3.9	9.5

In recent years, North Macedonia has become a leader in the Western Balkans in the introduction of renewable energy sources, [17]. Photovoltaic plants with an installed capacity of over 400 MW are already in operation. The installed electrical power in mini (1-10 MW) and micro (up to 1 MW) is estimated at 130 MW. About 75 MW have been installed in wind farms. However, it must be noted that the power of all vehicles in our country is about 10 times greater than the installed power of all electrical sources. This means that a rapid transformation of conventional vehicles into electric ones is impossible. New sources of electricity are necessary to replace conventional vehicles with electric ones. Creating a network of fast chargers, competitive with liquid fuel stations, is a priority task, primarily because of the foreign drivers passing through the country, but also because of possible domestic users.

B. Pollution in the production of lithium batteries

The main element of the battery of the electric battery is lithium (Li), the lightest of all known metals, which accounts for about 8 kg. In addition to lithium, the average battery contains 35 kg of nickel (Ni), 20 kg of manganese (Mn) and 14 kg of cobalt (Co), according to data from the American laboratory Argon. Lithium is also used for batteries of mobile phones and laptops. With the increase in the application for batteries of electric vehicles, its price is increasing. The largest lithium mines are located in South America, China and Australia, where it is heavily exploited, [5], [6]. The world's largest lithium mining company is known for destroying ecosystems around the world, and even for causing civil wars. Mining lithium has consequences for the ecosystem and can directly threaten human life and health. The environment is polluted primarily by toxic waste tailings, but also by the fumes of aggressive acids used in lithium processing. The production of 1 t of lithium requires about 1900 t of water. The scenario of ecosystem destruction has already been seen in Papua New Guinea, Namibia, Madagascar, Cameroon, Indonesia and other countries, during the mining of the ores needed for the battery. In Nevada, USA, it has been determined that the processes of ore processing have an impact on fish up to 250 km downstream from the mine. (As a reminder, in our country these are distances in the east-west and north-south directions). Cobalt, the most expensive element of the battery, is also a big problem, which is also toxic if not handled properly. In addition to mining the elements needed for the battery, its use can also have negative consequences. Proper handling of the battery is necessary, and in particular, care must be taken with their disposal after use. Used lithium-ion batteries react with certain substances and can cause a fire.
The production of a conventional car generates about 8 t CO2 eq, similar to the production of an electric car without a battery. When greenhouse gas emissions from battery production are added, the total emissions are about 15 t CO2 eq, [7]. It turns out that the greenhouse gas emissions from battery production are almost equal to the emissions from making the car.

C. Pollution from fossil fuel extraction

It is correct to analyze the pollution from the production of electricity for electric vehicles, in comparison with conventional vehicles, to consider the pollution from the extraction of fossil fuel.
Oil is usually found 1800 m underground, and is extracted by pumps on oil platforms, which usually uses electricity worth 120,000 kWh/year. That is the amount of electricity that would drive a Tesla Model 3 673,000 km. In the US alone, there are about 435,000 such oil platforms, and they consume enough electricity to power 15 million electric cars for the same period of time. It is clear that this is an exceptionally large amount of electricity, which is used only to extract oil from the ground. Diesel generators are used to extract oil from the sea to provide electricity. An inevitable problem with extracting oil from the sea is its occasional spillage into the water, which destroys the ecosystem. Oil transportation is also a complex, expensive and polluting process. Ships for transport also use highly polluting fuels. It is estimated that oil transportation emits 100x106 t CO2/year. The next step is oil refining, which also causes pollution and requires a significant amount of electricity, especially in cities and settlements close to humans. Finally, the refined fuel must be transported to liquid fuel stations, which is also a polluting process. The extraction, processing, and use of liquid fossil fuels for EVs is a dirty technology that significantly pollutes the environment at every stage of the process. If these enormous amounts of energy were used to power electric cars, the environment would be much less polluted.

D. Recycling of used batteries

To meet the projected market needs in the coming years, it is necessary to mine huge quantities of metals. In parallel with the increased demand for metals, the end of the life of used batteries is coming. Mining metals at the beginning and disposing of batteries at the end of use cannot continue indefinitely. For a sustainable system, it is necessary to establish an efficient recycling process for used batteries, [8]. However, a major problem is that recycling metals from lithium-ion batteries is now a more expensive process than mining metals. Therefore, due to the unprofitability of recycling, a solution is often sought in making new batteries. In such a case, used batteries are simply disposed of and become a dangerous source of environmental pollution. Lithium-ion batteries are also composed of phosphates, aluminum, copper, graphite, various types of harmful salts, and plastics, which are extremely harmful to the environment. To solve these problems, it is necessary to include new technologies and agreements between countries. The technology of developing lithium-ion batteries is well on its way to eliminating cobalt and nickel from the battery composition and to improve the recycling process.
The essence is to reduce or completely eliminate the participation of toxic and expensive metals and thus reduce the cost of recycling. By overcoming this problem, materials will be used more efficiently, the need for ore mining will be reduced and the use of electric cars will be facilitated.

IV. COMPARATIVE ANALYSIS OF AIR POLLUTION

To compare air pollution from the combustion of liquid fossil fuels in conventional ICE and from the production of electricity with dirty technologies, the Climobile App application is used. This application was developed at the Luxembourg Institute of Science and Technology in 2019. and is used to compare the CO2 eq emissions produced by a conventional car with an internal combustion engine powered by liquid fossil fuels and the electricity required to power an electric car, [1], [9]. The application allows the user to select the model of the conventional car with an internal combustion engine, the model of the electric car, the battery life of the electric car and the method of production of the electricity used by the car. It is possible to adjust several other relevant parameters.

For the EU and US countries, the method of production has already been defined, so only the country in which the battery is charged can be selected. For the remaining countries, the method of production of electricity can be selected, namely: biomass, coal, gas, geothermal sources, hydropower, nuclear energy, oil, solar panels and windmills, without the possibility of selecting more than 1 (one) source with the idea of making a comparison between the different sources. It should be commented here that in reality the source of electricity is combined and a real selection cannot be made. As an output, the user receives data on: the average range of the electric car, the amount of electricity required kWh/km, greenhouse gas emissions from the production of electricity with the spatial arrangement of the charging stations, and as the most important data the amount of CO2 eq/km from the conventional car and the selected source of electricity. For conventional cars, data is provided according to NEDC (New European Driving Cycle), which is a theoretical value, but also data on real emissions, which are mainly slightly higher values obtained with the calculations of ICCT (International Council on Clean Transportation), [9]. Each of the listed types of exhaust gas measurements has positive and negative sides and can be applied for different purposes. Laboratory tests refer to testing the car with dynamometers, as force measuring elements. The dynamometers simulate operating conditions according to a predefined test cycle, for stationary and dynamic conditions. All gas emission values displayed by the application are values that the vehicle emits over its entire life.

A. Comparative analysis of air pollution by different vehicle models

In this section, Table T.2 presents the results of comparing conventional cars with ICE and electric cars (E) from the same manufacturer, as well as similar cars from different manufacturers. The aim is to compare as similar car models as possible, with an emphasis on the pollution caused by ICE and the pollution from the production of electricity used by the car. Since the way in which the electricity is obtained to power the car is important for such calculations, the example of Germany is used in these comparisons. The origin of the electricity produced in Germany in 2019 is from the following sources: 47.3% from renewable energy sources, 39.6% from coal and gas, 13.1% from nuclear power plants (Deutsche Welle). The NEDC values represent laboratory conditions, and the real-world values are closer to actual emissions, [1].

Table 2. Comparative analysis of gas emissions of ICE and E cars

In Table 2: Model, Range and energy, EE and emissions

model	km	km	kWh/ km	gCO2/ km	NEDC/ p
Reno Fluence 1.5 dCi 2015 MBC	200000				177/ 223
Reno Fluence ZE 2015 E	200000	176	0.119	73.1	119
Toyota Aygo 1.0 2017 MBC	200000				141/ 178
Reno ZOE 2017 E	200000	285	0.137	84	138
KIA Soul 1.6 2017 MBC	240000				178/ 228
KIA Soul EV 2017 E	240000	201	0.127	78.3	135
Mercedes C-63 AMG 2017 MBC	400000				236/ 311
Tesla Model S 100D 2017 E	400000	600	0.158	97.3	150
Volkswage n Up 1.0 75 2017 MBC	240000				148/ 189
Volkswage n Up e 2017 E	240000	152	0.117	71.9	104

The results of the comparison of gas emissions (last column in T.2) in the considered examples are different and require comment. In the Reno Fluence model, the electric version emits significantly less pollution, and it is similar with the KIA Soul and Volkswagen Up models. In the higher-class cars, the Mercedes C-63 AMG and Tesla Model S 100D, the electric version emits almost half as much pollution. The results for the Toyota Aygo 1.0 and Reno ZOE are surprising, where the difference in pollution is almost negligible, especially for laboratory conditions. However, it is obvious that the pollution from electric cars in the considered examples is lower, taking the model for electricity production in Germany from renewable sources in the highest percentage of 47.3%.

B. Comparative analysis of air pollution in different countries

For the comparisons in this section, the car models Skoda Citigo 1.0 2017 ICE and Skoda CITIGOe iV 2020 E were used. Newer car models from the same manufacturer were taken, for a better comparison of pollution in countries from Europe and North America. The life span is set to 240,000 km. In table T.3, the second column shows the percentage of electricity obtained from non-renewable sources for each country. The third column shows the emission of polluting gases during the production and distribution of electricity. The fourth column shows the emission of polluting gases per km of the electric car.

Table 3. Comparative analysis of pollution from electric cars in different countries

Country	EE non-renewable 2019%	EE emissions gCO2/km	Emissions/km gCO2/km
United Kingdom	79	101	139
Germany	40	99.3	137
Norway	3	5.01	38
Slovenia	32	51.8	87.3
Serbia	68	94	131
Wyoming	87	150	190
Vermont	10(2018)	4.84	37.8

The countries were selected to reflect the differences in electricity generation and the impact on electric vehicle use, from Norway, which uses a lot of renewable energy, to Wyoming, which uses a high percentage of non-renewable energy. The results clearly show that states that generate more electricity from non-renewable sources have less potential benefit from electric vehicles. The results for greenhouse gas emissions are proportional to the share of non-renewable electricity sources, mainly from fossil fuels, primarily coal.

V. CONCLUSION

The aim of this paper is to objectively present the characteristics of electric cars. They are probably overestimated in their potential for improving the environment. Electric vehicles are not completely environmentally friendly. Improvement from an environmental perspective is primarily related to the development of the battery. Battery production must become more efficient, by reducing the number of materials and their environmental hazard, and thus decreasing their mass, accelerating charging and extending their lifespan. Electric cars usually pollute the environment less compared to conventional cars. The benefits of their use are also seen in the increase in the distance traveled, i.e. longer lifespan. It must be taken into account that their technology is at the beginning of development, while conventional vehicles with ICE have a development history of more than 1 (one) century. Here it is very effective to recall what ICE vehicles looked like 100 years ago, which would be analogous to today's level of development of electric cars.

It is very important how the electricity needed to power electric cars and for any application in general is obtained. The share of renewable sources of electricity must be increased, as the Scandinavian countries are an example.

The automotive industry for both electric and conventional vehicles must strive for technologies to reduce greenhouse gas emissions. This is the main priority to stop global warming and save planet Earth.

The Republic of North Macedonia has no chance of reaching 50% use of electric cars in the near future of 10 years. There are not enough electrical sources for that, of any kind. But therefore, intensive work needs to be done on public transport with electric vehicles in all urban areas. At the same time, it is necessary to improve rail traffic. And finally, but perhaps as a priority and most importantly, the network of fast charging stations for electric cars must immediately begin to be developed, for the needs of foreigners, but also as a necessary preparation for our users of electric vehicles.

LITERATURE

[1] N. Ivkovic, Analiza uticaja elektricnih vozila na zivotnu sredinu, Put i saobracaj, LXVIII, 1/2022.

[2] M. Carlier, Battery electric vehicles in use – worldwide 2016-2020, https://www.statista.com

[3] J. Quinn, T. Waldmann, K. Richter, M. Kasper, M. Wolfahrt-Mehrens, Energy Density of Cylindrical Li-Ion Cells: A Comparison of Commercial 18650 to the 21700 Cells, Journal of the Electrochemical Society, 2018.

[4] HEAL https://www.env-health.org

[5] Electric cars and batteries: how will the world produce enough? https://www.nature.com

[6] M. Azmi, A. Tokai, Environmental Risk Trade-off for New Generation Vehicle Production: Malaysia Case, Canadian Center of Science and Education, Ontario, 2016.

[7] E. Emilsson, L. Dahllof, Lithium - Ion Vehicle Battery Production, IVL Swedish Environmental Research Institute, Swedish Energy Agency, 2019.

[8] B. Huang, Z. Pan, X. Su, L. An, Recycling of lithium-ion batteries: Recent advances and perspectives, Journal of Power Sources, 399, 2018.

[9] Real-world vehicle fuel consumption gap in Europe at all time high, ICCT, https://theicct.org 2017.

[10] https://www.consilium.europa.eu/en/infographics/how-is-eu-electricity-produced-and-sold/#:~:text=A%20sunburst%20chart%20showing%20the,Gas%3A19.6%25

[11] https://www.enerdata.net/estore/country-profiles/north-macedonia.html

[12] Energy Development Strategy of Republic of North Macedonia (Final draft for public consultations), MANU, 2019.

[13] 3rd Biennial Update Report on Climate Changes, RNM Ministry for Environment and Space Planning, August 2020.

[14] Census in Republic of North Macedonia, 2021.

[15] https://economy.gov.mk

[16] https://solareyesinternational.com

[17] https://balkangreenenergynews.com

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Review Scientific Paper

Analysis of Urban Traffic Control Systems: Challenges, Strategies, and Innovations

Xhemile Sejdini[1]

Abstract – **In urban environments, traffic management primarily refers to optimizing the flow through the implementation of various signal control strategies. This paper provides an overview of diverse generations of urban traffic control systems based on a wide range of system implementations across different cities. The emphasis is on adaptive signal control, new technology trends, and the technological pressure on systems as they evolve to become more effective and adaptable.**

Keywords: **Traffic Control Strategies, Intelligent Transport Systems, Adaptive Signal Control, Urban Network.**

I. INTRODUCTION

The modern traffic network is not just a rigid physical foundation but grows into an organizational and technological system that needs to offer the user a complete and quality service, to respond to their numerous and complex requirements, and finally, to communicate with them to manage them efficiently. The main urban thoroughfares mainly have a mobility function and at the same time bear large traffic flows. The intersections of the main thoroughfares are most often controlled by traffic lights to allow for adequate traffic capacity. Traffic signals on the main corridors are usually coordinated, mainly to demonstrate the level of service, which is measured by the number of stops and the delays (time losses). Delays and the number of stops is reduced when the movements through the thoroughfare are progressive.

The basic conceptual diagram of urban traffic control systems is shown in Figure 1. With the development of new technologies such as cameras, detectors, is its easier to collect real – time information which is communicated to the control systems and then these data are shown to the users via VMS (variable message signs), car park guidance, the traffic signals are changed, etc.

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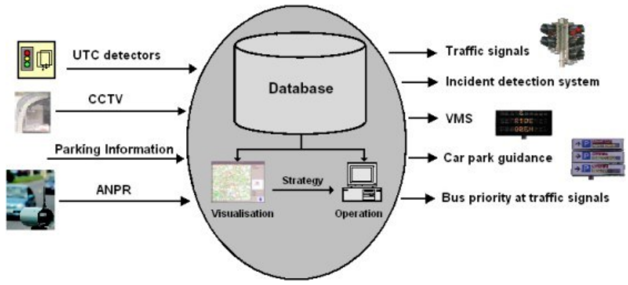

Figure 1. Conceptual diagram of Urban Traffic Management Systems [11]

Many urban areas suffer from saturated road corridors. Often, drivers choose to stay on the highway to avoid the uncoordinated signals on the main thoroughfares. Integrated management strategies for highways and major thoroughfares can be carefully designed to enable effective coordinated management, thereby reducing the effects of congestion in the city. Traffic control on a network involves a set of various strategies that optimize one or more indicators, such as delay, travel times, queues, air pollution, safety, fuel consumption, while providing special conditions for certain users.

This paper focuses on the analysis of various control systems and strategies in urban areas. The paper is structured as follows. Section 2 presents the theoretical part of signal control. Section 3 describes case studies used around the world and their focus in North Macedonia’s implementation of new technologies. Section 4 provides new trends for signal control strategies, as a fuzzy logic signal control system for minimizing the delay time and offering better traffic systems.

II. TOWARDS SIGNAL CONTROL STRATEGIES

The traffic control strategies in urban areas are divided as a fixed -time, actuated, and adaptive control strategies. In fixed control strategies, the signal cycle and its division are predetermined (calculated) and constant over a longer time interval. Their mode of operation is always the same, regardless of whether there are/are changes in the traffic flow. This drawback is eliminated by incorporating multiple programs (time during which one of the fixed signals operates). The capacity of the devices used today has the ability to accommodate 8 to 12 programs. Therefore, the day is divided into 8 to 12 time periods, and a separate program is given for each period. By introducing these programs, the flexibility of the system increases. By applying only three programs, significant results are visible. Software used to calculate the signal plans that are in function of the above-mentioned systems is: MAXBAND, MULTIBAND, PASSER II-90, AAPEX, PASSER IV, and TRANSYT.

Adaptive control strategies, precisely because of their adaptability, are much better. However, there must be a detector on the approach to the intersection. The elements that are determined are: the minimum green time, the extended green (which depends on how many vehicles will appear on the leg that has a green light), the maximum green (the longest green that can be given to the appropriate direction), the announcement interval (to extend the green time, the vehicle must announce itself to the detector in an interval shorter than the announcement interval (1.5-2 s). These include systems for online traffic control, such as SCOOT, SCATS, etc. SCOOT – Split, Cycle, And Offset Optimization Technique. This system was developed in the UK in 1973 and was implemented in the city of Glasgow in 1979. The system is based on measurements from the intersection counterflow detector. The model calculates the flow profiles for each traffic link every 4 seconds. It projects these intersection profiles downstream using the TRANSIT dispersion model. The principle of operation is as follows: one detector is required at the beginning of each branch in the managed network, at the exit of the "previous intersection-counterflow". According to the information from the detector and with the help of SCOOT, the profile of the vehicle column for one cycle is examined in the central computer. Based on information about the time and length of vehicle travel and the vehicle queue dispersion algorithm, SCOOT predicts the arrival of the flow at the end of the branch (at the next intersection), calculates delays, stops, changes the cycle length, green distribution, and green shift [9].

This traffic control system was developed in Sydney, New South Wales, Australia. The system operates in real time, using information from detectors (located in each lane, immediately before the STOP line) to adjust the signal (duration) by traffic demand and system capacity. SCATS uses two levels of control: strategic and tactical control. Strategic control determines suitable signal plans in zones and subzones based on the average traffic conditions prevailing. Tactical control refers to control at the level of an individual intersection. Today, SCATS is used in many cities around the world. It has recently been implemented together with AUTOSCOPE video detection systems in the Auckland area. Initially, 28 intersections were covered, of which 23 were equipped with a video processor for vehicle detection. The system was expanded to 95 more intersections, and the long-term goal included 800 SCATS intersections by 1996. SCATS distributes the calculations between the computer in the operations center and the existing controllers located in each zone. SCATS has the following advantages: automatically generates signal plans, thus freeing the control center from performing this task, and automatically calibrates the detectors. The benefits of this system include: (i) in the morning peak hour, when there are no significant deviations in the flow, SCATS shows a small reduction in delays, fewer stops by approximately 7-8%,, (ii) in the morning peak hour, when flows fluctuate by 20% to 30%, SCATS shows: reduction in stops by 8%, reduction in total losses by 3%, reduction in total fuel consumption by 3%, and reduction in exhaust gases (CO, HC and NOx) by 3 to 6% [10].

UTOPIA was created in the early 1980s, is a traffic control system with a wide range of applications and well-proven solutions, in over 50 cities across the globe. Supported Control Strategies include fully adaptive control, traffic actuated plan selection, time-based plan selection, and traffic response control. Also supports:

- Different control strategies in different regions
- Different control strategies in different time-of-day / day-of-week scenarios.

The Traffic Management and Control Centre (TMCC), utilizing the UTOPIA adaptive system, was built in Skopje in 2014 as a result of the FP7 project CIVITAS RENAISSANCE and with additional funding from an EBRD grant. Currently, it monitors and manages 90 intersections in real time [1].

III. CASE STUDIES

Automatic vehicle location and real-time passenger information at bus stops in Skopje. These services aim to improve the efficiency and friendly attitude of public transport to passengers. Public transport priority can be given by integration in urban traffic management systems. Public transport priority is a means to make the switch from individual to public transport more attractive. The introduction of the Automatic Vehicle Location (AVL) system in the public transport of the city of Skopje is the last project in this area. From 1 January 2016, electronic tickets and AVL system have been put into use in public transport, but problems regarding BUS locations are detected during system field testing. Electronic bus tickets became available in private transport on May 1, 2016. So far, the equipment has been installed in 377 buses, including GPS systems, processors, fiscal devices, audio devices for advertising, displays, etc. [2].

Public transport information for blind and partially sighted people in Brighton & Hove, United Kingdom [4]. To improve accessibility and public transport provision for blind or partially sighted passengers, the city of Brighton & Hove added audio devices, known as react units, to bus stops. When activated, the devices verbalize the information displayed on the bus signs, which includes details of which services are due and where they are going. Users have a battery-operated key fob that alerts them when they are near one of the "talking bus stops". The fobs are issued to relevant bodies representing blind and partially sighted people and to public transport users who apply for them. Feedback indicates that the introduction of technology has led to greater confidence and independence for blind and partially sighted bus passengers. The bus stops have won several national awards for innovation and for the promotion of accessibility, and there are now 42 of them in the city. Seventy-eight percent of survey respondents had found it difficult or very difficult to obtain bus information before the introduction of the talking bus stops, but this share had fallen to zero by the end of the CIVITAS intervention. Seventy percent of respondents said that the new system is their primary source of bus information. The level of satisfaction with the service is high, with 100 percent of respondents requesting that it be rolled out to further locations in the city and beyond. The combined project costs for the implementation of this measure came to EUR 49,916.

Public transport priority and urban traffic control in Monza, Italy. As an important node connecting cities in Switzerland and Italy, and as a hub for small and medium-sized enterprises, the Italian city of Monza suffers from high levels of traffic and congestion. Through CIVITAS, Monza set up an urban mobility system to encourage sustainable modes of transport. The city made a commitment to increase public transport use by making it more attractive to citizens, and by optimizing the flow of buses thanks to the application of ITS technology in conjunction with more systematic transport thinking. Monza managed to achieve significant results by using ITS in conjunction with an automatic vehicle location/automatic vehicle monitoring (AVL/AVM) system and an urban traffic control (UTC) system. These systems make it possible to identify the position, and delay, of each bus operating in the city in real time [6].

The systems also allow decisions to be made as to which buses need priority action. A decision-making module then decides which actions are more appropriate for resolving potential conflicts. If two delayed buses are approaching the same intersection from opposite directions, for example, a decision will be made as to which bus needs the right way. The UTC system then changes the traffic lights as requested. The implementation of the new systems resulted in a 5 percent increase in traffic flow and a 20 percent reduction in traffic density. The shorter traffic light times decreased waiting times for pedestrians and cyclists.

In the Municipality of Strumica, through "Strumica Transport", a detailed map and schedule of bus lines have been established that connect the urban and rural parts of the municipality daily. All stops are marked on the map, with clear and easily understandable signs. The lines lead to: schools, health institutions, the city center, and populated areas. These systems offer clear navigation, better connectivity, comfortable, safe, and economical travel.

Additionally, Bitola began using real–time information about public transport [8]. Passengers can easily find all bus stops around the city, check the timetable, and get updated information about the location of buses in real time. This innovation intends to support the development of public transport in the city, to reduce car congestion and thus make travel more practical, easier, and more enjoyable, and at the same time cleaner.

IV. INNOVATION AND CHALLENGES IN TRAFFIC SIGNAL CONTROL STRATEGIES

As the traffic, population, and number of vehicles are increasing daily, researchers are trying to find solutions to manage the traffic for having less congestion and better quality of life. Moreover, the complexity of managing traffic systems in real-time, with fluctuating traffic volumes and various external factors, calls for more dynamic and intelligent solutions. Traditional traffic management methods, which rely on fixed or manually adjusted signal timings, are increasingly inadequate in addressing these problems. [5]

The technologies that are used are shown in the picture below.

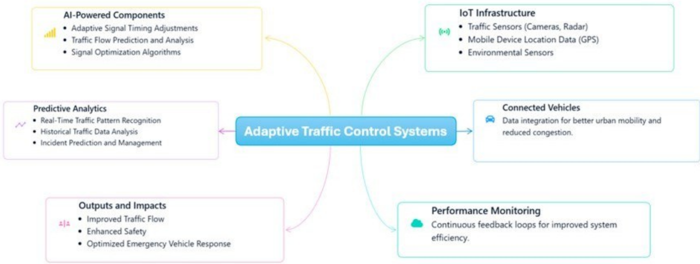

Figure 2. Adaptive Traffic Control Systems – Main Characteristics and New Technologies [12]

Among the strategies integrated into ITS is fuzzy logic, a method that allows for more flexible and adaptive decision-making in the face of uncertainty and imprecision. Fuzzy logic's [5] application has significantly improved traffic signal control systems, enabling them to adapt dynamically to real-time traffic conditions. Instead of relying on fixed timers or pre-set schedules, fuzzy-based systems adjust the traffic signal phases based on variables such as traffic density, speed, and environmental factors, allowing for smoother traffic flow and reduced congestion.

Integrating fuzzy logic with advanced technologies such as Artificial Intelligence (AI), Vehicle-to-Everything technology (V2X), Internet of Things (IoT), and big data analytics can significantly enhance system responsiveness, adaptability, and efficiency. Continued research and innovation in these areas will be critical to shaping the future of intelligent, sustainable transportation networks.

Under the pressure of new technologies, the systems are also facing challenges as follows:

- Many traffic management systems still rely on outdated infrastructure and lack access to real-time data, resulting in inefficient signal timing
- Coordinating multiple intersections in large networks adds another layer of complexity, especially during peak hours or emergencies.
- The integration of new technologies such as connected and autonomous vehicles requires significant improvements, both technical and financial.
- High implementation costs, limited budgets, and the need for specialized expertise often slow down innovation.
- Moreover, as systems become smarter, they are also becoming targets of cybersecurity threats, raising concerns about data protection.
- The environmental impacts of poor signal timing, such as increased traffic emissions, are also significant.
- Finally, institutional and human resistance to change can hinder the adoption of advanced control strategies, especially when there is a lack of training or understanding of the new systems. These challenges must be addressed to build smarter, safer, and more efficient traffic control systems.

V. CONCLUSION

A large number of adaptive traffic control strategies have been developed to adapt to the flow changes as well as to be capable for effective management of the signal time changes.

Advanced AI, connected vehicles, and smart infrastructure will likely lead to more efficient traffic management. However, it may take time to see substantial improvements, and the situation could worsen without proactive measures. By promoting sustainable transportation alternatives and embracing smart urban planning, we can work toward a future with less congestion and improved quality of life.

REFERENCES

[1] Xhemile Sejdini, Daniela Koltovska Nechoska. DESIGNING THE NATIONAL ARCHITECTURE OF INTELLIGENT TRANSPORT SYSTEMS. SUT Vol. 8, No. 15-16 / 2022.

[2] Koltovska Nechoska, D., Krmac, E., Comparison of Road Traffic Intelligent Transport Systems Application Levels in Republics of Macedonia and Slovenia, Proceedings of Second International Conference "Transport for Today's society", 17-19 May, Bitola, Republic of Macedonia, 2018.

[3] http://civitas.eu/content/introduction-avl-system-and-real-timepassenger-information-bus-stops

[4] Brighton & Hove City Council. (2013, August 28). Public transport information for blind and partially sighted people in Brighton & Hove, United Kingdom. CIVITAS Initiative.

[5] Xhemile Sejdini, Daniela Koltovska Nechoska. A review of Fuzzy Logic-Based Traffic Control Systems: Insights from Real-World Case Studies. SUT

[6] Confalonieri, P. G. (2012). Public transport priority and urban traffic control in Monza, Italy. CIVITAS Forum, Monza, Italy.

[7] https://strumica.gov.mk/javen-prevoz-strumica-transport

[8] https://bitolacitybus.mk/

[9] SCOOT® - TRL Software

[10] TransCore | SCATS

[11] Hounsell, N.B., Shrestha, B.P., Piao, J. and McDonald, M. (2009). Review of urban traffic management and the impacts of new vehicle technologies. Institution of Engineering & Technology, Intelligent Transport Systems, 3, (4), 419-428.

[12] Gheorghe. C; Soica, A. Revolutionizing Urban Mobility: A Systematic Review of AI, IoT, and Predictive Analytics in Adaptive Traffic Control Systems for Road Networks. Electronics 2025, 14, 719.

Session B:
Enhancing Traffic Safety and Infrastructure Planning

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Professional Paper

Pilot Implementation of a Network-Wide Road Safety Assessment Proactive Methodology in North Macedonia

Stevco Jolakoski[1] Daniel Pavleski[2] and Daniela Koltovska Nechoska[3]

Abstract – **Road safety assessment is carried out using different methodologies. This paper presents pilot implementation of Network Wide Road Safety Assessment Methodology in North Macedonia, focusing on proactively addressing high-risk sections. The challenges and results from the pilot implementation are presented and discussed.**

Keywords – **RISM, Network wide assessment, Road crashes, In-built safety, Proactive methodology.**

I. Introduction

Road safety analysis plays an important role in the efforts to reduce the fatalities and serious injuries on roads. It is a process that allows to investigate the level of safety of a specific road or road network and it can be carried out using different methodologies that can be broadly separated into two categories: methodologies that rely on crash occurrence (also known as reactive or ex-post) and those that evaluate the in-built safety of roads (known as proactive or ex-ante)

With the update of the Road Infrastructure Safety Management Directive (RISM) directive 2008/96/EC [1], the European Commission (EC) asks all member states to carry out a Network-Wide Road Safety Assessment (NWRSA), which must be based on: (1) "*primarly, a visual examination, either on site or by electronic means, of the design characteristics of the road (in-built safety)*", and (2) "*an analysis of sections of the road network which have been in operation for more than three years and upon which a large number of serious accidents in proportion to the traffic flow have occurred*". This implies that this new procedure required by the EC must include a safety analysis based on crashes (reactive approach), and an analysis based on visual inspection and evaluation of the in-built safety (proactive approach) [7].

In accordance with the revised RISM directive 2019/1936 [2], Member States must carry out the first network-wide road safety assessment of Motorways and Primary roads by 2024, and regularly thereafter. To help the public authorities in EU Member States to carry out the safety assessments of their road networks as required under the revised RISM Directive, European Commission in January 2023 published guidelines on NWRSA [3]. The methodology is developed within a project "Study on a Methodology for Network-wide Road Safety Assessment" by National Technical University of Athens, University of Zagreb and FRED Engineering s.r.I.

The objective of the NWRSA methodology is to provide a cost-effective safety assessment of the road network within the scope of the Directive. The safety assessment is to be based on the evaluation of both the design characteristics of the road (in-built safety) and historic crash data (if available), and serves a screening purpose in order to prioritize in an efficient way either targeted road safety inspections or direct remedial actions. Particular emphasis is placed on the needs of vulnerable road users, as required in Article 6b of the revised RISM Directive.

The methodology comprises two approaches: one for the assessment of roads on the basis of crash occurrence analysis (reactive methodology) and one for the assessment of the in-built safety of roads (proactive methodology). The two methodologies are both applied over the same network and the resulting assessment outcomes are combined via an integration methodology to provide the final road network rating and ranking.

The NWRSA reactive methodology is based on the assessment of crash data on fatal and injury crashes for the last three years (at least). If such data are unavailable the reactive methodology cannot be implemented, and the assessment will be based on the outcome of the NWRSA proactive methodology. Crash data includes crashes with all road users, namely motor vehicles, bicyclists and pedestrians. Three segmentation approaches are considered. In the first one, sections include both segments and junctions. In the second and third approaches, junctions are assessed separately from road segments and the difference between the approaches lies in the junction length; this can either be predefined based on the junction type or measured. Sections are defined with the objective to be roughly homogeneous based on number of lanes, junctions' presence and horizontal curvature. Recommended maximum section lengths are provided for each road type, with the objective to ensure large enough sections and so, adequate number of crashes per section. Then, available crash data is located to sections (and junctions). The next step is the definition of reference population per road type. Two safety performance metrics can be used for the assessment, namely crash density and crash rate and for each metric an upper and lower threshold are defined for the assessment. Based on the threshold, sections are classified as "High risk: or "Low risk". If the analysis does not yield to statistically significant results, sections are classified as "Unsure" [3].

The NWRSA proactive (in-built safety) methodology is initiated with the correct identification of the road type. The geographical limits of the assessment are clearly defined. The proactive methodology requires a first stage of data collection that is essential for the network segmentation. Two approaches are considered for the segmentation. Either a fixed length

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segmentation of short segments (e.g., of 500 m) or a varying length segmentation, focusing on the formation of roughly homogeneous sections. Roughly homogeneous sections that consist of segments and junctions are defined based on traffic volume, horizontal curve, speed limit and terrain type data. A second stage of data collection follows to gather all necessary road and operational data for the assessment of the parameters; six parameters are used for the assessment of urban and rural motorways and nine parameters are used for the assessment of primary (or other EU-funded rural) roads. A Reduction Factor (RF) is estimated for each parameter and based on the value of all RFs the final score of the section is estimated. Based on this scoring, each section is ranked as “High risk”, “Intermediate risk” or “Low risk”. An additional scoring criterion, related to the sections traffic volume, is applied: if the section has very low traffic volume compared to rest of the network (i.e., belongs to the lowest 15% of traffic ranking) and if the section has been classified as “High risk”, it is assigned to “Intermediate risk” class [3].

The integrated methodology combines the results of the proactive and the reactive methodologies. The integrated methodology assumes a five-class ranking system, namely “Very high priority”, “High priority”, “Intermediate priority”, “Low priority”, “Very low priority”. As the proactive and the reactive methodologies use a different segmentation approach, it is described how to combine these two different segmentation approaches and produce the final sections of the network [3].

In this paper Pilot Implementation of a Network-Wide Road Safety Assessment on selected road section using proactive (in-built safety) methodology is presented.

II. Methods and Materials

A. Selection of road section and determination of road type

For pilot implementation of a Network Wide Road Safety Assessment Methodology, a road section which is part of the state road A2 was selected. The A2 is an important route on TEN-T network (Corridor VIII) that serves several large towns along the southwest and northeast parts of the country. The road section of A2 selected for this pilot implementation of NWRSA is a 23.9 km section of rural road between Stracin and Kriva Palanka, which is part of the expressway that connects Kumanovo and Kriva Palanka. The location of the selected road section is showed on Fig.1.

Fig. 1. Location of the road section Stracin – Kriva Palanka

In terms of the road type, the road section is determined as primary undivided rural road with carriageway width of 12,5 m that consist of two drive lanes (one per direction) and two emergency lanes (one per direction). The typical cross section is shown on Fig. 2.

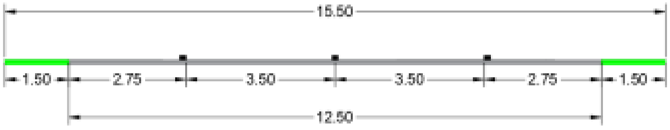

Fig. 2. Location of the road section Stracin – Kriva Palanka

B. Data collection

For the implementation of the network-wide in-built safety assessment methodology two types of data need to be collected: (1) Overview data at an aggregate level of detail that are needed for segmentation process and (2) Detailed data at a higher level of detail per segment needed for assessment process.

An overview data includes: traffic volume, number of lanes, speed limit and terrain type. As of primary undivided roads, the detailed data are related to the following nine parameters: lane width; roadside (clear zone width, obstacles, presence of barriers); curvatures; density of property access points; junctions; conflicts between pedestrians/bicyclists and motorized traffic; shoulder type and width; passing lanes; and signs and markings. An overview data and detailed data were derived from detailed design files, Google earth and recorded videos.

C. Segmentation of road section

The segmentation process involves dividing the road section into smaller parts. Two alternative approaches for segmentation can be considered, either sections of fixed length, indicatively 500m, or longer homogeneous sections in terms of traffic volume, number of lanes, speed limit, and terrain type. For segmentation of the road section Stracin – Kriva Palanka, an approach with homogenous sections was applied.

While not a mandatory criterion for segmentation, it is recommended the sections to be formed in a way that horizontal curves are either fully included or fully excluded from a section. Also, when homogeneous sections are formed, it is recommended that they should not exceed 2 km in length.

Following the aforementioned criteria for segmentation, the road section is divided on 13 segments presented on Fig. 3.

Fig. 3. Segments of the road section Stracin – Kriva Palanka

The length of the segments, the number of basic lanes and the speed limit per segments are presented in Tab. 1.

TABLE I
SEGMENTS OF ROAD SECTION STRACIN – KRIVA PALANKA

Segment	Start	End	L (m)	Basic Lanes	Speed Limit
1	0+000	1+700	1700	1	60
2	1+700	3+700	2000	1	110
3	3+700	5+300	1600	1	110
4	5+300	7+100	1800	1	110
5	7+100	8+700	1600	1	110
6	8+700	10+700	2000	1	110
7	10+700	12+700	2000	1	110
8	12+700	14+700	2000	1	110
9	14+700	16+700	2000	1	110
10	16+700	18+700	2000	1	110
11	18+700	20+700	2000	1	110
12	20+700	22+300	1600	2	110
13	22+300	23+900	1600	2	110

D. Estimation of reduction factors and final score

Each road segment is assessed based on a set of design or operational characteristics. Undivided rural roads are assessed considering both directions of traffic at the same time.

An ideally safe road segment receives a safety score equal to 100 points. Less safe segment gets a lower score, and reduction is determined with the use of Reduction Factors (RF). Each RF corresponds to a parameter used for the assessment of roads and expresses the safety level of the specific parameter. RFs range from zero (without being equal to zero) to one and one corresponds to the safest condition.

After estimating the final Reduction Factor (RF) for each parameter, the total score of the segment can be estimated based on the following equation:

$$RSS_i = 100 \cdot RF_{1i} \cdot RF_{2i} \cdot \ldots \cdot RF_{ni} \qquad (1)$$

Where RSSi is the safety score of the i-th road section. RSSi is a function of the RFji where j denotes the different parameters used for the assessment.

In addition to the parameters, operational characteristics such as traffic volume - AADT (if data is available), speed limit, operation speed V85 (if data is available) and presence of automated speed enforcement, affecting either the safety scoring (Reduction Factors) of selected parameters or the final ranking.

The estimation of the final CMFs and RFs for each parameter and of the final proactive assessment score per segment, was conducted using an excel-based tool developed to assist in coding the information for each parameter.

E. Classification and mapping of road segments

After obtaining the final score, the segment is assigned to a safety class, based on the final score value. For primary road section, the following class thresholds are recommended:

- Low Risk - Class 1: score ≥ 80%, colour coded as green
- Intermediate Risk - Class 2: 50% ≤ score < 80%, colour coded as yellow and
- High Risk - Class 3: score < 50%, colour coded as red

At the end of the proactive methodology implementation, every road segment is classified as "high risk", intermediate risk" or "low risk".

Once the classification was done, the road segments were visualized in red, yellow and green colour respectively on a map using geographic information system - QGIS.

III. RESULTS AND DISCUSSION

The results from the pilot implementation of the Network Wide Road Safety Assessment Proactive Methodology on the road section Stracin – Kriva Palanka are presented in Tab. 2 and shown on Fig. 4.

TABLE II
ROAD SAFETY SCORE AND CLASSIFICATION PER SEGMENT

Segment	Score	Classification
1	37,5	High Risk
2	64,8	Intermediate Risk
3	64,8	Intermediate Risk
4	64,9	Intermediate Risk
5	87,5	Low Risk
6	65,2	Intermediate Risk
7	87,5	Low Risk
8	87,5	Low Risk
9	87,5	Low Risk
10	87,5	Low Risk
11	67,9	Intermediate Risk
12	83,1	Low Risk
13	79,1	Intermediate Risk

Fig. 4. Mapping of road safety class per segments of the road section

As it can be noted from Tab.1 and Fig. 1, one segment of the road section is classified with High risk, six segments are classified with Intermediate risk and remained six segments are classified with Low risk.

The results related to distribution of road safety risk in terms of road section length is presented on Fig. 5.

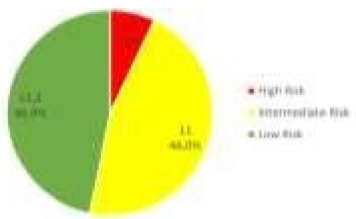

Fig. 5. Distribution of road safety risk in terms of road section length

The Fig. 4 shows that 1,7 km or 7,1 % of the road section are classified with High risk, 11,0 km or 46,0% are classified with Intermediate risk and 11,2 km or 46,9 km are classified with Low risk.

The NWRSA proactive methodology can be considered as fast and cost-effective procedure. It does not require highly-formed personnel for caring out. However, it relays on many high-level road data. The biggest challenge was the roadside Hazard Rating.

IV. Conclusion

The European Union has put a lot of effort and dedication into improving road safety, providing Road Safety Authorities (RSAs) with guidelines to manage the impact of road infrastructure on safety. With the update of the RISM directive 2008/96/EC, the procedure Network Wide Road Safety Assessment was introduced. The network wide road safety assessment proactive methodology has been tested on a primary undivided road section Stracin – Kriva Palanka in North Macedonia, categorized as expressway. The results prove the robustness of the NWRSA proactive methodology. However, to be proved its effectiveness it should be compared to actual level of road safety based on road crashes.

Road sections classified as "High Risk" and "Intermediate Risk" should potentially be subject to Road Safety Inspection (RSI), depending also on the results of the reactive (crash-based) assessment approach and on available funds. Based on the outcome of the RSI, follow-up actions will be determined. As road safety funds are not unlimited, it is important to effectively prioritize the further treatment of segments that affect a larger number of road users.

References

[1] European Commission, (2008). Directive 2008/96/EC of the European Parliament and of the Council on Road Infrastructure Safety Management.

[2] European Commission, (2019). Directive 2019/1936 of the European Parliament and of the Council amending Directive 2008/96/EC on Road Infrastructure Safety Management.

[3] G. Yannis, A. Dragomanovits, K. Deliali, M. Sevrovic, L. Ljubotina, A. Tripodi, P. Tiberi, E. Mazzia, Network Wide Road Safety Assessment - Methodology and Implementation Handbook, Written by National Technical University of Athens, University of Zagreb, FRED Engineering s.r.I., DG – MOVE, European Commission, 2023;

[4] N. Airaksinen, M. Rekola, J. Grohn, Pilot implementation of Network Wide Road Safety Assessment in Finlad, Finish Transport Infrastructure Agency, Workshop on Network Wide Road Safety Assessment Methodology, DG – MOVE, European Commission, 2023;

[5] D. O`Connor, Pilot implementation of Network Wide Road Safety Assessment in Ireland, Transport Infrastructure Ireland, Workshop on Network Wide Road Safety Assessment Methodology, DG – MOVE, European Commission, 2023;

[6] E. Silva, F. Morais, Pilot implementation of Network Wide Road Safety Assessment in Portugal, Road Administration, Workshop on Network Wide Road Safety Assessment Methodology, DG – MOVE, European Commission, 2023;

[7] A. Paliotto, M. Meocci, A. Terrosi, F. La Torre, Systematic review, evaluation and comparison of different approaches for the implementation of road network safety analysis. Heliyon. 2024.

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Original Scientific Paper

Influence of the Cyclist's Mass on the Throw Distance in a Central Collision with a Vehicle

Zoran Joshevski [1] Sonja Chalamani[2] Verche Koneska[3]

Abstract – **The paper examines the influence of the cyclist's mass on the throw distance, and a corresponding mathematical model is offered. The obtained data were analyzed by polynomial, exponential and power regression, and the accuracy of the models was confirmed by statistical tests.**

Keywords – **cyclist, collision, vehicle speed, throw distance, regression model.**

I. INTRODUCTION

Collisions between cyclists and motor vehicles are complex and therefore require careful analysis from different perspectives. This paper focuses solely on examining the influence of the cyclist's mass on the throw distance after a collision with a motor vehicle. The research is directed towards analyzing the statistical and mathematical correlation between these parameters, applying regression analyses and statistical tests. Understanding this relationship is essential for improving traffic accident reconstruction methods, as well as for developing better measures and recommendations aimed at protecting and enhancing cyclist safety. This study aims not only to explore the theoretical foundation of this phenomenon but also to offer practical solutions that can be applied in practice. The following sections of the paper will provide a detailed discussion of the methodology, the obtained results and their interpretation, as well as recommendations for further research in this field.

II. METODOLOGY

The research is based on a quantitative approach that combines accident simulations, mathematical modeling, and statistical analyses to determine the relationship between the cyclist's mass, the vehicle's speed, and the throw distance of the cyclist's body in a collision. The methodology is carefully designed to ensure statistical reliability and the practical applicability of the obtained results.

The research consists of several key steps:

1. Data Acquisition via Simulations – Development of 810 collision scenarios involving 10 distinct vehicle models at 9 velocity levels (20, 25, 30, 35, 40, 45, 50, 55, and 60 km/h) and a cyclist with a mass of 50, 70, and 90 kg, utilizing the PC Crash 9.0 software suite .
2. Mathematical Modeling of Dependencies – Implementation of mathematical functions to determine the most appropriate correlation among the examined parameters.
3. Statistical Validation of Models – Evaluation of the robustness and precision of the derived models through the application of various statistical tests.

The overarching objective of this methodological framework is to develop a comprehensive analytical model applicable in collision reconstruction, forensic investigations, and the formulation of safety enhancement measures. By integrating advanced simulation techniques with rigorous statistical analyses, the study ensures a high degree of result accuracy and practical implementation feasibility.

III. ANALYSIS AND EVALUATION OF REGRESSION MODELS FOR DEPENDENCY MODELING

Polynomial, exponential, and power regression methods were employed to model the dependency between the vehicle's velocity and the cyclist's throw distance upon impact. These regression models are commonly utilized for nonlinear relationships, providing a superior fit to the data compared to conventional linear regression.

The calculations encompass polynomial models of the 3rd, 4th, 5th, 6th, and 7th degrees, as well as power and exponential models, to determine which model provides the highest predictive accuracy. For each model, accuracy assessment was conducted using statistical error metrics, including Sum of Squared Errors (SSE), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE). The Python programming language was employed for computations and analysis, utilizing the following libraries: NumPy – for matrix operations, Pandas – for data processing, SciPy – for nonlinear curve fitting, Matplotlib – for graphical visualization of results. The Ordinary Least Squares (OLS) method was applied to determine the coefficients of the polynomial models through matrix operations involving the design matrix X.

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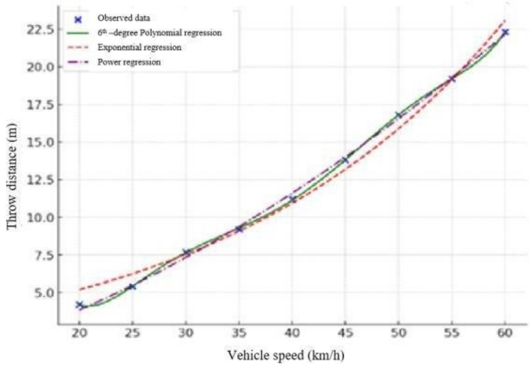

Fig. 2. Comparison of Regression Functions for a Cyclist Mass of 70 kg

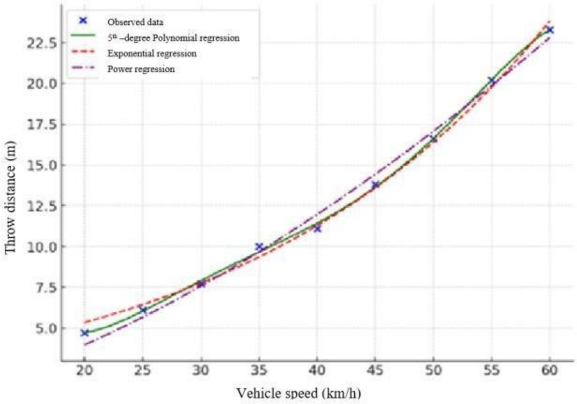

Fig. 1. Graph 1. Comparison of Regression Functions for a Cyclist Mass of 50 kg

Model Analysis and Selection of the Optimal Model for Cyclist Masses of 50 kg, 70 kg, and 90 kg

Based on the conducted comparative analysis, it has been determined that 5th-degree polynomial regression provides the best fit for the observed data, accurately capturing the original measurements and replicating natural variations in the dataset. This makes it the most suitable model for predictive purposes. Conversely, the exponential model exhibits an excessively rapid growth rate, leading to significant deviations from the actual data. Meanwhile, the power regression model introduces certain deviations from the overall trend, reducing its accuracy. These discrepancies can be visually observed in the presented graph.

An analogous analysis was conducted for a cyclist mass of 70 kg. As in the previous case, the 6th-degree polynomial regression was identified as the most optimal model, exhibiting minimal deviation between predicted and actual data points. Furthermore, its coefficient of determination indicates that nearly 100% of the variation in the dataset can be explained by this model, reinforcing its suitability for predictive purposes.

For the final dataset (cyclist mass of 90 kg), the results of the comparative analysis also indicated that 7th-degree polynomial regression is the most accurate model, precisely capturing nonlinear variations and providing stable and accurate predictions(Fig.3).

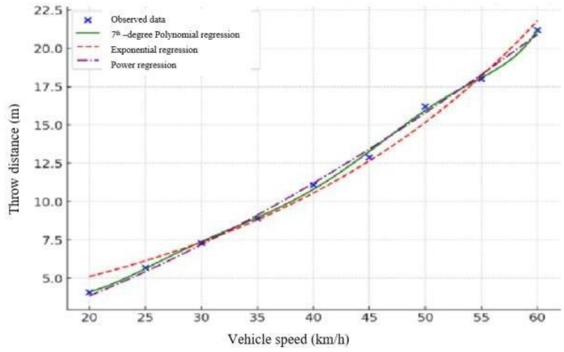

Fig. 3. Comparison of Regression Functions for a Cyclist Mass of 90 kg

IV. Determination of the functional relationship between vehicle speed and cyclist mass

The final functional relationship was formulated using a power function, further refined with logarithmic terms, which proved to be the most appropriate and universal model across all mass and speed variations.

Initially, for each cyclist mass, the most suitable regression function linking vehicle speed to throw distance was determined. The analysis revealed that these relationships follow power functions of the form: $S_{otfv} = a \cdot V_n^b$.

TABLE I
DERIVED POWER FUNCTIONS FOR ALL THREE MASSES

Mass (kg)	Function
50 kg	$S_{otfv} = 0,0338 \cdot V_n^{1,5908}$
70 kg	$S_{otfv} = 0,0322 \cdot V_n^{1,5956}$
90 kg	$S_{otfv} = 0,0382 \cdot V_n^{1,5402}$

The next step was to examine whether a functional relationship exists between the coefficient *a* and the cyclist's mass by analyzing the computed values of a for different masses. The regression analysis indicated that a can be expressed as a power function of the cyclist's mass.:

$$a = 0,0148 \cdot M_{ass}^{0,2017}, \qquad (1)$$

This implies that as the cyclist's mass increases, the value of a also increases, though with a minimal effect. Once the dependency of a on mass was established, it was substituted into the previously derived power equations for each mass. Through a combined analysis of the three individual functions, a universal function was formulated, establishing the relationship between vehicle speed, cyclist mass, and throw distance:

$$S_{otfv} = \left(0,0148 \cdot M_{ass}^{-0,2017}\right) \cdot V_{n}^{1,5760}. \tag{2}$$

Additionally, a direct nonlinear regression was performed on the entire dataset simultaneously, resulting in the following mathematical model:

$$S_{otfv} = 0,0590 \cdot V_{n}^{1,5760} \cdot M_{ass}^{-0,2017}. \tag{3}$$

The comparison of the two models indicated that the second model is more accurate, however, it still exhibits larger deviations from the actual data.

Although this model provided a good initial approximation, it was not sufficiently precise in all cases. The analysis revealed that at low speeds (20–30 km/h), the model underestimated values. At higher speeds (above 50 km/h), the model overestimated results. For higher cyclist masses (above 90 kg), significant deviations from actual values emerged, indicating that a simple power relationship was insufficient for fully and accurately modeling the phenomenon. Additionally, a statistical analysis was conducted on the obtained throw distance data using the newly developed model. As part of this process, the arithmetic mean was calculated, yielding a value of $\bar{x} = 8,66(m)$, the empirical variance was calculated to be 25.69 (m), while the standard deviation was found to be 5.07 (m). The results of the statistical analysis indicate a relatively high variability in the throw distance, which can be attributed to several factors.

- Vehicle speed – As speed increases, the throw distance also increases, leading to greater variability in the data.

- Collision-related factors – Variables such as impact position, angle, cyclist mass, and environmental conditions (e.g., weather, road surface) significantly influence the outcome at the moment of impact.

- Nonlinear growth of throw distance – It was observed that throw distance does not increase linearly with speed, contributing to increased variability.

Given the high values of variance and standard deviation, further analysis was required to enhance the accuracy of the model. This led to the development of combined models that account for the nonlinearity of the data, providing more precise predictions of cyclist throw distance under varying conditions.

The detailed analysis of the data revealed that the deviations from the initial model were not random, but rather followed a systematic trend. Specifically, it was observed that: The model systematically underestimated values at low speeds and overestimated values at high speeds. The effect of mass proved to be more complex, as it did not follow a pure power-law relationship. To overcome these limitations, a logarithmic correction was introduced, refining the model to eliminate systematic errors and enhance its predictive accuracy.

$$S_{otfv} = 0,002114 \cdot V_n^{2,363900} \cdot Mssa^{-0,179832} + 3,080076 \cdot \log(Vn) - 0,236038 \cdot \log(Mssa) - 5,097991 \tag{4}$$

The results of the statistical tests confirmed that the final model is highly accurate. The coefficient of determination explains 99.75% of the variation in the data, indicating extremely high precision, The F-statistic value is 9797,69 which indicates that the model is highly significant. Meanwhile, the p-value from the conducted F-test is $1,11^{e-16}$. These results confirm that the model accurately describes the relationship between the variables and is not a product of random chance.

TABLE II
OBTAINED VALUES FOR STATISTICAL TESTS

Statistical tests	
Test	Value
R^2 (Coefficient of Determination)	0,9974
MAE (Mean Absolute Error)	0,2311
MSE (Mean Squared Error)	0,0866
RMSE (Root Mean Squared Error)	0,2943

TABLE III
F – TEST AND *t* - TEST

Statistical tests	
Test	Value
F – test (Model Significance)	9797,6893
p – value (*F* – test)	1,1102
t – test (Difference Between Observed and Predicted Values)	0,0128
p – value (t – test)	0,9898

Additionally, an ANOVA test was conducted to analyze variance, demonstrating that there is no statistically significant difference in variability between the original and computed values. Furthermore, the following statistical tests were performed to validate the model: Pearson correlation test – The correlation values for all analyzed cyclist masses exceeded 0.998, indicating an almost perfect alignment between the observed and predicted datasets. Kolmogorov-Smirnov (*KS*) test – Provided additional confirmation of the model's accuracy by validating the distribution fit. Chi-square (X^2) test – Confirmed that the distribution of computed values is in complete agreement with the distribution of original data.

The new model is highly accurate and scientifically validated for estimating the throw distance of a cyclist following a collision..

V. Conclusion

Through the development of a mathematical model, this research has provided a consistent and reliable method for calculating throw distance across various combinations of vehicle speeds and cyclist masses. Traditional formulas, commonly used in forensic accident analysis, exhibit deviations ranging from 20% to 40%, whereas the new model significantly reduces this deviation to a range of 0.8% to a maximum of 6.9%, enabling a much more precise determination of throw distance in collision scenarios. This model can be directly applied in traffic accident analysis and reconstruction, offering a highly accurate and scientifically validated tool for forensic investigations.

Recommendations for Further Research

Future studies should investigate the effects of impacts at different angles and points of contact to identify additional factors influencing accident dynamics.

Analyzing the impact of various road conditions—such as wet, slippery, or uneven surfaces—is essential for gaining a more comprehensive understanding of how surface characteristics affect cyclist safety.

Validation of the model using real-world data from documented traffic accidents would be highly valuable in assessing its accuracy and practical applicability**.**

References

[1] Конеска Верче, магистерски труд „МОДЕЛ ЗА УТВРДУВАЊЕ НА РАСТОЈАНИЈА НА ОТФРЛУВАЊЕ НА ВЕЛОСИПЕДИСТ И ВЕЛОСИПЕД ПРИ СУДИР СО ВОЗИЛО СО ПРИМЕНА НА СОФТВЕРСКИ ПАКЕТ PC CRASH 9.0“, Технички факултет Битола, 2024

[2] Montgomery, D. C., & Runger, G. C. (2014). "Applied Statistics and Probability for Engineers" (6th ed.). Wiley.

[3] Draper, N. R., & Smith, H. (1998). "Applied Regression Analysis" (3rd ed.). Wiley.

[4] Seber, G. A. F., & Wild, C. J. (2003). "Nonlinear Regression" (1st ed.). Wiley.

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Professional Paper

Identification of Lighting System Conditions in Vehicles: Safety Aspects

Biljana Veljanovska [1] and Ivo Dukoski [2]

Abstract— **The functionality of vehicle lighting, including beam alignment and intensity, is crucial for road safety. Mandatory inspections assess compliance with regulations. Many vehicles fail due to misalignment, reduced intensity, or improper installation, increasing accident risk. Non-compliant lighting can cause glare, poor visibility, and ineffective signaling, endangering road users.**

Keywords – **headlight, glare, lux meter, light intensity, test methods.**

I. INTRODUCTION

The vehicle lighting system is a critical component of road safety, ensuring visibility for drivers and pedestrians under various weather and lighting conditions. Properly functioning lights are essential for signaling intentions, preventing accidents, and complying with road safety regulations.

II. EXAMINATION OF VEHICLE LIGHTING

A. Methods for Testing Headlight Light Intensity

Headlights are crucial for vehicle safety, ensuring visibility at night and during adverse weather conditions. Measuring and optimizing their intensity and beam angle is essential for compliance with road safety regulations. The intensity of headlight illumination is typically measured in lux (lx), representing the amount of light per unit area. This document explores the methods used to measure light intensity, the mathematical principles governing it, and the calculation of the incidence angle for safe vehicle operation.

Headlight illumination intensity is usually tested using lux meters or photometric testing equipment under controlled conditions. The primary methods include: using a lux meter, laboratory photometric testing, the projection method, the integrating sphere method, and camera-based systems.

Formulas used for calculating headlight light intensity:

Lux (lx) is mathematically defined as:

$$E = \frac{\Phi}{A}$$

For a point light source, lux is determined by the inverse square law:

$$E = \frac{I}{d^2}$$

This means that doubling the distance reduces the light intensity to one-quarter of its original value.

The headlight intensity is influenced by several mathematical parameters, including the distance from the headlight (d), beam angle (θ), reflector and lens efficiency (η), power, and luminous efficacy (P).

$$E = \frac{I \cdot \eta}{d^2} \cdot \cos\theta\theta$$

The safe incidence angle ensures that the emitted light does not blind other drivers, maintaining road safety.

B. Headlight Testing – A real-case study over a two-month period

To conduct headlight testing on motor vehicles, it is essential to understand the requirements outlined in Directive 99/17/EC and Article 11, Paragraph 2 of the Vehicle Law (Official Gazette of the Republic of Macedonia, No. 140/2008), as further specified by regulatory acts and technical specifications.

Regarding photometric values, no measured value should deviate by more than 20% from the prescribed standard.

In all inspected cases, the headlight must remain operational for an extended period until it reaches the required ignition time:

- **15 minutes** for the low beam filament to stabilize.
- **5 minutes** for all filaments to be fully operational.

For integrated lighting functions, all individual lights must be activated within the time specified by the manufacturer, considering the usage of integrated headlight functions. The power consumption must align with the values specified for a nominal 12V lamp voltage.

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According to regulations, the table below outlines the prescribed light intensity for motor vehicles and the beam inclination based on headlight mounting height. This research focuses on passenger motor vehicles.

TABLE I
PRESCRIBED HEADLIGHT TESTING VALUES

<table>
<tr><th>Light Type</th><th>Intensity (Lux)</th><th>Vehicle Type</th><th>Illuminated Road Height</th><th colspan="2">Beam Inclination° (min -max)</th></tr>
<tr><td rowspan="2">Low Beam</td><td>1 Lux</td><td>Motorcycles, Mopeds</td><td>50cm</td><td colspan="2">10</td></tr>
<tr><td>16 Lux</td><td>Motor Vehicles</td><td>60 cm</td><td>7,5</td><td>15</td></tr>
<tr><td rowspan="8">High Beam</td><td rowspan="2">32 Lux</td><td rowspan="2">Motorcycles, Mopeds</td><td>70 cm</td><td>9</td><td>17,5</td></tr>
<tr><td>80 cm</td><td>10</td><td>20</td></tr>
<tr><td rowspan="2">48 Lux</td><td rowspan="2">Vehicles with Halogen Lights</td><td>90 cm</td><td>11,5</td><td>22,5</td></tr>
<tr><td>100 cm</td><td>12,5</td><td>25</td></tr>
<tr><td rowspan="2">90 Lux</td><td rowspan="2">Vehicles with Four Xenon Lamps</td><td>110 cm</td><td>14</td><td>27,5</td></tr>
<tr><td>120 cm</td><td>15</td><td>30</td></tr>
<tr><td rowspan="2">180 Lux</td><td rowspan="2">Vehicles with Two Xenon Lamps</td><td>130 cm</td><td>16,5</td><td>32,5</td></tr>
<tr><td>140 cm</td><td>17,5</td><td>35</td></tr>
</table>

C. *Headlight Inspection at SN Vehicle Traffic Center*

As part of the SN Traffic Center, the SN Vehicle Technical Inspection facility conducts testing and evaluation of motor vehicle headlights. Between January 1st 2025, and February 28th 2025, I conducted inspections and measurements of headlight asymmetry and intensity (measured in lux) in passenger vehicles, categorized by age, manufacturer, and type of light bulbs used.

TABLE I I
ASYMMETRIC HEADLIGHTS- TESTED VEHICLES IN TECHNICAL INSPECTION

Month	Number of Vehicles
January	11
February	12

A total of 23 vehicles were analyzed during this period. It was observed that most headlights were neither cleaned nor properly aligned, which affected their performance. The following table presents the measured data, along with additional inspection results for further analysis.

TABLE I I I
HEADLIGHT BEAM INTENSITY IN ASYMETRIC HEADLIGHTS

Test Vehicle	L High beam	R High beam	L Low beam	R Low beam
1	39 Lux	40.8 Lux	5.6 Lux	6.2 Lux
2	94 Lux	106 Lux	26.9 Lux	26.3 Lux
3	66.5 Lux	57.2 Lux	17.5 Lux	14.8 Lux
4	2.5 Lux	2.5 Lux	3.6 Lux	3.5 Lux
5	3.9 Lux	3 Lux	4.3 Lux	4.2 Lux
6	104 Lux	114.2 Lux	27.9 Lux	28.4 Lux
7	2.5 Lux	2.4 Lux	3.6 Lux	3.1 Lux
8	2.8 Lux	3.4 Lux	14 Lux	17.6 Lux
9	2 Lux	2.8 Lux	12.4 Lux	12.6 Lux
10	16.1 Lux	17.7 Lux	8.1 Lux	4,6 Lux
11	9.2 Lux	9.2 Lux	0 Lux	7.3 Lux
12	16.1 Lux	16.5 Lux	8,1 Lux	0.1 Lux
13	13,8 Lux	15.6 Lux	12.9 Lux	7.1 Lux
14	3 Lux	3 Lux	4.4 Lux	3.2 Lux
15	16.1 Lux	16.6 Lux	7.3 Lux	0.1 Lux
16	1.7 Lux	2.2 Lux	12 Lux	11.4 Lux
17	2.8 Lux	3.9 Lux	13.5 Lux	13.7 Lux
18	2.5 Lux	2.2 Lux	14.5 Lux	12.3 Lux
19	38.4 Lux	42.6 Lux	5 Lux	5.2 Lux
20	3.5 Lux	2.7 Lux	12.7 Lux	13.9 Lux
21	40.0 Lux	43.6 Lux	6.6 Lux	7.4 Lux
22	97.6 Lux	100 Lux	31.2 Lux	30.3 Lux
23	3.3 Lux	3.1 Lux	15.7 Lux	13.9 Lux

D. *Discussion of Results*

The measured values of headlight beam intensity reveal significant differences between vehicles that comply with regulations and those that do not. The analysis highlights key safety concerns and underscores the need for stricter enforcement of lighting regulations.

Compliance rates:

- High beams meeting regulations – 33%
- High beams not meeting regulations – 67%
- Low beams meeting regulations – 51%
- Low beams not meeting regulations – 49%

The results of the headlight tests reveal significant differences between vehicles that meet regulatory standards and those that do not. The analysis of the compliance with high beam and low beam lighting highlights potential safety issues and emphasizes the need for stricter enforcement of lighting regulations.

1. High beam compliance:
• Only 33% of vehicles had high beams that complied with regulations, while 67% did not.
• This suggests that the majority of vehicles had misaligned, overly bright, or insufficient high beams.
• Non-compliant high beams can cause excessive glare, blinding oncoming drivers and increasing the risk of accidents.
2. Low beam compliance:
• 51% of vehicles had low beams that complied with regulations, while 49% did not.
• While the compliance rate for low beams is more balanced, a 49% non-compliance rate remains concerning.
• Improper low beams may fail to provide adequate road illumination or cause discomfort to other drivers due to excessive brightness or misalignment.
3. Causes of non-compliance:
The high percentage of non-compliant headlights indicates several possible factors:
• Lack of regular maintenance – Many drivers may neglect checking or adjusting their headlights.

- Headlight system aging – Over time, bulb wear, reflector blackening, or lens clouding can reduce performance.
- Improper aftermarket modifications – Some vehicles use non-standard HID or LED bulbs that do not align properly with reflectors, causing excessive glare.
- Misalignment issues – Incorrectly adjusted headlights can lead to poor road illumination or glare for other road users.

4. Safety risks and recommendations:

- The high non-compliance rate for high beams (67%) highlights the urgent need for stricter inspections and adjustments to prevent excessive glare.
- The 49% non-compliance rate for low beams suggests that regular headlight testing should be mandatory during vehicle inspections.
- Public awareness campaigns could educate drivers on the importance of headlight maintenance and proper use to enhance road safety.

III. CONCLUSION

A well-maintained vehicle lighting system is essential for road safety, visibility, and compliance with regulations. Regular inspections and functional tests ensure that all lighting components work properly, reducing the risk of accidents and improving communication between road users. Strict adherence to road safety laws related to lighting prevents hazards and enhances overall driving safety. By prioritizing the maintenance of lighting systems, drivers contribute to a safer road environment for themselves and others.

Measuring and adjusting vehicle headlights is crucial for road safety. Lux meters, photometric devices, and mathematical models help determine optimal lighting performance. The inverse square law governs light intensity, while safe beam angles ensure proper illumination without glare. Understanding these calculations enables consistent and effective headlight performance, improving night driving safety.

Failure to perform regular checks, cleaning, and alignment of headlights raises concerns about their functionality, compliance with regulations, and legal requirements. This is evident from the results in the table.

Test results show that a significant number of vehicles have misaligned lighting systems, posing a potential risk to road users. Addressing these issues through regular inspections, proper adjustments, and stricter regulations can enhance road safety and provide optimal nighttime visibility for all drivers.

REFERENCES

[1] "Automotive Lighting and Human Vision" by Burkard Wördenweber, Jörg Wallaschek, and Peter Boyce.

[2] "Vehicle Lighting: Performance and Design" by R. Y. B. Missen.

[3] "Advances in Automotive Lighting Technology" in the SAE International Journal of Passenger Cars - Electronic and Electrical Systems.

[4] "An Analysis of Vehicle Lighting Systems and Their Impact on Road Safety" published in the Journal of Safety Research.

[5] "The Role of Vehicle Lighting in Nighttime Road Safety: A Review" featured in the Transportation Research Part F: Traffic Psychology and Behaviour.

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Professional Paper

Improving Traffic Safety with Electrochromic Rear-View Mirrors

Ratka Neshkovska[1]

Abstract – **Electochromic mirrors use electochromic materials that change color from bleached to colored, depending on the amount of light falling on them. By changing color, they effectively reduce glare and contribute to improving traffic safety. The color change is fast, automatic and reversible. The change in optical properties (such as color, transmission, absorption and reflection) of electochromic materials is due to the insertion/extraction of charges in them or to chemical oxidation/reduction processes when a weak direct current or a small external voltage is applied.**

Keywords – **Electrochromism, electrochromic rear-view mirrors, auto-dimming mirrors.**

I. INTRODUCTION

Roads, vehicles, drivers and other road users affect traffic safety. To reduce traffic accidents and reduce the damage that occurs, the causes that lead to traffic accidents are first considered and appropriate active and passive measures are taken for the safe conduct of traffic. In order to reduce traffic accidents, requirements are defined that roads, vehicles and drivers should meet. One of the conditions for a road not to create conditions for traffic accidents is good visibility without blinding and disorientation of drivers at night and at dusk, as well as in complex meteorological conditions. Vehicles should enable the driver to drive the vehicle safely and with increased comfort. The driver should have good coordination of movement, quick and accurate reaction.

But, despite all measures, the number of traffic accidents that occur on the roads is large. Reducing traffic accidents and their more serious consequences is a problem that science is also interested in. No matter what roads are built, what vehicles are produced, traffic safety still depends mostly on the driver. Motor vehicle drivers are a central group of road users and are the main causes of traffic accidents. Therefore, it is necessary to consider all aspects of the so-called multisensory driver, with the aim of designing measures that will reduce traffic accidents. Quite often, the design of the vehicle and its parts are also a problem for drivers, especially if they obstruct visibility.

Interior and exterior rear-view mirrors allow the driver to have good visibility to the rear (behind the vehicle) and to the side. For greater safety and security in traffic, rear-view mirrors should provide the driver with good visibility to the side and rear with easy movement of the eyes and head left- right and back-and-forth. However, a problem occurs at night and at dusk, when the glare from the rear-view mirrors can blind the driver. Practice has shown that a large number of accidents occur due to the driver being blinded by the light from the headlights of vehicles moving backwards, behind the vehicle, which, after being reflected from the rear-view mirror, falls on the driver's eyes. When that second of blindness occurs, the blinded driver cannot change this condition, and it is beyond his control.

During the second of blindness, the driver's normal behavior is blocked, his movements are uncoordinated, his actions are inexpedient, his thoughts are blocked, and he can quickly and sharply change the path of movement. To avoid these problems, rear-view mirrors with variable reflectance are used.

II. REAR-VIEW MIRRORS

When light (electromagnetic radiation) falls on a surface, some of the incident light is reflected, some is absorbed, and some is transmitted through it. The ratio of the reflected flux to the incident flux is called the reflection coefficient. The higher the reflection coefficient, the greater the luminous flux reflected from the given surface. In physics, a mirror is any smooth surface that reflects the light that falls on it. According to the law of reflection of light, the angle at which light falls on a mirror (the angle of incidence) is equal to the angle at which light is reflected from it (the angle of reflection). The angle of incidence is the angle between the incident ray and the normal to the mirror drawn at the point of incidence, and the angle of reflection is the angle that the reflected ray of light makes with the normal. The incident ray, the normal, and the reflected ray lie in the same plane. Depending on the surface that reflects light, mirrors can be flat or curved. Mirrors are usually made of glass, the back of which is coated with a metal, reflective layer and a protective layer.

Rear-view mirrors are actually flat or curved (concave or convex) mirrors. Countries have different regulations regarding rear-view mirrors: in some countries they are flat mirrors, and in others they are curved (concave or convex).

Fixed rear-view mirrors in closed-body cars, which show what is happening behind the car, were first mentioned in 1906 [1]. In the same year, Bilal Ghanty patented the “Warning mirror for automobiles” [2]. Rear-view mirrors that could be moved and adjusted in order to see the road behind appeared in 1908 [3].

For the driver to have good visibility behind the vehicle, a sufficient amount of light should fall on the rear-view mirror, which, after being reflected from the rear-view mirror, will fall on the driver's eyes and cause visual stimulus. The problem occurs at dusk and at night. Then the light from the headlights of cars moving behind the vehicle falls on the rear-view mirror and can cause glare and blinding of the driver. Such reflected light is unpleasant for the driver and makes him difficult to see things and the road ahead and to the sides, as well as to look in the rear-view mirrors. The recovery time from night blindness that occurs in drivers who have been driving in the dark for a long time is individual and increases with age. Blindness can last for several seconds. Older drivers need up to 20 seconds and more to fully recover from the glare.

To reduce glare, so-called day/night rear-view mirrors began to be used in the 1940s (Figure 1 [4]). They are prismatic mirrors that can be tilted in two positions and thus reduce the brightness of the mirror, and reduce the glare from them. In this way, the reflected light flux that falls on the driver's eyes is smaller. These day/night mirrors are made of glass, whose front and rear surfaces are not parallel to each other, but are in the form of a wedge.

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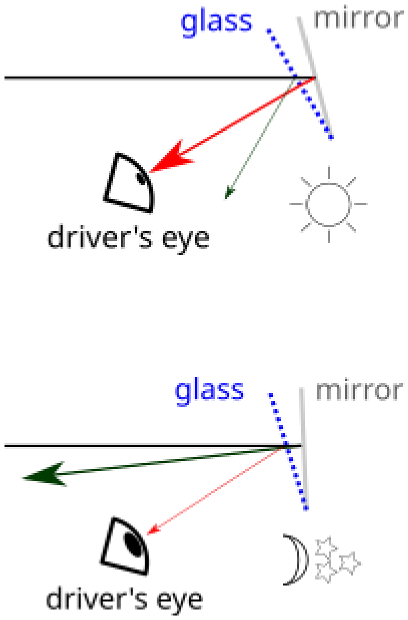

Fig. 1. Day/night prismatic mirror

Such prismatic mirrors have two reflective surfaces (positions) with a reflectivity of about 80% and 4% respectively and can be manually adjusted to two positions: one with a higher reflectivity (day position) and the second one with a lower reflectivity (night position). When the mirror is set to a position with a lower reflectivity, in most cases the driver is protected from glare and thus his visibility of the front stimuli is increased, as well as his comfort. However, this position provides reduced visibility of the rear stimuli seen through the mirror.

To avoid these problems, mirrors with variable reflectivity are used. This means using mirrors with appropriate technology that allows the reflectivity of the mirrors to change reasonably over a wide range. When using these mirrors, a compromise is made between the three problems that the driver faces at night: first, to have good visibility forward and to the sides (without glare), second is his comfort, and third is the visibility of stimuli coming from behind, which the driver sees in the rear-view mirror. The compromise between these three problems refers to the fact that reduced visibility in the rear-view mirror improves the other two factors, and for different situations it is necessary to decide which combination of the three problems to accept.

A solution to these problems is the use of mirrors with variable reflectance that dynamically changes over a wide range. Such are electrochromic mirrors. In electrochromic mirrors, the reflectance can be changed quickly, continuously and over a reasonably wide range. Thus, in conditions of varying brightness, the reflection coefficient can be changed dynamically and unobtrusively automatically. These flexible mirrors offer a choice of different reflection coefficients under different lighting conditions, and thus offer the best compromise between the visibility of objects in the mirror and the protection of the driver from glare from the mirror.

III. Electrochromism

Electrochromic materials change color, and thus change their optical properties (transmission and reflection) under the influence of an external electric field. Optical changes occur by applying a weak electric current at a small direct voltage of the order of fractions of a volt to several volts. The optical properties of electrochromic materials are reversible, which means that by changing the polarity of the applied voltage, the material returns to its initial state. Large number of organic and inorganic substances, in liquid or solid state exibits electrochromic properties.

Polymers are also included in the group of organic materials that possess electrochromic properties. Inorganic electrochromic materials are generally oxide thin films, which possess ionic and electronic conductivity. The reversible and visible change in transmission and (or) reflection in electrochromic materials is associated with oxidation and reduction reactions. The color of electrochromic materials usually changes from a transparent (bleached state) to a colored state, or the change may be between two colored states. In some substances, more than two electrochemical redox states may exist, in which case electrochromic materials exhibit several colors and can be called poly-electrochromics, or can be said to possess multi- electrochromism.

According to the potential at which the coloring occurs, they can be divided into two main groups: materials with cathodic coloring and materials with anodic coloring. Materials with cathodic coloring possess a reduced colored state, i.e. they color at a negative voltage, while materials with anodic coloring are those that possess an oxidized colored state, i.e. they color at a positive voltage [5]. So, when the electrochromic material that possesses cathodic coloring is connected to the negative pole of the source, it will be colored and will retain that colored state until the polarity of the applied voltage is changed. The electrochromic material in the colored state has a lower coefficient of transmission and/or reflection. The electrochromic material retains its colored state until the polarity of the applied voltage is changed. If we want to bring the material into a bleached state, we will change the polarity of the applied voltage, that is, we need to connect the electrochromic material to the positive pole of the voltage source. In the bleached state, the electrochromic material/film has different optical properties, such as higher transmission and reflection. Materials that possess anodic electrochromism are brought into a colored state when they are connected to the positive pole of the source, and when they are connected to the negative pole of the source, they are in a bleached state. By alternately connecting the film to the negative and positive poles of the source, we bring the material to the desired colored or bleached state and thus we obtain a film with the desired optical properties, which are different from the optical properties of the electrochromic material in the state as deposited (obtained). Therefore, we say that electrochromic materials possess a reversible change in optical properties. Such a transition from an uncolored to a colored state under the action of an electric field is called "optical switching". The application of electrochromic materials in devices does not depend on the type of material (cathode or anodic coloring), but on the properties they possess, durability, their cost, etc. The reversible change in optical quantities can be the result of the formation of coloring centers, the formation of a new type of zone-zone transitions, defects or electrochemical reactions [5].

Different materials have different colors in the as-prepared, colored, and bleached states. Figure 2 shows photographs of electrochromic films of copper(I) oxide (Cu_2O) deposited on a glass substrate with a transparent conductor [6] in as- prepared, colored and bleached state. It is important to note that the color and optical properties of an electrochromic material depend on both the applied voltage and the coloring/bleaching time. This is another advantage of these materials when used in various devices.

Fig. 2. Electrochromic Cu_2O films in as-prepared, colored and bleached state.

A. Electrochromic devices

To study the properties of electrochromic materials, as well as for their application, electrochromic devices (ECD) are constructed.

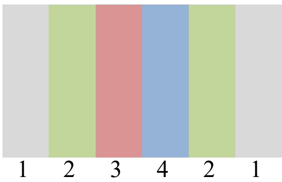

Fig. 3. Electrochromic devices

There are different designs of electrochromic devices. Fig. 3 shows one possible design. Almost all variants of ECD have the same arrangement of layers: 1. glass substrate, 2. transparent conductor, 3. electrochromic film, 4. ion conductor (electrolyte)/ion storage film (can also be an electrochromic film) and finally transparent conductor (2) and glass substrate

(1) again. Each layer in an ECD has a thickness of fractions of a micrometer to several micrometers. The presented design is suitable for considering electrochromic devices in the general case. The electrochromic film possesses ionic and electronic conductivity, so when ions are inserted into the film from the electrolyte (or from a suitable ion conductor) under the action of an applied external electric field, then, in order to preserve electroneutrality, a corresponding flow of electrons appears from the transparent electron conductor to the film. The electrons remain in the electrochromatic film as long as the ions are there. The electrons in the film cause a change in it's optical properties.

B. Mechanism of Electrochromism

In the electrochromic device (ECD), electrochromic substances with cathodic coloring are connected to the negative pole of the voltage source. Between such a cathode and the anode, which can also be a conductive film on a glass substrate, an ionic conductor (4 in Fig. 3) is placed, which gives light positive ions, such as: Li^+, K^+, Na^+ etc. The coloring of the electrochromic film in this case is due to the process of reduction, i.e. the injection of electrons. When an appropriate electric field is applied to the cathode and anode, the positive light ions from the ionic conductor (electrolyte) come into the electrochromic film. Electrons from the cathode also move towards it. Under the action of the positive ions and electrons, the electrochromic film is brought into a reduced, colored state. When the external electric field is turned off, the electrochromic film returns to its basic, uncolored state. The time it takes for the material to return to the uncolored state varies for different materials and is known as the memory of the electrochromic substance [5]. Materials with anodic coloring are colored by oxidation, i.e. by extraction (loss) of electrons. In an electric field, negative light ions, such as hydroxyl (OH^-) ions from the ion conductor and holes from the anode come to the electrochromic film. As a result, the film loses electrons, i.e. is oxidized and changes from a basic uncolored state to a colored, oxidized state. The anodic coloring material also returns to the basic, uncolored state when the electric field is turned off. The recovery time again depends on the memory of the electrochromic material [5].

So, the coloring of electrochromic materials, cathodic and anodic, is an electrochemical phenomenon caused by the applied electric field, under the action of which the ions formed by the dissociation of the molecules in the electrolyte move towards the electrochromic material, in which they bind to the host molecules. Depending on the charge of the ions and the accompanying electrons or holes, oxidation or reduction of the electrochromic material occurs. These materials are most often multivalent and possess different optical absorption spectra, which correspond to the different oxidation states. Different materials possess different colored states, depending on which part of the spectrum they selectively absorb.

Each part of an electrochromic device (ECD) must possess certain optical, electrical, and mechanical properties, depending on the application of the device. All of them are in a solid state, except for the electrolyte (the ion conductor), which can be in a liquid state or be an organic or inorganic substance in a solid state.

The ability of electrochromic materials to change the color and reflection/transmission of radiation falling on ECD has practical applications in the so-called "smart windows", in displays, rear-view mirrors in the automotive industry [8], for camouflage of objects, etc.

Each ECD can have different designs, depending on whether the device is transparent or reflective, i.e. whether it is used to modulate transmitted or reflected radiation.

The ECD shown in Figure 3 is suitable for modulating the transmitted light through it. It can be easily adapted to modulate reflected light, if a mirror or other element that provides diffuse light scattering is placed behind the electrochromic film. In some cases, the electrochromic film itself is reflective.

Devices used to modulate reflected light (such as rear-view mirrors) can reflect incident light diffusely or specularly. Diffuse reflection is required in information displays, so that the information they show can be visible from different angles, and specular reflection is required in anti-glare rear-view mirrors. For different versions of the ECD, analyses are performed on durability, contrast – a quantity defined as the ratio of the reflection coefficient when the electrochromic film is in a bleached state and the reflection coefficient when the film is in a colored state, the dependence of the coloring efficiency on the number of cycles, the response time (the time it takes for the film to achieve a certain absorption/reflection coefficient), etc.

IV. Electrochromic Variable Reflectance Rear-View Mirror

Electrochromics rear-view mirrors are auto-dimming mirrors which use modern technology to solve the age-old problem with headlights glare from trailing vehicles. Electrochromic mirrors are actually a type of electrochromic device described above. They have a layer of electrochromic film, applied to a conductive glass substrate and an electrolyte in the form of a gel between the electrodes of the device. One of the glasses of this device is reflective. Such mirrors have a sensor that measures the light coming from behind and falling on them. When the sensor detects a larger incident light flux on the mirror, it sends a signal to another sensor that turns on the electrical circuit. Than, for a certain time a current will flow in the circuit, in which the electrochromic material is incorporated. This current will lead to automatic darkening of the electrochromic film. In such a colored state, the film immediately increases its absorption and reduces reflection (Figure 4 [8]).

Fig. 4. Difference in glare between a classic (prismatic) and electrochromic rear-view mirror

In this way, the light flux reflected from the mirror is reduced. Thus, the driver's eyes will be illuminated with low intensity light and thus the driver is protected from the glare of the headlights of vehicles coming from behind. When this increased illumination of the rear-view mirror passes, the sensor detects this state and returns the electrochromic film to the bleached state again. In the bleached state, the reflection coefficient is higher and the visibility in the rear-view mirror is greater, normal. Such switching between the colored and bleached states is fast and automatic, which is one of the advantages of these self-dimming rear-view mirrors. The darkening (diming) of the mirrors is proportional to the amount of light falling on them, which means that the mirror will darken more when the headlights behind us are brighter or closer to the vehicle. The mirror darkening is appropriate at the lighting conditions in any time. In addition, the driver does not need to manually adjust the position of the rear- view mirror during night driving. And most importantly, such electrochromic auto-dimming mirrors in the darkened state provide greater visibility of stimuli coming from behind than conventional technologies.

If there is a downside to these mirrors, it could be that they can break down at an inappropriate time, like any electronic device. These mirrors are more difficult to repair than conventional ones.

However, these auto-dimming electrochromic mirrors protect the driver from the effects of long-term glare, the inconvenience of it, and improve objective driving performance, reducing driver fatigue or negative emotional reactions. In this way, they improve night driving, and thus increase traffic safety.

V. CONCLUSION

For efficient vehicle control, rear-view mirrors (internal and external) also play a significant role, providing the driver with normal visibility. Glare from rear-view mirrors is a major problem for drivers. Practice shows that a large number of traffic accidents occur due to a state of blinding, i.e. a second of blinding of drivers. To reduce blinding, auto-dimming mirrors have been used in vehicles for the last few decades. These mirrors are electrochromic mirrors that automatically and quickly change their color from bleached to colored (darker) and vice versa, when a weak electric current and voltage of fractions of a volt to several volts is applied through them. Electrochromic materials reversibly change color, and thus change other optical properties, such as transmission, reflection and absorption of light. The greater absorption of these mirrors in a colored state reduces the light reflected from them. Thus, a smaller luminous flux falls on the driver's eyes, which does not lead to blinding of the driver and protects him from the negative effects of this phenomenon. On the other hand, the darkening of the mirrors is proportional to their increased brightness, which allows the driver to have good visibility of stimuli coming from behind. The non-blinded driver has better driving performance with them, which also increases traffic safety at night.

REFERENCES

[1] The Automobile (weekly), Thursday, 27 December 1906, p. 910
[2] "Brevet d'invention : dispositif de miroir avertisseur pour automobiles". *Institut national de la propriété intellectuelle*. 8 January 190.
[3] Cycle & Automobile Trade Journal, 1 December 1908, p249.
[4] https://en.wikipedia.org/wiki/Rear-view_mirror.
[5] C. G. Granquist, *Handbook of Inorganic Electrochromic Materials*, Elsevier, Amsterdam, 1995.
[6] R. Neshkovska, Proceedings of the First International Conference „Transport for today`s society“, 19-21 May 2016, Bitola, R. Macedonia, pp 106-111.
[7] R. Neškovska, M. Ristova, J. Velevska, M. Ristov, *Thin Solid Films* (2007).
[8] https://gazer.com.

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Professional Paper

The Impact of Lane Width on Pedestrian and Cycling Safety in Urban Environment

Kristina Ickovska[1], Slobodan Ognjenovic[2] and Riste Ristov[3]

Abstract – **This scientific paper examines the impact of lane width on pedestrian and cycling safety in North Macedonia, where most streets feature 3.50-meter lanes designed for speeds of 80–100 km/h, despite a 50 km/h speed limit. By analysing regulations and standards, the research advocates for optimal lane widths to enhance safety for pedestrians and cyclists, promoting sustainable urban mobility.**

Keywords – **Traffic Lanes, Safety, Urban Mobility, Cyclists, Pedestrians.**

I. Introduction

A traffic lane is a marked or unmarked portion of the carriageway designated for the movement of a single line of vehicles. Traffic lanes accommodate the movement of passenger and freight vehicles, and, where there are no dedicated lanes for public transport or cycling, they also serve buses, trolleybuses, and bicycles. The width of a traffic lane is one of the key parameters in urban streets design, influenced by the design speed. The minimum lane width is directly influenced by the vehicle width (maximum 2.50 m) and the required safety clearance between vehicles. To ensure safe passage, a protective distance is necessary between vehicles and between the edge of the road and the vehicles. These distances are influenced by the speed, as wider lanes tend to encourage higher speeds.

According to the Law on Road Traffic Safety, the allowed speed in urban areas in the Republic of North Macedonia is limited to 50 km/h.[1] Consequently, the width of traffic lanes where the maximum allowed speed is applied should be designed for a speed of 50 km/h. However, it is often observed that, when designing urban streets, traffic lanes with a greater width are adopted. For example, in the General Urban Plan of the City of Skopje (2012 – 2022)[2], 97% of the streets are planned with a traffic width of 3.50 m, a width suitable for speeds of 80 to 100 km/h. Designing traffic lane width according to the design speed on urban streets is crucial for the safety of all users. When the width of the traffic lane exceeds the appropriate width for the designated speed, it leads to a mismatch between drivers' expectations and their behavior. Drivers feel less restricted by the lane markings and can achieve higher speeds and more flexible positioning on the roadway. Wider lanes reduce the perception of risk, which can result in dangerous speeding. Therefore, a very careful approach is required when determining the width of traffic lanes.

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II. Traffic Lane Width

The design speed determines the width of the traffic lane, while the number of lanes is influenced by the traffic load and the level of service (LOS). The minimum width of traffic lane is directly related to the vehicle's width and the lateral safe distance between vehicles. Fig. 1 illustrates two vehicles on a roadway with two traffic lanes passing adjacent to one another. When two vehicles pass each other at a specific speed, a safe distance (denoted as "c") must be maintained between the vehicles, as well as a safe distance (denoted as "d") between the vehicle and the outer edge of the roadway. These distances are speed–dependent, meaning that the required lane width increases with higher design speeds.[6]

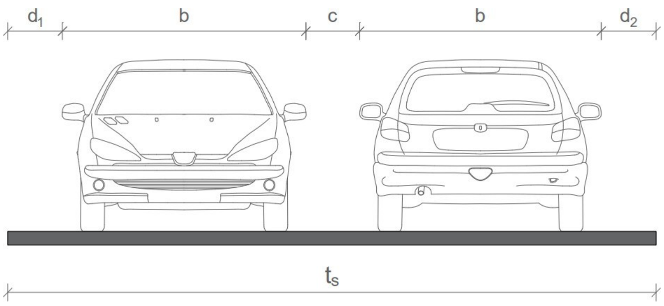

Fig. 1. Carriageway with two traffic lanes

Total lane width, the value of the lateral safe distance between vehicles and the lateral clearance to the edge of the road depends on the speed of the vehicles and can be calculated using the following equations:

$$t_s = d_1 + 2b + c + d_2 \quad (1)$$
$$d_1 = 0.2 + 0.005 \times V_1 \quad (2)$$
$$d_2 = 0.2 + 0.005 \times V_2 \quad (3)$$
$$c = 0.4 + 0.005 \times (V_1+V_2) \quad (4)$$
$$t_s = (0.2 + 0.005 \times V_1) + b_1 + b_2 + ((0.4 + 0.005 \times (V_1+V_2)) + 0.2 + 0.005 \times V_2 \quad (5)$$

Table I
Lane width according to design speed

Design speed [km/h]	Lane width [m]	$2 \times b = 2 \times 2.50$	
		c [m]	d [m]
≥ 100	**3.75**	1.70	0.40
$80 \leq V_r < 100$	**3.50**	1.30	0.35
$60 < V_r < 80$	**3.25**	1.00	0.25
$40 < V_r \leq 60$	**3.00**	0.80	0.10
$V_r \leq 40$	**2.75**	0.30	0.10

These values are defined in *Article 29* of the *Rulebook on Standards and Norms for Design in the Republic of Macedonia*[3] and in *Article 83* of the *Rulebook for Technical Elements for the Construction and Reconstruction of Public Roads and Road Structures*[4]. However, the *Rulebook on Urban Planning* is not aligned with these two regulations and the scientifically defined lane widths according to design speed. In the *Rulebook on Urban Planning of the Republic of North Macedonia*[5], the width of traffic lanes is defined in *Article 145*, where it states: The width of the traffic lanes depends on the category of the street and the planned capacity, its minimum and maximum width are as follows:

TABLE II
LANE WIDTH ACCORDING TO THE RULEBOOK ON URBAN PLANNING

FUNCTIONAL CLASSIFICATION	Lane width [m]
Arterial Street	3.50 – 3.75
Urban arterial street	3.00 – 3.50
Arterial street in a village	3.25 – 3.50
Collector street	3.00 – 3.50
Service street	3.00 – 3.25
Residential street	2.75 – 3.00

A. Traffic flow and Level of Service

Urban streets and highways differ primarily in their functional roles and spatial characteristics. One key distinction is the higher number of intersections, which determines whether a street or a road will have a continuous or interrupted flow.

Continuous flow implies that there are no permanent external factors along the segment that would necessitate a vehicle to stop, except in the case of non–recurring incidents or issues inherent to the vehicle itself.

Interrupted flow implies that there are permanent external factors along the segment that cause vehicles to stop temporarily, such as traffic signals, stop signs or similar control devices.

Subject of this paper are streets with interrupted traffic flow, as they represent a significant part of the urban street network.

The figure 2 illustrates the calculation framework for evaluating the performance of the signalized intersection in terms of its service to motorized vehicles.[8]

The first step is used to determine the lane groups associated with each intersection approach. The second and third steps are used to determine how the left-turn, through, and right-turn drivers on each intersection approach distribute themselves among the lane groups. The fourth step is used to predict the saturation flow rate for each group. The fifth step is used to quantify the effect of upstream signals on the arrival flow rate for each group. If a phase is actuated, the sixth step is needed to estimate the average duration of this phase. In the seventh step, lane group capacity is evaluated in terms of flow rate to capacity. This ratio is used in step 8 to estimate the control delay for each lane group. This estimated control delay is used in step 9 to estimate the level of service (LOS) for each lane group, approach, and intersection. The tenth step can be optionally used to estimate lane group queue length and storage ratio.

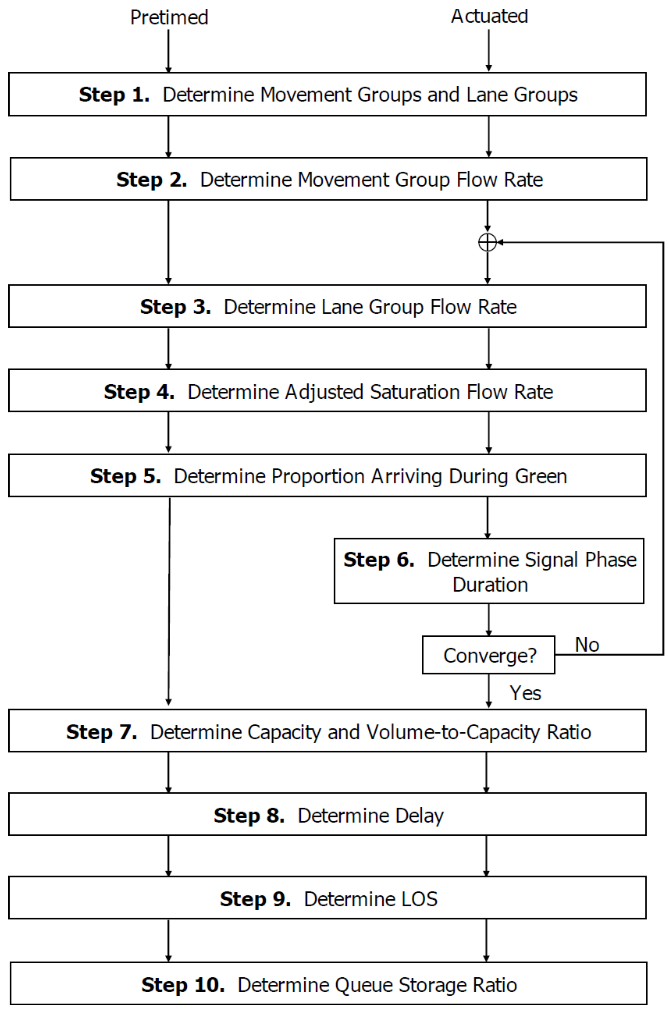

Fig. 2. Determinating LOS of Motorized Vehicles on Signalized Intersections

B. Saturation Flow Rate

The adjusted saturation flow rate reflects the application of various factors that adjust the base saturation flow rate to the specific conditions present at the intersection.

$$s = s_o\, f_w\, f_{HVg}\, f_p\, f_{bb}\, f_a\, f_{LU}\, f_{LT}\, f_{RT}\, f_{Lpb}\, f_{Rpb}\, f_{wz}\, f_{ms}\, f_{sp} \qquad (6)$$

Where:
s = adjusted saturation flow rate (veh/h/ln),
s_o = base saturation flow rate (pc/h/ln),
f_w = adjustment factor for lane width,
f_{HVg} = adjustment factor for heavy vehicles and grade,
f_p = adjustment factor for existence of a parking lane and parking activity adjacent to lane group,
f_{bb} = adjustment factor for blocking effect of local buses that stop within the intersection area,
f_a = adjustment factor for area type,
f_{LU} = adjustment factor for lane utilization,
f_{LT} = adjustment factor for left-turn vehicle presence in a lane group,

f_{RT} = adjustment factor for right-turn vehicle presence in a lane group,
f_{Lpb} = pedestrian adjustment factor for left-turn groups,
f_{Rpb} = pedestrian–bicycle adjustment factor for right-turn groups,
f_{wz} = adjustment factor for work zone presence at the intersection,
f_{ms} = adjustment factor for downstream lane blockage, and
f_{sp} = adjustment factor for sustained spillback.

The lane with adjustment factor f_w accounts for the negative impact of narrow lanes on saturation flow and allows for an increased flow rate on wide lanes. Values of this factor are listed in Table III:

TABLE III
ADJUSTMENT FACTOR FOR LANE WIDTH

Average Lane Width [m]	Adjustment Factor f_w
< 3.00	0.96
≥ 3.00 – 3.90	1
> 3.90	1.04

It can be concluded that on urban streets with interrupted traffic flow, a traffic lane width ranging from 3.00 to 3.90 m, has no impact on the street's capacity. Factors such as signal timing and coordination, intersection design, number of lanes, and lane groups play a more significant role in determining the street's capacity.

III. IMPACT OF TRAFFIC LANE WIDTH ON PEDESTRIAN AND CYCLING SAFETY

The impact of traffic lane width on the safety of pedestrians and cyclists is most significant on streets that feature bike lanes on the carriageway and adjacent sidewalks, where no physical separation exists between the carriageway and the space for bicycles and pedestrians. The impact of traffic lanes on the safety of vulnerable street users can be considered indirectly, through speed. Referring to Table II, it is observed that a lane width of 3.00 m is required for a design speed of 50 km/h. A speed of 50 km/h is the maximum allowed speed in urban areas, according to the Law on Road Traffic Safety in North Macedonia.[1]

Vulnerable street users, such as pedestrians and cyclists, face a significantly higher risk of severe or fatal injuries in the event of a collision with a motor vehicle. The probability of fatality for pedestrians increases dramatically with impact speed. Studies indicate that adult pedestrians have 90% chance of survival when the impact speed is 30 km/h. Analysis of 20 studies assessing the risk of fatality for pedestrians reported that for every 1 km/h above 30 km/h that speed increases, the chance of pedestrian death increases by 11%.[9]

As vehicle speed increases, the required stopping distance also increases, thereby elevating the risk of a traffic collision. For example, when traveling at 80 km/h on dry asphalt, the distance required to react to an event is approximately 22 m and the total stopping distance is around 57 m. In a scenario where a pedestrian runs onto the street 36 m ahead of the vehicle, the probability of a fatal outcome for the pedestrian is high if the driver is traveling at 70 km/h or faster. However, if the pedestrian appears 15 m ahead of the vehicle, the probability of fatal injury for the child increases even at 50 km/h.

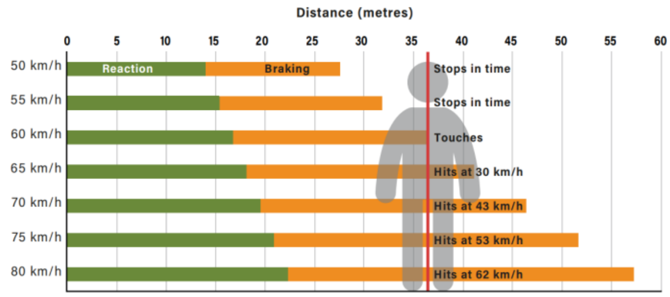

Fig. 3. Stopping distance driving an average car on a dry asphalt

Considering these facts, it becomes more evident why the width of the traffic lane should be aligned with the design speed of the street.

Figure 4 illustrates the relationship between costs and benefits for various speed control measures. The speed control measure with the most favorable cost-benefit ratio is lane narrowing, which has a benefit-cost ratio of 17. This indicates that lane narrowing is particularly effective compared to other measures listed. Implementing lane narrowing appears to provide the highest return on investment in terms of safety benefits relative to costs. [9]

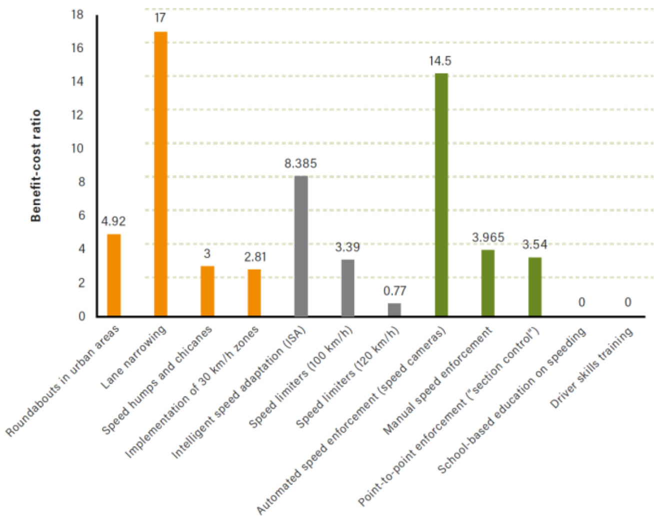

Fig. 4. Stopping distance driving an average car on dry asphalt

The width of the traffic lane not only poses a risk to vulnerable street users due to the speed of motor vehicles but also directly influences the crossing distance at pedestrian and bicycle crossings. This can significantly affect the time required for crossing the carriageway, particularly for older pedestrians. The average walking speed of an adult pedestrian ranges from 1.00 to 1.20 m/s, while this speed decreases to 0.60 – 0.85 m/s for children and elderly pedestrians. In densely built areas, the selection of lane width can impact space utilization, specifically regarding the potential for incorporating median safety islands.

Specific data on pedestrian and cyclist fatalities in North Macedonia is limited, but some insights can be drawn from available statistics. According to the State Statistical Office of North Macedonia, between 2014 and 2024, a total of 1,497 people lost their lives in traffic accidents, with speeding identified as primary contributing factor in most of these collisions. Of these fatalities, an estimated 365 were pedestrians and 62 were cyclists.

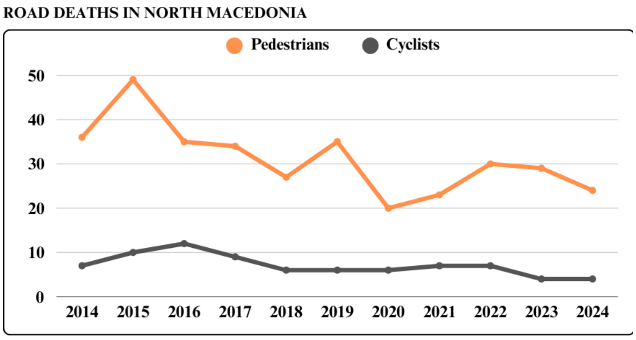

Fig. 5. Pedestrian and cyclists deaths in North Macedonia

IV. CASE STUDY: “MANAPO” STREET

“Manapo” St. is located in the Municipality of Karpoš in the city of Skopje. It has a total length of approx. 440 m and according to the functional classification is collector street. The existing cross-section includes four traffic lanes, each 3.50 m wide, along with sidewalks of variable width ranging from 3.00 to 3.70 m. The street does not have bicycle lanes or paths, meaning that cyclists are required to travel on the right edge of the carriageway.

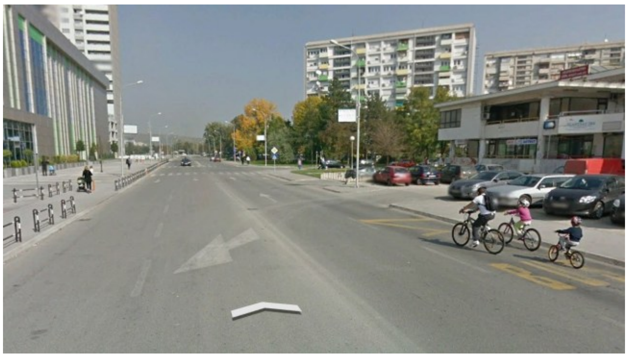

Fig. 6. Existing conditions on “Manapo” street

To enhance the safety of pedestrians and cyclists, it is proposed to reduce the width of the traffic lanes from 3.50 m to 3.00 for the outer lanes, and from 3.50 m to 2.75 m for the inner lanes. This reallocation will enable the implementation of bicycle paths on both sides of the carriageway, each with a width of 1.50 m. These bicycle paths will link the existing cycling paths on boulevard “Partizanski Odredi” and Boulevard “Ilinden”. Building safe infrastructure for cyclists is a key factor in enhancing overall street safety. Specifically, the implementation of separated and protected bike lanes and paths has been shown to reduce fatalities and improve safety outcomes for all street users.[10]

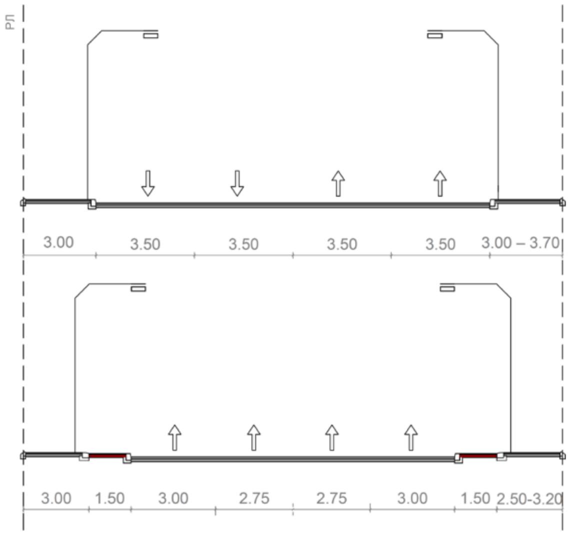

Fig. 7. Existing and proposed cross-section of “Manapo” street

CONCLUSION

This paper indicates that the city of Skopje requires a reduction in the width of traffic lanes both in urban planning documentation and on existing streets to align the lane width with the allowed speed for motor vehicles. Specifically, the width of traffic lanes on streets with interrupted flow within urban areas should not exceed 3.00 m. The only exceptions are high-speed urban roads with continuous traffic flow, where a higher speed is planned. In such cases, the lane width must be aligned with the design speed. This alignment will enhance safety for all street users, including pedestrians, cyclists, drivers, and passengers in motor vehicles.

In addition to improving safety for all traffic participants, reducing the lane width on urban streets will also facilitate more rational dimensioning for the elements of the cross- section. The space gained by reducing lane width can be utilized for the implementation of bike lanes or paths, widening sidewalks, and increasing green strips, depending on the specific needs of the street.

REFERENCES

[1] Law On Traffic Safety, Official Gazette of the Republic of Macedonia No.169/2015,226/2015 and 55/2016, Article 35.

[2] General Urban Plan of the City of Skopje, Agency for Spatial Planning, City of Skopje, 2012.

[3] Rulebook on Standards and Norms for Design in the Republic of Macedonia, Official Gazette of the Republic of Macedonia 60/12, 29/15,32/16, 114/16 and Official Gazette of the Republic of North Macedonia 211/20.

[4] Rulebook for Technical Elements for the Construction and Reconstruction of Public Roads and Road Structures, Ministry of

Transport and Communications, Official Gazette of the Republic of Macedonia 110/2009.
[5] Rulebook on Urban Planning, Ministry of Transport and Communications, Official Gazette of the Republic of North Macedonia 225/2020.
[6] O. Lindov, Sigurnost u cestovnom saobraćaju, Fakultet za saobraćaj i komunikacije, pp 110-112, Sarajevo, 2007.
[7] Rulebook on Urban Planning, Ministry of Transport and Communications of North Macedonia, 2020.
[8] Highway Capacity Manual: A Guide for Multimodal Mobility Analysis, Chapter 19: Signalized Intersections, pp. 19-45, 2022.
[9] Speed Management: a Road Safety Manual for Decision-Makers and Practitioners, second edition. Global Road Safety Partnership, International Federation of Red Cross and Red Crescent Societies, Geneva; 2023.
[10] R. Sturtz, Cycling Lanes Reduce Fatalities for all Road Users, University of Colorado Denver, 2019.
[11] MAKSTAT database

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Professional Paper

Multi-Criteria Decision Analysis of the Class I State Road "Vožd Karađorđe" Optimal Corridor Selection

Nemanja Stepanović[1], Marijo Vidas[2], Miloš Tubić[3]

Abstract - ***The aim of this paper is to present an innovative approach and basic results of applying multi-criteria assessment within the Conceptual Design of the class I state road "Vožd Karađorđe" in Serbia. The "TOPSIS" method was selected for the relative ranking of design variants, and the results were confirmed through a comparative analysis with four most commonly used multi-criteria ranking methods. The results showed that the South variant was better for the "A2-Trbušnica" corridor, while the North variant was better for the "Partizani-Viševac" corridor.***

Keywords - ***multi-criteria decision analysis, TOPSIS method, optimal corridor selection.***

I. INTRODUCTION

Multi-criteria decision-making represents the process of making decisions, or selecting the optimal alternative from a set of alternatives, in cases where there are multiple criteria that are often mutually conflicting [1, 2].

The process of creating planning and design solutions essentially involves designing real corridors – routes with the technical and operational characteristics that will effectively satisfy all functional traffic requirements in line with established goals, while respecting the stated limitations. The process of creating design solutions of the road network, simply put, is based on balancing the demand (i.e. traffic requirements), goals and limitations on one side, and the supply expressed in the creation (or existence) of real solutions on the other side. This balancing is realized through suitable design solutions built on appropriate foundations, which are based on the general level of knowledge from various scientific disciplines, intuition, and creative capabilities of the expert team. When it comes to building new road networks, there are significant (not only indirect) effects that are very difficult to analyse analytically and difficult to convert into a common denominator (monetary unit). In addition, there are goals and criteria of a subjective nature related to both the decision-maker and the complete environment. It is obvious that the assessment of the effects that cannot be measured but that arise from certain design solutions of the road network (such as quality of life, aesthetic value, environment pollution, emergency situations, etc.) can vary significantly depending on the group of people. Their conversion into common denominators is practically impossible. The only viable and logical solution in such situations is the application of some of the multi-criteria assessment methods.

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In the real world, decisions are most frequently made in the presence of multiple criteria that are inherently conflicting and expressed in different units of measurement. Multi-criteria assessment (MCA) involves making decisions in the presence of multiple and mutually conflicting criteria. The criteria represent the standards of judgement or rules that are followed when assessing acceptability.

The aim of this paper is to present an innovative procedure and basic results of applying multi-criteria assessment within the Conceptual Design for constructing the class I state road "Vožd Karađorđe" on the corridor sections from Lazarevac (connection to the A2 motorway) to Trbušnica and from Partizani to Viševac, where two corridor variants have been defined for each section, namely: [3, 4]

- "Lazarevac-Trbušnica" corridor – NORTH (1.2) and SOUTH variant (1.1) (Figure 1)
- "Partizani-Viševac" corridor – NORTH (3.1) and SOUTH variant (3.2) (Figure 2).

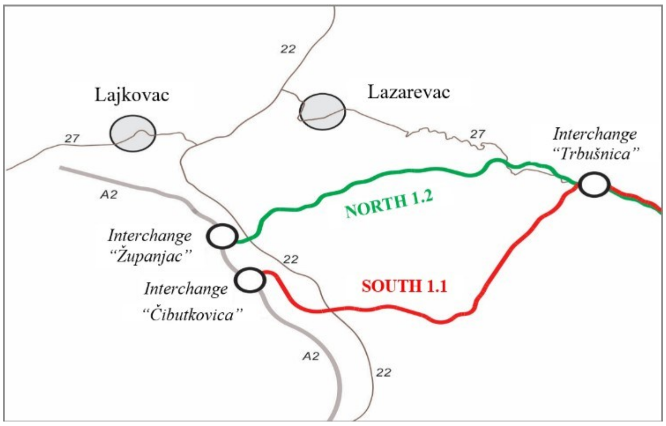

Figure 1. Presentation of the corridor variants on the section from Lazarevac to Trbušnica

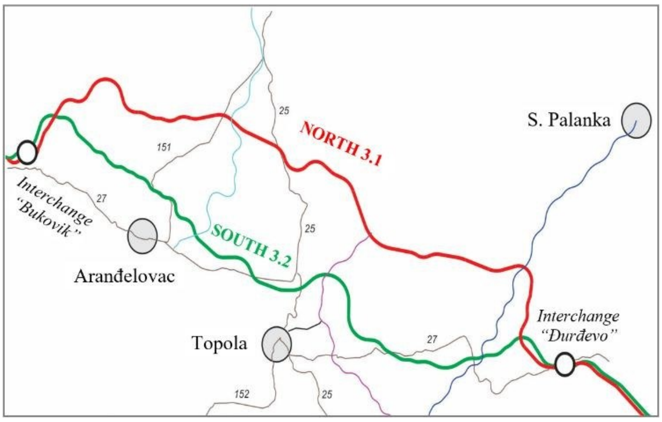

Figure 2. Presentation of the corridor variants on the section from Partizani to Viševac

The Methodology chapter presents the procedure for selecting the appropriate criteria, determining their values and importance, as well as the basic principles of the "TOPSIS" method. The Results chapter provides the results of the multi-criteria assessment of the variant solutions for the studied corridors and a comparative analysis of the results obtained using the "TOPSIS" method and the results from the four most popular multi-criteria assessment methods. At the end of the paper, the Conclusion chapter presents the authors' concluding considerations and the final selection of the optimal variant solutions for the studied corridors.

II. METHODOLOGY

The realization (construction and operation) of each of the analysed variants will result in a series of direct and indirect, positive and negative effects. The purpose of applying multi-criteria assessment is to identify the most significant effects for each variant, use them as assessment criteria with the aim of minimizing negative and maximizing positive effects, and, based on the applied method, compare and rank the variants in order to select the most acceptable variant of the motorway corridor. The "TOPSIS" method was chosen and applied for ranking the mentioned design variants of the class I state road on the corridor sections from Lazarevac to Trbušnica and from Partizani to Viševac. "TOPSIS" is one of the most popular and most frequently applied methods in engineering because it evaluates variants according to an overall quality measure which simultaneously takes into account the smallest Euclidean distance from the "ideal" solution and the largest Euclidean distance from the "anti-ideal" solution.

A. Selection of assessment criteria

The most significant objectives of constructing the class I state road "Vožd Karađorđe" involve:

- Improving the level of service for the projected traffic flows on the road network within the planned road corridor.
- Improving the level of traffic safety for the projected traffic flows on the road network within the planned road corridor.
- Decreasing the operational costs of users for the projected traffic flows on the road network within the planned road corridor.
- Ensuring the optimal service of the high-capacity and high-quality road for existing settlements, functional units, and the road network.
- Maximum preservation of the environment within the planned road corridor. Enabling faster development of the catchment area.

Using a detailed analysis of all specificities of the project variants, five main criteria groups were selected from the above-mentioned objectives. These groups provided the criteria used for the multi-criteria assessment of the studied variants (Table 1).

Table 1. Criteria of the multi-criteria assessment of the analysed variants

A. Spatial and urban planning characteristics of the variants	
A.1	*Conflict of the variants with other infrastructural systems*
A.2	*Characteristics of the variants in terms of demolishing buildings and other facilities*
A.3	*Conflicts of the variants with other urban agglomerations (centres, cities and settlements)*
B. The environment protection and preservation characteristics	
B.4	*Characteristics of the variants in terms of noise emission*
B.5	*Characteristics of the variants in terms of air pollution emissions*
B.6	*Characteristics of the variants in terms of the usurpation of agricultural and forest areas (ha)*
B.7	*Endangerment of the existing drainage basins and drainage areas*
C. Technical characteristics	
C.8	*Length (km)*
C.9	*Curvature*
C.10	*Representation of large facilities, bridges, tunnels and viaducts (total number and length)*
C.11	*Characteristics in terms of the elevation profile of the route and elevation changes – ascent+descent (m)*
C.12	*Geotechnical conditions*
D. Traffic and operational characteristics	
D.13	*Transport work (veh/km)*
D.14	*Travel time (min)*
D.15	*Traffic safety*
E. Economic characteristics of the variants	
E.16	*Project implementation costs (€)*
E.17	*Expressway maintenance costs (€)*
E.18	*User costs (operation and travel time) (€)*

B. Determining the values of the selected criteria

The indicator values have been taken from the relevant studies and the Project Documentation of the Conceptual Design for the construction of the class I state road "Vožd Karađorđe". On the basis of the quantitative and qualitative values of 18 selected indicators, it is possible to perform the ranking of the design variants using the selected multi-criteria assessment method – the "TOPSIS" method. The following tables provide a summary of the values of the indicators (criteria) in different dimensions (the so-called base matrices) for the considered corridor variants.

Out of 18 criteria from the multi-criteria assessment for the corridor from Lazarevac (connection to A2) to Trbušnica (Table 2), the NORTH variant (1.2) has an advantage according to 6 criteria, while the SOUTH variant (1.1) has an advantage according to 11 criteria. The variants are equal according to 1 criterion.

When it comes to the first group of criteria, i.e. spatial and urban planning characteristics of the variants, it can be concluded that the SOUTH variant (1.1) is better according to two criteria, while the variants are equal according to 1 criterion. Considering the environment protection and preservation, the SOUTH variant (1.1) has an advantage in 3 criteria, while the NORTH variant (1.2) has an advantage in 1 criterion. When it comes to technical characteristics, the SOUTH variant (1.1) has an advantage in 4 criteria, while the

NORTH variant (1.2) has an advantage according to the road length criterion. Within the group of criteria related to traffic and operational characteristics, the NORTH variant (1.2) has an advantage in 2 criteria, while the SOUTH variant (1.1) has an advantage according to traffic safety. Regarding economic characteristics, the NORTH variant (1.2) has an advantage in 2 criteria, while the SOUTH variant (1.1) has an advantage according to the criterion related to the project implementation costs.

Table 2.Presentation of indicators/criteria by variants - Base matrix 1

Indicator/ Criterion		"Lazarevac-Trbušnica" corridor	
		NORTH (1.2)	SOUTH (1.1)
		Input values	
A.1	**Min**	3	**2**
A.2	**Min**	3	**2**
A.3	**Min**	**4**	**4**
B.4	**Min**	4	**3**
B.5	**Min**	3	**2**
B.6	**Min**	6	**2**
B.7	**Min**	**3**	4
C.8	**Min**	**17.77**	19.24
C.9	**Min**	2	**1**
C.10	**Min**	6	**2**
C.11	**Min**	3	**1**
C.12	**Min**	3	**2**
D.13	**Max**	**644,269,540**	475,831,756
D.14	**Min**	**12**	13
D.15	**Min**	25.92	**19.64**
E.16	**Min**	221,836,614	**176.378.088**
E.17	**Min**	**287,873**	307,646
E.18	**Min**	**93,399,174**	99,242,767

Out of 18 criteria from the multi-criteria assessment for the "Partizani-Viševac" corridor (Table 3), the NORTH variant (3.1) has an advantage according to 12 criteria, while the SOUTH variant (3.2) has an advantage according to 6 criteria.

Table 3.Presentation of indicators/criteria by variants - Base matrix 2

Indicator/ Criterion		"Partizani-Viševac" corridor	
		NORTH (3.1)	SOUTH (3.2)
		Input values	
A.1	**min**	**2**	4
A.2	**min**	**2**	7
A.3	**min**	**2**	8
B.4	**min**	**2**	4
B.5	**min**	**2**	3
B.6	**min**	4	**3**
B.7	**min**	5	**3**
C.8	**min**	41.59	**38.59**
C.9	**min**	**2**	3
C.10	**min**	**2**	7
C.11	**min**	**2**	4
C.12	**min**	**2**	3
D.13	**max**	1,485,747,052	**1,566,390,089**
D.14	**min**	28	**25**
D.15	**min**	**50.07**	54.98
E.16	**min**	**338,685,888**	527,170,814
E.17	**min**	677,418	**634,511**
E.18	**min**	**111,472,505**	112,436,491

When it comes to the first group of criteria, i.e. spatial and urban planning characteristics of the variants, it can be concluded that the NORTH variant (3.1) has an advantage according to all criteria from this group. Considering the environment protection and preservation, both variants have an advantage according to two criteria. When it comes to technical characteristics, the NORTH variant (3.1) has an advantage in 4 criteria, while the SOUTH variant (3.2) has an advantage according to the road length criterion. Within the group of criteria related to traffic and operational characteristics, the SOUTH variant (3.2) has an advantage in 2 criteria, while the NORTH variant (3.1) has an advantage according to the traffic safety criterion. In terms of economic characteristics, the NORTH variant (3.1) has an advantage in 2 criteria, while the SOUTH variant (3.2) has an advantage according to the criterion related to road maintenance costs.

C. Determining the weights of the criteria

One of the important characteristics of multi-criteria assessment is that criteria do not have to carry the same importance. Determining the importance of criteria is a subjective activity which involves interpreting the value system in a specific multi-criteria assessment task.

In this specific case, the author team chose the survey of experts from various fields and the method of direct determination of weights as the most suitable procedures, considering the complexity of the task of comparing the variants for the "Lazarevac (connection to A2)-Trbušnica" corridor and the "Partizani-Viševac" corridor. Within this method, the surveyed experts expressed their (subjective) opinion on the importance of the criteria numerically, using a predefined scale. The direct weighting method consists of 3 steps, namely:

1. Determining the weights of the main group of criteria
2. Determining the local weight of criteria
3. Determining the global weight of criteria

Table 4 shows the obtained local and global weights of the main groups of criteria and individual criteria.

Table 4. Weights of the main groups and individual criteria

Criterion/Group of criteria		Local weight	Global weight
A.	**Spatial and urban planning characteristics of the variants**	0.1817	-
A.1	*Conflict of the variants with other infrastructural systems*	0.359	0.0610
A.2	*Characteristics of the variants in terms of demolishing buildings and other facilities*	0.2964	0.0539
A.3	*Conflicts of the variants with other urban agglomerations (centres, cities and settlements)*	0.3677	0.0668
B.	**The environment protection and preservation characteristics**	0.1979	-
B.4	*Characteristics of the variants in terms of noise emission*	0.2253	0.0446
B.5	*Characteristics of the variants in terms of air pollution emissions*	0.2551	0.0505
B.6	*Characteristics of the variants in terms of the usurpation of agricultural and forest areas (ha)*	0.2477	0.0490
B.7	*Endangerment of the existing drainage basins and drainage areas*	0.2719	0.0538

C.	**Technical characteristics**	0.1994	-
C.8	*Length (km)*	0.1912	0.0381
C.9	*Curvature*	0.1875	0.0374
C.10	*Representation of large facilities, bridges, tunnels and viaducts (the total number and length)*	0.2038	0.0406
C.11	*Characteristic in terms of the elevation profile of the route and elevation changes – ascent+descent (m)*	0.1949	0.0389
C.12	*Geotechnical conditions*	0.2226	0.0444
D.	**Traffic and operational characteristics**	0.2181	-
D.13	*Transport work (veh/km)*	0.3152	0.0687
D.14	*Travel time (min)*	0.3409	0.0744
D.15	*Traffic safety*	0.3440	0.0750
E.	**Economic characteristics of the variants**	0.2029	-
E.16	*Project implementation costs (€)*	0.3354	0.0681
E.17	*Maintenance costs of the expressway (€)*	0.3228	0.0655
E.18	*User costs (operation and travel time) (€)*	0.3418	0.0694

In this specific case, the scale ranged from 1 (minimum rating) to 10 (maximum rating). An electronic survey of 65 experts from the fields of civil engineering, traffic engineering and architecture was conducted. The number of valid responses was very satisfactory, amounting to 52, or 80%.

D. The "TOPSIS" method

"TOPSIS" is one of the most popular multi-criteria ranking methods. This method evaluates alternatives (or variants) based on their distance from the "ideal" and "anti-ideal" solutions. The total measure of the variant's quality (i.e. relative closeness) simultaneously takes into account its distance from the "ideal" and "anti-ideal" solution. The best variant is characterized by the smallest Euclidean distance from the "ideal" solution and the largest Euclidean distance from the "anti-ideal" solution. The "TOPSIS" method consists of 6 steps, which are [5]:

1. **Vector normalization of the base matrix**

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}}, i = 1, \dots, m; j = 1, \dots, n, \quad (1)$$

where x_{ij} represents the value of variant A_i (i=1, ..., m) for criterion K_j (j=1, ..., n); r_{ij} is the normalized value of variant A_i for criterion K_j.

2. **Weighting of the normalized base matrix**

$$v_{ij} = w_j^* \cdot x_{ij}, i = 1, \dots, m; j = 1, \dots, n, \quad (2)$$

where v_{ij} represents the weighted normalized value of variant A_i according to criterion K_j; $w^* = (w_1^*, \dots, w_n^*)^T$ is the vector of global criterion weights, where $w_j^* \in [0,1]$ and $\sum_{j=1}^{n} w_j^* = 1$.

3. **Forming the "ideal" and "anti-ideal" solutions**

The ideal solution $A^+ = \{z_1^+, \dots, z_j^+, \dots, z_n^+\}$ is defined as:

$$z_j^+ = \begin{cases} \min_{1 \le i \le m} V_{ij} & \mid C_j \in C^- \\ \max_{1 \le i \le m} V_{ij} & \mid C_j \in C^+ \end{cases}, j = 1, \dots, n, \quad (3)$$

where z_j^+ represents the best (i.e. the smallest for minimization criteria and the largest for maximization criteria) weighted normalized value according to criterion K_j; C^+ and C^- denote the set of maximization and minimization criteria, respectively.

The "anti-ideal" solution $A^- = \{z_1^-, \dots, z_j^-, \dots, z_n^-\}$ is defined as:

$$z_j^- = \begin{cases} \max_{1 \le i \le m} V_{ij} & \mid C_j \in C^- \\ \min_{1 \le i \le m} V_{ij} & \mid C_j \in C^+ \end{cases}, j = 1, \dots, n, \quad (4)$$

where z_j^- represents the worst (i.e. the largest for minimization criteria and the smallest for maximization criteria) weighted normalized value according to criterion K_j; C^- and C^+ denote the set of maximization and minimization criteria, respectively.

4. **Calculation of the Euclidean distance of each variant**

The distance from the **"ideal solution"** is defined as:

$$h_i^+ = \sqrt{\sum_{j=1}^{n} (V_{ij} - z_j^+)^2}, i = 1, \dots, m. \quad (5)$$

The distance from the **"anti-ideal solution"** is defined as:

$$h_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - z_j^-)^2}, i = 1, \dots, m. \quad (6)$$

5. **Calculation of the relative closeness of each variant**

$$b_i = \frac{h_i^-}{h_i^- - h_i^+}, i = 1, \dots, m, \quad (7)$$

where $b_i \in [0,1]$ represents the relative closeness of the variant A_i.

6. **Ranking of the variants**

The ranking of the variants, from first to last, corresponds to the order of the b_i values arranged in a descending sequence.

III. ASSESSMENT RESULTS

The following text contains the summarized results of (4)
multi-criteria assessment using the "TOPSIS" method for the ranking of the studied variants [3, 4]. Table 5 shows the output results of multi-criteria ranking for the corridor from Lazarevac (connection to A2) to Trbušnica, while Table 6 presents the results for the corridor from Partizani to Viševac.

A. Corridor from Lazarevac (connection to A2) to Trbušnica

Table 5. Results of multi-criteria ranking for the Corridor from Lazarevac (connection to A2) to Trbušnica

Variant	Distance from the "ideal solution"	Distance from the "anti-ideal solution"	Relative closeness	Ranking
NORTH (1.2)	0.0615	0.0191	0.2370	**2**
SOUTH (1.1)	0.0191	0.0615	0.7630	**1**

The results presented in the table above indicate that the variant **SOUTH (1.1)**, whose relative closeness is 0.7630, is better. The complete ranking order is:

Rank I	**SOUTH (1.1)**
Rank II	NORTH (1.2)

B. Corridor from Partizani to Viševac

Table 6. Results of multicriteria ranking for the corridor from Partizani to Viševac

Variant	Distance from the “ideal solution”	Distance from the “anti-ideal solution”	Relative closeness	Ranking
NORTH (3.1)	0.0221	0.0828	0.7893	**1**
SOUTH (3.2)	0.0828	0.0221	0.2107	**2**

The results presented in the table above indicate that the variant **NORTH (3.1)**, whose relative closeness is 0.7893, is better. The complete ranking order is:

Rank I	**NORTH (3.1)**
Rank II	SOUTH (3.2)

C. Comparative analysis

In order to comprehensively examine the consistency of the obtained ranking results for the variants for the Corridor from Lazarevac (connection to A2) to Trbušnica and the Corridor from Partizani to Viševac, what follows is the comparative analysis of the “TOPSIS” method with four highly influential methods of multi-criteria ranking, namely: (1) “MABAC” method, (2) “WASPAS” method, (3) “CODAS” method and (4) “CoCoSo” method [6, 7, 8, 9].

Table 7. Comparative analysis results for the “Lazarevac-Trbušnica” corridor

“Lazarevac-Trbušnica” corridor			
Method	**Indicator**	**NORTH (1.2)**	**SOUTH (1.1)**
“TOPSIS“	**Relative closeness**	**0.2370**	**0.7630**
	Variant rank	**2**	**1**
“MABAC“	Assessment score	–0.0444	0.2159
	Variant rank	2	1
“WASPAS“	Generalized criterion	0.7240	0.9160
	Variant rank	2	1
“CODAS“	Assessment score	–0.0440	0.0440
	Variant rank	2	1
“CoCoSo“	Assessment score	1.6430	3.1400
	Variant rank	2	1

Table 7 shows the comparison results for the Corridor from Lazarevac (connection to A2) to Trbušnica. A perfect correlation of ranks of the analysed methods was identified. All five methods of multi-criteria ranking identified **SOUTH (1.1)** as a better variant for **the Corridor from Lazarevac (connection to A2) to Trbušnica.**

Table 8. Comparative analysis results for the “Partizani-Viševac” corridor

“Partizani-Viševac” corridor			
Method	**INDICATOR**	**NORTH (3.1)**	**SOUTH (3.2)**
“TOPSIS“	**Relative closeness**	**0.7893**	**0.2107**
	Variant rank	**1**	**2**
“MABAC“	Assessment score	0.2363	-0.0648
	Variant rank	1	2
“WASPAS“	Generalized criterion	0.9120	0.6650
	Variant rank	1	2
“CODAS“	Assessment score	0.2730	-0.2730
	Variant rank	1	2
“CoCoSo“	Assessment score	3.2120	1.6400
	Variant rank	1	2

Table 8 shows the comparison results for the Corridor from Partizani to Viševac. A perfect correlation of ranks of the analysed methods was identified. All five methods of multi-criteria ranking identified **NORTH (3.1)** as a better variant for **the Corridor from Partizani to Viševac.**

IV. CONCLUSION

Multi-criteria decision making is a process of making decisions, i.e. selecting the optimal alternative from a set of alternatives, in the situations when there are several criteria that are often mutually conflicting [1, 2].

The aim of this paper was to present an innovative procedure and basic results of applying multi-criteria assessment within the Conceptual Design for the construction of the class I state road “Vožd Karađorđe” on the corridor sections from Lazarevac (connection to A2) to Trbušnica and from Partizani to Viševac, with two variant corridors defined, namely: [3, 4]

- “Lazarevac (connection to A2)-Trbušnica” corridor – variants NORTH (1.2) and SOUTH (1.1)
- “Partizani-Viševac” corridor – variants NORTH (3.1) and SOUTH (3.2).

Eighteen assessment criteria were selected based on the most significant objectives of constructing the class I state road “Vožd Karađorđe”. The weights of the criteria were determined in a survey of 52 experts specializing in the fields closely related to the subject of the project. The “TOPSIS” method was used for the multi-criteria ranking of the variants of the observed corridors.

Based on the “TOPSIS” method, it was concluded that the ranking of the variants for the **Corridor from Lazarevac (connection to A2) to Trbušnica** was as follows:

1. **SOUTH (1.1)**
2. NORTH (1.2)

Based on the “TOPSIS” method, it was concluded that the ranking of the variants for the **Corridor from Partizani to Viševac was the following:**

1. **NORTH (3.1)**
2. SOUTH (3.2)

The consistency of the obtained results from the multi-criteria ranking of the corridor variants was verified by means of the comparative analysis of the “TOPSIS” method and the “MABAC”, “WASPAS”, “CODAS” and “CoCoSo” methods. It was concluded that all five multi-criteria ranking methods identified **SOUTH (1.1)** as the best variant for the **Corridor from Lazarevac (connection to A2) to Trbušnica** and **NORTH (3.1)** as the best variant for the **Corridor from Partizani to Viševac**.

Within this paper, a real-life example was used to show the significance of applying multi-criteria decision-making for selecting the optimal variant solution. Considering its broad application and ability to consider different factors in decision-making, multi-criteria assessment should become an obligatory part of analysis and decision-making. It should not only be used in transportation projects but also in other engineering fields, whenever there is a need to choose between several alternatives which are mutually conflicting regarding different parameters. According to the specific characteristics and requirements of a particular project, it is necessary to consider advantages and disadvantages of different methods and select the most appropriate method for multi-criteria decision-making to ensure adequate results.

REFERENCES

[1] Kuzović, Lj., „Vrednovanje u upravljanju razvojem i eksploatacijom putne mreže“, Saobraćajni fakultet Univerziteta u Beogradu, Srbija, 1994. god.

[2] Dimitrijević, B., „Višeatributivno odlučivanje: primene u saobraćaju i transportu“, Univerzitet u Beogradu Saobraćajni fakultet, Srbija, 2017. god.

[3] Tubić, V., „Prethodna studija opravdanosti sa generalnim projektom izgradnje državnog puta I reda „Vožd Karađorđe” - Saobraćajna studija“, Javno Preduzeće „Koridori Srbije”, Saobraćajni fakultet - Institut saobraćajnog fakulteta, Beograd, 2022. g.

[4] Tubić, V., Prethodna studija opravdanosti sa generalnim projektom izgradnje državnog puta I reda „Vožd Karađorđe” - Prethodna studija opravdanosti“, Javno Preduzeće „Koridori Srbije”, Saobraćajni fakultet - Institut saobraćajnog fakulteta, Beograd, 2022. g.

[5] Hwang, C. L., & Yoon, K. (1981). Methods for multiple attribute decision making. In *Multiple attribute decision making* (pp. 58-191). Springer, Berlin, Heidelberg.

[6] Pamučar, D. and Ćirović, G., 2015. The selection of transport and handling resources in logistics centers using Multi-Attributive Border Approximation area Comparison (MABAC). *Expert Systems with Applications*, *42*(6), pp. 3016-3028.

[7] Zavadskas, E.K., Turskis, Z., Antucheviciene, J. and Zakarevicius, A., 2012. Optimization of weighted aggregated sum product assessment. *Elektronika IR Elektrotechnika*, 122(6), pp. 3-6.

[8] Keshavarz Ghorabaee, M., Zavadskas, E.K., Turskis, Z. and Antucheviciene, J., 2016. A new combinative distance-based assessment (CODAS) method for multi-criteria decision-making. *Economic Computation & Economic Cybernetics Studies & Research*, 50(3), pp. 25-44.

[9] Yazdani, M., Zarate, P., Zavadskas, E.K. and Turskis, Z., 2019. A Combined Compromise Solution (CoCoSo) method for multi-criteria decision-making problems. *Management Decision*, 57(9), pp. 2501-2519.

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Professional Paper

Analysis of Safety Aspects of Highways in the Construction Process

Natasha Gredoska[1]

Abstract – **Traffic accidents in construction zones pose global risks. This study examines safety during the reconstruction of the Kichevo–Ohrid section of North Macedonia's A2 highway, a part of Pan-European Corridor VIII, highlighting the need for a balance between infrastructure development, traffic safety and the construction process.**

Keywords – **road safety; accident rates; transport; mobility; construction.**

I. INTRODUCTION

According to the World Health Organization, road traffic crashes are the leading cause of death and disabling injury among children and young adults aged 5 to 29. Globally, they represent the eighth leading cause of death across all age groups, accounting for approximately 1.35 million fatalities each year. The burden of this issue disproportionately affects low- and middle-income countries, where the risk of road traffic deaths is nearly three times higher than in high-income nations [5].

Construction and maintenance work zones have long been recognized as hazardous areas within the highway environment. Research consistently shows that accident rates in these zones are higher compared to similar periods before the work zones were established [1–3]. Several contributing factors have been identified, including:

(a) Inappropriate use of traffic control devices, (b) poor traffic management, (c) inadequate work zone layout, and (d) a general lack of understanding of the unique challenges posed by construction and maintenance zones.

Proper and effective use of traffic control devices and signs is critical for alerting drivers to upcoming roadway conditions and potential hazards, as well as for ensuring their safe navigation through construction and maintenance work zones.

A large amount of research has been dedicated to enhancing safety within construction and maintenance work zones. Major focus areas include the proper implementation of traffic control devices, optimal scheduling of construction activities, and thorough training of personnel. For example, the Federal Highway Administration (FHWA), has developed and disseminated specialized training programs to address these critical issues. Furthermore, many state highway agencies have placed growing emphasis on establishing clear work zone traffic control policies and ensuring that their staff receive adequate and ongoing training.

This paper is organized into four main sections. The introduction outlines the general influence of traffic accidents in construction zones and emphasizes the importance of analyzing the Kichevo–Ohrid highway section. In this section, the data analysis presents traffic accident records from the period of 2022 to 2023, categorized by severity. The third section proposes various preventive measures, such as engineering solutions, enforcement strategies, and educational activities, along with institutional recommendations aligned with EU regulations and standards. The conclusion summarizes the key findings, highlights the importance of enhanced traffic safety in construction areas, and provides recommendations for future research.

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II. DATA ANALYSIS

The Kichevo–Ohrid section is over 57 kilometers and represents one of the most complex segments of the project, marked by numerous deep cuts and high embankments. Reconstruction work on this section began in 2014 and remains ongoing. Utilizing data provided by the Ohrid Department of Internal Affairs, a traffic accident analysis was conducted for the period between 2022 and 2023. The traffic accidents were categorized by severity into three distinct groups: accidents with minor injuries, serious injuries, and accidents with fatalities, as presented in Figure 1.

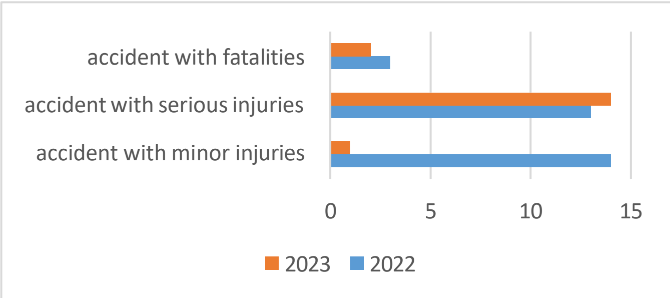

Fig. 1. Number of traffic accidents by consequences (2022/2023) – highway under construction Ohrid - Kichevo, [8]

The data indicates a notable shift like traffic accidents on the Ohrid–Kichevo highway under construction between 2022 and 2023. While the total number of minor injury accidents significantly decreased in 2023, there was a slight increase in serious injury accidents. Fatal accidents also showed a small decrease. This trend suggests that although the frequency of less severe accidents dropped, the severity of accidents may have increased, highlighting a possible need for improved safety measures on the construction site.

Table 1 presents an overview of traffic accidents involving fatalities that occurred in the period of 2022 and 2023, including specific details such as dates, locations, types of vehicles involved, and the individuals who lost their lives.

Table 1. Detailed information on two fatal traffic accidents that occurred on the Main Road A2 Ohrid–Kichevo in the period of 2022 and 2023 [8]

	Date	*Location*	*Vehicles*	*Died in a traffic accident*
1.	21.2.2022	Main road A2 Ohrid Podmolje (ALDO deviation)	1. PV Audi 2. PV Polo	Vehicle driver
2.	15.6.2022	Main road A2 Church St. Petka, village Botun	1. PV Audi 2. PV BMV	Vehicle driver
3.	10.11.2022	Main road A2 Ohrid Podmolje, near the monastery St. Erasmus and Kocare motel	1. PV Kia 2. PV Polo 3. PV Audi	Vehicle driver
4.	11.3.2023	Main road A2 Ohrid – Kichevo, village Novo Selo	1. PV Honda	Passenger
5.	31.5.2023	Main road A2 Ohrid – Kichevo, entrance to Slavej Mountain	1. HV Fiat 2. PV Volkswagen	Vehicle driver

Analysis shows that from 2022 to 2023, the number of fatal traffic accidents decreased from 3 to 2. However, both years involved a mix of locations and vehicle types, including both passenger and heavy vehicles. While the slight reduction in fatalities is a positive sign, continued attention to road safety is crucial, especially in construction zones and high-risk areas. The data suggests that while minor injuries have dropped, serious accidents with fatalities still occur, reinforcing the need for stricter enforcement, clearer signage, and better road infrastructure during the ongoing construction.

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III. PREVENTIVE MEASURES FOR REDUCING TRAFFIC ACCIDENTS

A new era of living has caused a great influence the human engineering treatment. This is an era of cosmopolitanism, whereas the human factor is losing its national paroxysm and starts to be a sophisticated world discipline. Establishing international standards in human engineering would not have been possible if national and cultural variables were not considered. It deals with a new approach philosophy, which is an integrated, multinational approach to a cosmopolitan technology, enabling all of us to live together in harmony within the system called Earth.

Human engineering is a complex of psychology, physiology, medicine, anthropology, and engineering. Thus, the engineer can not solely and independently know everything about the human, despite the moral obligation to consider all their characteristics.

When traffic safety is led primarily by various design solutions, the behavior and motivation are assumed on a secondary level. Thus, the situation approach in revealing human errors accepts people the way they are, and not the way we want to see them.

The behavior ranges from sudden acceptance of the environment to flagrant disobedience of regulated procedures. Human behavior is difficult to understand and even more difficult to predict. This is the reason why research in the area of behavior is being carried out, in particular because of the effects of modern technologies and the stress that very often might lead to a traffic accident occurrence.

Road traffic safety activities need to be considered from a cross-sectoral, multidisciplinary, and multidimensional perspective. This includes road development and management, ensuring safe vehicles, and prompt response in the event of traffic accidents. Road traffic safety relies on modern advanced traffic management systems, standards for road design, construction, and maintenance, as well as the production and maintenance of safe vehicles.

Analyzing traffic accident data during road reconstruction is essential for several reasons:

1. **Monitoring the impact of construction activities** Road reconstruction often changes traffic patterns, reduces lane widths, and introduces temporary obstacles—all of which can increase the risk of accidents. Data analysis helps assess whether the reconstruction is negatively affecting road safety.
2. **Identifying high-risk zones in real time** During reconstruction, accident data can reveal specific locations where drivers are more likely to crash (e.g., near detours, sharp curves, or poorly marked areas). This allows authorities to take immediate corrective action, such as improving signs or adjusting traffic flow.
3. **Protecting workers and road users** Construction zones are shared by workers and drivers. Traffic accident analysis highlights safety threats to both groups and supports the development of better safety measures, like physical barriers or reduced speed limits.
4. **Improving traffic management plans** Before and during roadwork, traffic management plans are required. Ongoing data analysis helps evaluate the effectiveness of those plans and refine them based on real-world outcomes.
5. **Reducing delays, costs, and fatalities** Accidents in work zones can cause significant delays, economic losses, and even fatalities. Using data to prevent such incidents contributes to a safer and more efficient reconstruction process**.**
6. **Ensuring compliance with safety standards** Many countries require roadwork projects to be monitored for safety. Data analysis helps ensure compliance with national regulations and international safety guidelines.

The following preventive measures are proposed to improve traffic safety on the Ohrid–Kichevo road section:

1. **Establish a legal and institutional framework aligned with EU regulation and standards**

- Develop and implement a National Road Safety Strategy harmonized with EU Directives.
- Assign responsibilities to local and national agencies to continuously monitor and evaluate road safety in reconstruction zones.
- Require mandatory road safety audits during planning, construction, and post-construction phases of all major infrastructure projects.

2. **Identify and analyze high-risk zones**

- Use the accident data map to identify accident-prone segments.
- Conduct field inspections to assess signage, road surface quality, visibility, and lane management in these locations.

3. **Implement preventive and corrective measures**

Since traffic accidents are the product of several factors, the probability of an accident occurring can be reduced in several ways.
In continuation, a set of proposed measures is presented aimed at addressing these safety concerns.

a. Proposed engineering measures:

- Improve temporary infrastructure:
  - Install reflective warning signs, rumble strips, and speed bumps near high-risk zones.
  - Ensure clear detour routes and proper lane markings during construction stages.
- Provide barriers between construction zones and traffic areas to protect workers and drivers.

b. Enforcement measures:

- Increase police presence and mobile patrols in high-risk areas.
- Deploy speed monitoring cameras with instant penalties in construction zones.
- Introduce alcohol and drug checkpoints near critical locations during weekends and holidays.

c. Education and awareness

- Launch road safety campaigns focused on:
  - Speed control in construction zones
  - Understanding temporary traffic signs
  - Defensive driving techniques
- Conduct school-based road safety education in nearby municipalities.

4. **Monitoring, evaluation, and public engagement**

- Develop a real-time traffic monitoring system using sensors and mobile data.
- Conduct monthly safety evaluations with contractors, police, and municipalities.
- Launch a public reporting tool (app or hotline) where drivers can report unsafe conditions or near-misses.

The selection of appropriate and effective measures depends on a thorough understanding of the traffic safety problem.

The improvement of the existing infrastructure leads to a decrease in the frequency and severity of traffic accidents. By giving them an explicit (open, direct) configuration, you can influence user behavior. The concept of "roads that explain themselves" improves the behavior of drivers through good information for appropriate speeds. The creation of a safe road environment (side protection fences) with the help of which human error does not lead to death or serious injury, makes the road safer. The "White Paper on EU Transport Policy" notes that when new road projects are reviewed, a safety impact assessment must be carried out in order to determine whether the project will have an adverse effect on safety [9]. An EU methodology should be established for the implementation of impact assessments, which are called safety audits (assessments). Improving the road means saving lives. There are two main means of doing this: 1) creation of technical guidelines at the EU level for voluntary application by traffic safety experts, and 2) harmonization of engineering procedures for traffic safety, standards and equipment for the trans-European road network. The EC intends, within the framework of the law, to harmonize the definition of black spots, vertical signage, signs with variable messages, information for drivers and signs. The European road rating programs aim to provide drivers with good information about risks and to raise awareness for investing in road improvement. The ultimate goal is to reduce the proportion of high-risk E-roads and tunnels. In this context, the EC will propose a guide for infrastructure safety and information for drivers. Priorities include: low-cost measures in high-risk locations, security audits, urban security management, and speed reductions.

New development technologies in the vehicle have the potential to increase or decrease the risk of injury during the road construction process. At the moment, there is uncertainty among security experts in relation to the security effects of some technologies that are widely promoted in the name of security. A clear framework is needed for the identification, assessment, monitoring, and reporting of safety-enhancing technologies. It is necessary to demonstrate that e-security measures are effective before they can be widely implemented.

IV. Conclusion

The reconstruction of the Ohrid–Kichevo highway is a critical infrastructure project for North Macedonia, aiming to enhance regional connectivity and support economic development. However, construction zones inherently pose increased risks to both workers and road users. Data analysis from 2022 to 2023 indicates a decrease in minor accidents but a slight increase in serious injuries and fatalities, underscoring the need for improved safety measures.

Analyzing traffic accident data during road reconstruction is essential for several reasons: it enables monitoring of construction impacts, identification of high-risk areas in real time, protection of both workers and road users, enhancement of traffic management plans, reduction of delays, costs, and fatalities, and ensures compliance with safety standards.

Future research could focus on comparing crash characteristics before, during, and after construction periods to highlight both safety differences and similarities between work zone and non–work zone environments. Additionally, further analysis could explore the influence of road conditions on accident rates or investigate whether issues stem from the design and effectiveness of the traffic management plan.

REFERENCES

[1] .J. L. Graham, R. J. Paulson, and J.C. Glennon. Accident Analyses of Highway Construction Zones. In *Transportation Research Record 693,* TRB, National Research Council, Washington, D.C., 1978.

[2] J. J. Wang and C. M. Abrams. *Planning and Scheduling Work Zone Traffic Control- Technical Report.* Report No. FHWA/RD-81/049. FHWA, U.S. Department of Transportation, 1981.

[3] Z. A. Nemeth and D. J. Migletz. Accidents Characteristics Before, During, and After Safety Upgrading Projects on Ohio's Rural Interstate System. In *Transportation Research Record 672,* TRB, National Research Council, Washington, D.C., 1978

[4] J.G. PIGMAN and K. R. AGENT Highway Accidents in Construction and Maintenance Work Zones *TRANSPORTATION RESEARCH RECORD 1270*

[5] World Health Organization (2018). Global status report on road safety 2018. Paprika. Paris, France.

[6] Instituto de Desarrollo Urbano IDU (2016) Diagnóstico Malla Vial 2016.

[7] S. C. Mangoes M[a, *], J. A. Garcia M[a], D.O. Holguin M[a], D.A. Orjeula L[a] . Differences in road–traffic crash rates during construction and non-construction times on arterial streets: a comparative statistical analysis. *14th Conference of Transport Engineering: 6th- 8th July 2021*

[8] mvr.gov.mk

[9] White paper on transport, Roadmap to a single European transport area: towards a competitive and resource-efficient transport system, 2011

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Professional Paper

Physics behind Road Safety and Traffic Control

Mihail Naumovski[1] and Daniela Koltovska Nechoska[2]

Abstract – **To ensure safe driving, it is essential to adhere to road signs and signals. Inattention can increase speed and jeopardize road safety and traffic control. Physics helps manage this risk, particularly by defining the breaking distance. This paper explores increasing speed is worthwhile and highlights physics' role in safer decision-making.**

Keywords –Traffic control, road safety, braking distance, speed.

I. Introduction

To ensure that the driver operates the driving car at an appropriate speed, it is must be emphasized that the importance of adhering to road signs and signals. Even a brief moment of inattention can result in an unintended increase in the speed, jeopardizing both Road Safety and Traffic Control. Physics plays a vital role in determining and managing this kind of risk, particularly by defining braking distance [10] [23]. By comparing the distance at which an approaching hazard appears to the breaking distance, the appropriate speed for maintaining road safety and control in traffic can be determined, by reducing the likelihood of an accident. This paper explores whether it is worthwhile for a driver to consciously increase the speed. Ultimately, the decision rests with us – would we make the same choice as the driver does? – Regardless of the choice, physics offers us valuable insights to guide safer decisions in any scenario. Not only the braking distance, in such a situation, the driver's reaction distance is even more important. This reaction distance is directly related to the reaction time [3]. The driver's abilities and his readiness to drive should tend to reduce this time, and thus reduce the reaction distance. In this way, the space for manipulating the stopping distance will increase, i.e., the possibility of the vehicle not reaching the danger before hitting it. This paper deals with the issue of the probability of a collision between a vehicle and a bicycle when the vehicle encounters it at an increased speed compared to the prescribed speed on the road. All this, as a result of the driver's decision whether to drive according to the rules of the road or not [4].

II. Distances that drives the driver crazy

A. From Reaction Time to Reaction Distance

As an unexpected, but one of the most important aspects of dealing with the uncertainty of risk occurrence in traffic is the **driver's reaction time.**

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A. From Reaction Time to Reaction Distance

As an unexpected, but one of the most important aspects of dealing with the uncertainty of risk occurrence in traffic is the **driver's reaction time**. It is defined as a time between the driver's danger perception and the reaction to it, as well [15]. Therefore, many independent circumstances can affect the duration of a driver's reaction time, particularly. It is not the same when a driver drives during the day or at night, and the difference between them is even more emphasised whether it is a young driver or an adult one. However, the most important circumstance of increasing the uncertainty of risk occurrence, when it comes to a danger in traffic, is the cognitive load of the driver. This cognitive load is initially aimed at the driver's abilities, but mostly at the driver's conscience of correct traffic, adhering to road signs and signals [8].

At a given moment, while driving conscientiously, the driver may reach a state of impaired cognitive load. An impaired cognitive load would imply overcoming the conscientiousness with awareness. The driver, with such an issue, is brought into a state of unconscious driving, which affects the driver's reaction time [5]. In general, most of the drivers, somehow, can deal with this issue, but unfortunately, there are also many of them that can not. Many studies support the same opinion that driver experience enhances reaction awareness, thereby reducing reaction time. Also a fact that a male driver can deal better with reducing the reaction time than a female one, sometimes stays so, but sometimes not. Nowadays, females have proven to be very good drivers just because of their high level of conscientiousness and awareness, which takes precedence over males once [6]. The only certain thing is that the use of psychotropic substances and driving under the influence of alcohol can only prolong a driver's reaction time, and thus increase the likelihood of a traffic risk occurring.

Ultimately, neither the experience of the driver nor the other driver's abilities can reduce the occurrence of traffic danger in order to reduce the time to react. The only thing the driver can do is to pay attention to road signs and signals, i.e., consciously adhere to the conscientious management of the vehicle within the prescribed limits. This means that if the prescribed speed limit is 50km/h, the driver must not knowingly drive at 55km/h, in continuation: 50km/h – initial driving speed and 55km/h – cheating driving speed [2] [15].

This paper does not emphasize the factors that influence the driver's reaction time, but emphasizes its constant value **(t=1.5seconds)**, which has been empirically obtained. To avoid confusion, this reaction time is not define as a reaction time of an expected event ($t_{expected}$=0.7seconds), nor as a reaction time of an unexpected event ($t_{unexpected}$=1.25seconds), but as a reaction time of a surprising event. Essentially, the surprising time is divided into two parts, i.e., 1.2 seconds perception time and 0.3 seconds the reaction time of the perception [4]. Accordingly, all conclusions shown about the impact of Physics on Road Safety and Traffic Control, in this paper, are just based on a constant value of driver's reaction time, which does not provide a wider framework for further consideration of modelling the time factor, which already defines a subjective character from driver to driver. Precisely because of that, this approach provides a general framework in which a single conclusion can be drawn: All drivers, regardless of their subjective characteristics, must adhere to what is meant by prescribed rules and norms on the road and in traffic [3].

Figure 1. shows a driving car moving on a road with an initial speed (speed limit) of 50km/h, i.e., the driver, who is driving, is in a normal state with the reaction time of 1.5seconds. For this reason, such a car movement is defined as a brief part of a complex motion with a constant speed (v_0), beginning from the start position till the moment of the driving car danger perception. At this speed, a driving car moves a distance of 20.8m (50/3.6m/s·1.5s=20.8m), so this distance is also defined as a distance before the driver starts braking, when it comes to a driving car danger, an oncoming bicycle, shown in the final position. Additionally, this distance is named in this paper as a **reaction distance** due to the reaction time. Moving at an increased speed of 55km/h, which is defined as a cheating speed, the same driving car moves a distance of 22.9m (55/3.6m/s·1.5s=22.9m) [7].

The difference between the two distances, acquired both at the initial speed (50km/h) and the cheating speed (55km/h), is almost 2.1m, at the same reaction time. Although is a small between distance, it may be fatal in terms of occurring a traffic risk, that may cost even an innocent life of the bicyclist, and also of the driving car driver. So, it is up to the driver to decide if is it worth cheating while driving or not.

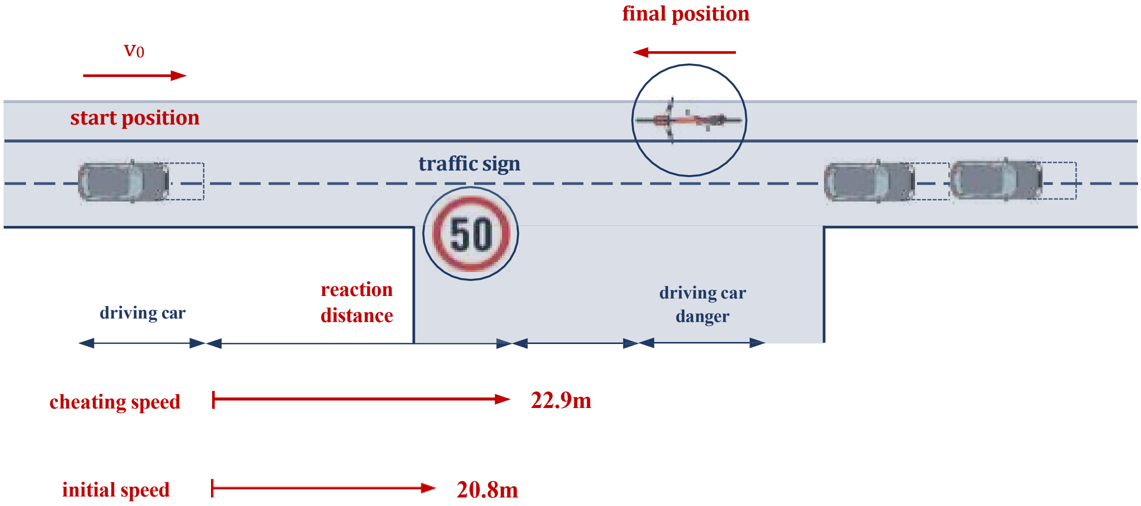

Fig. 1. Reaction distance showed when a driving car drives with an initial speed and with a cheating speed at the same reaction time.

B. Braking Distance can predict or not the Traffic Danger

When it comes to a **braking distance**, there is a definition that remains at the moment when the driver becomes aware of the traffic danger and begins to brake. So, the braking distance is named as the distance between the moment when the driver starts braking till the driving car stops. Braking distances are always the subject of study in Physics, when it comes to several factors that affect them. Namely, such distances depend directly on the driver's ability to consciously press the brake and thus generate as much deceleration as possible. The driving dynamic characteristics of the road, friction with the surface, driving car characteristics, the environment, and lateral friction are just some of the factors that affect the braking distances. However, when a general solution to such a problem needs to be given, all simplifications that dictate a constant value of the deceleration must be taken into account [12] [17] [18].

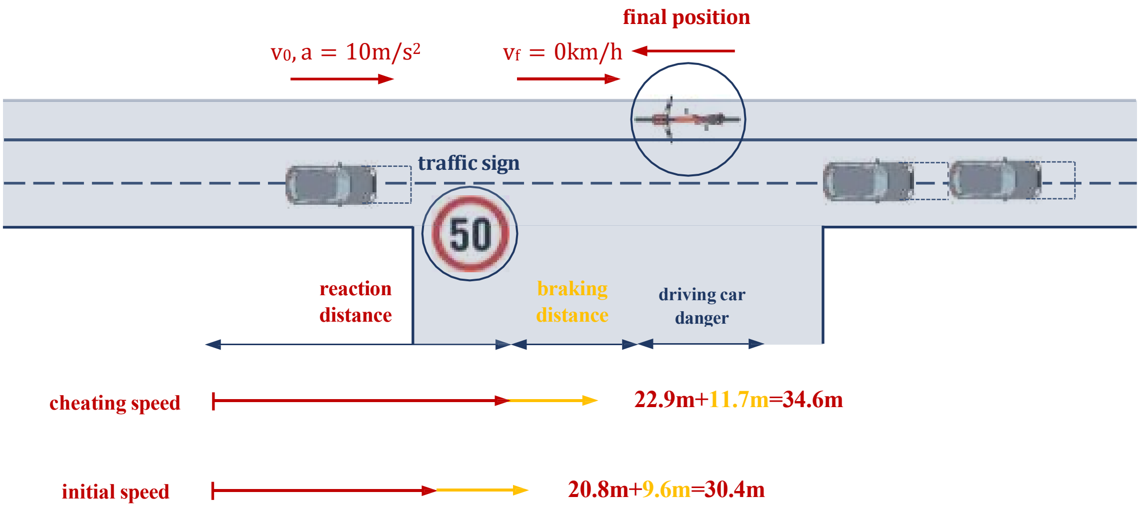

Fig. 2. Braking distance showed when a driving car drives with an initial speed and with a cheating speed at the same reaction time.

The constant value of deceleration **(a=10m/seconds²)**, in this paper, is taken as an average value from empirical analyses, obtained as a result of the driver's willingness to deal with such a surprising event.

Figure 2 shows the essence of the braking distance, before the driving car reaches the traffic danger and stops. This part of the movement is defined as a brief part of the complex motion, discussed in part *A. From Reaction time to Reaction Distance*, with a deceleration of the initial speed or the cheating speed. Accordingly, the only thing known, when determining this distance, is that the driving car should eventually stop, i.e., it should completely expend its speed ($v_f = 0\text{km/h}$). With this, the driving car will reach the final position, i.e. it will reach the danger, without hitting it or hitting it by throwing it out.

Braking distance can be calculated by the formula:

$$v_f^2 = v_0^2 - 2ad \quad \Rightarrow \quad 0 = v_0^2 - 2ad \quad \Rightarrow$$
$$\Rightarrow \quad d = \frac{v_0^2}{2a}$$

where all the contained variables are shown or discussed before in the paper [10] [11].

Moving at the initial speed of 50km/h, the driving car moves additional 9.6m (d=(50/3.6m/s)²/(2·10m/s²)=9.6m) – the barking distance, so the total distance before it stops is 20.8m+9.6m=30.4m. If the driving car is moving at the cheating speed of 55km/h, than it moves additional 11.7m (d=(55/3.6m/s)²/(2·10m/s²)=11.7m) – the barking distance, so the total distance before it stops is 22.9m+11.7m=34.6m.

The difference between the two distances, acquired both at the initial speed (50km/h) and the cheating speed (55km/h), is 4.2m, that is doubled than 2.1m, the between reaction distance. This fact indicates that with just a reckless increase in speed by 5km/h, the reaction distance doubles compared to the braking distance. This can be not only a warning to the driver, but also a philosophy of driving the driving car [14].

C. Stopping distance – to be or not to be!?

Stopping Distance = Reaction Distance + Braking Distance (S=R+B)

A simple mathematical sum can provide the answer to the question of whether a driving car will hit the bicycle or not, which means to be or not to be. By summing the reaction distance and the braking distance, a driver can be aware of what the **stopping distance** means [20]. In this case, the stopping distance is defined as the known distance of the driving car's danger (bicycle), except for the reaction distance. The driver's assessment of the distance to the traffic is, in most situations, accurate, as shown by many studies. This refers to the fact that when the driver is in a normal state, he can react appropriately and in a timely manner, in order to avoid the traffic danger by achieving an adequate stopping distance. This driver awareness will not accurately define the stopping distance, but it will encourage him to use his awareness to reduce reaction time, which in turn directly affects reaction distance, and thus braking time [21] [22].

The stopping distance of a driving car danger can be calculated by the formula:

$$d^* = d - s$$

, where d is the known distance that a driver can predict about the traffic danger and s is the reaction distance.

The known distance, where the bicycle is, compare to the driving car, is **(d=30m)**, as a referent value, taken in this paper. Moving with the cheating speed of 55km/h, the driving car is certainly in a disadvantageous position, compared to the moving of the driving car with the initial speed of 50km/h. Therefore, in the paper, the disadvantageous position is briefly shown with a reaction distance of 22.9m and appropriate stopping distance of 7.1m (d*=30m–22.9m=7.1m) [19].

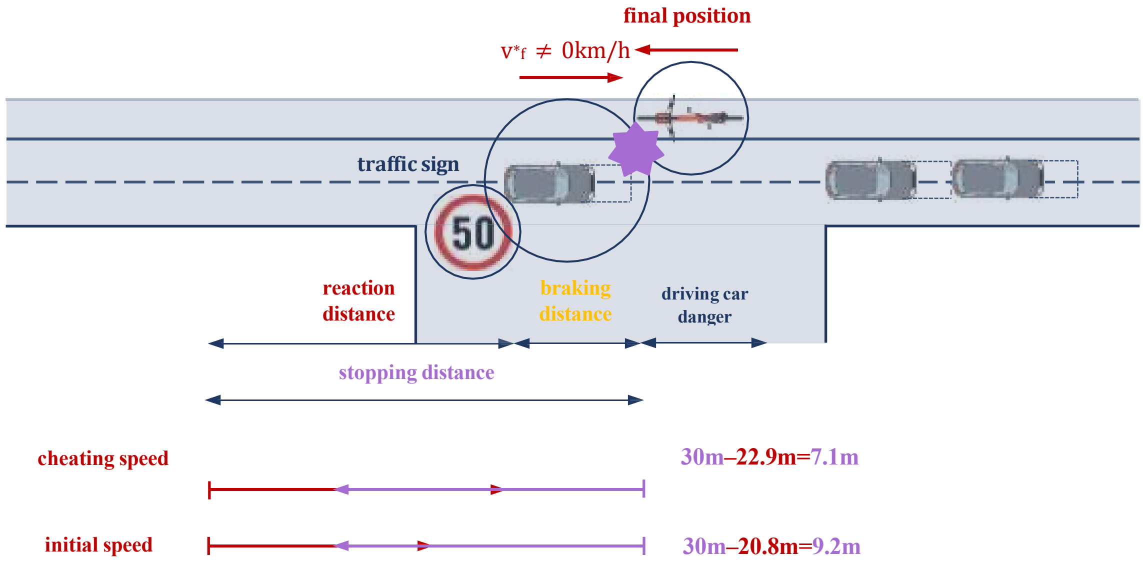

Fig. 3. Stopping distance showed when a driving car drives with an initial speed and with a cheating speed at the same reaction time.

As it is shown in Figure 3., by moving with a cheating speed of 55km/h, there is less distance from the driving car to the driving car danger, compere to the moving with an initial speed of 50km/h, where the remaining distance to the driving car danger is wider (9.2m>7.1m).

By comparing the final speed of the driving car (v^*_f), with the real cheating speed of 55km/h, before it hits the bicycle or it doesn't, using the formula:

$$v^{*2}_f = v_0^2 - 2ad^* \quad \Rightarrow \quad v^*_f = \sqrt{v_0^2 - 2ad^*}$$

, a clear answer of this to be or not to be, can be given.

The final speed of the driving car is calculated almost at a value of 34.5km/h ($v^*_f = \sqrt{(55/3.6\text{m/s})^2 - 2 \cdot 10\text{m/s}^2 \cdot 7.1\text{m}} =$ =34.5km/h), which means that comparing with a value of 55km/h, this value is lower. This approach to determining the final speed, compared to the existing one, the cheating speed of 55km/h, which is controlled by the driver, does not state that the danger occurs at a speed of 34.5km/h, which means that at a speed of 55km/h all this would have a fatal end. So, by controlling the speed, the driver can only use Physics to prevent a fatal outcome, and of course that is the goal of this paper.

III. CONCLUSION

The concept of using fundamental sciences, such as Physics, in traffic engineering, especially when it comes to Road Safety and Traffic Control, is based on defining a framework that provides a clear position in relation to solving a traffic problem accompanied by a driving car danger [1] [24]. In this paper, the framework is set on the basis of three characteristic distances: reaction distance, braking distance and stopping distance, which are defined depending on the start position, in which the driving car is located, and the final position, in which the driving car danger is located. By manipulating these three distances, starting from the driver's abilities, up to his willingness to approach the management of the vehicle on the road seriously, the conclusion is reached that the driver is the one who is primarily responsible, first of all for himself, and then for others. According to this, Physics can only teach the driver about reckless driving, through a small increase in speed, as it was shown in this paper just a 5km/h, but cannot decide on his behalf how he will act. Therefore, this seriousness of the problem from a subjective perception must not be allowed to experience objectivity, because the better we react as individuals, the better we influence others in the environment.

REFERENCES

[1] Frampton R., 2007, Crach! The Physics of vehicle testing, Physics World 20(6):27-30. (DOI:10.1088/2058-7058/20/6/33)

[2] Green M., 2000, "How Long Does It Take to Stop?" Methodological Analysis of Driver Perception-Brake Times, Transportation Human Factors 2(3):195-216. (DOI:10.1207/STHF0203_1)

[3] Zhuk M., Kovalyshyn V., Tcir R., 2015, Defining Duration of Driver Reaction Time Components Using the NeuroCom Complex, ECONTECHMOD AN INTERNATIONAL QUARTERLU JOURNAL – 2015, Vol. 04, No. 2, 39-44. (https://bibliotekanauki.pl/articles/411357)

[4] Green M., Driver reaction time, an online article. (https://www.visualexpert.com/Resources/reactiontime.html)

[5] Culík K., Kalašová A., Štefancová V., 2022, Evaluation Of Driver's Reaction Time Measured in in Driving Simulator, Sensors 2022, 22, 3542. (http://doi.org/10.3390/s22093542)

[6] Jurecki R. S., Stańczyk T. L., 2014, Driver reaction time to lateral entering pedestrian in a simulated crash traffic situation, Transportation Research Part F Traffic Psychology and Behaviour 27:22–36. (DOI:10.1016/j.trf.2014.08.006)

[7] Ruiz J. M., 2021, Speed, acceleration, and distance plots from a racecar speedometer (0–300 km h), IOP Physics Education August 2021, 56(5):55035. (DOI: 10.1088/1361-6552/ac1529)

[8] Nilsson J. E., Aust J. M., Engstörm J., Savanberg B., Lindén P., 2018, Effects of cognitive load on response time in unexpected lead vehicle barking scenario and the detection response task (DRT), Transportation Research Part F: Traffic Psychology and Behaviour, Volume 59 Part A, November 2018, Pages 463-474. (https://doi.org/10.1016/j.trf.2018.09.026)

[9] Sabri M., Fauza A., 2017, Analysis of vehicle barking behaviour and distance stopping, IOP Conference Series: Materials Science and Engineering, Volume 309, TALENTA - Conference on Engineering, Science and Technology 2017 (TALENTA-CEST 2017) 7–8 September 2017, Sumatera Utara, Indonesia. (DOI:10.1088/1757-899X/309/1/012020)

[10] Allam S., Nader F., Abdelwahed K., 2022, Vehicle Braking Distance Characterization using Different Brake Types, International Research Journal of Engineering and Technology (IRJET), Volume: 09, Issue: 03. (e-ISSN: 2395-0056, p-ISSN: 2395-0072, rjet.net/archives/V9/i3/IRJET-V9I3200.pdf)

[11] Šarkan B., Holeša L., Ivánek P., 2013, Measurement of the braking distance in dependence on the momentary vehicle weight, Transport and Communications, 2013, Vol. I., Pages 29-32. (DOI:10.26552/tac.C.2013.1.7)

[12] Pfaff R., 2023, Braking distance prediction for vehicle consist in low-speed on-sight operation: a Monte Carlo approach, Springer Natural, Railway Engineering Science, Volume 31., Pages 135–144. (https://doi.org/10.1007/s40534-023-00303-7)

[13] Ilie F., Cristescu A-C., 2023, Experimental Study of the Correlation between the Wear and the Braking System Efficiency of a Vehicle, Automotive Safety and Security Engineering: From Theories to Practices, 13, 8139. (https://doi.org/10.3390/app13148139)

[14] Demira A., Oz A., 2019, Evaluation of vehicle braking parameters by multiple regression method, Sci. Iran. 2019, 6, 3334–3355. (DOI:10.24200/sci.2019.51584.2262)

[15] https://www.science.org.au/curious/technology-future/physics-speeding-cars

[16] https://www.brake.org.uk/get-involved/take-action/mybrake/knowledge-centre/speed/stopping-distances

[17] https://www.bbc.co.uk/bitesize/guides/zs9mfcw/revision/1

[18] https://www.bbc.co.uk/bitesize/guides/z29dqty/revision/6

[19] https://www.theaa.com/breakdown-cover/advice/stopping-distances

[20] https://www.td.gov.hk/en/road_safety/road_users_code/index/chapter_5_for_all_drivers/stopping_distance_/index.html

[21] https://www.nsw.gov.au/driving-boating-and-transport/roads-safety-and-rules/safe-driving/safe-stopping-distance

[22] https://collierandcollier.com/five-factors-of-stopping-distance/

[23] https://d37y5k2fagl7yg.cloudfront.net/physics-of-speed/index.html

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Professional Paper

Comprehensive Analysis of Performance and Safety Aspects of Roundabouts: A Case Study

Darko Sokolovski[1]

Abstract – **This evaluates a four-leg intersection in Radovish, proposing its redesign as a roundabout. Using the SIDRA Intersection software, the analysis reveals improved traffic flow, reduced delays, and increased safety. The findings support the roundabout as an effective urban traffic management solution, promoting efficiency and sustainability in road network performance.**

Keywords – **Roundabout, Traffic Analysis and Simulations, Traffic Flow, Safety.**

I. INTRODUCTION

Conventional four-way intersections—particularly those without traffic signals—often encounter challenges such as congestion, extended queues, and an increased number of conflict points, all of which negatively impact traffic performance and compromise road user safety [5].

This paper presents a detailed analysis of a four-leg intersection situated at the junction of "Bulevar Aleksandar Makedonski" (oriented East–West) and the main urban artery "Makedonska" (formerly the regional Štip–Strumica road, oriented North–South) in the Municipality of Radoviš. The research aims to evaluate the functional efficiency of the existing intersection using advanced traffic simulation tools and, based on the findings, to propose its redesign from a conventional four-leg configuration to a modern roundabout.

To support the analysis, a traffic count was conducted on 26 June 2024 during the morning peak hour. The recorded data were processed and analyzed using the SIDRA INTERSECTION software. Unlike conventional models, SIDRA INTERSECTION evaluates each traffic lane individually, offering a detailed assessment of the current intersection and the potential benefits of the proposed redesign.

The proposed redesign is expected to enhance intersection performance, improve traffic safety, and reduce environmental impact. The following sections will present a comprehensive overview of the theoretical aspects of roundabouts, including their advantages and disadvantages, the criteria for their implementation, and a detailed analysis of the current intersection conditions alongside the proposed traffic solution.

II. ROUNDABOUTS – THEORETICAL ASPECT

Compared to conventional intersections, the implementation of roundabouts offers numerous advantages [2, 5]:

- Significantly improved traffic safety: Roundabouts have fewer conflict points than conventional at-grade intersections. The reduced vehicle speeds through the circular layout result in less severe outcomes in the event of a collision. High-risk crash types, such as head-on and right-angle impacts—common in traditional intersections—are virtually eliminated. The need for drivers to decelerate before entering the roundabout further enhances overall safety.
- Reduction in noise and emissions: Lower vehicle speeds and minimized stop-and-go conditions lead to reduced noise pollution and lower emissions. As a result, roundabouts contribute to a more environmentally sustainable traffic system compared to signalized intersections..
- Reduced queues at approaches: Although the extent may vary depending on traffic volumes, well-designed roundabouts generally facilitate more efficient traffic movement, leading to shorter queues and reduced congestion at entry points.
- Effective for intersections with balanced traffic volumes: In scenarios where main and secondary roads carry comparable traffic loads, roundabouts provide an equitable distribution of right-of-way, preventing the dominance of a single direction and ensuring smoother overall flow.
- Suitable for multi-leg intersections (five or more approaches): Roundabouts offer an effective solution for complex intersections with numerous entry and exit points, simplifying their geometry and significantly enhancing safety and navigability for all road users.
- Reduced maintenance costs: Unlike signalized intersections, roundabouts eliminate the need for costly traffic signal equipment and ongoing maintenance, resulting in lower long-term operational expenses.
- An effective traffic-calming measure in urban environments: By requiring drivers to slow down, roundabouts naturally promote calmer and more controlled traffic flow—an especially valuable benefit in residential and commercial zones where pedestrian activity is higher.
- Possibility of spatial integration and landscaping: The central island of the roundabout offers the opportunity to be landscaped with horticulture or other decorative elements, which improves the aesthetic appearance of the environment.

Despite their numerous advantages, roundabouts also have certain disadvantages [2, 3]:

- Decreased safety with high traffic volumes and multilane designs: While roundabouts reduce conflict points compared to traditional intersections, those with more than one circulating lane can be challenging for drivers. Lane-changing manoeuvres may lead to increased collision risk, particularly for inexperienced users. As a result, single-lane roundabouts are generally recommended where feasible.
- Incompatibility with coordinated signal systems ("green wave"): Unlike signalized intersections, roundabouts do not support coordinated traffic flow systems such as the

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"green wave," which facilitates continuous vehicle movement through multiple signals along a corridor.

- Spatial constraints in built-up areas: Constructing a roundabout requires a larger physical space than conventional intersections, which can pose significant challenges in densely developed urban environments with limited available space.
- Limited suitability near facilities for vulnerable populations: Roundabouts may not be ideal in front of institutions serving the blind or visually impaired, as well as hospitals, nursing homes, and health centers, where pedestrians rely on signalized crossings for safe passage.
- Not optimal near schools and kindergartens: In areas with frequent movement of children—especially in groups—roundabouts can present safety risks if not accompanied by additional protective infrastructure and traffic-calming measures.
- Conflicts with high volumes of pedestrians and bicycle flows: Where pedestrian and cyclist flows are intense, particularly at single-lane roundabouts, conflicts may occur at entry and exit points unless adequate crossings and separation measures are implemented.
- Inefficient for traffic with frequent left turns: While roundabouts typically improve flow, scenarios involving a high volume of left-turn movements (relative to the circulating direction) can lead to congestion and reduced operational efficiency.
- Limited benefit from adding traffic signals: Installing traffic signals at roundabouts generally does not improve throughput and may compromise the operational advantages inherent to their design.
- Longer travel distances for vehicles and pedestrians: Compared to signalized intersections, roundabouts may result in slightly longer routes for both vehicles and pedestrians, potentially increasing travel time in some scenarios.

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A. Criteria for the Implementation of Roundabouts

There are several criteria for implementing a roundabout, which differ according to their purpose and define the reason for designing a roundabout [5].

In the research, the following recommended design criteria were considered:

- Functionality: This criterion refers to the intersection's ability to ensure smooth and efficient traffic flow under typical operating conditions.
- Capacity: Defines the maximum volume of traffic the intersection can accommodate within a given time frame without causing significant delays or congestion.
- Spatial Criterion: Involves assessing the availability of sufficient space to construct a roundabout, taking into account the required dimensions of the central island, circulating roadway, and approach lanes.
- Design and Technical Criterion: This includes key engineering parameters such as turning radii, gradients, drainage systems, and other technical specifications necessary to ensure a safe, functional, and durable roundabout design.
- Traffic Safety: Is one of the most critical criteria and must be evaluated in all scenarios, whether for new construction or reconstruction projects. Generally, traffic flow and safety are directly related. If head-on collisions (e.g., between a left-turning vehicle and an oncoming through vehicle) are predominant, a roundabout is typically justified. In contrast, if most collisions involve right-turning vehicles, the implementation of a roundabout may be unwarranted, as a dedicated right-turn lane would be a more appropriate and cost-effective solution.

The applied methodology is presented in the following section.

METHODOLOGY

The analyzed intersection is located at the southwestern entrance to the Municipality of Radoviš and is a four-leg unsignalized junction (Figure 1). Its immediate surroundings include gas stations and large industrial facilities. The main traffic corridor runs in the north–south direction along "Makedonska" Street, the city's arterial road, which also forms part of the old regional road Štip–Strumica. This route carries a significant volume of heavy goods vehicles, as it borders the municipality's industrial zone. Due to safety concerns, a redesign of the existing at-grade intersection is being considered, with the implementation of a roundabout proposed as a safer and more efficient solution.

Figure 1. Micro location of the study intersection
Source: Google Maps

B. Traffic flow analysis

Traffic flow data were collected through a manual traffic count conducted at the analysed intersection. The traffic count was performed during the morning peak period, on 26 June 2024, between 07:00 and 09:00. The recorded data are presented in Table 1.

Tab. 1**.** Traffic flow data

	APPROACH					
	East					
	Passenger vehicle	Heavy vehicle	Motorcycle	Bus	Bikes	Pedestrians
East						
West	40	8	2		3	
North	160	36	4	6	2	1
South	125	12	8	1	5	3

	APPROACH					
	West					
	Passenger vehicle	Heavy vehicle	Motorcycle	Bus	Bikes	Pedestrians
East	5	6				
West						
North	2					
South	3	2				

	APPROACH					
	North					
	Passenger vehicle	Heavy vehicle	Motorcycle	Bus	Bikes	Pedestrians
East	67	18	5	3	2	1
West	6		1			1
North						
South	3	1				

	Approach					
	South					
	Passenger vehicle	Heavy vehicle	Motorcycle	Bus	Bikes	Pedestrians
East	78	14	8	1	5	1
West	2					
North	18	2		1		3
South						

As expected, the analysis and accompanying graphical representations indicate that the eastern approach—Aleksandar Makedonski Boulevard—is the most heavily congested. This is attributed to the fact that, during the morning peak, a significant number of residents of the Municipality of Radoviš travel toward their workplaces located in the city's industrial zone.

The traffic flow structure by approaches is visually represented in Figure 2.

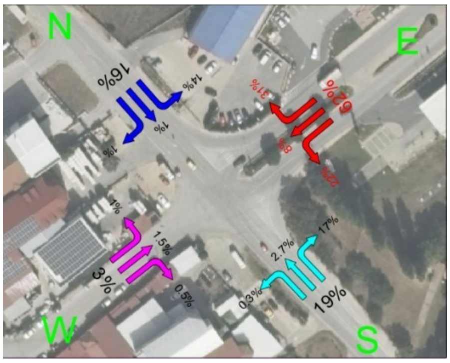

Fig. 2. Traffic flow structure by approaches

C. Design and Technical Elements

The proposed roundabout is designed with the following technical features:

- Radius of the central island: The central island has a radius of 12.00 meters and includes a truck apron with a width of 1.50 meters. This feature ensures the accommodation of large vehicles—such as heavy goods vehicles (HGVs) and buses—allowing them to navigate the roundabout without operational difficulty.
- The circulating carriageway is 9.00 meters wide and is designed into two lanes, each 4.50 meters in width. Although multilane roundabouts may pose safety concerns under certain conditions, in this case, the proposed design achieves a Level of Service (LOS) A and a saturation level below 0.6, indicating optimal performance for both current and projected traffic volumes (as detailed in section Results). Safety is further ensured through the precise geometric design of the entry and exit radius.
- Approach lane width: Approximately 7.00 m.
- Number of approach lanes: All approaches, except the western one, have two approaching lanes.
- Entry radius: They range from 9.00 m to 34.00 m; this geometric parameter is of critical importance, as they directly influence the ability of vehicles to enter the roundabout safely and smoothly.

The implementation of the proposed roundabout design is expected to provide the Municipality of Radoviš with a modern, efficient, and safe intersection solution, significantly enhancing traffic flow, reducing congestion, and improving safety for all road users.

III Results

The performance analysis of the proposed roundabout, conducted using the SIDRA INTERSECTION software and based on existing traffic load data, indicates a significant improvement in key indicators of functional efficiency. To evaluate the feasibility and effectiveness of this transformation, a performance analysis of the proposed roundabout was conducted using the SIDRA INTERSECTION software [3]. This analysis provides a clear assessment of the intersection's operational performance under circular traffic flow conditions. The level of service (LOS) is illustrated in Figure 3, providing a visual representation of the intersection's operational efficiency.

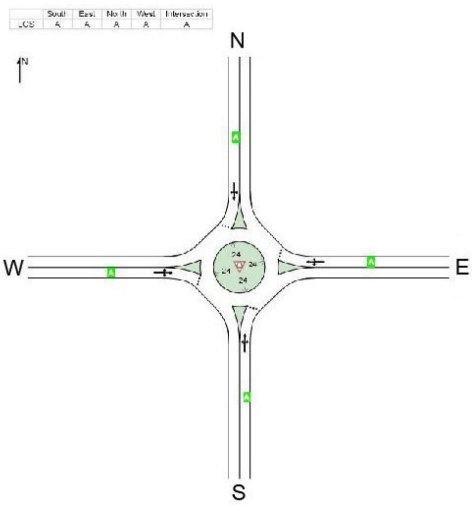

Fig. 3. Level of service

1. Level of Service - A: This is an exceptionally good result, indicating excellent traffic flow with minimal delays. Service level "A" means that vehicles move with free flow, or with minimal delays.

Additional performance parameters obtained from the analysis include:

2. Degree of saturation - <0.6: Degree of saturation is a critical indicator for the efficiency of cross-linkers. A value of less than 0.6 indicates that the intersection is operating below its capacity, which means that it has enough free capacity to handle a large traffic volume without overloading.

3. Queue length - max 12m: The maximum queue length of 12 meters indicates minimal waiting for vehicles before entering the intersection. This is particularly important for the eastern approach, which is currently the most congested. Short queues contribute to reducing congestion and improving the overall flow.
4. Travel speed – 23.4 km/h: This speed is suitable for an urban roundabout. It is low enough to ensure safety and enable easy maneuvering, but at the same time, high enough to maintain efficient traffic flow.
5. Delay - max 6.9s: The maximum delay of 6.9 seconds per vehicle is exceptionally low. This indicates that drivers experience minimal delay at the intersection, which directly enhances travel efficiency and contributes to improved user satisfaction.

Based on the analysis conducted using the SIDRA INTERSECTION software and the results obtained, it can be concluded that the implementation of a roundabout will lead to a substantial improvement in overall intersection performance. The redesigned intersection is expected to operate at Level of Service A, indicating smooth traffic flow and minimal delays. Queue lengths and waiting times—particularly on the heavily congested eastern approach—will be significantly reduced. Safety, as a primary consideration, will be substantially improved through the elimination of conflict points typical of conventional intersections, thereby minimizing the risk of head-on and right-angle collisions. Additionally, the reconstruction will enhance visibility, especially from the eastern approach, where current sight limitations pose safety concerns. Due to the elevation difference between Aleksandar Makedonski Boulevard and the proposed roundabout, it will be necessary to adjust a longer section of the boulevard to ensure proper alignment with the new intersection and existing access points.

IV Conclusion

The analysis confirms that converting the existing four-leg intersection in Radoviš into a roundabout offers significant advantages in terms of traffic efficiency and safety. The results indicate an improvement in the level of service, with reduced queue lengths, shorter delays, and smoother traffic flow, particularly on the previously congested eastern approach. Additionally, the roundabout design minimizes the number of conflict points, thereby lowering the likelihood of severe collisions. Considering these benefits, the roundabout represents a practical, efficient, and forward-looking intervention for improving mobility within the Municipality of Radoviš.

References

[1] Guidelines for the design of roundabouts on state roads – Faculty of Civil Engineering, University of Rijeka, 2020.

[2] Designing manual roads in the Republic of Serbia – Public enterprise Roads Serbia, 2019.

[3] Akcelik & Associates PTY LTD. Sidra Intersection, Innovative software for intersection and network analysis and design, SIDRA INTERSECTION | Micro-analytical software used as an aid for the design and evaluation of single intersections and networks of intersections | SIDRA SOLUTIONS, 2025.

[4] Li Li, Zai Zhang, Zhi-Gang Xu, Wen-Chen Yang, Qing- Chang Lu., The role of traffic conflicts in roundabout safety evaluation: A review. Accident Analysis & Prevention Volume 196, March 2024, 107430

[5]

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Professional Paper

Black Spot Management

Elmir Mustafai[1] and Merita Mustafai[2]

Abstract – **This paper focuses on the management of "black spots" and "black sections" to improve road safety. Using modern methodologies, GIS, and statistical techniques, high-risk road sections are analyzed, particularly the A2 highway in North Macedonia. The development of a national strategy for reducing traffic accidents and improving road infrastructure is recommended.**

Keywords – **Traffic accidents, Black spots, Road safety, GIS (Geographic Information Systems), National Strategy**

I. INTRODUCTION

Traffic accidents represent a global challenge with serious consequences for human lives, the economy, and society. Within modern engineering and management approaches to enhancing road safety, the concept of Black Spot Management (BSM) holds key importance. These locations, identified by a high frequency of traffic accidents, are often the result of suboptimal infrastructure conditions, unfavourable road geometry, or a lack of proper traffic signage.

In scientific and engineering literature, black spot management is treated as an integral part of systemic traffic safety solutions. The methodologies used to identify and analyze them include statistical approaches, modeling of traffic conditions, and the use of Geographic Information Systems (GIS). Different countries apply specific standards and practices based on local conditions, data availability, and the technologies at hand.

Identifying and managing these critical locations is essential for improving road safety and reducing the frequency and severity of traffic accidents. Analyzing the contributing factors to accidents allows for more effective planning of infrastructure interventions and the strengthening of preventive measures for all road users.

II. DEFINING BASIC TERMS

Defining a traffic accident is extremely important, both theoretically and practically. According to the UNO definition: "A road traffic accident is any accident involving at least one moving vehicle on a public or private road to which the public has access, resulting in at least one injured or deceased person." [European Commission [8].

- In the United Kingdom, *"black spots"* are defined as locations with a higher number of accidents than expected, based on statistical models that consider factors such as the road environment and visibility. These locations are monitored and published regularly, and safety measures include accident cause analysis and redesigning road infrastructure where necessary. [11]

- In Germany, *"black spots" (Schwarze Stellen)* are defined as road locations with a significantly higher number of accidents compared to other parts of the road network. Germany uses a classification system for black spots that includes parameters such as the number of accidents, severity of injuries, and other factors like travel conditions and infrastructure. Statistical methods such as the Poisson distribution are used to predict high-risk road areas, and safety improvement measures may include changes or redesigns in traffic infrastructure, as well as updates to traffic rules and regulations. [13]

The causes of traffic accidents in these locations can be divided into two categories:

- Objective factors, including: poor road visibility (inadequate signage, overgrown or obstructed road areas), damaged pavement surfaces, and inappropriate road geometry.

- Subjective factors, including: excessive speed, unsafe and illegal overtaking, failure to yield, not maintaining a safe following distance, driving on the wrong lane, improper passing of vehicles, and driving under the influence of alcohol.

Traffic accidents in dangerous zones most often occur due to poor horizontal and vertical signage, illegal pedestrian and cyclist movements, vehicles running off the road due to poor road geometry, rear-end collisions between vehicles traveling in the same or opposite directions, and side-impact collisions.

III. STATISTICAL ANALYSIS OF TRAFFIC ACCIDENTS ACCORDING TO WHO AND THE EU

"Each year, approximately 1.19 million lives are lost worldwide as a result of road traffic accidents, while 20 to 50 million people suffer non-fatal injuries. Road traffic injuries are the leading cause of death among children and young people

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aged 5 to 29, and two-thirds of traffic victims are between the ages of 18 and 59." [8]

"Increases in average travel speed are directly linked to the likelihood of a crash occurring and the severity of its consequences. For example, every 1% increase in average speed results in a 4% increase in the risk of fatal crashes and a 3% increase in the risk of collisions. The risk of death for pedestrians struck by the front of a vehicle rises sharply, by 4.5 times, as speed increases from 50 km/h to 65 km/h. In collisions between two vehicles, the risk of fatal injury for vehicle occupants is 85% at a speed of 65 km/h." [8]

Vehicle occupants make up 45% of all traffic fatalities, pedestrians account for 18%, motorcyclists and moped users 19%, and cyclists 10%. In urban areas, vulnerable road users are particularly at risk. Vulnerable road users represent nearly 70% of all road traffic fatalities." [9]

According to an extensive WHO study, which covers data from 2010 to 2019, Bosnia and Herzegovina recorded an annual road traffic fatality rate of 15.6 per 100,000 inhabitants, followed by Albania with 12.7, Montenegro with 11.8, and Croatia with 10.4 deaths per 100,000 inhabitants. Among neighbouring countries, the lowest road fatality rates were recorded in Serbia (8.1) and North Macedonia (7.9) per 100,000 inhabitants, marking the lowest levels of road deaths in the Balkans.

IV: Statistical Analysis of Traffic Accidents in North Macedonia

Traffic accidents represent a significant issue in the Republic of North Macedonia, with considerable impact on the safety of all road users, economic losses, and societal costs. Statistical analysis of accidents enables the identification of the main causes, patterns, and trends that appear across different regions and road segments. Through detailed data processing, this analysis can serve as a foundation for creating effective measures to reduce traffic accidents and improve road safety. In our country, statistical analysis is conducted by the Ministry of Internal Affairs (MoIA) and the State Statistical Office (SSO).

The collected data is processed and analyzed with the aim of:

- strategically plan actions for improving road safety,
- design and implement comprehensive strategies by competent institutions,
- as well as support efforts by other organizations involved in road safety management.

"Between 2010 and 2019, over 103,000 traffic accidents occurred on the roads of the Republic of North Macedonia, or approximately 10,300 accidents annually, resulting in fatalities, serious and minor injuries, as well as material damage." [10]

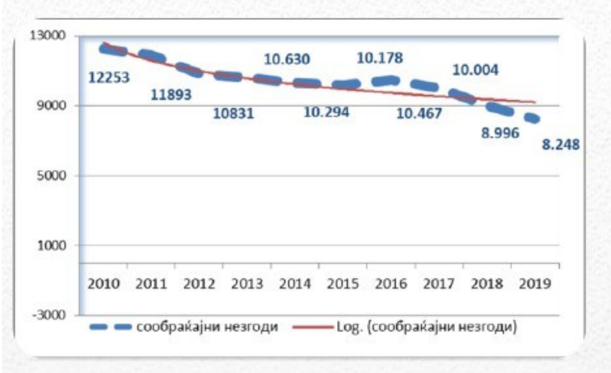

Fig. 1. Traffic Accidents in the Republic of North Macedonia

Source: *Bureau for Public Security, Department for Criminal Intelligence and Analysis, "Analysis of Traffic Conditions on the Roads in the Past Ten Years", No. 22.4-1305/1, Skopje, 09.07.2020.*

V: Methodology for Defining Black Spots

The identification of black spots, as a spatial-temporal phenomenon, involves analyzing the geographic location and weather conditions at the time of traffic accidents. Typically, this analysis examines specific locations on the road network over defined periods to determine areas with a high concentration of accidents, known as black spots. By assessing these problematic segments, researchers can identify the root causes of increased collision rates, such as road design, traffic volume, driver behaviour, weather conditions, and infrastructure.

However, challenges in identifying black spots include limited availability and quality of data, as well as the complexity of evaluating contributing factors. Additionally, changes in road design, infrastructure, and vehicle safety technologies can affect the analysis and determination of these road segments. Each country develops its methodologies for defining traffic accident “black spots,” involving advanced data analysis, predictive modeling, and practical interventions. The "key" lies in combining geographic analysis, statistics, and local conditions to maximize road safety improvements.

A. Statistical Analyses

The use of statistical techniques such as regression analysis and time-series analysis is a common approach for identifying relationships between traffic accidents and factors such as road design, traffic volume, driver behaviour, and weather conditions. These techniques have a long history of application in road safety modeling.

B. GIS-Based Analysis

Geographic Information System (GIS) technologies can be used to map traffic accidents and identify "hotspots" on the road network. GIS can reveal spatial relationships that are not easily detected using non-spatial databases.

In recent decades, numerous studies have been conducted on the use of GIS technology in road safety and accident analysis, with many organizations and researchers reporting successful applications. These analyses include intersection analysis, segment analysis, cluster analysis, and density modeling techniques.

C. Accident Reconstruction

Accident reconstruction involves using various techniques, such as computer simulation models, to recreate the conditions that led to a traffic accident in order to understand the causes and contributing factors. By simulating the scenarios that lead to accidents, researchers can identify key factors and test various scenarios in controlled environments, which is much safer than real-world testing. These models are generally cost-effective for evaluating road network safety, eliminating the need for physical testing and conserving resources.

D. Road Safety Evaluation

Road safety evaluations include a comprehensive analysis of the road network and its surroundings, focusing on identifying problems in road design and infrastructure that could contribute to accidents. These evaluations are usually conducted by teams of experts using various tools and techniques, such as simulation models, to assess the road system. This method is holistic, considering multiple aspects of the road network and environment, such as road design, traffic volume, weather conditions, and driver behavior. The goal of holistic approaches is to understand the overall road conditions and identify areas in need of improvement. Through exploration of the road network and its surroundings, fundamental causes of accidents can be uncovered, such as poor road design, lack of signage or lighting, and obstacles that may impair driver visibility.
Different countries use various statistical methods to identify traffic black spots. For example:

- Denmark and Norway use Poisson regression
- Hungary applies accident indexing
- Germany and Portugal use the weighted factor method
- Greece uses absolute accident counts
- Switzerland employs both accident indexing and the weighted factor method

Another example is the methodology used in Austria. Black spots in Austria are defined according to the Austrian Guideline Code for planning, designing, constructing, and maintaining roads, published in November 2002. According to this guideline, accident-prone locations are categorized as black spots and hazardous locations, based on the recorded number of traffic accidents at those sites. To be classified as a black spot, specific locations must meet one of the following criteria:
Three or more similar traffic accidents involving serious or minor bodily injuries within 3 years, and a relative risk coefficient (Rk) ≥ 0.8.
Starting from 1995, traffic accidents in Austria that result in only material damage are no longer recorded.

Therefore, the identification of black spots is entirely based on the first definition involving accidents with injuries.
To identify and calculate black spots, the sliding window method with a length of 250 meters is used (Figure 2). The window follows the road alignment and marks any location where one of the two black spot criteria is met.

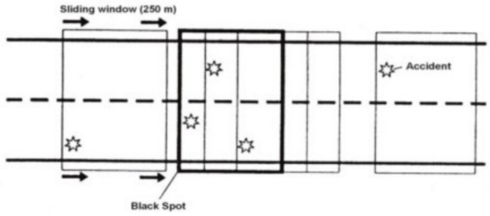

Fig. 2. Identification of black spots in Austria using the sliding window method
Source: Ministry of Internal Affairs, "International Scientific Journal: SECURITY", No. 6/2021, Skopje, 2022

The critical value of Rk = 0.8 is reached under the following conditions:

- 3 traffic accidents with injuries within 3 years and AADT ≤ 10,700 vehicles/24h
- 4 traffic accidents with injuries within 3 years and AADT ≤ 16,700 vehicles/24h
- 5 traffic accidents with injuries within 3 years and AADT ≤ 22,600 vehicles/24h
- 6 traffic accidents with injuries within 3 years and AADT ≤ 28,600 vehicles/24h

VI: Analysis of Black Spots in the Republic of North Macedonia

In the year 2023, there were 4,274 traffic accidents on the country's roads, of which:

- 118 involved fatalities,
- 4,156 involved injured persons,
- There is no official data on the number of accidents that caused only material damage.

In North Macedonia, there is still no clearly defined concept of what constitutes a "black spot," as the term is not defined in the Law on Public Roads, the Law on Road Traffic Safety, or in any secondary legislation.
Facing the challenge of the growing number of traffic accidents and their severe consequences, in November 2008, the Republic Council for Road Traffic Safety (RSBSP) adopted a decision to publish the:
"National Strategy of the Republic of Macedonia for the Promotion of Road Traffic Safety 2009–2014."
In alignment with the European Union's norms and plans, the goal of this National Strategy was to reduce the number of traffic fatalities by 50% and to reduce the number of children killed in road accidents to zero by 2014. [1]

The National Strategy provides a detailed analysis of the traffic accidents that occurred, identifies the causes and consequences, and addresses the problem of hazardous locations (black spots), while also proposing specific measures for improving road traffic safety. The strategy includes solutions aimed at reducing the number of traffic accidents and eliminating black spots. Certain sections of the road network in North Macedonia have long been recognized as potentially dangerous areas for road users.
For this reason, the Republic Council for Road Traffic Safety (RSBSP) constantly reminds drivers about the black spots where traffic accidents most frequently occur — locations that require the greatest caution. Among the potentially dangerous black spots (*see Figure 6.1*), the following road segments are particularly highlighted:

- In the Skopje Basin:
    - “Hipodrom” interchange,
    - “Ilinden” interchange,
    - the section from the “Petrovec” toll station to the “Kadino” interchange,
    - the bridge near the village of Katlanovo.
- On the A2 motorway from Skopje to Ohrid, the most dangerous spots include:
    - the road segment from Želino to Tetovo,
    - the stretch between the “Tetovo South” toll station and the “Gostivar” toll station,
    - the area near the village of Zajas (Gostivar–Kičevo section),
    - the village of Mešeišta (Kičevo–Ohrid section),
    - the bridge over the Sateska River near the village of Botun (Kičevo–Ohrid section),
    - the interchange for entering Ohrid near the village of Podmolje (Ohrid–Struga section).
- On the regional road R1301 (Ohrid–Sveti Naum), the most dangerous areas are:
    - near the tourist complex “Sveti Stefan” (Hotel “Granit”),
    - the intersection at the entrance to the “Inex Gorica” resort,
    - the settlement of Rača,
    - and the village of Peštani.
- In the central and eastern parts of the country:
    - the Demir Kapija–Udovo segment of the highway,
    - the A4 highway section from Štip to Radoviš, specifically the areas known as “8th kilometer” and “Pilaftepe”.

Other particularly dangerous locations include:

- On the regional road R1201 (Debar–Struga):
    - near the villages of Velešta and Vraništa.
- On the regional road (Prilep–Kruševo):
    - the location known as Smilevski Trla.
- On the regional road R1305 (Kičevo–Demir Hisar):
    - the segments known as Čakor and Pribilečki Curves.

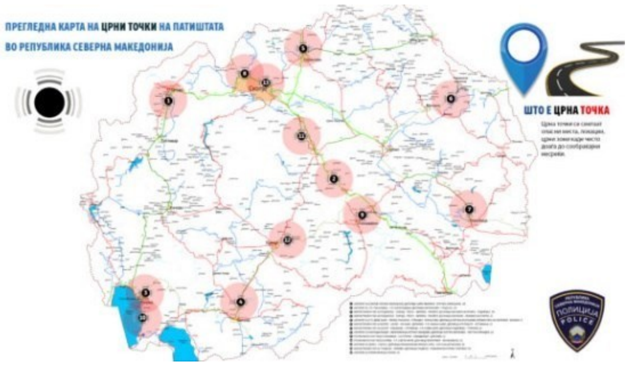

Fig. 3. Overview Map of Black Spots on the Roads of the Republic of North Macedonia

Source:https://fokus.mk/gi-snemuva-tsrnite-tochki-od-makedonskite-patishta/

E. Specific Analysis of the A2 Highway in the Context of Traffic Black Spots

From the previously conducted generalized analysis, it is evident that one of the most critical road corridors in the country is the A2 highway (known as “Mother Teresa”), which is part of the European Route E65. This corridor runs in a northeast–southwest direction and serves as the main road artery in Western North Macedonia.
The A2 highway begins as a motorway at the junction with the A1 motorway near Miladinovci, continues west, bypasses Skopje, and then connects to Tetovo. On the 25-kilometer stretch between Tetovo and Gostivar, the highway consists of two lanes in each direction but lacks a hard shoulder, making it classified as an express road under some standards.
From Gostivar, the road continues for 46 km as a two-way carriageway to Kičevo, then extends another 55.8 km to the village of Podmolje near Ohrid. It is important to note that as of February 12, 2024, the construction of a new 54 km motorway section from Kičevo to Ohrid has begun and is still in progress. From Podmolje, the road turns west toward Struga

and ends at the Qafasan border crossing, continuing into Albania as E852, spanning a length of 19.3 km.

Despite the lack of a legally defined concept of "black spots" in our country, the Ministry of Internal Affairs has mapped and reported locations considered critical or potentially dangerous due to a high number of traffic accidents.

On the A2 highway, based on daily bulletins from the Ministry of Internal Affairs and other available data, the following are identified as potential black spots and hazardous segments:

- Tetovo–Skopje motorway section: High speeds exceeding posted limits, poor winter weather conditions, and high traffic volumes in summer are notable risk factors. Particularly critical are the entry and exit ramps near the village of Saraj.

- Tetovo–Gostivar section: Issues include insufficient safety barriers, frequent speeding, and illegal overtaking. Dangerous spots include sharp curves and connection ramps to/from nearby settlements.

- Gostivar–Kičevo section: Characterized by mountainous terrain, sharp and blind curves, reduced visibility, and slippery conditions due to rain, snow, or ice. The Straza pass is a particularly hazardous area.

- Kičevo–Ohrid section: Key problems include a lack of vertical signage, poor road surface condition, narrow lanes, etc. Notable black spots include the area near the village of Zajas and connection ramps to/from the cities of Kičevo and Ohrid.

- Based on the research conducted into globally implemented methodologies and local observations in North Macedonia, it was concluded that there is no standardized national methodology for defining and marking black spots on specific road segments.

- As a proposed methodology, I suggest the one actively used in Austria, described earlier in Section V, which I believe is both easily applicable and yields effective results. With proper coordination and involvement of domain experts, it is also possible to implement a hybrid methodology combining approaches used in other countries, as discussed in this study.

Conclusion

Black Spot Management (BSM) is essential for improving road safety, particularly in light of the increasing number of traffic accidents and their serious consequences. This study demonstrates that systematic identification and evaluation of critical points in the road network are fundamental to reducing accident risk.

The application of advanced statistical methods, Geographic Information Systems (GIS), accident reconstruction, and comprehensive road safety assessments represents an interdisciplinary approach that ensures accuracy and effectiveness in addressing hazardous road segments.

The analysis of the A2 highway, one of the most important transport corridors in North Macedonia, reveals that although it is strategically vital, there are numerous challenges in terms of safety. The Tetovo–Skopje section, in particular, experiences high speeds, intense summer traffic, and harsh winter conditions, making it one of the most critical zones. Entry and exit points, especially the Saraj interchange, pose a significant risk, underscoring the need for better speed control and improved signage.

Although the A2 plays a vital role in the national transportation network, the findings indicate that ongoing maintenance, signage, and road geometry are insufficient to meet modern safety standards.

A strong recommendation is made for the development of a national strategy that includes clear definitions and standardized methodologies for black spot identification. Experience from Austria and other countries shows that an integrated approach—based on statistical and geographic analyses—can be successfully adapted and implemented in North Macedonia.

Adopting such practices would likely result in fewer accidents, reduced fatalities, lower material damages, and contribute to a safer, more efficient road infrastructure.

In conclusion, this study highlights the urgent need to implement modern methodologies and strengthen institutional cooperation in order to meet road safety goals. Only through coordinated and long-term actions can sustainability and continuous improvement of road infrastructure be achieved, reducing traffic risks and protecting all road users.

References

[1] Ministry of Internal Affairs, *International Scientific Journal “Security”*, No. 6/2021, Skopje, 2022

[2] Ioannis Karamanlis, Alexandros Kokkalis, Vassilios Profillidis et al., *Identifying Road Accident Black Spots using Classical and Modern Approaches*, WSEAS, Athens, Greece, May 29, 2023

[3] Institute of Transport Economics – Norwegian Centre for Transport Research, *State-of-the-art Approaches to Road Accident Black Spot Management and Safety Analysis of Road Networks*, Oslo, September 2007

[4] Ioannis Karamanlis, Alexandros Kokkalis, Vassilios Profillidis et al., *Deep Learning-Based Black Spot Identification on Greek Road Networks*, MDPI, Basel, Switzerland, June 16, 2023

[5] Verche Koneska, *Model for Determining the Throw Distance of a Cyclist and Bicycle in Vehicle Collisions Using PC CRASH 9.0 Software*, Master's Thesis, Technical Faculty Bitola, November 2024

[6] European Union (European Commission), Brussels, *Glossary for Transport Statistics*, 5th Edition, Brussels, 2019

[7] Ministry of Internal Affairs of RNM, Skopje, *Law on Road Traffic Safety*, “Official Gazette of the Republic of Macedonia” Nos. 169/15 and 226/15

[8] World Health Organization, Geneva, *Road Traffic Injuries*, Geneva, 2023
[9] European Union (European Commission) – Directorate-General for Mobility and Transport, *2023*
[10] Bureau for Public Safety, Department for Criminal Intelligence and Analysis, *Analysis of Road Traffic Conditions Over the Past Ten Years*, No. 22.4-1305/1, Skopje, July 9, 2020
[11] Ioannis Karamanlis, Alexandros Kokkalis, Sokrates Basbas et al., *Towards Sustainable Transportation: The Role of Black Spot Analysis in Improving Road Safety*, MDPI, Basel, Switzerland, October 4, 2023
[12] https://fokus.mk/gi-snemuva-tsrnite-tochki-od-makedonskite-patishta/
[13] https://www.itf-oecd.org/

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Professional Paper

Transport and Climate Change: The National Frame in RNM

Beti Angelevska[1] and Vaska Atanasova[2]

Abstract – **Addressing transport impact on climate change requires policies and measures across a wide range of policy sectors, each with a precise contribution to the overall achievement of national climate commitments. This analysis is prepared according to the goals and recommendations in the three most important national strategies in RN Macedonia. The analysis starts with defined measures in transport, as well as activities for inter-sector cooperation and strengthening institutional capacities towards reduction of greenhouse emissions. Then, recommendations and PESTLE analysis are given for fulfilment of obligations in the strategies and improvement of transport impact on climate change.**

Keywords –**Transport, Climate change, National strategies.**

I. Introduction

In RN Macedonia transport is one of the main sources in terms of negative impacts on climate change [1]. This is due to several aspects especially in road transport, such as old fleet of registered passenger vehicles, as well as the high consumption of fossil fuels (in 2024: oil with 62.2% and gasoline with 26,8%) [2]. According to the same statistical source, the total number of passenger vehicles is 552 934 with average age of 19.5 years. Mainly because these reasons, transport is in second place in terms of its share with 28% in the largest national source of greenhouse emissions (the energy sector).

Reducing the impact of transport on climate change is high on the EU agenda, and also on our national agenda [1]. The development and creation of national policies and strategies based on the principles of sustainable development is one of the conditions for the Republic of North Macedonia to become a member of the EU. In the focus of this analysis are three national strategies that include transport and climate change: National transport strategy 2018-2030, National strategy for sustainable development 2009-2030 and Long- term climate action strategy with an Action plan (2050).

Although since the moment of their implementation there has been positive progress in many aspects in the sustainable development of the RNM, there are still some main issues considering transport that need to be worked on.

Therefore, after presenting the implementation path of the measures and activities in the national strategies, recommendations for the transport sector are given considering strategic alignment, organizational capacities and the execution of tasks in order to achieve results in transport sector. Finally, the PESTLE analysis is presented, which identifies and analyzes critical drivers of change outside the transport sector in order to improve the situation in the transport sector and climate change impacts.

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II. Projections of Transport Greenhouse Emissions

The Long-term Climate Action Strategy with Action Plan [3] develops two climate change mitigation scenarios that, unlike other documents, additionally consider the period 2040-2050. One is a scenario that assumes a transition using existing policies and measures (WEM), and the other considers a more radical transition using additional policies and measures (WAM). WEM scenario includes following mitigation policies and measures: electrification of the transport sector, greater entry of biodiesel and CNG and advanced mobility. WAM scenario includes: further electrification of transport, application of hydrogen for heavy goods vehicles, increased entry of biodiesel and CNG and advanced mobility.

Analyzing greenhouse gas emissions by sector, including emissions from international aviation and electricity imports, in the WEM scenario, total emissions increase from 9 Mt in 2017 to 10.6 Mt in 2050 (or 18%), mainly due to increased emissions from industry and transport (Fig. 1).

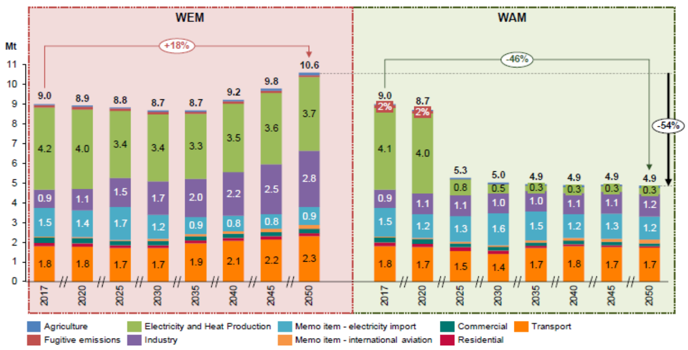

Fig. 1. Development of greenhouse gas emissions by sector, including MEMO emissions items (imports + aviation) [3]

In terms of sectoral contribution to total greenhouse gas emissions in 2050, electricity and heat generation accounts for 35%, followed by industry with 27%, **transport** with 22%, electricity imports with 9%, and other sectors contribute the remaining 7%.

In the WAM scenario, total emissions are estimated to fall by 46% in 2050 compared to 2017, or by 54% compared to the WEM scenario (Fig. 1). On the other hand, emissions from the transport sector are estimated to decrease slightly (6%) as a result of the introduction of more advanced technologies that use less carbon-intensive fuels.

III. GOALS AND RECOMMENDATIONS IN THE NATIONAL STRATEGIES

Next, three most significant national strategies that directly address the issue of transport and climate change are summarized.

A. National Transport Strategy 2018-2030

The National Transport Strategy (NTS) demonstrates the ambition for integration into the European Union through the development of a sustainable transport sector which has an intermodal infrastructure fully integrated into the Trans-European Transport Network (TEN-T) and which is appropriately regulated in accordance with EU rules and regulations [4].

NTS proposes medium- and long-term activities and measures to effectively address the key challenge of improving the quality of transport infrastructure and services. The connection with climate issues is through the construction of a "green" transport system that reduces emissions and limits the consumption of resources and energy.

The general objective 3 is defined as: "To introduce green mobility and logistics focused on the eco-efficiency of the transport sector". The expected result of general objective 3 is a reduction in greenhouse gas emissions from transport by 15.1% in 2025 and by 18.6% in 2030 compared to the levels in the corresponding years in the Do Nothing scenario.

In the frame of general objective 3, three specific measures with a positive impact on greenhouse emissions are defined:

1. to develop and promote environmentally friendly and low-carbon transport systems
2. to stimulate modal shift
3. to increase the importance of intermodal and multimodal transport in national transport policy.

In parallel, work should be done on institutional strengthening and capacity building at the central level, i.e. the Ministry of Transport and Communications should be the central institution for creating transport policies.

Monitoring the implementation of these measures, but also monitoring the complete NTS as a key document for the national transport policy, is under the jurisdiction of the Sector for European Union at the Ministry of Transport and Communications - Department for Negotiations and Integration [4]. This will ensure effective management of reform processes and resources within a single framework.

All of these measures, together with the development of sustainable modes of transport, simultaneously affect the reduction of both pollutant emissions and greenhouse gases. The responsibility for their implementation lies with the local government units and the competent sectoral ministries, especially the Ministry of transport and communications and Ministry of economy. In the NTS, the priority of these measures is defined as medium-term, with a realization period of up to 6 years. According to the current situation with the implementation of such measures in the municipalities, where modest steps are being made in the development of sustainable transport, it is obvious that this period will be exceeded, even by several years.

B. National Strategy for Sustainable Development 2009-2030

From this strategy [5], a review of the consolidated conclusions of several working groups is presented, which have an indirect impact on sustainable transport sector and climate change. Considering that this strategy was developed in 2009, since when several legislative and strategic aspects of sustainable development have been amended and harmonized, the presented conclusions have been selected according to their relevance and unrealizableness at the time of preparation of this paper.

- Insufficiently developed awareness, understanding and commitment to the concept and principles of sustainable development.
- Incompletely developed legal and regulatory framework to support sustainable development policy.
- Need for strategic reorientation in certain segments in the energy sector.
- The capacity of the Ministry of Environment and Spatial Planning needs to be strengthened.
- To intensify the focus on alternative energy sources. The fulfillment of this conclusion is particularly important for transport, where despite being one of the largest national sources of greenhouse gas emissions, fossil fuels are still the most widely used.
- The need for a significant improvement of the railway network. This conclusion has already received attention for practical implementation (next section).
- The need for strategic focus in the area of road planning and construction. Today it can be emphasized that the construction of road infrastructure at the national level is aimed at connecting to the EU TEN-T network, and attention is also paid to ensuring the climate resilience of the infrastructure.
- Weak capacity for strategic work based on sustainable development - planning, administration and implementation.

Hence, in the National Strategy for Sustainable Development, back in 2009, some problems were pointed out in relation to the development and harmonization of the legal framework, the development of an intersectoral approach in solving problems and strengthening capacities, which are still relevant today. More than 12 years after, these shortcomings are also pointed out in the Long-Term Climate Action Strategy with an Action Plan [3] and in the National Energy and Climate Plan [6].

C. Long-term climate action strategy with an Action plan

C1. Proposed activities in transport

The following are the proposed activities to reduce the climate impacts of the transport sector, defined in the Action Plan for the first phase of the implementation of the Long- Term Strategy [3]:

- greater utilization of the railway
- renewal of the national car fleet
- improved mobility

- construction of a railway line to the Republic of Bulgaria
- transport electrification.

These activities in the transport sector, due to the larger scope of impact, have a longer implementation period of 20 years, with a deadline of 2040. The main institutions responsible for their implementation and monitoring are primarily the Ministry of Transport and the Ministry of Energy with the Energy Agency. Regardless of the long implementation period of all activities, their final implementation will contribute to the development of sustainable transport, which will no longer be among the main national sources of greenhouse gas emissions.

C2. Horizontal coordination for the implementation of the objectives

Climate mainstreaming can be significantly improved with strengthened institutional capacities and the establishment of sound mechanisms for cross-sectoral cooperation. Currently, the climate capacities of the Ministry of environment and physical planning (MEPP) are limited, especially in terms of technical expertise for reporting to international organizations, as well as for monitoring and reporting on policies, measures and projections [3].

The project report [7] made a specific proposal for 8-10 new jobs, half of which would be systematized in the Climate Change Department of the MEPP, and the other half in a newly established Greenhouse Gas Inventory Department within the Macedonian Environmental Information Center. The advantage of this approach is that all climate change- related issues would be covered within a single organizational unit under the supervision of the Head of the Department.

Also, the project report [7] identifies the Ministry of Economy and the Energy Agency as institutions that will have a key role in certain processes or in the processing of data on climate change. The former has a key role in the preparation of plans and reports on energy and climate change, while the latter is responsible for the management of information systems and energy efficiency platforms. Therefore, very detailed working assignments are proposed for these two institutions, which do not imply that new positions must be systematized, but that they can be incorporated into existing positions.

Apart of these institutions, there is a need to strengthen institutional capacities and human resources, especially in the Ministries of Environment and Public Health, to implement climate-integrated plans and policies. Other institutions, sectoral bodies and authorities that are relevant to greenhouse gas impacts can contribute by developing horizontal coordination more effectively to achieve the activities envisaged in the climate action strategy.

IV. RECOMMENDATIONS AND IMPROVEMENT PATH

Recommendations are proposed in three directions: strategic compliance, organizational capacities and performance of work tasks [8].

Strategic compliance

- It is necessary to adopt the Law on Climate Action.
- Consistent achievement of the strategic goal – introduction of green mobility and logistics, focused on the environmental effectiveness of the transport sector and achieving the expected result of reducing greenhouse gas emissions from transport by 15.1% in 2025 and by 18.6% in 2030.
- Strengthening the coordination of all stakeholders in the process of reporting and informing on greenhouse gases.
- Continuous efforts for timely preparation of national documents on climate change.

Organizational capacities

- A functional analysis of individual entities should be conducted in order to detect the conditions in the existing acts for internal organization and systematization in them.
- Key positions, especially managerial positions, should be filled with persons with appropriate professional qualifications and work experience.
- Work on continuous education and development of the work skills of employees.

Performance of work tasks for the achievement of the results

- If such are not already established, protocols for handling work processes and decision-making should be developed, i.e. clear written procedures for communication between entities within the sector.
- If such are not already established, protocols for handling public relations at the sector level should be developed.
- To conduct a more detailed analysis of the situation and needs with IT technology, software and other work tools, as well as appropriate staff.
- To take advantage of the opportunities provided by the programs of the EU and other countries and organizations for applying for projects, and in particular to develop staff that will monitor these projects and will be appropriately trained to use them.

V. PESTLE ANALYSIS

PESTLE analysis shows and predict certain factors that have an impact on the transport sector. It identifies and analyzes critical drivers of change outside the sector and is an evaluation to review the goal, characteristics, plans or strategies. It can be used to start formulating a strategy or to periodically review such a strategy by reviewing indicators.

PESTLE analysis is usually applied to six areas (Fig. 2).

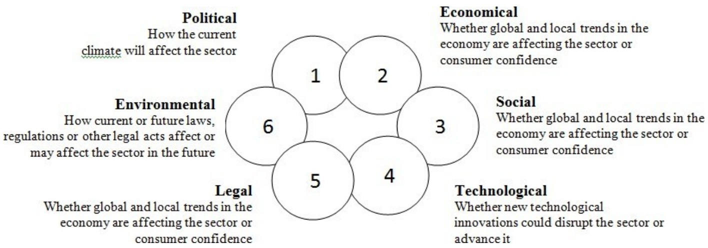

Fig. 2. Areas in the PESTLE analysis [8]

According to this analysis, the following emerges.

1. Political - RNM follows all international obligations undertaken by the ratification of international institutions and organizations in the area of climate change. However, despite the political will, RNM is already late in regulating issues related to climate change mitigation, evident from the fact that the Draft Law on Climate Action was drafted in 2022 and is still not adopted.

2. Economic - global trends in the economy are reflected directly on local ones. The current level of economic uncertainty, especially energy, is unfavorable, and as a global trend, and due to the global energy crisis, there is an impact on the increase in the price of transport services.

3. Social - from the aspect of social issues, a decline in the population is noted, which demographically has implications in all sectors, including transport. Emigration is one of the biggest threats, and internal rural-urban migration is also a visible trend. The consequences in the transport sector are noticeable in terms of the reduction in the number and frequency of passenger transport lines in suburban and intercity traffic.

4. Technological – the state of IT is at a standard level, taking into account the capabilities of society and the state as a whole. New technological innovations, including IT, can only advance the sector as a whole.

5. Legal – Climate change is not related to national legislation, but taking into account the effects of climate change, regulation is primarily at the international level. However, the regulation on the impact of the transport sector on greenhouse gases should be clearly regulated and should constitute the basis for creating an insight into this sector on climate change in the RNM.

6. Environmental – the transport sector has a significant negative impact on climate change. At the national level, in the energy sector, transport is the second largest source of greenhouse emissions. On the other hand, climate change also has an impact on the sector, especially in terms of the resilience of the transport infrastructure [9].

VI. Conclusion

Transport is a second source of greenhouse emissions in the RNM. Reduction of its impact on climate change is addressed in the most relevant national strategies, which envisages the implementation of all identified activities that will further reduce greenhouse gas emissions and transport contribution. Recommendations and PESTLE analysis are performed in order to address how to effectively engage institutional and human resources to deal with the problem of climate change, and also to achieve comprehensive organizational development and institutional strengthening.

It is of crucial importance to fully implement national strategic planning documents and to overcome the obstacles that hinder their results. Vision and objectives of these strategies should be integrated into the agendas of line ministries and into the relevant sectoral policies, through enhanced horizontal policy coordination. The general remark is that climate aspects need to be placed higher on the national political agenda in order for the country to allocate resources to engage additional human and institutional capacities at all levels.

References

[1] *Environmental Report with an Indicator Approach 2020*, Ministry of Environment and Physical Planning, Macedonian Environmental Information Center, RNM, 2020.

[2] State Statistical Office, RNM, MakStat data base, 2025.

[3] *Long-term strategy for climate action with an Action plan*, Ministry for Environment and Physical Planning, RNM.

[4] *National transport strategy 2018-2030*, Ministry of Transport and Communications, RM, 2018.

[5] *National strategy for sustainable development in the R Macedonia part I/II 2009-2030*, Ministry for Environment and Physical Planning, RN Macedonia, 2010.

[6] Government of the RNM, *National Energy and Climate Plan of the Republic of North Macedonia, draft version,* German Society for International Cooperation (GIZ), 2020.

[7] *Conducting Climate Change Administrative Capacity Assessment*, Draft Report on Institutional Capacity Assessment, HEAT GmbH - Habitat, Energy Application & Technology, Germany, 2020.

[8] Angelevska, B., Zafirov, H.Z., *Analysis of the development and sustainable planning of transport in the Republic of Macedonia from the aspect of climate change impact*, Macedonian Association of Young Lawyers, Skopje, RNM, 2023.

[9] *Study on the climate resilient infrastructure in the Republic of North Macedonia*, E co. Ltd, UNDP North Macedonia, 2022.

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Review Scientific Paper

Exploring Technological Innovations in Environmental Assessment: Trends and Impact

Ejupi Resmi[1]

Abstract – **Technological innovations in transportation and environmental systems, such as electric vehicles, smart mobility solutions, and renewable energy technologies, play a crucial role in advancing sustainable development. This review paper critically examines their current implementation, assesses their environmental implications, and explores their long-term potential. It underscores the importance of integrated, policy-oriented strategies to foster ecological sustainability within urban environments.**

Keywords - **Technology innovations, environmental assessment, smart transport systems**

I. INTRODUCTION

Urban transport systems are major contributors to greenhouse gas (GHG) emissions and air pollution. With rising urban populations and increased vehicle ownership, cities face growing congestion, deteriorating air quality, and elevated public health risks. Traditional traffic management has prioritized mobility over environmental outcomes, often exacerbating ecological degradation.

Recent technological innovations now enable urban planners to integrate environmental considerations into transportation systems. Intelligent Transport Systems (ITS), incorporating real-time data, sensors, and communication tools, manage traffic more efficiently while reducing emissions and conserving energy.

Core ITS components include: (i) Adaptive signal control systems (e.g., SCATS, SCOOT), which adjust signal timing based on traffic flow; (ii) Smart signs and real-time traffic guidance, informing drivers of current conditions; (iii) Centralized traffic control centres, which synthesize sensor data to coordinate traffic across networks. These systems have been shown to reduce travel time by up to 20%, cut CO_2 emissions by 10–15%, and lower fuel consumption by minimizing stop-and-go driving [1].

These advancements in intelligent transport infrastructure mark a significant step toward more sustainable urban mobility. However, to further enhance system responsiveness and environmental performance, cities are increasingly turning to Artificial Intelligence (AI) and other emerging technologies.

II. TOWARDS TECHNOLOGICAL APPROACHES BASED ON ARTIFICIAL INTELLIGENCE

The use of Artificial Intelligence (AI), Predictive Analytics, and the Internet of Things (IoT) is changing how cities handle transport and environmental problems. These smart, data-based technologies help improve traffic flow, lower emissions, and make urban mobility systems more flexible and efficient in real time.

AI has emerged as a transformative tool in urban traffic optimization. By leveraging large volumes of real-time and historical data, AI algorithms can dynamically adjust traffic signal timings, forecast congestion hotspots, and identify pollution-prone zones. This enables proactive traffic control, significantly reducing idle times, stop-and-go conditions, and vehicle emissions.

Empirical evidence from pilot projects across Europe and Asia demonstrates that AI-enhanced traffic control systems can lead to emission reductions of up to 30%, underscoring their immense potential in supporting cleaner, more climate-resilient urban transport strategies [3].

Complementing AI, IoT, and sensor networks provides the digital infrastructure necessary for comprehensive environmental and mobility monitoring. IoT-enabled sensors continuously collect data on key environmental indicators—such as nitrogen dioxide (NO_2), particulate matter (PM2.5), traffic density, vehicle speed, and ambient noise levels. This information forms the basis for several key applications:

- Real-time pollution alerts, enabling timely public health responses;
- Dynamic traffic redirection, diverting vehicles from high-emission or high-congestion zones;
- Granular environmental datasets, informing urban planning and environmental policy.

By allowing constant monitoring and quick reactions, these systems help make city transport networks more flexible and better able to handle problems. When used together with AI, they create the main technology behind smart mobility, helping

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transport systems work more efficiently while also supporting goals related to sustainability, climate, and public health.

Smart technologies help improve traffic control and environmental monitoring, but they are only one part of the bigger changes happening in city transport. To fully understand how innovation is changing urban sustainability, it's important to look at new road transport technologies, especially those that affect emissions, energy use, and how people travel [4] [10].

In response, a wave of technological innovations has emerged, aiming to reshape how cities manage mobility, reduce environmental impacts, and enhance overall transport efficiency. This section explores four major areas of innovation—Electric Vehicles (EVs), Autonomous Vehicles (AVs), Smart Traffic Management, and Mobility-as-a-Service (MaaS)—and evaluates their environmental implications.

A. Electric Vehicles (EVs)

Electric vehicles (EVs) are one of the most important new developments in modern road transport. Unlike traditional vehicles with internal combustion engines (ICEVs), EVs do not produce emissions from their tailpipes. This means they do not release local air pollutants like nitrogen oxides (NOx), carbon monoxide (CO), and fine particles (PM2.5), which are linked to breathing and heart problems. In addition to improving local air quality, EVs can also lower greenhouse gas (GHG) emissions over their full life cycle, especially when they use electricity from renewable sources like solar or wind power.
Technological advances in battery chemistry—including solid-state batteries and lithium-iron-phosphate (LFP) variants—are increasing vehicle range, improving charging speeds, and enhancing safety. In parallel, the rapid expansion of EV charging infrastructure, including fast chargers and smart grid integration, is making EV adoption more feasible for both personal and commercial fleets. However, the environmental footprint of battery production, especially related to the extraction of lithium, cobalt, and other rare earth elements, must be addressed through sustainable sourcing practices and expanded battery recycling programs [9].

B. Autonomous Vehicles (AVs)

From an environmental point of view, autonomous vehicles (AVs) offer several benefits. One of the main advantages is their potential to reduce emissions, especially when they run on electric power. AVs are designed to drive smoothly, avoid unnecessary stops, and choose the best routes, all of which help save energy and lower pollution. When connected to smart transport systems, they can also help reduce traffic congestion, making the whole system more efficient.
However, there are still some important challenges to think about. The advanced sensors and computer systems needed for AVs to operate require a lot of energy. If this energy comes from non-renewable sources, it can reduce the overall environmental benefits. Another issue is that autonomous travel is very convenient, which may encourage people to take more trips or travel longer distances than they would with regular cars. This increase in total travel is called "induced demand," and it can lead to higher overall emissions.
To reduce these negative effects, strong policies are needed. Governments should promote shared use of AVs, such as in ride-sharing services, instead of supporting private ownership. They should also invest in public transport, cycling, and walking infrastructure to encourage people to choose greener ways of getting around. By combining AVs with sustainable transport options, cities can move toward cleaner, more efficient, and more balanced mobility systems [4][5].

C. Smart Traffic Management

Smart traffic management plays a key role in improving how road transport works. By using Intelligent Transport Systems (ITS), cities can gather and respond to real-time data about traffic, vehicle movement, and the environment. Systems like SCATS (Sydney Coordinated Adaptive Traffic System) and SCOOT (Split Cycle Offset Optimization Technique) help manage traffic lights by adjusting them based on how busy the roads are. This reduces traffic jams, stop-and-go driving, and pollution [1][10].
When smart traffic systems work with Internet of Things (IoT) sensors, they can also track air quality, noise, and vehicle speed. This helps cities take action early to protect the environment. These systems have shown real benefits, such as cutting travel time by up to 20% and lowering CO_2 emissions by 10–15% in cities that use advanced traffic control. They also help emergency services respond faster and give priority to public transport.

D. Mobility-as-a-Service (MaaS)

Mobility-as-a-Service (MaaS) brings together different types of transport—like buses, ride-hailing, car-sharing, bike-sharing, and scooters—into one digital platform. These platforms let people plan, book, and pay for their trips using just one app, making travel easier and more efficient.
MaaS encourages people to use shared and eco-friendly transport instead of owning a private car. This helps reduce the number of vehicles on the road, cuts emissions per person, and lowers damage to roads and other transport systems.
Environmentally, MaaS helps decrease traffic congestion, greenhouse gas emissions, and air pollution. It also supports more walking, cycling, and the use of public transport [8]. However, to make MaaS work well, cities need strong partnerships between public and private groups, systems that can work together, and fair access for everyone, so that it doesn't increase inequality or leave out people without digital tools.
Together, these new technologies offer different ways to reduce the environmental impact of road transport.
Electric and autonomous vehicles give direct ways to lower emissions, while smart traffic systems and MaaS platforms improve how transport works and encourage more sustainable travel habits.
To get the most environmental benefits, these tools must be used together in smart ways. This includes using good data systems, clean energy, and strong transport policies.

III. Environmental Benefits and Stakeholder Analysis

New technologies in road transport offer several environmental benefits. One of the most important is the reduction of greenhouse gas (GHG) emissions. This happens through the use of electric vehicles and smart systems that reduce fuel use and time spent idling in traffic. Air quality also gets better, as zero-emission vehicles and systems that cut congestion help lower harmful pollutants like nitrogen oxides (NOx) and fine particles (PM2.5), which can cause breathing and heart problems. Another benefit is less noise pollution, since electric vehicles are quieter than regular cars, making cities more pleasant to live in.

However, these technologies also bring some challenges. Important materials like lithium, cobalt, and rare earth elements. These mining activities can damage the environment and raise ethical concerns in some areas. Another problem is electronic waste (e-waste), which includes used batteries and digital parts that are hard to recycle. Also, the systems that support smart transport—like data centers, sensors, and AI tools—use a lot of energy, especially if they rely on fossil fuels [7].

There is also a risk that more convenient and automated travel, such as self-driving cars or on-demand services, could lead people to travel more often or farther. This "induced demand" could reduce the environmental benefits unless strong policies are in place to manage it [5].

Many different actors—including governments, private companies, and citizens—play important roles in how these technologies are used and what effects they have (see Table 1).

Table 1. Stakeholder Analysis

Stakeholder Group	Roles and Contributions
Government and Policy Makers	-Develop regulatory frameworks - Incentivize sustainable practices - Fund infrastructure (e.g., EV chargers, smart systems)
Technology Providers & Industry	- Design and build EVs, AVs, and smart platforms - Maintain systems and services - Ensure ethical sourcing and sustainability of innovations
Urban Planners & Transport Authorities	- Integrate technology into city infrastructure - Design low-emission zones and smart corridors - Balance efficiency and environmental priorities
Citizens and End Users	- Adopt and use sustainable transport options - Respond to environmental data and alerts - Demand accountability and accessibility
Academia & Research Institutions	- Conduct life-cycle and impact assessments - Provide evidence for policy development - Support long-term urban sustainability research
Environmental NGOs & Advocacy Groups	- Promote transparency and ethical practices - Hold stakeholders accountable - Advocate for environmental justice and responsible innovation

Working together is important for all the people and groups involved, so that new transport technologies support both environmental and social goals. When different stakeholders share ideas and take responsibility, cities can reduce the negative effects of smart mobility. This collaboration also helps make sure the benefits are fair and include everyone.

IV. Conclusion

Technological innovation is playing a critical role in transforming urban transport toward a more sustainable and environmentally responsible future. Advances such as electric and autonomous vehicles, smart traffic management systems, and Mobility-as-a-Service platforms offer substantial potential to reduce greenhouse gas emissions, improve air quality, and promote more efficient and inclusive mobility.

However, realizing these benefits fully requires a comprehensive, systems-based approach that considers the entire lifecycle of technologies, from production to disposal. Environmental trade-offs—such as resource extraction, energy consumption, and electronic waste—must be proactively addressed through circular economy strategies, sustainable sourcing, and robust regulatory frameworks.

Moreover, the effectiveness of these technologies depends on their integration into a broader urban policy context that emphasizes equity, accessibility, and climate resilience. Moving forward, coordinated action among governments, industry stakeholders, and civil society is essential to ensure that technological progress aligns with long-term environmental and social sustainability goals.

References

[1] UN-Habitat. (2022). *The Climate Emergency and Cities: Impact, Mitigation, and Adaptation*. United Nations Human Settlements Programme. Retrieved from https://unhabitat.org

[2] Gonzalez, M., Sharma, R., & Tanaka, T. (2021). *Artificial Intelligence and Traffic Flow Optimization: Case Studies from Europe and Asia*. *Transportation Research Part C: Emerging Technologies*, 125, 102954. https://doi.org/10.1016/j.trc.2021.102954

[3] International Energy Agency (IEA). (2023). *Global EV Outlook 2023: Catching Up with Climate Ambitions*. International Energy Agency. Retrieved from https://www.iea.org/reports/global-ev-outlook-2023

[4] European Environment Agency (EEA). (2021). *Transport and Environment Report 2021: Decarbonising Urban Mobility with Electric Vehicles and Smart Technologies*. https://www.eea.europa.eu/publications

[5] World Economic Forum. (2020). *Shaping the Future of Mobility: The New Mobility Ecosystem*. Retrieved from https://www.weforum.org

[6] Zhang, Y., Zhao, P., & Xu, Y. (2022). Environmental impacts of smart transportation systems: A review. *Sustainable Cities and Society*, 76, 103470. https://doi.org/10.1016/j.scs.2021.103470

[7] Jochem, P., Babrowski, S., & Fichtner, W. (2015). Assessing CO_2 emissions of electric vehicles in Germany in 2030. *Transportation Research Part A: Policy and Practice*, 78, 68–83. https://doi.org/10.1016/j.tra.2015.05.007
[8] Shaheen, S., & Cohen, A. (2019). Mobility on Demand (MOD) and Mobility as a Service (MaaS): Early Understanding of Shared Mobility Impacts and Public Policy Issues. *TRB Annual Meeting*. https://escholarship.org/uc/item/4f16p0ns
[9] U.S. Department of Energy (DOE). (2021). *The Role of Critical Minerals in Clean Energy Transitions*. Retrieved from https://www.energy.gov
[10] International Transport Forum (ITF). (2021). *Smart Transport Infrastructure: Focus on Intelligent Transport Systems*. OECD Publishing. https://www.itf-oecd.org

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Professional Paper

Impact of Traffic on Ambient Air Quality in the City of Bitola

Vladimir Mijakovski[1] and Monika Lutovska[2]

Abstract – **Traffic is one of the main sources of suspended solid particles (particulate matter – PM particles) in urban areas. The impact of traffic in the non-heating season in Bitola is analysed in this paper. Analysis is based on measurements of PM particles of different diameters conducted on several locations in Bitola. The distribution of particles at locations with intensive traffic, shows an increase in particles concentration of all diameters.**

Keywords – **air pollution, solid particles, particulate matter – PM.**

I. INTRODUCTION

The main sources of anthropogenic, i.e. artificial particles are formed by stationary combustion of coal for electricity production, firewood and pellets for space heating in households, burning of biomass for industrial processes and emissions related to traffic (street dust).

In this regard, indicative measurements of the mass concentration of PM10 particles in the urban environment of Bitola have been carried out. The measurements were carried out at five locations throughout the city. These measurements are later compared to PM10 limit values prescribed by the law and analysed to determine the source of pollution.

Suspended particles in urban environments are a complex mixture of particles from multiple types of sources. The majority of sources emit both primary particles and gases to form secondary particles.

Most anthropogenic PM is emitted in relatively small urban and industrial areas, resulting in hotspots with high concentrations of PM and other air pollutants.

The distinction between sources, anthropogenic and natural sources of PM and emitted particles is sometimes difficult to make, for example, dust emissions and biomass combustion. In addition, there are large differences in the relative importance of different sources from one geographical area to another. Namely, the majority of primary PM emissions in eastern parts of Europe originate from stationary sources and combustion processes, while in western parts of Europe emissions are evenly distributed across all economic sectors, although transport emissions play the most significant role in many locations, [1].

Traffic-related sources of PM are a significant contributor to ambient air PM, particularly in urban areas and larger cities. Traffic-related PM emissions can be classified into two groups: road traffic emissions caused by exhaust gases resulting from incomplete combustion of fuel and evaporation of engine lubricant during the combustion process, and traffic-related PM emissions arising from non-exhaust sources of vehicles (other than exhaust gases) such as wear of brakes, tires, transmission joints and road surfaces. These sources contribute significantly to the concentration of PM particles in urban ambient air, [2].

II. EMISSIONS FROM TRAFFIC

Research suggests that exhaust and non-exhaust sources of traffic emissions contribute almost equally to total PM10 emissions in ambient air. Most research in the last three decades has largely focused on exhaust emissions. Strict regulations and new technological solutions have resulted in a large decrease in exhaust emissions. However, despite these reductions, emissions from road vehicles are still present. Even with zero exhaust emissions, traffic will continue to be an important source of PM in ambient air through physical friction/mechanical dispersion processes and resuspended dust [3]. In the future, most of the emissions from road traffic to ambient air will be caused by sources other than exhaust. Some researchers, [4], predict that in central Europe, the PM concentration from the contribution of non-exhaust emissions to total traffic emissions will increase by 80-90%, [5]. As a result, research into this type of emissions will be of increasing importance. Figure 1 shows PM_{10} emissions from traffic in Germany in the period 2000 to 2020 expressed in Gg/year [6].

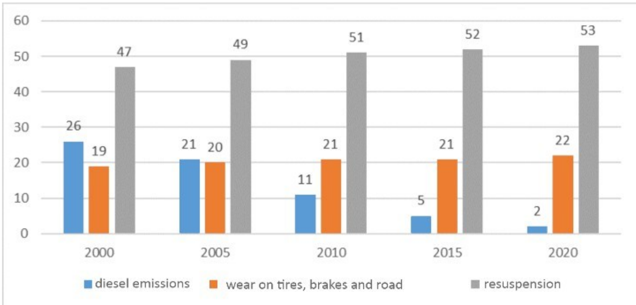

Fig. 1. PM_{10} emissions according to PAREST- Reference scenario, [6]

A key reason for investigating this type of emissions is their tendency to act as carriers of heavy metals and carcinogenic compounds, thereby violating existing standards and norms of ambient air [3]. Although particles from non-exhaust emissions have a larger aerodynamic diameter than particles from exhaust gases, they are still within the size range that can penetrate the respiratory system and cause adverse effects on human health.

Most studies conducted in this area show that brake wear produces about 16-55% of the total PM_{10} emissions associated with non-exhaust sources in urban areas, while on highways this percentage is lower due to the reduced frequency of

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braking. The contribution of tire wear is about 5-30%, [7]. In most studies, when showing the mass distribution of PM_{10} from brake wear, it can be concluded that most of the mass refers to particles with a size of 2-6 µm. On the other hand, in tire wear, most of the mass refers to particles with a size of 5-9 µm. For both sources, most of the mass is generated in the coarse range of $PM_{2.5} – PM_{10}$, [8].

It is estimated that 40-50% of the mass of particles generated from brake wear and 1-10% of the mass of particles generated from tire wear are emitted as PM_{10}, [9]. Thus, exhaust emissions are mainly dominated by particles up to 2.5 micrometers in size, while non-exhaust sources are dominated by particles up to 10 micrometers in size [9], [10]. The contribution of non-exhaust sources to ambient PM_{10} concentrations in the case of tire wear is estimated to range between 0.8-7% by mass and depends on various parameters such as location and sampling methodology. Tire wear corresponds to an ambient PM_{10} concentration of 02-11 µm/m^3. Resuspended dust in ambient concentrations ranges from 1-10 µm/m^3.

III. Measurements of suspended particles and analysis of obtained results

Five measurement locations have been identified to measure the mass concentration of suspended particles in the urban part of the city of Bitola, [12], [13]. The locations are located at relatively equal distances along the length of the city. The results of the mass concentration measurements will serve to determine the impact of the main sources of PM_{10} particles in the ambient air. In this study, the main sources relate to biomass combustion for heating households and the impact of traffic. For this purpose, three measurement locations have been identified to determine the impact of biomass combustion and two measurement locations to determine the impact of traffic.

One measurement location is on the roundabout in the immediate vicinity of supermarket Vero - location marked with 4. This location is characterized by high frequency of vehicles throughout the day. At this location, most of the vehicles that move are mostly passenger vehicles. There are no industrial or other combustion processes near this location during the measurement. The second location is located on the roundabout at the eastern entrance to the city, location marked with 5. Also, this location is characterized by a high frequency of vehicles of all types (passenger, freight and buses), but due to its geographical location next to the industrial part of the city, there are also several concrete preparation plants nearby.

Figure 2 shows the disposition of the measurement locations distributed along the city.

Fig. 2. Disposition of measurement locations for determining the PM_{10} concentration in Bitola

The measurements were made with a Turnkey-Dustmate handheld detector. Three measurements were made consecutively at each location, with the measuring device considering the average value of the measured values. At the five locations, in the months from October 2016 to March 2017, the measurements were made in the evening at 7 p.m., in a time interval of 20 minutes.

An excerpt from the measurements on locations marked 4 and 5 is given on Table 1 and Table 2 below. Ambient air temperature and relative humidity were also measured, but due to limitations in the paper preparation template, they are not shown in the tables below.

Table 1. Measured values for the concentration of total solid particles (TSP), PM_{10}, $PM_{2.5}$ and PM_1 expressed in µg/m^3 at measurement location 4

Date	*TSP*	*PM_{10}*	*$PM_{2.5}$*	*PM_1*
01.10.2016	36.70	22.30	7.73	1.91
02.10.2016	80.30	17.80	9.87	3.82
03.10.2016	33.50	28.90	13.32	6.14
04.10.2016	44.60	26.80	9.86	4.41

Table 2. Measured values for the concentration of total solid particles (TSP), PM_{10}, $PM_{2.5}$ and PM_1 expressed in µg/m^3 at measurement location 5

Date	*TSP*	*PM_{10}*	*$PM_{2.5}$*	*PM_1*
01.10.2016	204.40	125.50	55.0	17.47
02.10.2016	140.0	53.60	29.59	9.39
03.10.2016	444.10	276.40	129.96	60.68
04.10.2016	168.90	77.60	21.81	5.71

Average PM_{10} concentration value for the measurement period from 01.10.2016 to 13.02.2017 expressed in µg/m^3 for locations 1, 4 and 5 is shown on Figure 3.

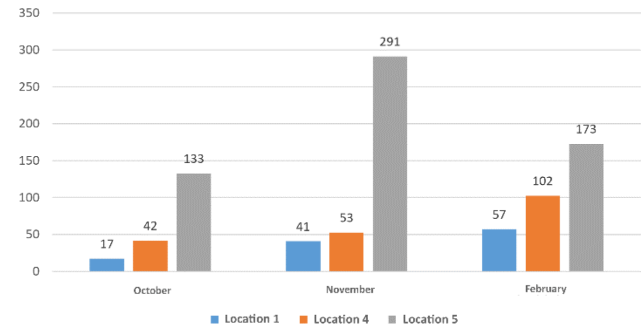

Fig. 3 Average PM_{10} concentration value for the measurement period from 01.10.2016 to 13.02.2017 expressed in $\mu g/m^3$ for locations 1, 4 and 5

After performed measurements, the data were processed, including the maximum, minimum, average values and standard deviations. They were presented in tables and graphs in order to analyze them to determine the sources of biomass combustion in the winter period and the impact of traffic during the period when there is no biomass combustion. The obtained data were used to draw conclusions about the current situation in the urban environment of the city of Bitola.

As a result of the nature of these data, a model is needed to interpret them. Conceptual modeling techniques were applied in this research. A conceptual model provides reliable, although not necessarily accurate, explanations for sources, zones of influence, transport from remote areas and the time of day of emissions. The conceptual model can be set up from research in similar areas, from small pilot studies, air quality analyses and meteorological data, [11].

From the measurement results we can conclude that a small number of peaks can be seen during the measurement period at locations 1, 2 and 3 and they appear in different periods of the measurement. This means that the urban environment of the city should not be considered as a single volume, i.e. each measurement location has its own specificity and characteristics in terms of ambient air. Each measurement location is affected by a different number of sources and they all affect with different intensity, which means that the condition at one location is not a benchmark for the entire urban environment but applies only to that location.

The situation is similar at measurement location 4 with uniformity of measured concentrations and a small number of peaks, while the situation at measurement location 5 is different from all the others.

Measurement location 5 records a large unevenness of the measured values with a large number of peaks throughout the entire measurement period and is characterized by a high concentration of PM_{10} during all measurements. Although this location was set up to determine the impact of traffic, the values indicate that this location is also affected by other sources that do not arise from biomass combustion, since a large unevenness can also be observed in October when there is no biomass combustion. Due to the complexity of this location, it will not be included in the analysis of the impact of traffic on PM_{10} emissions in ambient air in the urban part of the city.

For the analysis of the impact of traffic on PM_{10} emissions in ambient air, locations 1, 2 and 4 are included. In the period when there is no biomass burning in the month of October, the average value of the concentrations at location 4 is 42 $\mu g/m^3$ and is 25 $\mu g/m^3$ higher than at location 1 which is 17 $\mu g/m^3$ or expressed in percentages around 60%. The average value of the concentration at measuring location 2 for the month of October is 48 $\mu g/m^3$ and is higher than at location 1 by around 65%.

If we compare the $PM_{2.5}/PM_{10}$ ratio at all measurement locations in October 2016, it can be concluded that the values of the ratio are approximately equal at all locations in the period when it is not the heating season. The results show that the locations with high frequency of traffic, marked 4 and 5 respectively, have an approximately equal ratio compared to the locations with low frequency of traffic. This indicates that in this period, all locations are dominated by coarse PM_{10} particles. The uniform values of the ratio are not the case during the heating season. Graph on Fig. 4 shows the impact of PM_{10} emissions from traffic on the total PM_{10} emissions in the ambient air for the month of October when there is no biomass combustion in all three locations, which is at least 60%.

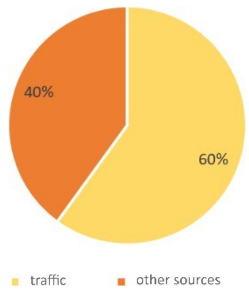

Fig. 4 Impact of PM_{10} traffic concentrations on total PM10 emissions in ambient air in Bitola in October 2016 expressed in %

IV. Conclusion

The burning of firewood proved to be the dominant source of PM_{10} emissions in the total emissions in the urban part of the city of Bitola during the winter. The average values of the measurements performed indicate consistently high concentrations during the measurement period at all measurement locations.

From the differences in measurement results in locations 1, 2 and 4 in October 2016 when the heating season had not yet started, it follows that the concentrations at measurement location 4, which has an increased frequency of vehicles, are higher than at location 1 by about 60% and 65% compared to location 2. The impact of traffic led to an increase in the concentration of PM_{10} by at least 60% and is the dominant source of particles in the urban part of the city during the period when it is not the heating season.

From the measurement results, it is clear that the traffic is the second source of PM_{10} emissions in the city of Bitola during heating season and most likely, first source of PM emissions during the non-heating season in the city.

References

[1] Marko Vallius, Characteristics and Sources of Fine Particulate Matter in Urban Air, University of Kuopio, Department of Environmental Sciences, Kuopio, Finland, 2005, ISBN 951-740-507-3.

[2] Magdalena Penkała, Paweł Ogrodnik and Wioletta Rogula-Kozłowska, Particulate Matter from the Road Surface Abrasion as a Problem of Non-Exhaust Emission Control, Environments 2018, doi:10.3390/environments5010009.

[3] Pant, P & Harrison, RM, 'Estimation of the contribution of road traffic emissions to particulate matter concentrations from field measurements: A review' Atmospheric Environment, vol. 77, pp. 78-97. 2013, DOI: 10.1016/j.atmosenv.2013.04.028.

[4] Vicente Franco, Marina Kousoulidou, Marilena Muntean, Leonidas Ntziachristos, Stefan Hausberger, Panagiota Dilara, Road vehicle emission factors development: A review,

Atmospheric Environment 70 (2013) 84-97, http://dx.doi.org/10.1016/j.atmosenv.2013.01.006.

[5] Roy M. Harrison, Alan M. Jones, Johanna Gietl, Jianxin Yin, and David C. Green, Estimation of the Contributions of Brake Dust, Tire Wear, and Resuspension to Nonexhaust Traffic Particles Derived from Atmospheric Measurements, dx.doi.org/10.1021/es300894r | Environ. Sci. Technol. 2012, 46, 6523−6529.

[6] Wolfram Jörß, Ulrike Kugler, Jochen Theloke, Teilbericht zum F&E - Vorhaben „Strategien zur Verminderung der Feinstaubbelastung - PAREST“, Emissionen im PARESTReferenzszenario 2005-2020, 43/2013.

[7] Theodoros Grigoratos and Giorgio Martini, Brake wear particle emissions: a review, Environ Sci Pollut Res (2015) 22:2491–2504 DOI 10.1007/s11356-014-3696-8.

[8] Theodoros Grigoratos and Giorgio Martini, Non-exhaust traffic related emissions. Brake and tyre wear PM, ISBN 978-92-79-38302-1 (PDF), European Union 2014.

[9] Pant Pallavi, Harrison Roy, Critical review of receptor modelling for particulate matter: A case study of India, University of Birmingham, 2012, doi:10.1016/j.atmosenv.2011.11.060.

[10] Mahmoud Abu Allaban, John A. Gillies, Alan W. Gertler, Russ Clayton, David Proffitt, Tailpipe, resuspended road dust, and brake-wear emission factors from on road vehicles, Atmospheric Environment 37(2003) 5283-5293, doi:10.1016/j.atmosenv.2003.05.005

[11] John G. Watson, Tan Zhu, Judith C. Chow, Johann Engelbrecht, Eric M. Fujita and William E. Wilson, Receptor modeling application framework for particle source apportionment, Chemosphere 49 (2002) 1093–1136.

[12] Z. Trajkovski, determination of the main sources of PM_{10} particles through modeling and their impact on ambient air quality in Bitola, PhD thesis, Faculty of Technical Sciences, University “St. Kliment Ohridski”, Bitola, 2019.

[13] Trajkovski Z., Popovska-Vasilevska S., **Mijakovski V.**, Dimitrieska C., *Particulate Emission (PM10 and PM2.5) from Residential Wood Combustion in Bitola*, Full papers proceeding of 18th international symposium on thermal science and engineering of Serbia – SIMTERM 2017, October 17-20, 2017, Sokobanja, Serbia, ISBN 978-86-6055-098-1, pp. 726-734.

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Review Scientific Paper

The Transport Policy and Pan-European Transport Corridors in the Republic of Macedonia

Verica Danchevska [1] and Dejan Danchevski [2]

Abstract – **Transport systems of Macedonia and the European Union in historical retrospective were formed partly on equal and partly on divergent principles, interests, and influences. As a candidate country, Macedonia is adapting its transport policy to that of the EU. Institutional adaptation will not be controversial, but the practical implementation of the policy compliant with the European one can be subject to delays due to historical heritage and present limitations. The paper presents a comparative analysis between transport policy in the Republic of Macedonia and transport policy of the European Union, and the importance of Pan-European transport corridors in the Republic of Macedonia.**

Keywords - **Transport policy, Pan-European transport corridors, Republic of Macedonia, European Union, challenges to transport policy.**

I. Introduction

Transport, in its theoretical and practical aspects, is one of the basic factors of the economy in every country. Furthermore, the effective economic growth and development mostly depend on traffic policy and total development of the traffic.

Traffic policy in the Republic of Macedonia, as well as in the other transitional countries, is not given enough attention, nor is practically all the relevant factors that influence on the development of traffic and transport. On account of the positive influence that the developed transport system can hold the economy of a country, it is necessary to research the role of the traffic policy in the Republic of Macedonia and its economy.

The existence of the economic market inevitably follows the development of the traffic system. The necessity to include the Republic of Macedonia in the European traffic flows, as well as its interest in associating with the European Union, is imperative, which is set for the Government of the Republic of Macedonia and its citizens.

The advanced intercorrelation in the economy with the linearization of the goods and services flow, as well as creating conditions for capital flow, should follow a previous consistent traffic policy. In spite of a developed traffic policy, as well as for better organization of the traffic system, it is possible to increase current flow and to create new market flows, which could have an effect on the export–import balance.

II. Transport policy and Pan–European corridor in the Republic of Macedonia

The Macedonian transport policy has been formed over a long history. The transport policies of the Turkish Empire, the Kingdom of Yugoslavia after World War I, and Socialist Yugoslavia after World War II left behind both positive and negative consequences. After a long historical period and then independence, the key strategic tasks for Macedonian transport policy remain and are the following:

- Quality transport connections of Eastern and Western Macedonia.
- Quality transport connections between Macedonia and its neighbors - Greece, Albania, Kosovo, Bulgaria and Serbia.
- Improvement of transport connections between Macedonia and European countries.
- Intensive inclusion of Macedonia in the international railway transport system.
- Intensive inclusion of Macedonia in the international air transport system.
- Intensive inclusion of Macedonia in the international intermodal transport system.

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Map 1. The Republic of Macedonia
Recource:https://mk.wikipedia.org/wiki:North_Macedonia_Map.png

Only after independence (September 8, 1991), Macedonia was able to formulate and implement transport strategies and policies. From independence to the present day, there has been enough time to eliminate the negative legacy effects present in the Macedonian transport network. The transition and the relatively long period as a candidate country for membership in the European Union have further reduced the economic resources needed for radical changes in the development of transport. However, the emphasis of transport policy is placed on investing in new transport infrastructure (construction of highways and motorways), as well as on the development of the railway transport system.

The air transport system has experienced a "revolution" in the increase in the number of passengers with the modernization of the Skopje airport and the Ohrid airport, as well as with the introduction of low-cost airlines.

Less attention has been paid to the maintenance, reconstruction, and modernization of the transport system. Equally neglected is the orientation towards modern organization and quality business operations, and the elimination of imbalances between certain transport sectors. Railway transport is seriously underdeveloped compared to road transport.

The current transport policy attempts to correct the weaknesses of the transport policy before independence. It is aimed at developing the transport network, especially pan-European corridors.

III. Fundamental Strategies of Macedonian Transport Policy

Fundamental strategies of Macedonian transport policy emerge from official documents, laws and regulations passed by the Macedonian Parliament and Government. The document, which is of particular importance, is the proposal for the National Strategy for Integration of the Republic of Macedonia into the EU**.** The starting point for transport policy is based is Macedonia's interests in appropriately evaluating are most important transport routes. Of special importance are: Pan – European corridors VIII and X across Macedonia, then geopolitical changes in the Macedonian geographical environment, structural changes to the Macedonian economy related to transport and the application of modern technology and ecological standards to transport.

Map 2. European Road Corridors in Republic of Macedonia
Recourse: http://www.roads.org.mk/cor-e2.htm

Macedonia's developmental transport policy is based on the following strategic goals:

- Evaluation of Macedonia's geographical transport position within the European main transport corridor network.
- Appropriate development of transport infrastructure and transport operations to include the Macedonian economy in international processes and economic development.
- Creating opportunities for direct foreign investment and international financing for infrastructure development programmes.
- Developing integrated transport.
- Constantly raising the level of safety within transport activities.
- Balancing transport development with protection of the environment.
- Restructuring large state–owned transport companies, thereby providing them with market market-oriented approach.
- Regulating relations in administration, construction, and use of transport infrastructure, in particular that which is public property.

The functioning of the Macedonian transport system places the above-mentioned goals in an international context, which assumes a strict application of the rules and norms from international conventions signed by Macedonia. Equally, the implementation of transport development is focused on minimizing the total construction and usage costs of the transport system.

Taking into account transport strategy and developmental policy, which are gradually implemented by the measures and instruments arising from current transport policy, and other supporting policies and the necessity of coming into line with the European model of transport, the following framework of Macedonian transport policy is proposed:

- Focusing on the integration of the Macedonian transport system into the European. This means the formation of the integrated transport network based on the principles of intermodality and subsidiarity, especially in main transport routes, that is, international European corridors.
- Balancing the development of transport sectors, with the emphasis on appropriate price policies and an increase in transport system efficiency.
- Strengthening domestic and international dimensions of the transport market, with an emphasis on attracting international carriers.
- Restructuring the transport system: (a) restructuring nationaltransport companies, (b) privatising carriers and the management of routes, (c) separating transport management, carriers and route management, (d) increasing transport competitiveness in a free transport market, (e) creating conditions for the commercial management of infrastructure.
- Focused management of transport routes, with an emphasis on complementary and regulatory transport policy, and consistent intersector cooperation in formulating regional, investment, fiscal, and social policy, taking into account social issues in transport policy.
- Harmonising transport laws, regulations, norms, and standards with those of the EU.
- Compensating for the negative consequences of privatisation, deregulation, and liberalisation of the transport market.
- Removing or reducing the damaging consequences of transport on the environment with the emphasis on programmes that stimulate ecologically acceptable modes of transport, for example, rail, air, public, and combined transport.
- Continuous formulation and application of programmes that increase transport safety.
- Efficiently satisfying individual transport needs, focusing on sustainable mobility, especially in populated urban areas.
- Unifying all transport authorities within the Ministry of Transport and regulating this by law.
- Formation of a multidisciplinary body in charge of transport policy, planning, and management, and which is regulated by law.

Conclusion

EU legislation in transport and transport policy is focused on improving the functioning of the internal transport market. In this sense, efficient and environmentally friendly transport services in road, rail, and air transport are promoted. EU transport standards also cover market liberalisation, technical safety, and social regulations and norms in the context of a unified European transport market. Also, the Stabilisation and Association Agreement between the EU and the Republic of Macedonia contains regulations on: infrastructure development, railways, combined transport, easier access to the transport market, simplification of transit procedures and application of technical, environmental and social norms in land transport.

From the above point of view, a practical and institutionalised Macedonian transport policy is contained in the laws and documents of the Macedonian Parliament, the Government and other central and decentralised government institutions, and is largely complemented by the basic strategies and requirements of the EU. Macedonia has started and is in the process of making its transport policies compatible with those of the European Union. However, the European Commission's findings show the enormous efforts that Macedonia must make before and after EU accession. This also applies to the transport infrastructure, which has sufficient capacity, but is in a small part in average to poor condition. The Commission's findings indicate that increased efforts are needed in the administration of the transport system, with an emphasis on road, rail, and air transport, so that the structure of the transport system will be more aligned with that of the EU.

References

[1] Padjen, J.: Prometna politika, Informator, Ekonomski institut, Zagreb, 1996.
[2] European Commission: White paper European transport policy for 2010: Time to Decide, 2001.
[3] Dančevska, V.: Сообраќајната политика во функција на одржливиот развој во стопанството на Република Македонија, Докторска дисертација, Технички факултет – Битола, 2005.
[4] http://www.factmonster.com/atlas/country/macedonia.html
[5] http://www.roads.org.mk/cor-e2.htm

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Original Scientific Paper

The Importance of Waste Transport to a Regional Landfill

Blagoj Dimovski[1], Cvete Dimitrieska[2] and Marjan Angeleski[3]

Abstract – **The study of the possibility of using waste as an "energy" is part of the scientific fields of Zero Waste Technology, Waste Management and Waste Transport, which are closely related and whose development is constantly on the rise. The purpose of this paper is to present the factors that affect the quality of "waste" such as energy, which are related to its transport to landfills.**

Keywords – **Waste, Transport, Landfill, Factors, Energy.**

I. INTRODUCTION

One of the biggest problems of modern lifestyles, especially in urban areas, is the enormous increase in the amount of municipal waste, which needs to be properly collected, selected, recycled, transported, treated, used, destroyed. Efforts to harness unconventional energy sources are increasingly focused on the use of waste as energy, known as "zero waste" technology. There are developed mathematical models that give projections of the energy potential of deposited organic waste in one form or another. Such analyses are influenced by waste management, with an emphasis on Waste Transport, which encompasses the fleet of utility companies, road infrastructure, access to landfills, which are some of the conditions for proper landfilling, i.e. sustainable dynamics and quality of delivery of waste to the disposal site.

II. WASTE MANAGEMENT

A feature of today's modern way of life is the need for efficient, economical and safe use of available resources by man, in conditions of great movement of people, goods, materials, energy, money and information. All this cannot be imagined without the application of logistics, as a scientific discipline and tool, with which a large number of social activities are managed and carried out.

Logistics involves planning, designing, organizing, and managing the logistics flows that form the structure of modern social and economic concepts. Waste occurs in all streams, from the procurement of primary raw materials, the production itself, distribution and sale of finished products, packaging, transshipment, transportation, storage, etc. Every product becomes waste at the end of its life. Therefore, waste is defined as a material that occurs in everyday life, manufacturing, or other activities that no longer has a "use" value. Waste management is a very important issue in every country and involves a series of measures related to the prevention of waste generation from a particular source, its sorting and collection, recycling or other methods of reuse and use of waste materials, which comes down to its safe and environmentally sustainable permanent disposal in sanitary landfills.

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III. WASTE TRANSPORT

The opportunities for the use of waste as energy, i.e. the development of Zero Waste technologies, increase the need for organized, modern and high-quality transportation of waste to the place of disposal or use, which is part of waste management. The Waste Transport area focuses on the development of methods and their application on appropriate mechanisms for more efficient, economical and safer operation of utilities and companies dealing with waste management issues. There is a large number of papers in the literature dealing with this area known as Waste Transport, Waste Logistics, [1], [2]. The same is related to environmental protection, given the nature of unused waste, but also the manner in which waste is distributed from the place of generation, to the place of disposal, to the landfill (illegal or sanitary) [5], [6].

In the literature [1], [4], two approaches to waste management are encountered. The first concerns the classical systems that are known in the region and used in our country, which provide for a low level of waste selection and processing. The other modern, so-called urban system, involves a high level of waste selection and processing. Emphasis is placed on the efficient, economical and safe operation of utilities in the waste collection and transportation sector. This is realized through the application of modern methods of planning tours and routes of utility vehicles, their dynamic monitoring with corrective actions and implementation, a high degree of maintenance of the utility equipment that is in operation.

IV. WASTE MANAGEMENT SYSTEM

The establishment of a waste management system is directly related to local authorities and utility companies under their jurisdiction, which deal with municipal waste management. In their work, there are usually several key organizational and technical problems, such as: low awareness of the local population, insufficient number of vehicles and equipment for the performance and implementation of utility activities, obsolete transport and utility equipment that is out of use, high costs for operation and maintenance of obsolete utility equipment, etc.

In developed countries, the approach is quite different, i.e. based on an efficient, economical and secure system. It consists of the collection, removal, treatment and reuse of waste materials. Based on European and German experiences, technologies and modern waste management systems are proposed in the countries of the region and in our country, which include: selection (separation) of waste at the source; determination of origin (organic – inorganic, hazardous – non-hazardous waste, from households, industry, trade...); application of new standardized containers, containers for waste selection; development and application of new types of "smart" vehicles only for waste collection without auxiliary personnel, with a replaceable container with the ability to measure the mass (volume) of waste, with built-in modern technologies for tracking vehicles in operation (GPS system); development and application of appropriate computer programs for planning and optimization of tours and routes of movement with the possibility of dynamic network planning in order to achieve more efficient operation and minimal costs for waste collection; setting up transshipment stations (terminals) in areas where waste is collected, in order to replace the full containers of transport vehicles for waste with empty ones; the use of other means of transport that move at higher speeds and over greater distances, thereby efficiently transporting the collected waste for further treatment (processing and disposal); organization of so-called regional landfills to which waste from a large number of urban and rural areas will be carried, to which waste will be delivered by sorting machines, waste processing plants, energy plants for waste incineration, etc.; the disposal of small quantities of waste in sanitary facilities, where the burial of waste is envisaged; raising awareness and approach to waste reuse and appropriate treatment, etc.

The stages of the modern waste management method are illustrated in Figure 1, [1]. The reason for the increased cost of providing services in many utilities engaged in waste management is the so-called "empty drains". The introduction of information technologies in maintenance allows for constant and high-quality monitoring of procedures, preventive and corrective maintenance. It is estimated that with better organization, using logistical tools and new technical solutions, it is possible to improve the efficiency of utility activity by as much as 30 - 40%, which is statistically proven in other developing countries [1], [5].

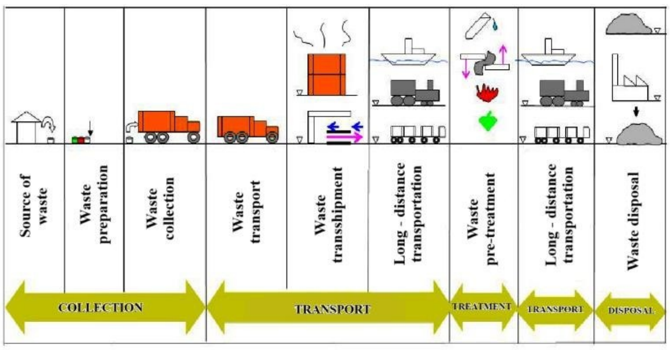

Fig. 1. Stages of a Modern Waste Treatment System

V. Impact of Waste Transport on Waste Quality

The transport of waste from "source" to "sinkhole" has a significant impact on the retention of the "quality" of the waste, as well as the possibility of its use at the last stage, when disposing of an open landfill, due to the production of methane, which is released "uncontrollably" after that process, as a natural and expected phenomenon, [4]. The following are the main influences:

A. Efficient Waste Transport and Sorting

• Amount and type of waste: Transporting waste to landfills directly determines the amount of waste deposited, which is a primary factor in methane production. More waste, especially organic, such as food scraps, paper, yard waste, lawns, garden waste, leads to higher methane emissions when decomposing under anaerobic (oxygen-free) conditions in landfills. If waste transport systems are not efficient or organic waste is not separated from inorganic matter, more methane is produced in open-pit landfills, which is the most common case in practice. Also, if the transport of waste is of poor quality, the necessary conditions for anaerobic digestion can be compromised and adversely affect methane production. Aerobic decomposition does not produce methane, but carbon dioxide CO_2.

• Higher quality transport systems can provide better waste selection, which can reduce the presence of non-biodegradable materials in landfills. Biodegradable organic waste, such as food and wood waste, is a major source of methane production. The better the waste is selected and the more organic materials are insulated, the greater the potential for methane production, but it also means better control over its production.

• Faster delivery of waste: With efficient transportation systems, waste reaches landfill faster. The faster the waste is deposited in a landfill, the more efficiently the microbial activity that generates methane begins. This means that better methane capture needs to be implemented to prevent its release into the atmosphere.

B. Landfill Operational Efficiency

• Landfill management: If high-quality transportation systems allow for landfill maintenance and expansion and more efficient waste management, overall methane production conditions can be improved. For example, waste can be more efficiently deposited in layers or better compacted with a certain time dynamics, leading to an optimal anaerobic environment for methane-producing microbes.

• Drain control: Poor-quality transportation systems can lead to greater contamination or uncontrolled liquid production in landfills, potentially affecting moisture levels, which in turn affects the microbial activity that produces methane. Too little moisture can impede methane production, while too much leaching can create a poor environment for anaerobic processes.

• Landfill age: Older landfills that accumulate waste for years produce large amounts of methane, with the rate of production decreasing as the waste decomposes. Transporting new waste can encourage or increase methane production in landfills.

• Landfill gas management: Some landfills have methane capture systems that collect the gas before it "escapes" into the atmosphere. However, not all landfills have these systems, and their efficiency can vary depending on the infrastructure and technology in place. Waste transportation can affect the efficiency of these systems because it affects the total amount of waste that is landfilled, which in turn affects gas production rates.

C. Indirect effects of waste transport

• Waste diversion: Transportation systems that prioritize recycling, composting, or other methods of diverting waste away from landfills significantly reduce methane production. Organic waste is most often used primarily as compost instead of being disposed of directly in landfill, which significantly reduces potential methane production in the open air.

• Public awareness and behavior: Effective transport systems can encourage the selection of waste at source (such as in homes or business premises), where organic waste is separated from recyclable and non-recyclable waste. This reduces the amount of organic waste sent to landfills and thus reduces methane emissions.

• Distance to landfills: The greater the distance to landfills, the more fuel is consumed, i.e. transporting waste over long distances is not an efficient method, which contributes to higher emissions and greater environmental impacts, although it is not directly related to methane production in an open landfill.

• Alternative transportation: Some cities and regions are using more sustainable methods of transporting waste, such as electric trucks or rail transportation, which can reduce the emissions associated with the transportation process.

D. Transportation Infrastructure and Landfill Management

• Transshipment stations: Some regions use transshipment stations, which play a key role in waste management systems, serving as intermediary facilities where waste is collected from smaller collection vehicles and then transported to larger vehicles for transportation to landfills, recycling centers, or waste treatment facilities.

• Access to recycling facilities: Proper sorting and transportation of recycled waste ensures less resource waste, resulting in less organic waste in landfills. Efficient waste transportation systems provide easy access to recycling centers.

E. Public Health and Environmental Impact

• Air and water pollution: Waste trucks, especially if poorly maintained or inefficient, can contribute to local air pollution. Similarly, improperly managed landfills can result in leaching (liquid waste) that contaminates soils, i.e. groundwater and surface water.

• Landfill location: At longer distances of waste disposal and proximity to settlements, the effects of transport systems, i.e. the equipment used to transport waste to landfill, are negative due to noise and air pollution, the environment.

VI. Conclusion

The impact of transporting waste from the source of generation to the sinkhole, the landfill, is significant in many ways. Waste is by definition treated as a pollutant, but practices show that with proper selection, reuse, disposal, transportation, and maintenance, it can also have a positive impact on converting it into energy. Organic waste, if not used in the first stage as compost, biomass and if disposed of in an open landfill, produces methane, which can be captured even in such circumstances, i.e. it must not be allowed to be uncontrolled discharge into the atmosphere according to legal regulations that are increasingly restrictive and apply to our country. Methane is known as gas 23, which is so many times more dangerous than carbon dioxide, which together is in the group of dangerous greenhouse gases, [4], [5], [6].

Sustainable transport practices, waste reduction and recycling programs, adoption of the National Waste Management Strategy [3], affect methane production and the negative impact of landfills on the environment.

References

[1] P. Z. Marinković, M. Jovanović, D. Janošević, “Waste Management Logistics”, IMK-14 - Research and Development, vol. 16, no. 1, pp. 17-22, 2010.

[2] M. Rabe, “The impact of waste quality on a sustainable waste management model”, Economics and Organization of Logistics, vol. 5, no. 2, pp. 97–104, 2020.

[3] Waste Management Strategy of the Republic of Macedonia for the period 2008–2020, Skopje, Government of Macedonia, 2008.

[4] Waste-to-Energy Options in Municipal Solid Waste Management, A Guide for Decision Makers in Developing and Emerging Countries, Bonn and Eschborn, GIZ Eschborn, 2017.

[5] D. Starkowski, P. Bardziński, “Municipal Waste Transport Process Analysis. Principles Of Waste Management, Packaging, Rules Of Registration, Storage And Fines For Irregularities And Infringements Within The Scope Of Municipal Waste Management”, Ekonomia i Środowisko, 3 (66), pp. 93-105, 2018

[6] H. R. Wati, M. A. Budihardjo, P. Andarani, “Waste Transportation Environmental Impact Using Life Cycle Assessment: Bibliometric Analysis and Systematic Review”, Pol. J. Environ. Stud. Vol. 34, No. 1, pp. 563-571, 2025.

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Professional Paper

Using Comparative and GEH Analysis to Test Traffic Research Results, Case Study

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Abstract – **In this paper, the current situation of the demand in the three points of the cordon counting in the city of Bitola, and the predicted traffic flow in the future will be analyzed. Validation of the model has been done on the entered values.**

Keywords – **Model's validation, analysis, cordon counting, PTV VISUM.**

I. INTRODUCTION

Macroscopic traffic models for the creation of transport demand are widely used in traffic engineering for the analysis and evaluation of the projected transport system, traffic operations, the selection of alternative solutions, transport demand forecasts, etc. They are simpler to apply, cheaper, more efficient, faster, in contrast to the analyzes and tests that are performed directly in the field. When planning traffic in urban environments, the use of sophisticated software tools is quite a challenging branch for a traffic engineer.

With the application of the modern software tool PTV VISION VISUM, a calculation and forecast of the transport demand is made at three points from a cordon count performed in the territory of the city of Bitola. The accuracy of the data entered is of great importance for good output results.

The aim of this paper is to make a comparative analysis of the modeled and forecasted sizes as well as the validation of the model.

II. GENERAL DATA FOR THE CITY OF BITOLA

Bitola — a city in the southwestern part of Macedonia and the seat of the municipality of the same name, Bitola, an administrative, cultural, economic, industrial, educational and scientific center for that part of the country.

In the results published by the State Statistics Office for the census held in September 2021, the Municipality of Bitola has a population of 85,164 inhabitants.

Bitola is bordered by the following neighboring major cities: to the northeast is Prilep (43 km), the connection is made via the A3 highway and the regional road P1101, to the south it borders the Republic of Greece (33 km) via the A3 highway, while to the northwest the city of Resen (29 km) via highway A3.

III. CORDON COUNTING IN THE TERRITORY OF THE CITY OF BITOLA

On May 20, 2022 (Friday) from 14:00-15:00, a cordon counting of vehicles was carried out together with a group of students from the traffic department at the Technical Faculty-Bitola.The aim of the research is to give an estimate of the number and structure of vehicles that transit through the territory of the city of Bitola.

The cordon supports an imaginary border line around the city of Bitola, and the counting of vehicles was carried out on all roads that cross the cordon line, namely:

1. Road with approach to - from Prilep.
2. Road with access to - from Ohrid.
3. Road with approach to – from Greece.

These checkpoints are placed in such a way that they cross all the roads entering the city of Bitola, in order to avoid the problem of vehicles turning, which makes it unclear whether they enter the defined space or not. That is,

Zone 100-Prilep
Zone 101 Ohrid
Zone 102 Greece

Figure 1 shows the cordon line of the city of Bitola and the counting points.

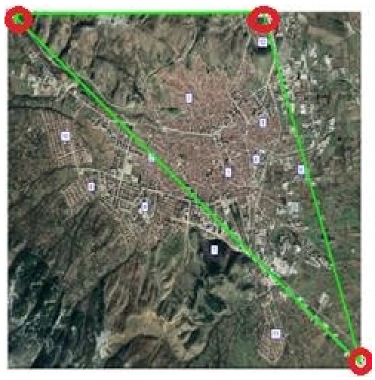

Fig. 1. Shows the cordon line and the counting points

IV. RESULTS OF THE COUNTS BY DIRECTIONS OF MOVEMENT

With the help of Corodon counting, we obtained the data for direction and structure movement.The results of the counts between 14:00 and 15:00 are shown in the following table by structure of vehicles and by direction of movement.

TABLE 1
RESULTS OF COUNTS BY DIRECTIONS OF MOVEMENT

	Greece - Bitola	Bitola - Greece	Ohrid - Bitola	Bitola - Ohrid	Prilep - Bitola	Bitola - Prilep
Car	534	491	141	143	613	586
Bus	47	13	1	1	16	27
HGV	31	23	49	22	36	69
Sum	612	527	191	166	665	682

HGV - heavy goods vehicles

From the obtained results we can conclude that the most intensive flows are on the direction from and to Prilep - Bitola, about 660 vehicles were registered and in the opposite direction about 680 vehicles, while the second place in terms of intensity was the road from and to Greece - Bitola. There is a greater deviation on the road from and to Ohrid - Bitola, where we have registered about 190 vehicles. The largest flow of heavy goods vehicles appears on the road direction Bitola-Prilep, while the lowest flow of heavy goods vehicles occurs on the road direction Bitola-Ohrid, together with the direction Bitola-Greece.

V. MODELLING OF THE TRANSPORT DEMAND OF THE CITY OF BITOLA, AT THE THREE CORDON POINTS

With the previous research on source-destination journeys, that is, the creation of the O-D matrix, the modal sizes were obtained, which represent sizes generated by the PTV VISION VISUM software based on the actual data entered.

By creating the model and entering the necessary input data, the modal sizes are calculated. The modal sizes are shown in the following photos on the entry-exit routes from the city, that is, on the points where cordon counting was performed. Figure 2 shows calculated modal sizes from Bitola to Prilep and Prilep – Bitola.

Fig. 2. Shows calculated modal sizes from Bitola - Prilep, and Prilep - Bitola

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Figure 3 shows the calculated modal sizes from Bitola to Ohrid and vice versa.

Fig. 3. Shows the calculated modal sizes form Bitola- Ohrid, and Ohrid – Bitola

Figure 4 shows the calculated modal sizes from Bitola-Greece and Greece – Bitola.

Fig. 4. Shows the calculated modal sizes from Bitola – Greece and Greece – Bitola

VI. THE GEH STATISTIC

The verification of the developed models is based on the assessment of the similarity between the real system and the model system. Transport systems models are homomorphic models which means that not all elements of the real system are described by means of a model system.

The GEH Statistic is a formula used in traffic engineering, traffic forecasting, and traffic modelling to compare two sets of traffic volumes. The GEH formula gets its name from Geoffrey E. Havers, who invented it in the 1970s while working as a transport planner in London, England. Although its mathematical form is similar to a chi-squared test, is not a true statistical test. Rather, it is an empirical formula that has proven useful for a variety of traffic analysis purposes.

The formula for the "GEH Statistic" is:

$$\mathrm{GEH} = \sqrt{\frac{2*(M-C)^2}{M+C}} \quad (1)$$

Where are:

- peak hour from current model (or new counts),
- peak hour from current of counting (or previous counts).

Presentation of comparison of these results according to traffic counts and modelling by PTV Visum with application of GEH formula test is shown in the following table.

TABLE 2
COMPARISON OF RESULTS ACCORDING TO CORDON COUNTERS, MODELLING BY PTV VISUM AND GEH TEST

Direction	Traffic Count 2022	Modal sizes	Difference in	GEH test %
Bitola – Prilep	682	682	0	0 %
Prilep – Bitola	665	649	16	0,62 %
Bitola – Ohrid	166	219	-53	3,81 %
Ohrid – Bitola	191	200	-9	0,64 %
Bitola – Greece	527	527	0	0 %
Greece – Bitola	612	612	0	0 %

The boundaries that determine the match between the real and the model flows they are:

- If GEH<5, then the modeled and measured clock flows are fine fit together. Smaller GEH values mean a better fit to the streams from the actual count model.
- If 5<GEH<10, further investigation can be performed;
- If GEH>10, then it is very likely that there is a problem with the model either for traffic demand or data.

The comparison show that for all locations results are fulfilled under condition < 5 %, and by comparing results gained by traffic counting with results by modeling using PTV Visum we can conclude that they are under acceptable level.

Testing the model, with Assignment analysis tool in software package PTV Vision Visum, got values from 0.9955 or 99.6% (figure 5) which is quite high value and indicate suitability for modal used.

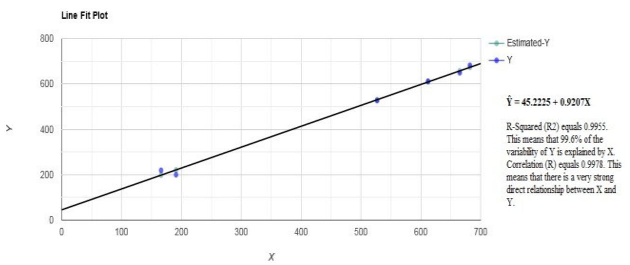

Fig. 5. Testing the model

VII. Forecast of the Transport Demand of the City of Bitola, at the Three Points of the Cordon Counting

Forecast is scientific prediction of some phenomena that exist of great importance to human society. Based on created synthetic model, corrections are made and forecast on vehicles in Bitola town, for the next 10 years. In the process of forecasting the increase of 2% annually is taken into account.

Figure 6 shows the forecast of transport demand from Bitola to Prilep and from Prilep to Bitola.

Fig. 6. Shows the forecast of transport demand from Bitola to Prilep and from Prilep to Bitola

Figure 7 shows the forecast of transport demand from Bitola to Ohrid and from Ohrid to Bitola.

Fig. 7. Shows the forecast of transport demand from Bitola to Ohrid and from Ohrid to Bitola

Figure 8 shows the forecast of transport demand from Bitola to Greece and from Greece to Bitola.

Fig. 8. Shows the forecast of transport demand from Bitola to Greece and Greece to Bitola

VIII. Comparative Analysis with the Application of PTV VISUM at the Level of the City of Bitola

In the frame of data collected analysis, in the traffic engineering practice often are used different statistical tests.

Common used tests are the following:

- Testing the reliability of the sample,
- Compared or „Before and after” tests,
- Unparametric tests

The comparative analysis is done to make it easier to see the difference between the modal and the forecast sizes of the traffic trips. The following table shows the difference between the modal sizes and the forecast sizes obtained through the development of a macroscopic model for the transportation demand at the level of the city of Bitola.

TABLE 3
COMPARATIVE ANALYSIS OF MODAL AND FORECAST SIZES

Direction	Modal sizes	Forecasted sizes
Bitola – Prilep	682	1321
Prilep – Bitola	649	1239
Bitola – Ohrid	219	379
Ohrid – Bitola	200	357
Bitola – Greece	527	1054
Greece – Bitola	612	1224

The difference between the modeled and forecasted values is in the appropriate range. The forecast for the next 10 years prefers an increase in traffic on the inbound and outbound routes.

IX. CONCLUSION

The use of software tools for planning and forecasting transportation demand is of great importance to traffic engineers. One such tool is PTV VISION VISUM, the world's leading software. Data collection was carried out, that is, cordon counting at three points on the territory of the city of Bitola. The data was analysed by structure and movement direction. Based on the collected data, it was entered into the software and a comparative analysis of the modelled and forecasted sizes was carried out. From the output results, it can be concluded that they have an acceptable deviation of modal values from counted values which means suitability for modal usage Model testing, with a task analysis tool in the PTV Vision Visum software package, indicates the suitability for modal that has been used. The GEH output results in the values 0 and 3 which is less than 5, and with this we get criteria that the modal values to have GEH values less than 5. Because this criterion is fulfilled, it means that the model is good. A regression analysis was made, where the accuracy was to a large extent i.e. 99.6 %. The use of statistical analyses is of great importance for model validation.

REFERENCES

[1] https://mk.wikipedia.org/wiki/%D0%91%D0%B8%D1%82%D0%BE%D0%BB%D0%B0

[2] V. Atanasova, B.Angelevska, N. Krstanoski, TESTING OF THE SYNTHETIC MODEL FOR TRANSPORT DEMAND AND FOR FORECAST ON VEHICLES, THE CASE STADY, MACHINES, TECHNOLOGIES, MATERIALS, International Scientific Journal, Year XIII, Issue 1/2019 str. 41-44, PRINT ISSN 1313-0226, WEB ISSN 1314-507X, Sofija, 2019

[3] Valerie Bojku Bibaj, Vaska Atanasova, "The Modeling of Travel Demand in the Road Network of Pristina Region", DOI 10.20544/TTS2021.1.1.21.p39 UDC••656.11:339.133(497.115)

[4] https://docs.canterbury.gov.uk/files/adopted-local-plan-evidence-base/adopted-local-plan-2017-evidence-base/8%20Transport/CDLP%208.7%20Canterbury%20VISUM%20Transportation%20Local%20Model%20Validation%20Report-%20Jacobs(June2012)_Redacted.pdf

[5] Kristina Hadzipetkova, Creation of a macroscopic model for city and region transport demand, Master thesis, Faculty of Technical Sciences, Bitola 2015

[6] https://en.wikipedia.org/wiki/GEH_statistic

[7] Atanasova Vaska, Stojanoska Marija, Krstanoski Nikola, "Cordon counting in the territory of the city of Bitola", Trans Motauto World Vol. 8 (2023), Issue 1, pg(s) 18-20

[8] R. Duraku, V. Atanasova, N. Krstanoski, „Building and Calibration Transport Demand Model in Anamorava Region'', Technical Gazette, Vol 26 No.6, 2019, str.1784-1793, IMPACT FACTOR IF 0,644

[9] V.Atanasova, M.Stojanoska, „Zoning of the city of Bitola and specificities of the PTV VISION VISUM software", International Journal of Latest Engineering and Management Research - IJLEMR (ISSN: 2455-4847), Volume 08, Issue 04, April 2023, PP. 69-72, (doi.org/10.56581/IJLEMR.8.4.69-72) PUBLICATION IMPACT FACTOR 3,46

[10] V.Atanasova, M.Stojanoska „Private transport planning for a small city using PTV VISION VISUM software", Danish Scientific Journal No77/2023, Vol.1, ISSN 3375-2389, Cosmos Impact Factor- 3.556, Copenhagen, Denmark 27.10. 2023

[11] M.Stojanoska, "Planning of Public City Transport in small towns using the PTV Vision VISUM software" Master thesis, Faculty of Technical Sciences, Bitola 2023

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Professional Paper

Transport Insurance: Investment in Safe and Reliable Business Transport

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Abstract – **The safety and security of your goods during transport is essential to any successful business. Transporting from point A to point B may seem routine, but the reality is that unforeseen risks can occur at any time that endanger the goods.**

Theft, damage or loss can significantly affect business interests. To protect yourself from these unwanted situations, transport insurance becomes a key investment.

Keywords – ***Transport insurance, investment, transport, reliable transport.***

I. INTRODUCTION

Let's take a closer look at how this protection works. Transport insurance, in essence, is the key link between you as the shipper and the transport company that will transport the goods from point A to point B.

Basically, this insurance is a concluded contract between you, as the shipper, and the shipping company. Through this agreement, both parties determine the rules and conditions related to the safety of the goods during transportation.

Without transport insurance, these goods would only be insured based on the minimum standards imposed by national and international conventions. This means that, in the event of damage or loss, the compensation amount may be significantly less than the actual value of your goods.

In order to protect themselves from these potential risks, many companies that regularly use transport services decide to additionally insure their goods. This additional insurance guarantees that you will be compensated for any damage or loss, at least financially, that may occur during transportation.

It is important to note that the type and price of transport insurance depend on various factors, including the mode of transport and the value of your goods.

To make the best decision about insuring your goods, it is important to carefully assess your needs and consult with shipping and insurance experts. This will allow you to invest in safe and reliable business transport, freeing yourself from the worry of potentially unforeseen situations.

II. TYPES OF TRANSPORT INSURANCE

When it comes to transportation insurance, it is important to understand that there are many different types of insurance that are tailored to different types of transportation. Thus, they provide specific protection depending on the type of transport you use. Here is an overview of several main types of transport insurance:

Marine insurance: This type of insurance covers risks that arise during maritime transportation.

Generally, marine transport insurance protects against general damage to goods, as well as loss or damage during delivery. If, for example, a situation occurs where part of the cargo needs to be thrown from the ship for safety reasons, this insurance provides compensation.

Land cargo insurance**:** For road and land transport, there is a different level of risk depending on the distance and conditions of travel. Ground cargo insurance is usually recommended, especially for trucking, as it covers damage or loss during transport. This insurance can vary in coverage, so it is important to carefully consider the mode of transport.

Air cargo insurance: Transport by air also requires special insurance. This policy covers material damage and loss during transport, both in the air and on land or sea, before and after the flight. There is a variety of coverage offered, allowing you to choose the one that best suits your needs and budget.

Understanding the different types of transport insurance allows you to properly protect your goods during the various stages of transport.

Properly chosen insurance will give you extra peace of mind, knowing that your goods are protected regardless of the mode of transport you use.

Transport insurance is a key element in managing risk within the logistics and transport sector. It protects companies against financial loss if goods are damaged, lost, or stolen during transit.

Understanding the different types of transport insurance—and how they fit into a company's overall transport strategy—is essential for any business involved in shipping goods

Transport strategy refers to a company's long-term plan for how it will manage and organize its transport and logistics operations.

A good strategy sets clear goals for cost efficiency, safety, speed, environmental sustainability, and customer satisfaction. This may include choosing the most suitable transport modes (such as road, rail, sea, or air), investing in technology like real-time tracking systems, and building strong partnerships with reliable carriers and service providers. A well-developed strategy helps companies respond to changes in the market and improve their competitiveness over time.

III. INCOTERMS: ESSENTIAL FOR UNDERSTANDING TRANSPORT OBLIGATIONS

Incoterms, short for International Commercial Terms, are universal terms created by the International Chamber of Commerce to standardize obligations and responsibilities between sellers and buyers during the international transport of goods. These terms are an essential vocabulary that allows parties to contracts for the sale or purchase of goods to precisely define their roles and responsibilities.

One of the key things that Incoterms define is who is responsible for insuring the goods during transport. This decision directly affects whether you, as a buyer or seller, will need to provide transport insurance for your goods.

For example, if you use an Incoterm that places responsibility for the goods in the hands of the buyer at the beginning of transport, this means that the buyer will be responsible for insuring the goods. On the other hand, if the Incoterm transfers responsibility to the seller during transport, the seller will be responsible for insurance.

Choosing the right Incoterm is essential in order to have clear rules on who is responsible for insurance during transport. A proper understanding of Incoterms is the key to achieving safe and efficient international business.

In the traffic and transport sector, the efficient and safe movement of goods is at the heart of daily operations. Whether you are a freight forwarder, logistics manager, or carrier, a clear understanding of Incoterms (International Commercial Terms) is vital for managing responsibilities, costs, and risks throughout the supply chain. Incoterms are standardized trade terms published by the International Chamber of Commerce (ICC) that precisely define the obligations of buyers and sellers involved in the international transportation of goods.

They are an indispensable tool for anyone working in logistics and transport because they determine who is responsible for arranging transport, paying for shipping, handling customs procedures, and covering insurance at every step.

For professionals in the traffic and transport industry, Incoterms ensure everyone—from consignor to consignee, and all carriers in between—knows their role in the chain of custody.

This clarity helps avoid confusion and disputes, especially when goods change hands multiple times on their way to the final destination.

Key Functions of Incoterms in Transport

- Defining Transport Responsibilities - Incoterms specify who arranges and pays for each segment of transport, whether by road, rail, air, or sea. For example, under FCA (Free Carrier), the seller delivers the goods to a carrier or another nominated party at a named place. After that, the buyer assumes responsibility for the main transport.
- Determining Points of Risk Transfer - Each Incoterm indicates exactly when risk passes from seller to buyer. In logistics, this means knowing who is liable if goods are lost or damaged in transit. For example, under DAP (Delivered at Place), the seller bears all risks until the goods are ready for unloading at the destination.
- Clarifying Insurance Requirements - The traffic and transport industry must ensure goods are properly insured. Some Incoterms, like CIF (Cost, Insurance and Freight) or CIP (Carriage and Insurance Paid to), require the seller to provide insurance for the buyer's benefit. Others, such as EXW (Ex Works), put the onus on the buyer to arrange insurance from the point of collection.

Understanding Incoterms is crucial for anyone involved in the transport and logistics industry. Incoterms clearly define who is responsible for each part of the transport process, when the risk transfers from seller to buyer, and who must arrange insurance for the goods. By using the correct Incoterms, companies can avoid misunderstandings, reduce the risk of disputes, and ensure that every shipment is handled smoothly and securely.

Choosing the right Incoterm helps protect both parties' interests and supports reliable, efficient international trade.

IV. Attention to the Carrier's Responsibilities

When entrusting your goods to carriers, it is important to understand their responsibilities regarding transportation insurance. The carrier has responsibility for the safe transport of your goods, but this responsibility is not unlimited. National and international conventions place limits on the liability of transport companies.

For example, in the event of damage to goods, reimbursement by the carrier will usually be based on the weight and volume of your goods, or their weight rather than their value.

This reimbursement will also be limited to a maximum amount. It is important to note that there are also factors that can release carriers from liability, such as strikes.

The legal framework and conditions of carriage will usually be set out in the contract with your carrier, which defines the limits of their liability and the terms of compensation in the event of any problems. Before entrusting your goods to a carrier, you must read these conditions carefully to understand what to expect.

In order to protect yourself from possible losses and problems, transport insurance is essential. This additional protection ensures that in the event of damage or loss of goods during transport, you will receive compensation.

In the transport sector, carriers are the companies or individuals responsible for moving goods from one place to another. It is very important for everyone involved—shippers, logistics providers, and customers—to understand what the carrier is required to do. If these responsibilities are not clear, problems such as delays, extra costs, or even lost or damaged goods can occur.

The main responsibilities of the carrier include delivering the goods safely and on time to the agreed destination, following the instructions in the contract or given by the sender.

Another important responsibility is the carrier's liability for loss or damage. If the goods are lost or damaged during transport, the carrier can be held responsible, but their liability is usually limited by international conventions or contracts.

Because of these limits, it is important for companies to read the transport contract carefully and understand exactly what is covered. If the goods being shipped are especially valuable, it may be necessary to arrange extra insurance to make sure any losses will be fully covered.

Giving accurate and complete information about the goods and any special requirements to the carrier is also essential for a successful shipment.

If there is a problem, such as loss or damage, there are specific procedures for making a claim, including deadlines for reporting issues and providing the right documents. Knowing these rules is important for protecting your rights to compensation.

To achieve greater safety in transport and logistics, companies should take a proactive and comprehensive approach. This starts with choosing reliable and experienced carriers and logistics partners, and always checking their reputation and certifications.

Proper packaging is also essential; goods should be packed securely using high-quality materials suitable for the chosen method of transport to prevent damage. Clear and accurate communication is necessary at every stage, including providing detailed information and any special instructions to all parties involved.

Regular training for staff on safe handling, loading, and unloading procedures helps reduce the risk of accidents, while the use of tracking technology allows companies to monitor shipments in real time and respond quickly to any issues. Ensuring that vehicles and equipment are well-maintained further reduces the chance of breakdowns or accidents during transport. Companies should also be prepared for emergencies by having clear procedures and contacts in place in case of accidents, loss, or theft.

Additionally, all transport contracts should be reviewed carefully to understand the responsibilities and liabilities of each party, with agreements confirmed in writing. For valuable or sensitive goods, arranging extra insurance coverage can provide additional peace of mind. By combining these steps with comprehensive transport insurance, companies can significantly enhance the safety and reliability of their logistics operations, protect against unexpected losses, and maintain strong business relationships.

V. Conclusion

Ultimately, transport insurance is not just an added cost, but a key part of your approach to transport strategy. Understanding the risks and challenges faced by goods during international transport is critical to successful business.

If you are sending smaller shipments, you can ask the carrier to insure the goods on your behalf. This will allow you to feel safe and secure, knowing that you are protected in case of unforeseen situations.

References

[1] Zelenika, R.,: Inkoterms, Ekonomski faku;ltet Rijeka, 2002.

[2] European Commission: White paper European transport policy for 2010: Time to Decide, 2001.

[3] Dančevska, V.: Сообраќајната политика во функција на одрживиот развој во стопанството на Република Македонија, Докторска дисертација, Технички факултет – Битола, 2005.

[4] : http://www.factmonster.com/atlas/country/macedonia.html

[5] : http://www.roads.org.mk/cor-e2.htm

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Review Scientific Paper

Water Transport and Water Transport Strategy Until 2034

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Abstract

The long-term plan for the maintenance and development of the water regime in the territory of the Republic of Serbia, in one or more water areas or a part of the water area, ensures continuity in the long-term planning of the functioning of the water sector, based on the principle of sustainable development, regulation and use of water, protection of water from pollution and regulation of watercourses and protection from the harmful effects of water, as well as other necessary jobs and activities for functioning and development. The strategy and other strategic documents and programs at the level of the Republic of Serbia ensure the satisfaction of the interests of the obligees - users of water management.

Keywords: Laws, Strategies, Water traffic

I. Introduction

The new infrastructure policy of the European Union (hereinafter: EU) is defined by Regulation 1315/2013 of the European Parliament and of the Council on guidelines for the development of the trans-European transport network, which was published in December 2013. This decree carried out a fundamental reform of infrastructure policy since the 80s of the last century. The European Commission has published new maps showing the nine main corridors that will be the backbone of traffic within the European single market. They significantly change the connections between the East and the West of Europe. Encouraged by the European Union's Water Directive, the countries in the Danube basin cooperate to achieve the environmental goals established by the "Water Management Plan for the Danube River Basin" which was created as part of the work of the expert groups of the International Commission for the Protection of the Danube River (ICPDR). The plan, which was updated in 2021, recognized the issue of sediment balance as one of the "Significant Water Management Issues (SWMI)". The Danube Sediment and SIMONA projects also indicated the need for further sediment analysis, considering the occurrence of either an excess or a deficit of sediment along the Danube as well as the presence of pollutants in the sediment.

The territory of the Republic of Serbia represents a unique water area for water management (Article 26 of the Law on Water) and includes parts of the basins of the Black, Aegean and Adriatic Seas, parts of the basins and sub-basins of the watercourses that belong to them. The boundaries of the sub-basins on the territory of the Republic of Serbia are determined by the corresponding by-law. The largest part of the territory of the Republic of Serbia, about 92%, belongs to the Black Sea basin, i.e. the Danube basin. The Danube River, with a catchment area of about 801,463 km2 and an average flow at the mouth of the Black Sea of about 6,500 m3/s, is the 24th largest river in the world, and the second largest in Europe. The Danube rises in Germany and flows into the Black Sea in the border area of Romania and Ukraine. On the territory of the Republic of Serbia, the Danube enters from Hungary, and leaves it after the mouth of the Timok, at the tri- border with Romania and Bulgaria. In the territory of the Republic of Serbia, several very important tributaries flow into the Danube: Tisa, Sava and Velika Morava, as well as several smaller ones. The southern border of the Black Sea basin is formed by the watershed towards the Aegean Sea basin, from which on the territory of the Republic of Serbia there are parts of the Vardar (Pčinja, Lepenac) and Struma (Dragovištica) basins, as well as the Adriatic Sea - the Drim basin (Beli Drim, Plavska reka). The largest left tributary of the Danube is the Tisa (catchment area about 157,186 km2, in the Republic of Serbia about 10,856 km2), which is also the largest tributary of the Danube in terms of the total area of the catchment.

II. Laws and Strategies in the Republic of Serbia

The Water Law ("Official Gazette of RS", No. 30/2010 and 93/2012) regulates the legal status of water, integral water management, management of water facilities and water land, sources and method of financing water activity, supervision of the implementation of this law, as well as other issues important for water management. The provisions of this law refer to watercourses that form or cross the state border of the Republic of Serbia, as well as groundwater belonging to them, to the exploitation of river sediments that do not contain admixtures of other useful mineral raw materials. Water assets, in the sense of this law, are water and water land. Water is a good of general interest and belongs to the state, and it is a public water good, which is inalienable.

Surface waters in the territory of the Republic of Serbia, according to the importance they have for water management, are divided into waters of the first order and waters of the second order, based on established criteria: the position of the watercourse in relation to the state border, the size and characteristics of the watershed, the regime and characteristics of the watercourse from the aspect of water use, water protection and protection against the harmful effects of water.

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The government determines the list of waters and order, and interstate waters are necessarily classified as waters of the first order, and all surface waters, which are not determined as waters of the first order, are considered waters of the second order. In order to preserve or achieve a good ecological, chemical and quantitative status of waters or their good ecological potential, water bodies of surface waters, including artificial water bodies, significantly altered water bodies, as well as groundwater bodies, are determined. Water bodies of surface waters are classified into types, based on mandatory (altitude latitude and longitude, geology, basin size) and optional (distance from the source, morphological parameters, valley shape, etc.) parameters. The planning documents for water management are: 1) Water management strategy on the territory of the Republic of Serbia; 2) water management plan; 3) annual water management program; 4) plans governing protection against the harmful effects of water, namely: flood risk management plan, general and operational flood defense plan, as well as plans governing water protection (water pollution protection plan and monitoring program).

By the Law on Navigation and Ports on Inland Waters ("Official Gazette of RS", no. 73/2010, 121/2012, 18/2015, 96/2015- other laws, 92/2016, 104/2016 - other laws, 113/2017 - other laws, 41/2018, 95/2018 - Law No. 37/2019 - Law No. 9/2020 and No. 52/2021), regulate the conditions and manner of safe navigation on the inland waters of the Republic of Serbia, waterways and navigation, crew, search and rescue, ports and piers, and other issues related to navigation on inland waters. The provisions of this law apply to international, interstate and state waterways of the Republic of Serbia, as well as to other internal waters. Navigation safety includes conditions, rules, technical rules and measures that must be met by vessels and crews, waterways, ports and docks that ensure safe navigation and are under the jurisdiction of the Ministry of Transport, the Port Authority, the Administration for determining the seaworthiness of ships, the Directorate for Waterways, the Port Management Agency. Technical maintenance of state waterways is the responsibility of the authorized legal entity for technical maintenance of state waterways. International and interstate waterways are determined by the Government, and the categorization of state waterways is determined by the minister. Technical maintenance of international, interstate and national waterways is carried out in accordance with the annual technical maintenance program, which is adopted in accordance with the action plan. Winter camps are formed on waterways or in harbors and piers. Winter cabins must meet the conditions for the safe stay of the vessel in them. Winter storage can be used by all vessels under equal conditions Navigation charts must be made in the form of an electronic navigation chart - ENC in accordance with the international Inland ECDIS standard, and they can also be made as classic navigation charts according to cartographic standards. It is important to note that it is prohibited to discharge, pour or throw harmful objects or substances from the vessel into internal waters, including oil, oil derivatives, which can cause pollution of internal waters, as well as the burning of garbage, sludge, sediment and special waste on the vessel and the discharge of waste water from: 1) vessels intended for the transport of passengers with more than 50 cabins; 2) passenger vessels intended for the transport of more than 50 passengers.

The water management strategy on the territory of the Republic of Serbia until 2034 was prepared on the basis of the Law on Water ("Official Gazette of the RS", no. 30/10 and 93/12) and by-laws, which determine the long-term directions of water management on the territory of the Republic of Serbia. The strategic and planning documents are rarmonized with each other upon and represent sustainable development, sustainable use of natural resources and goods, environmental protection, and many other areas. In the process of adopting the Strategy, a strategic assessment of the impact on the environment was made, in accordance with the regulations. The strategy is a document on the basis of which the reform of the water sector is carried out, in order to reach the necessary standards in water management, including organizational adaptation and systemic strengthening of professional and institutional capacities at the national, regional and local levels. The strategic determinations and goals determined by this document are the basis for the development of the Water Management Plan for the Danube River Basin in the territory of the Republic of Serbia and water management plans in the water areas, including the financing aspect. At the same time, the framework set by this strategy must be respected when developing strategies and plans for spatial planning, environmental protection and other areas that depend on water or have an impact on water. The research required for the development of the Strategy was carried out in accordance with the Law on Water and includes: assessment of the current state of water management; goals and guidelines for water management; projection of the development of water management and measures to achieve the established goals of water management. The general data in this chapter are given on the basis of the Water Management Foundation of the Republic of Serbia and data collected in the competent institutions of the Republic of Serbia were used: the Republic Hydrometeorological Institute (hereinafter: RHMZ), the Environmental Protection Agency, the Nature Protection Institute, the Health Protection Institute and the Republic Institute of Statistics (hereinafter: RZS).

The goals and guidelines of the Strategy represent a basic document for the implementation of reforms and development of the water sector, the achievement of the basic strategic and operational goals from this document must be based on the adopted concept of water management and established starting points and must take place in accordance with established. priorities. It is important to say that water management is influenced by natural conditions, social and economic frameworks, as well as the legislative structure of this and related areas (Figure 1 and Figure 2.).

An effective water management system requires appropriate institutional and organizational solutions that can, in terms of structure and capacity, respond to requirements in all stages of development (from planning to construction) and functioning of the water sector, and defined sources and mechanisms for providing the necessary funds. The improvement of the situation in the water sector can only be ensured with the adequate implementation of the necessary measures, that is, if all the necessary functions within the current business (operation, maintenance and supervision) and development activities (planning, preparation of investments and construction) are carried out in an appropriate manner, and regulation, financial resources, information systems, international cooperation and public participation represent the common denominator for both groups of activities (Fig 3).

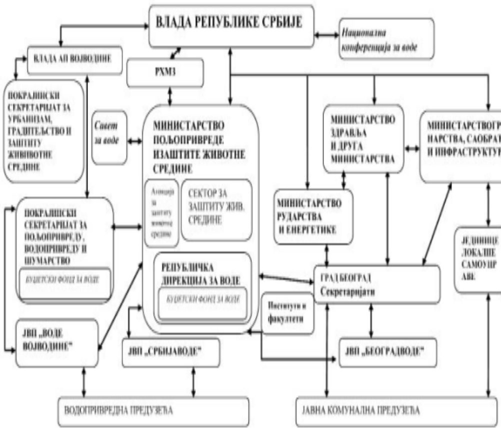

Fig 1. Organization of integral water management of RS

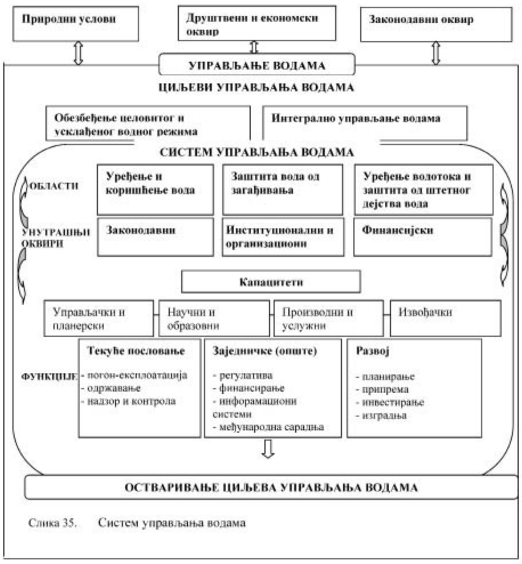

Fig 2. Water management sistem of RS

Fig 3. Balanse units on the territory of Serbia with the water areas

Measures to achieve the established goals for water management, an efficient and rational water management system in accordance with sustainable development can only be achieved if: an appropriate legal environment is provided, including the regulation of property rights; an established organizational and institutional system capable of enabling integral water management on the territory of the Republic of Serbia; stopped depopulation and provided conditions for the development of industry; environment created for investment and profitable business; defined system of state priorities and provided incentives and more favorable credit lines for their financing; established system of stable financing of the water sector, through the application of the "user pays" and "polluter pays" principles and reaching the economic price of water in accordance with the economic and social status of service users, as well as financing from the budget; defined tariff system in the area of water supply and sewerage of settlements; it is necessary to strengthen personnel capacities and bring the price of water into the economic category, and where the optimal solution is the construction of regional water supply systems, all means of financing should be considered, including EU and other international funds; defined way of using EU funds; established legal framework for public-private partnership, ensured regulatory function and established business standards in the water sector; increased degree of cooperation between state administration bodies, public companies and institutions, professional, scientific and financial institutions; established a better relationship in the field of planning, financing, investment in capital infrastructure facilities, in the relationship between the republic - autonomous province - local self-government. In order to implement the given goals, it is necessary to implement the following basic measures-functions: planning and implementation of plans: preparation and realization of investments; provision of funds and capacities; maintenance of facilities and systems; supervision and control and other measures (functions). Priority measures and activities in certain areas of the water sector are: activities to improve the water regime and the overall situation, in accordance with the possibilities of the economy and society, taking into account the priorities that will be determined by planning documents. The preparation of appropriate planning and technical documentation in accordance with it is of particular importance, in the areas of water activity, which should be given priority in the implementation in the next ten years.

In Navigation and Inland Waterway Action and Development in Europe (NAIADES II) - a priority area of the Danube Strategy, one of the goals is the development of efficient multimodal terminals in Danube ports to connect inland waterways with rail and road traffic by 2020, while the action plan of the European program includes the integration of water traffic into the multimodal chain. The European Commission stimulates the development of multimodal transport with various measures, such as the MARCO POLO project, which co-finances projects aimed at relieving traffic congestion or changing the type of traffic. The expected result of the mentioned measures is an increase in the participation of multimodal traffic, where a significant increase in the turnover of containerized goods is predicted. The increase in container handling requirements will justify the specialization of terminals into high throughput container terminals.

Today, ports represent multimodal hubs where traffic changes occur, which makes them places where multimodal traffic directly competes with road traffic. Multimodal transport uses maritime, rail and inland water transport, while road transport is used exclusively for the final delivery of goods, the so-called last mile delivery. The share of terminal costs in the total transport costs of multimodal traffic ranges up to 20%, which to some extent makes it less competitive. Ports and wharves are important pieces of infrastructure that enable the transport of goods on inland waterways. Connecting the network of inland waterways and land modes of transport, ports are the main hubs of the transport network, attract economic activities and enable the development of the region. Effective connection of road, rail and water transport is a prerequisite for stimulating the growth of traffic on inland waterways and integrating the transport of goods on inland waterways into the intermodal transport chain. Today, the port cannot only function as a single industrial plant, but as an asset of general interest, which must contribute to the development of the wider economic region located in its hinterland. By reducing transport costs, multiple transshipments and the time spent in traffic and transit, total logistics costs are reduced, which affect the price of goods, i.e. their competitiveness, which is in the interest of the end consumer. Healthy intra-port competition and determination of port tariffs will eliminate the possibility of creating a monopoly.

The Republic of Serbia, as a continental country without a sea coast, with its strategic commitment to the development of inland waterways and the planning of the development of each individual port, enables its own economy to increase the export of agricultural products and fertilizers, non-ferrous and ferrous metallurgy products, as well as other mass goods, but also the import of raw materials, semi-finished and finished products, consumer goods and other types of goods. The list of priority projects for the development of inland water traffic are: Projects in the area of ports and piers; Projects in the field of inland waterway transport infrastructure; Development projects of intelligent transport systems in inland water traffic. In order to effectively implement this strategy, in 2015 the Government adopted an Action Plan for the implementation, monitoring and improvement of this strategy - Action Plan. For each individual strategic measure, the action plan determines the appropriate activities for the purpose of implementation, the holders and participants in the implementation, the method of implementation. In order to effectively implement this strategy, in 2015 the Government adopted an Action Plan for the implementation, monitoring and improvement of this strategy. The action plan determines for each individual strategic measure the appropriate activities for the purpose of implementation, the holders and participants in the implementation, the method of implementation, such as: Water use; Provision of sufficient quantities of water of appropriate quality for different categories of users, primarily for water supply to the population, while the environment must not be endangered; Protection of water from pollution: Achieving and maintaining a good status and good ecological potential of water bodies of surface and underground water, in order to protect human health, preserve water and coastal ecosystems and meet the needs of water users; Regulation of watercourses and protection against harmful effects of water: Reducing the risk of harmful effects of water; Regional and multipurpose hydrosystems: water regime, that is, elimination of temporal and spatial mismatch between available water resources and water needs, protection of water from pollution and protection from water, development of regional and multipurpose hydrosystems; Legal and institutional framework: Completion of the legal reform of the water sector in accordance with the needs of adaptation to social conditions and EU requirements and efficient organization of the water sector and Economic policy: Establishing a system for sustainable, long-term financing of the water sector on the principle of self- financing, which implies stable sources of financing, a continuous flow of funds and established mechanisms for their collection. The action plan determines the obligations of state bodies and organizations in accordance with the legally established powers of competence in the field of water transport, bodies and institutions whose competences have an impact on the development of this branch of transport, the dynamics of implementing measures, and the way of managing risks in the process of achieving the special and strategic goals of the Strategy. In addition to the Water Transport Development Strategy of the Republic of Serbia from 2015 to 2025, in part 6. Development of the maritime economy and section 6.3. Vision, mission and strategic goals, it is given under section 6.3.3. point 1a Full implementation of binding IMO instruments: implementation of Resolution A.1070(28) Rulebook on the implementation of IMO instruments (III Rulebook), as amended and implementation of Resolution A.1121(30) 2017 List of obligations in accordance with the Rulebook on the implementation of IMO instruments, as amended. In Appendix 4 of the Law on Navigation and Ports on Internal Waters, Appendix No. 4 provides an analysis of traffic in ports and wharves, a forecast of passenger and tourist traffic in the period 2015-2025 in the following appendix (fig. 4, 5, 6, 7)

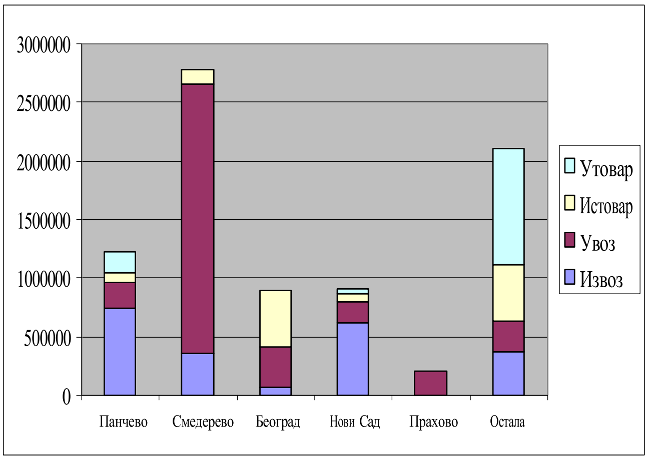

Fig 4. Overview of goods traffic in individual ports in the listed cities in the Republic of Serbia by type of traffic

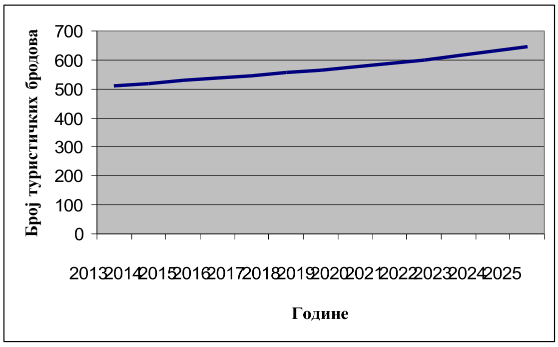

Fig 5. Forecasted number of tourist boats for the period from 2013 to 2025

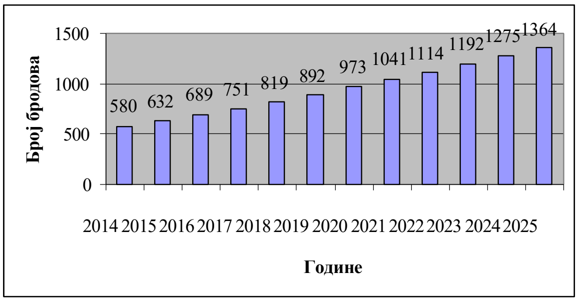

Fig 6. Forecasted number of passenger ships in Belgrade 2014-2025

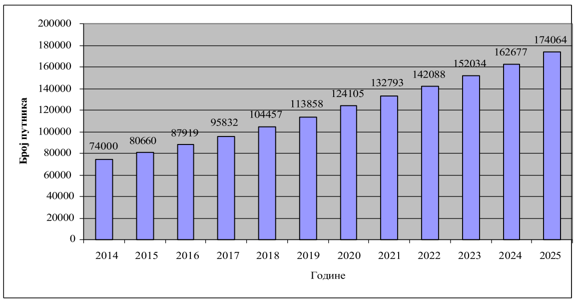

Fig 7. Forecasted number of passengers on passenger ships in Belgrade 2014-2025.

The Ministry is responsible for the implementation of measures and the achievement of the goals set by the Strategy, as well as the activities that will be set by the Action Plan, periodically reporting every other year to the Government on the implementation of the Strategy and the Action Plan. The basis for monitoring the implementation of strategic goals is the result indicators established for each individual goal of the Strategy, which is made up of the Committee for Implementation, Monitoring and Improvement of the Strategy, whose members are responsible for: preparing reports on the implementation of the Action Plan activities and will participate in the evaluation of the Strategy: determining quantitative indicators for monitoring the implementation of this strategy in accordance with the established objectives: determining the leading institution and/or individuals within key institutions who will coordinate the monitoring, evaluation and improvement of this strategy; implementation of the annual evaluation and improvement of all parts of this strategy in cooperation with the authorities and organizations to which the Strategy refers.

III. Conclusions

Laws, strategies and programs are adopted at the level of the Republic of Serbia in the field of spatial development, sustainable development, sustainable use of natural resources and goods, environmental protection and other strategic documents are harmonized with each other. The water management plan in the water area is adopted in accordance with the Strategy. Water is part of the balance of ecological, economic, social and political forces and acts in three domains: mineral, plant and animal, creating time spaces that are models, or even structural models of historical development. Water has an important place in every territorial planning policy, whether it is about its protection or water supply. Water is at the center of social life and an object of culture and causes strategies and counter-strategies. The French scientist Claude Bernard used to say: "Life is organized water."

References

[1] Strategi of the Republic of Srbia until 2034**.** was prepared on the Law on Water ("Official Gazette of the RS", no. 30/10 and 93/12)30/10 i 93/12).

[2] The Water Law ("Official Gazette of RS", No. 30/2010 and 93/2012)

[3] The Law on Navigation and Ports on Inland Waters ("Official Gazette of RS", no. 73/2010, 121/2012, 18/2015, 96/2015- other laws, 92/2016, 104/2016 - other laws, 113/2017 - other laws, 41/2018, 95/2018 - Law No. 37/2019 - Law No. 9/2020 and No. 52/2021),

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Professional Paper

Potential for Development of Intermodal Freight Transport in Republic of North Macedonia

Zoran Krakutovski[1] and Ivona Nedevska Trajkova[2]

Abstract – **This paper presents the potential of development of intermodal freight transport in Republic of North Macedonia. The road freight transport remains dominant transport mode in the country. The area around the capitol Skopje is the crossroads of TEN-T Corridor 8 and Corridor 10, providing the main hub of trade and potentially good location for construction of intermodal terminal.**

Keywords – **Intermodal transport, freight transport.**

I. Introduction

The definition of the Intermodal transportation is “the Intermodal freight transport consists of transporting goods in a single loading unit (such as a container) using a combination of modes of transport: road, rail, waterways or air” [1]. The Intermodal terminals are the contact point between different transport modes. The primary function of a terminal is to handle and tranship freight since modes are physically separated. The shipping containers move between different modes of transport: road, rail river, sea and air, without any unpacking. The goods can be transported in containers, swap-bodies, trailers for trucks and semi-trailers and non-standard containers (longer than standard), Fig (1).

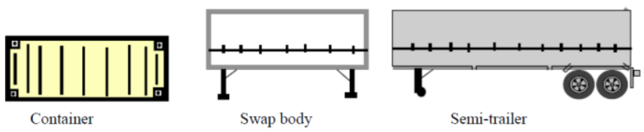

Fig. 1. Container, swap body and semi-trailer

Very important question concerning the intermodal transport is about of type of products that can be transported through intermodal terminals. The answer is anything that would normally be safe to ship in a container. There are also special containers with thermal properties, insulation, refrigeration (reefers), heating, tanks and so on can also travel through intermodal terminals if the terminals are able to handle them. Shipping regulations vary between countries and regions, but generally, they prohibit the transport of anything that is flammable and toxic, plants and animals, or weapons and ammunition.

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The Intermodal transport in Republic of North Macedonia is not developed as a result of several factors, the most important of which are the following:

- There is no intermodal terminal in the country that would be the main hub for intermodal transport between rails and trucks,
- Insufficient containerization of import/export cargoes,
- Unfavourable price of container transport by train compared to this by trucks,
- Underdeveloped logistics services for intermodal transport,
- Poor condition of rail transport due to obsolete infrastructure and insufficient number of railway vehicles.
- Lack of official statistical records for the transport of containers by trucks.

However, the potential for development of intermodal freight transport in the Republic of North Macedonia exist and the opportunity of this progress need realization of appropriated transport policy. The intermodal transport road – rail is very important for international transport of goods.

II. Current Situation in the Freight Transport in the Country

The road sector is most important in the freight transport market in the country. There were more than 95% of the transported goods by road in the last decade to arrive until 98.2% in 2023. The total transport of goods in 2023 were 68.9 million tons and only 0.82 million tons carried by rail.

The dominant part of the road freight transport is in the national transport with more than 80% of the total transport of goods per year, and the international transport has a part of about 20% (Table I).

Table I
Freight transport by road in 2023 & 2024 (in 1000 tons)

Year	2023	2024
National transport	54 673	68 553
International transport	13 436	15 794
Total	**68 108**	**84 347**

Source: SSO [2]

The transport of goods by containers statistically is collected only for containers transported by rail. The number of containers transported just by trucks are not officially registered. The original data concerning the number of containers carried by trucks is collected based on the number of declarations for export and import of goods by border crossing registered by the Customs Administration. These two data are presented in the next Tables II and III.

TABLE II
INTERMODAL TRANSPORT - TOTAL BY RAIL IN 2023 & 2024

Year	2023	2024
International transport – in tonnes	347 043	199 808
International transport - net tonne-km (in 1000)	84 580	47 992
Loaded ITUs, nb. of containers	22 614	11 161
Empty ITUs, nb. of containers	831	754

Source: SSO [2]

TABLE III
INTERMODAL TRANSPORT - TOTAL BY TRUCKS IN 2023

Year	2023
Number of declarations for import of goods by border crossing – containers with trucks	38 003
Number of declarations for export of goods by border crossing – containers with trucks	7 194

Source: Customs Administration

The data for number of containers by trucks shows that the import of goods carried with containers is more important than this for export.

The number of containers transported by rails indicates that the dominant number of intermodal transport by rail is for transit with about 90% of carried containers by rail (Fig. 2). The transit of containers is mainly from the port of Thessaloniki to the neighbouring and EU countries.

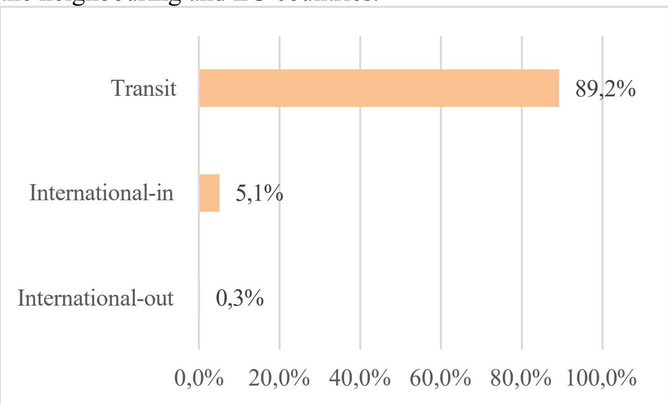

Fig. 2. Parts of containers transported by rails for import/export and transit

III. INTERMODAL TERMINAL PLANNING IN REGION OF SKOPJE

The new intermodal terminal, envisaged as a central hub for rail-road transhipment of containers and general cargo, is planned in the region of Skopje. This area is the crossing point between the TEN-T Corridor 8 and Corridor 10 (Fig.3).

The principal port for intermodal transport in the region is the port of Thessaloniki in Greece with about 470.000 TEUs containers in 2021. The Port of Durres in Albania is with the largest annual growth in capacities and transportation of TEUs, and in 2019 there were about 146.000 TEUs [3]. The railway connection on Corridor X provides access to the port of Thessaloniki and intermodal transport has so far been taking place from there. The missing sections of railway line on Corridor 8 with Bulgaria and Albania is planned to be built by 2030-2035. The investment in the railway connection with Bulgaria and Albania should improve freight transport connections in the region and increase the efficiency of intermodal transport in the future.

The new railway infrastructure will allow the freight transport along the axis East-West and the access to the ports in Bulgaria on Black See and in Albania on Adriatic See.

The distances between Skopje and Thessaloniki in Greece is about 200 km and the distance from Skopje to Durres in Albania is 240 km.

Fig. 3. Indicative extension of TEN-T rail network in the Balkan

The Marshalling yard Trubarevo, near to Skopje, is chosen as an optimal location for construction of intermodal terminal (Fig.4). The main marshalling area, including buildings, has about 330,000 m^2.

Fig. 4. Location of existing Marshalling yard Trubarevo

The existing Marshalling yard Trubarevo is built as a gravity marshalling yard with two special groups of railway tracks, one receiving tracks for freight trains entrance and the second for classification and freight trains dispatch. The existing railway infrastructure should be adapted to the needs of the intermodal terminal, and a new road access road should be constructed to allow rapid and safe access of trucks to the terminal. The services that should be supported at the initial construction stage of intermodal terminal development include container handling (road and rail), container storage, container repair, small commercial space for operator and all necessary utilities. Optional services may be provided at a later stage, on the basis that they are commercially viable and include customs clearance facilities, warehousing, truck parking, commercial spaces for clients, and vehicle repair/maintenance. The Ro-La terminal will be also built as independent part where the loading and unloading of vehicles will be with an escort, according to the technology when the trucks are slipway onto wagons self-propelled. The Ro-La technology needs at minimum one straight railway track with at least 500 m length for loading and unloading of trucks (Fig. 5).

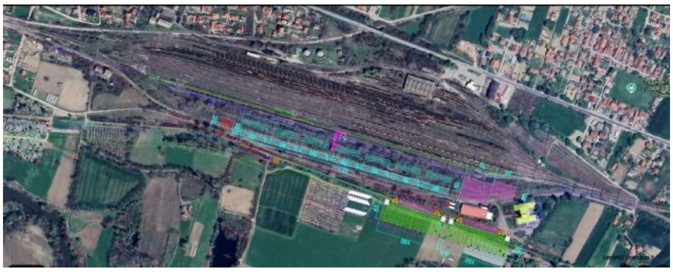

Fig. 5. Planned situation of Intermodal terminal Trubarevo

IV. Transport demand potential for intermodal transport rail - road

The analysis of modal split from truck to rail consider only freight volumes carried over longer of 200 km distances, because the rail transport has relatively high cost over short distances which increases with the extra cost for delivery at the Intermodal terminal. This means that only the freight flows that have origins or destinations in other country (export-import) should be considered in the modal split forecast. The transit cargo volumes are not included because they have not impact of cost reducing for operation of Intermodal terminal. However, not all goods for export and import will pass through Intermodal terminal. Practically, many import/export cargos are directly transported by trucks or direct trains from origin to destination and do not require transhipment. However, the Intermodal terminal could be a very pertinent facility for small in volume or weight consignment of goods, i.e. less than truck or container load in rail. Usually, these goods are not directly delivered to the final customer and they need to be stocked in warehouses and distributed following the demand of the customers e.g. the retailers in consumer cities areas or after the Customs duties paid.

The assessment of potential of diverted road traffic to rail transport considers only the transport with long supply chains i.e. international traffic flows with O-D over distance of above 150-200 km. For the reason that the distances between the biggest cities in the country and between the borders crossings are mostly less than 200 km, so the intermodal terminal is not relevant for domestic traffic. The import/export traffic flows are assessed, but the transit transport is not taken into account, because it not depend on the economic activities in North Macedonia but only from trade between foreign countries. The allocation of modal shift from road to rail transport is possible with application of TRANSCAPE methodology from 2008 [4]. This Methodology uses the Eurostat transport statistics that show that a modal shift potential is follow:

- 5% of the volume transported by road for the distance of 50-150 km,
- 40% for 150-500 km and
- 100% for distances in excess of 500km.

The rail transport is indeed most cost economic than road transport for long distances. However, the observed rail cost from Thessaloniki port to Skopje (combination of Greek and North Macedonia rail transport cost) is exceeding the road freight transport cost. This undesired situation should be improved and rail transport tariffs from distant origins or to distant destinations need to be lowered to create a competitive environment that stimulates the modal shift.

The national intermodal data analysis in the period 2018-2022 show that the yearly number of carried containers is between 20.000 TEUs and 36.000 TEUs per year. About 95% of the containers were loaded and 5% empty. The international intermodal transport with containers in the period 2018-2022 was used by domestic companies almost only for import, but not for export of goods, with about 1.000-2.000 TEUs per year. The most represented was the transit container transport with about 90-95% of the total containers transported by rail across the country.

However, the potential for the development of intermodal transport in the future, and especially for exports of goods from the domestic companies, is great if we take into account that the transport distances for exports driven by trucks are over 700 km in the period from 2018-2022.

The intermodal transport supply in the country is not sufficient and the project for development of Intermodal terminal should contribute to increase rapidly the demand for container transport of goods. The liberalization of transport operations by rail in the next years will participate for diversification and improvement of railway transport services and transportation costs.

In the first years of project development, the capacity of terminal (reloading equipment, storage capacity, parking area) should be such as to provide about 6.000-8.000 TEUs/year. The expectation is that the attractiveness of the Intermodal terminal will increase rapidly and the first phase of project provide profits (satisfactory return on capital) in a short time period. In the further second stage, it would be possible to set up further or larger warehouses or new specialized areas for different services if the demand for TEU traffic increases. The transport projections assessed that in 2040 there are about 100.000 TEUs/year and 2.0 million tons general cargo passing through the intermodal terminal. The Ro-La technology shall be also developed in the second stage of project with construction of railway tracks and surface area for this technology.

V. Regional context and particular issues for terminal building

The regional context of the intermodal terminal in Trubarevo principally concerns the ports of the neighbouring countries, respectively the port in Thessaloniki in Greece and the port of Durres in Albania. Other 4 ports in the region are at the distance of planned terminal less than 1000 km (Fig. 6). The nearest already built intermodal terminal is located in Niš, Serbia in the new industrial zone.

Fig. 6. Regional situation of Intermodal terminal Trubarevo

The development of the terminal is envisaged in two stages:

- The first stage involve construction of infrastructures and provision of equipment for containers handling,
- The second stage concerns construction of warehouses in the terminal area and provision of Gantry Crane.

The first stage include the following investment works for reconstruction of existing railway infrastructure and construction of new access road to the intermodal terminal:

- Reconstruction and adaptation of existing railway tracks infrastructure including the electrification and signalling. Four tracks are envisaged for handling of containers from trains in the container storage area,
- Construction of new road connection from the national road network to the intermodal terminal with a length of 2,03 km,
- Construction of storage container area with a surface of 36,400 m^2,
- Construction of general cargo open storage area with a surface of 5,250 m^2,
- Reconstruction of interior space of existing administrative building for administrative and service works,
- Reconstruction of existing building to adapt it in custom inspection warehouse,
- Construction of railway track for Ro-La to transport trucks and semitrailers along certain sections of their route across Europe by rail, thus combining road and rail transport.
- Provision of 2 Reach Stackers in the first stage of intermodal terminal development.

In the second stage of project development is envisaged following investment:

- Provision and installation of Gantry Crane,
- Construction of 2 warehouses with a max. dimension of 45 x 150 m,
- Construction of one additional railway track for loading/unloading directly in/from warehouses,
- Construction of warehouse for container maintenance.

The estimated cost for the first stage of intermodal terminal development is about 25 mil. Euro, and for the second stage is about 18 mil. Euro. The adaptation, reconstruction, construction and arrangement of existing railway and road infrastructure represents about 32%-35% of the total cost of intermodal terminal construction in the first stage, or the estimated cost for the infrastructures is about 10 million Euro. The assessed costs in the second stage of project development are essential for construction of 2 new warehouses with an amount of 12.7 million Euro. The yearly operating costs of the intermodal terminal are assessed of about 2.7 mil. Euro. The main service offered by an intermodal centre is handling of intermodal units, and on the basis of this service the operator will realise the main revenues. However, it must be specified that the centre will also perform ancillary services, such as, for example:

- storage of containers and other intermodal units,
- internal train shunting,
- administrative and management services, such as customs handling,
- provision of parking areas for vehicles.

Concerning the environmental impact assessment of the project, it is important to note that the proposed technical design options are part of the river Vardar watershed and the most important environmental impact is evaluated from the proximity to the river. The access road form the terminal to the planned boulevard in the general urban plan of Skopje is also assessed regarding the nature protected area near the terminal and the living houses area concerned by the project.

VI. Conclusions

The development of an intermodal terminal in Republic of North Macedonia has the potential to improve freight transport efficiency, reduce road congestion, and enhance international trade logistics. Strategic investment in intermodal infrastructure, competitive rail pricing, and logistics service improvements are essential to achieving this goal.

References

[1] Special report: Intermodal freight transport – EU still far from getting freight off the road, European Court of Auditors, EN 2023
[2] State Statistical Office - MAKSTAT database (https://www.stat.gov.mk/default_en.aspx)
[3] https://www.durresport.al/index.php/en/port/
[4] https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni reports/etcacc_tp_2008_18_transport_model_shift_potential/@@download/file/ETCACC_TP_2008_18_transport_modal_shift_pots.pdf

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Original Scientific Paper

Optimization in the Function of Flight Network Planning

Ana Lazarovska[1] , Violeta Manevska[2] and Verica Dancevska[3]

Abstract - **This research explores the interrelationship between transport economics and sustainable development through the establishment of a mathematical model tailored for a new sports and school airport in Gevgelija, Macedonia. By applying the theory of equilibrium and conducting a cost-benefit analysis, the study aims to assess the airport infrastructure's development and its contribution to sustainable growth in air traffic. The ultimate goal is to inform decision-making processes that prioritize projects with substantial indirect benefits, thereby aligning with European aviation standards and enhancing Macedonia's integration into the modern aviation network. This comprehensive approach not only addresses the specific needs of sports and school aviation but also seeks to optimize resource allocation for the overall development of the transport economy in the region. The optimization of airport infrastructure is critical for efficient air transport, necessitating a comprehensive approach that considers the airspace around a planned airport. This process requires the integration of neighboring airports, fostering collaboration to allocate an optimal number of aircraft according to flight schedules while maintaining safety and efficiency. By treating the optimization model as an interactive process, stakeholders can enhance overall air traffic management, improve operational capacity, and ensure that airports operate synergistically within the regional airspace network, ultimately leading to a more effective and sustainable aviation system.**

Keywords: **Planning, Optimal, Supply, Demand, Model.**

I. Introduction

Sport- shool airport infrastructure is crucial for safe and efficient air traffic, enhancing trade both domestically and internationally. Effective transport economics informs strategic decisions regarding air traffic growth and airport development, aligning with the principles of sustainable development to address the challenges posed by resource exploitation and environmental concerns. Research suggests that a well-managed air traffic system, coupled with stakeholder adaptability, can positively influence the transportation economy, promoting higher quality standards in airport infrastructure in the Republic of Macedonia and aligning it with those of advanced European nations.

The scientific hypothesis posits that air traffic and airport infrastructure are vital for the growth of the international transport economy, especially in sustainable development contexts, illustrated by the Gevgelija sports and school airport project. It highlights the importance of legal frameworks, cost management, and optimization strategies in enhancing national and international transport connections. However, while it provides insights into reverse knowledge transfer and airport categorization, it also identifies limitations, such as insufficient industry differentiation and a lack of focus on airport infrastructure preservation in Macedonia. The study's transverse methodology suggests the potential for more comprehensive longitudinal research in the future, reinforcing the link between equilibrium theory and sustainable airport development while advocating for deeper stakeholder engagement and collaborative practices for improved airport-community relations.

II. Static Models

Static models for analyzing the demand and supply of transport services are separated and described with the basic models.[4]

A. Planning the Optimal Number of Aircraft in the Network

- By definition, there are two basic types of planning in aviation: strategic planning, which focuses on long-term goals and framework for the airport network, including infrastructure development and market positioning, and tactical planning, which deals with shorter-term decisions related to scheduling, fleet allocation, and operational efficiency. Both types are essential for optimizing the aircraft deployment strategy to meet demand and regulatory requirements effectively while adapting to market fluctuations and operational constraints.
- Strategic planning long-term plans,
- Operational planning by individual sectors or subsystems.

The air traffic planning process is a complex and strategic effort that integrates problem diagnosis with the establishment of developmental goals and performance metrics, aiming to enhance air traffic management. It underscores the critical interplay between demand activities, planning concepts, and design functions, optimizing the delivery of transport services while considering various influences such as policy frameworks, community requirements, and existing infrastructures. Achieving effective air traffic management requires a holistic approach that acknowledges the intricate interdependencies and processes that significantly affect spatial, economic, and social environments.[5]

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[4] Mehanović, M.: Mreže u saobraćaju i komunikacijama, Fakultet za saobraćaj i komunikacije, Sarajevo, 2015

[5] Ibidem

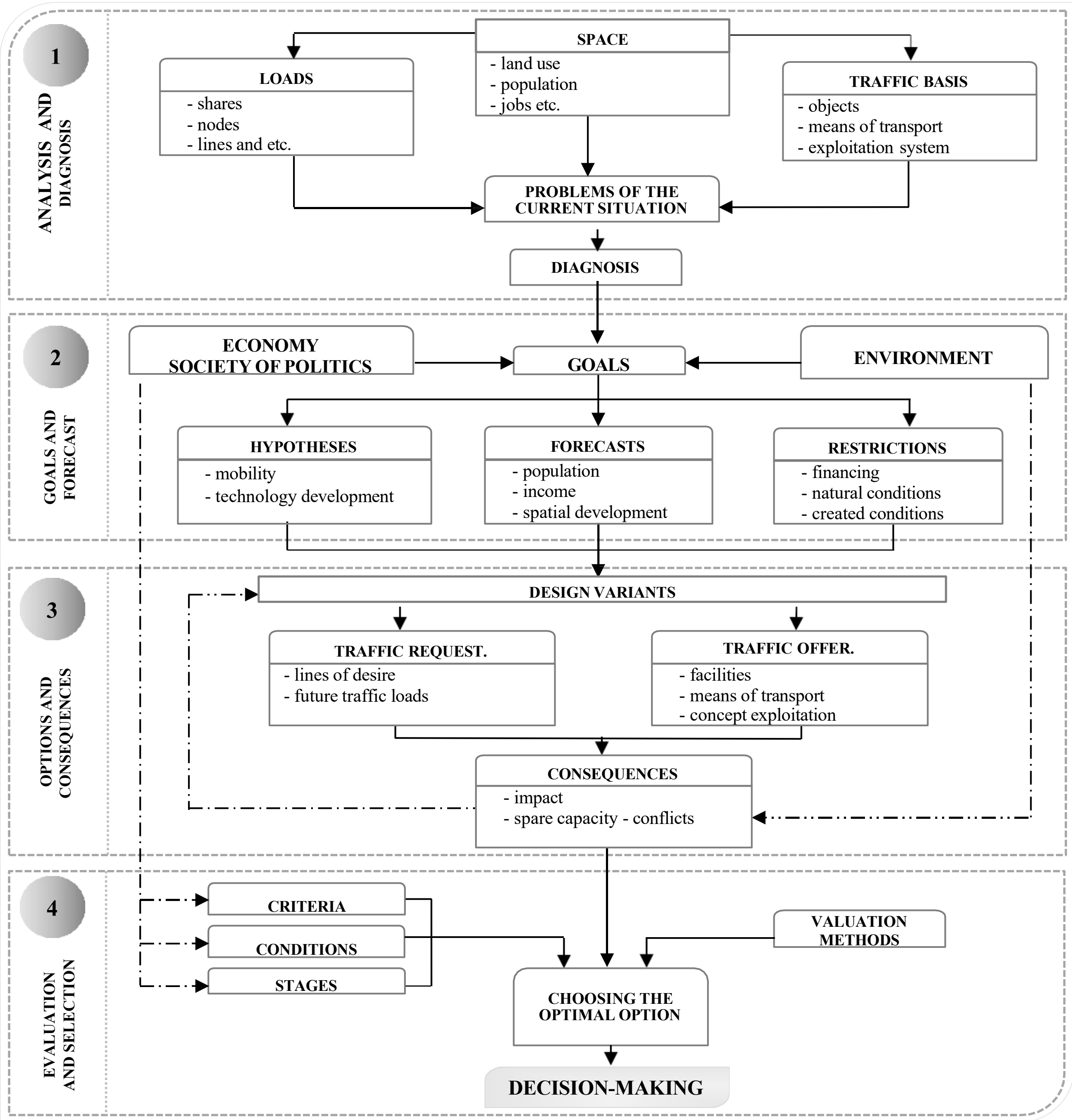


Figure 1, Basic steps in traffic planning[6]

B. Planning the Optimal Number of Aircraft for a Given Flight Schedule in the Network

An example of a relationship is presented by the flight schedule that determines the supply of transport services between the three places A, B and C at time t.

For the planned 13 flights, the question is what is the minimum number of aircraft with which transportation can be organized, assuming that the flights are nodes of the network xi and the path along which one aircraft can make a chain in the network.

The flight schedule is in the form of a grid following the flight, which is realized by moving the vehicle from location A to location B, performing flights 5,6,9,10,13, meaning that from nodes x1 there is a branch orientation towards nodes x_5, x_6, x_9, x_{10}, x_{13}.

In this network there is a branch directed from node xi to the node xj only if the flying xj can be done after flying xi, i.e. flying xi ends at the same location where driving begins xj, and the start of the ride xj is after the end of the ride xi, so that:

- ❖ the minimum number of aircraft is determined,
- ❖ an example of determining the minimum number of aircraft to execute the planned flight schedule,
- ❖ according to the set flight schedule, the calculation of the minimum required number of aircraft is presented to maximize the flow.

A bichromatic graph for a network represents a sequence of departures from a node s_1, and those are the branches (s_1,t_5), (s_1,t_6), (s_1,t_9), (s_1,t_{10}) and (s_1,t_{13}), that is, the first branch (s_1,t_5) assign intensity flow *1*. From the node s_1 can emit a stream with the highest intensity *1*, that the other branches (s_1,t_6), (s_1,t_9), (s_1,t_{10}) and (s_1,t_{13}) have a flow of intensity *0* which leads to the conclusion that all branches entering the node t_5 have flow *0*, given that in the node t_5 the flow of intensity is already penetrating *1*. The flows for other nodes are determined in the same way (s_2, s_3,.....s_{13}) while branches of the bichromatic graph whose flow equals 1 are indicated by a thicker line on the graph.

The marked branches of the biochromatic graph in which the flow intensity is 1 mean that the maximum value of the total flow through the biochromatic graph$|D| = 8$.
The number of nodes in the initial graph INI=13 is the minimum number of aircraft required to execute a given flight schedule

$$|C| = |N| - |D| = 13 - 8 = 5$$

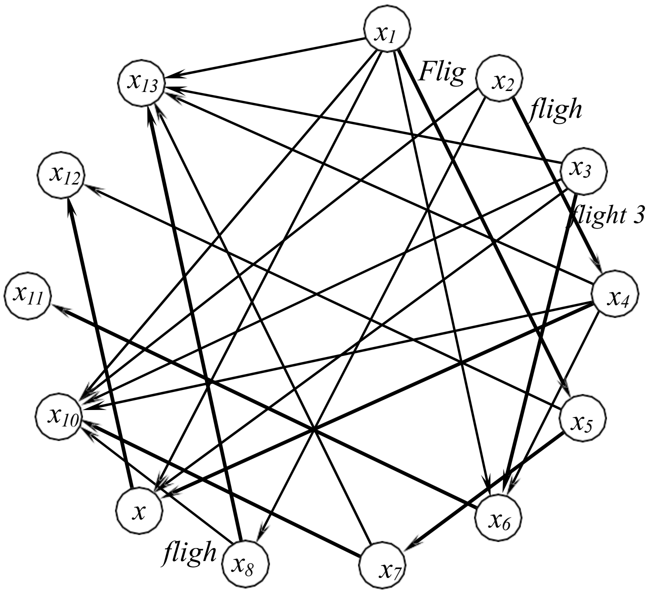
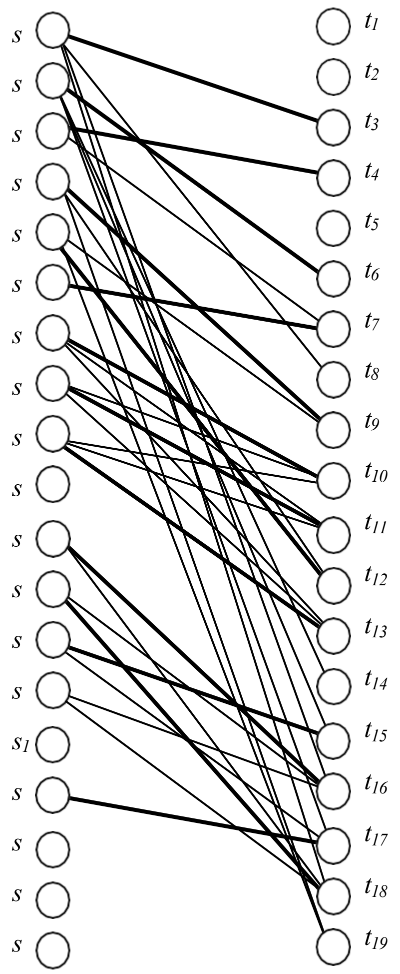


Figure 2, Aircraft paths on decomposed acyclic graphic chains[7]

The procedure of maximizing the flow through the biochromatic graph by constructing all branches from nodes si is performed by assigning a flow with intensity 1 to the first 10 branches out of 13 branches and the maximum value of the total flow through the biochromatic graph $|D| = 13$

If the number of nodes in the initial graph is $|N| = 19$, The minimum number of aircraft required to execute a given flight schedule can be calculated as $|C| = |N| - |D| = 18 - 13 = 5$.
If the number of flights *Vr* = 5 represents the minimum number that can perform the flight, provided that the aircraft fly at places is:

- *Location*-S - 2 take-off and 1 landing,
- *Location*-T - 1 take-off and 2 landing,
- *Location*-L - 1 take-off and 1 landing,
- *Location*-B - 1 take-off and 1 landing,
- *Location*-N - 1 take-off and 1 landing.



Graph 3, Bichromatic fly plot with flow intensity limits marked 1.[8]

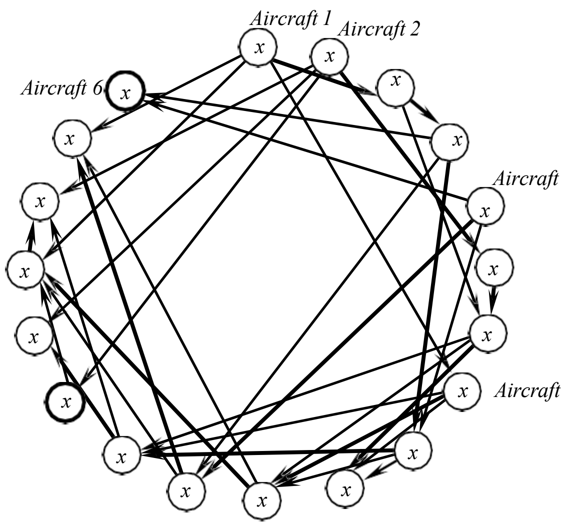


Figure 4, Aircraft chain network[9]

The aircraft can arrive at any location after the end of the flight until the start of the next flight by connecting a certain number of routes and reducing the number of aircraft to 13 to perform flights 1,3,4,9,10,13,15 and 17 starting at location-S and ending at location-B. The second aircraft performs flights 2,6,7,12,14,16 and 19 starting and ending at location-S and the

[7] Ibidem

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third aircraft will perform flights 5,8,11 and 18, starting at location-L and ending at location-N

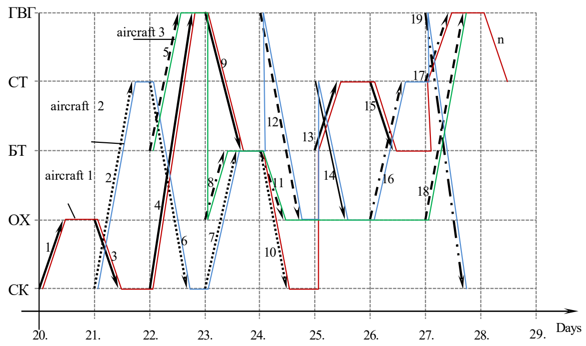

Figure 5, Flying from specific location under the animation where each plane can start flying at a different location

III. Discussion of the Results

In summary, the preliminary assessment of the airport construction project near Gevgelija underscores the importance of a comprehensive evaluation of financial viability, economic impact, and associated risks, offering valuable insights for informed decision-making and strategic planning as we progress with the project's development. The financial analysis highlights that the total investments incorporating EU funds have a negative net present value, indicating that these funds are essential for the project's viability. Furthermore, since EU funding accounts for 75% of the total investment in constructing international airports without causing over- financing, it suggests that the resources are allocated efficiently, which is crucial for the project's success. The project's profitability has been affirmed through rigorous sensitivity and risk analyses, revealing resilience against a 10% investment increase and a 50% decrease in benefits, while maintaining favorable economic indicators. With a low risk profile, the project is poised for progression to detailed research and design phases, supported by a potential 75% co-financing from EU funds if alternative financing is not pursued. Furthermore, in addressing sustainable development within modern general aviation airports, the application of game theory, particularly the Nash equilibrium, emerges as a vital tool for optimizing resource management and operational strategies, reflecting the complexities of these optimization challenges. It addresses challenges such as inadequate documentation and data access, offering a model designed specifically for Macedonia to enhance the precision of runway obstacle assessments. By supporting risk-based decision- making on airport location, it highlights the importance of minimizing operational risks and protecting public health and the environment. However, the model's effectiveness is limited by the absence of flight data, indicating the need for future studies to refine this framework and align it with sustainable development goals for improved applicability at the Gevgelija airport.

IV. Conclusion

The continuous scientific research and thoughtful deliberation culminated in a formulation grounded in a wealth of empirical data, which highlighted the essential interplay between transport economics and the optimal functioning of air traffic systems. By synthesizing insights from doctoral dissertations and comparing literature across different languages, I developed a model for airport infrastructure that addresses the unique needs of the region around Gevgelija. This model leverages a multi-index framework to effectively tackle the complexities of the air traffic system, underscoring the significant role of transport economics in fostering developmental progress.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Pavlin, S.: Aerodromi, Sveučilišni udžbenik, drugo izdanje, Fakultet Prometnih Znanosti, Sveučilište u Zagrebu, 2006.
2. Aerodromes, Annex 14 to the Convention on International Civil Aviation, Volume I, Aerodrome Design and Operations, International Civil Aviation Organization, Fifth Edition, 2009
3. Stolport Manual, Doc. 9150- AN/899, International Civil Aviation Organization, Second Edition, 1991
4. Carr, D.: City Airports still at centre of controversy, Jane`s Airport Review, September 1995
5. Gevgelija aerodrome location selection, Ana Lazarovska, Opatija conference, The International Conference on Traffic Development, Logistics & Sustainable Transport, 2017, Opatija
6. Stages of aerodrome sustainable category development evaluation in the vincinity of the Gevgelija city through Nash`s theories of equilibrium, Ana Lazarovska, Verica Dancevska, Violeta Manevska, https://www.researchgate.net/publication/
7. Improving Gevgelija aerodrome of the most favorable location for runway with risk point of view, Ana Lazarovska, Verica Dancevska, Violeta Manevska, ijrcms.com/uploads2022/ijrcms_04_159.pdf
8. Improving the Gevgelija aerodrome project methodology through the eye of logic optimization, Ana Lazarovska, Verica Dancevska, Violeta Manevska, https://ijrcms.com/link3.php?id=159
9. Improving the Bitola aerodrome category through the Ana Lazarovska`s „Codex on the sustainable aerodrome development„ parallel to Leonardo da Vinci`s „Codex on the flight of birds„ , Ana Lazarovska, Verica Dancevska, Violeta Manevska, https://www.researchgate.net/publication/363045614_Improving_the_Bitola_Aerodrome_Category_through_the_Ana_Lazarovska's_Codex_on_the_Sustainable_Aerodrome_Development_Parallel_to_Leonardo_da_Vinci's_Codex_on_the_Flight_of_Birds
10. Key microeconomics notes: „Steps for Gevgelija aerodrome infrastructure development investment", Ana Lazarovska, Verica Dancevska, Violeta Manevska, https://ijrcms.com/key-microeconomics-notes-steps-for-gevgelija-aerodrome-infrastructure-development-investment/
11. Mehanović, M.: Mreže u saobraćaju i komunikacijama, Fakultet za saobraćaj i komunikacije, Sarajevo, 2015
12. www.linkedin.com/pulse/basic-steps-management-planning-process-terry-mullane
13. www.scribd.com/doc/261870744/PLANIRANJE-U-SAOBRACAJU-I-parcijala-docx
14. www.scribd.com/document/216493894/SAOBRA%C4%86AJNO-PLANIRANJE-seminarski-rad

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Review Scientific Paper

Traffic Management from the Perspective of Environmental Pollution

Merita Mustafai[1], Verica Dancevska[2] and Elmir Mustafai[3]

Abstract – **This paper examines traffic management from the standpoint of environmental pollution. Traffic levels in urban areas continue to rise, leading to increased air pollution, particularly in densely populated regions. Key pollutants such as particulate matter (PM), nitrogen oxides (NOx), and ground-level ozone significantly degrade air quality and pose serious public health risks. Addressing these challenges requires integrated traffic management strategies focused on sustainability and pollution reduction.**

Keywords –**Traffic, Air Pollution, Environmental Impact, Sustainable Transport, Ecological Engineering**

I. INTRODUCTION

According to recent data from the World Health Organization (WHO), 99% of the global population breathes air that exceeds recommended WHO guidelines. Road traffic is a major contributor to ambient particulate matter (PM) in urban environments, accounting for approximately 25% of such emissions worldwide. As regulatory standards for exhaust emissions become stricter, non-exhaust sources—such as brake and tire wear—are projected to dominate PM emissions from road transport by 2035.

The European Environment Agency (EEA) reported that in 2020, road transport was the leading source of nitrogen oxides (NOx) emissions, contributing 37% of the total. Between 2014 and 2020, nearly two-thirds of reported air quality exceedances were linked to heavy urban traffic and proximity to major roadways, primarily due to NOx emissions. In Europe alone, fine particulate matter (PM2.5) is estimated to reduce life expectancy by roughly eight months. Additionally, compounds like benzo[a]pyrene and volatile organic compounds (VOCs) may pose health concerns when present in high concentrations.

Pollution from traffic is not limited to fuel combustion. Particulate matter is also generated through mechanical wear, such as friction from braking and tire degradation, further contributing to airborne pollutants. These fine particles are inhalable, accumulate in the lungs, and can lead to inflammation and chronic respiratory diseases.

The overall level of traffic-related emissions depends on several key factors:

- Vehicle volume (flow rate per hour or day)
- Vehicle composition (type and age structure)
- Driving behavior
- Road infrastructure characteristics

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Effective traffic management strategies aimed at reducing environmental pollution should prioritize enhancing transport efficiency, promoting cleaner mobility options, and mitigating congestion. Achieving this vision requires coordinated efforts among urban planners, policymakers, and the public to foster a sustainable and environmentally responsible transportation future.

II. DEFINING KEY CONCEPTS AND THE SITUATION IN NORTH MACEDONIA WITH EMPHASIS ON TETOVO

Air pollution is the leading cause of premature mortality and an increased incidence of disease among the population. It represents the most significant environmental health risk to citizens across Europe, where, according to data from the European Environment Agency (EEA) and the World Health Organization (WHO), it is responsible for approximately 400,000 premature deaths annually.

Unfortunately, the Republic of North Macedonia ranks among the worst in Europe regarding air quality, according to the latest report by the EEA on air pollution in Europe. North Macedonian cities suffer from the highest levels of air pollution on the continent. In 2017, Skopje, Bitola, and Tetovo were among the top ten most polluted cities in Europe. According to the latest analyses by the WHO, air pollution is the main cause of over 1,300 deaths per year in North Macedonia and contributes to an increased number of individuals suffering from respiratory illnesses.

In recent years, air pollution levels have reached alarmingly high levels, raising public concern about its effects on human health. Suspended particles, commonly referred to as PM10, are among the most significant air pollutants in cities like Skopje, Tetovo, and Bitola. These particles, with a diameter of 10 microns or less, originate from road dust, industrial emissions, and combustion processes. The primary sources of this pollution include motor vehicles, industrial facilities, construction sites, and the use of low-quality fuels for household heating.

PM10 particles are small enough to penetrate into the thoracic region of the respiratory system. The health effects of inhaling suspended particles (PM10) are both short-term (over hours or days) and long-term (over months or years), and they include cardiovascular and respiratory diseases, as well as lung cancer. Vulnerable groups, such as individuals with pre-existing respiratory or heart conditions, the elderly, and children, are especially at risk. For example, exposure to PM10 can affect lung development in children, causing reversible reductions in lung function, as well as chronic deficits in growth rate and long-term pulmonary performance.

Air pollution is a critical issue in most large urban areas in the country, particularly during the winter months when polluted air tends to persist for extended periods. Traffic congestion exacerbates vehicle emissions and significantly deteriorates ambient air quality. In North Macedonia, the quality of ambient air varies depending on the location of monitoring stations, and is primarily influenced by factors such as population density, proximity to industrial facilities, types of industrial production, energy generation methods, and the transport of goods and people.

The quality of ambient air in the Republic of North Macedonia is continuously monitored, with regular reporting conducted by the Ministry of Environment and Physical Planning through the North Macedonian Environmental Information Center (MEIC). The Ministry manages the State Automatic Air Quality Monitoring System, which comprises 21 fixed monitoring stations and one mobile station. These include: 5 stations in Skopje, 2 in Bitola 1 station each in the municipalities of Veles, Ilinden, Kičevo, Kumanovo, Kočani, Tetovo, Kavadarci, Gostivar, Strumica, Gevgelija, Prilep, Berovo, Ohrid, and the village of Lazaropole

In 2023, the mobile monitoring station was positioned in the municipality of Gjorče Petrov in Skopje.

The automatic air quality monitoring stations measure concentrations of the following pollutants (Figure 1):

- Sulfur dioxide (SO_2)
- Nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Ozone (O_3)
- Suspended particles with a diameter of up to 10 micrometers (PM10)
- Suspended particles with a diameter of up to 2.5 micrometers (PM2.5)

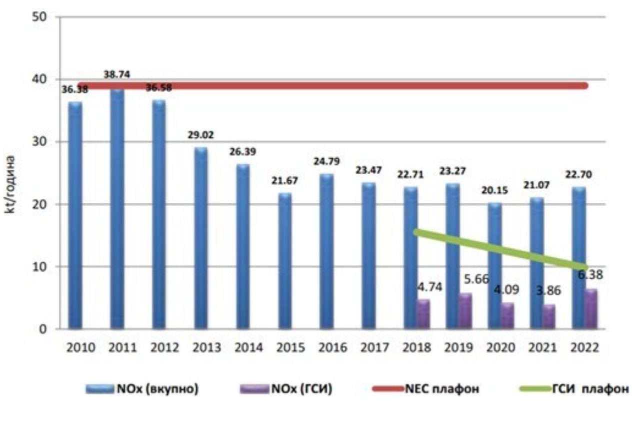

Figure 1. Comparison of NOx Emissions with National Limit Values

Figure 1 illustrates the comparison between measured nitrogen oxide (NOx) emissions and the corresponding national limit values established by environmental regulations. The data is derived from monitoring stations across urban centers in North Macedonia. The results reveal that in several locations—particularly in Skopje, Tetovo, and Bitola—NOx concentrations frequently exceed the annual limit value of 40 µg/m³ (micrograms per cubic meter), highlighting a persistent challenge to air quality. These findings underscore the importance of implementing targeted policies for controlling traffic and industrial emissions.

Tetovo, with a population of approximately 70,000, is located about 40 km west of the capital city Skopje. The Tetovo air quality monitoring station was established in April 2004 and is situated in the courtyard of the "St. Cyril and Methodius" Primary School. The station is positioned only 5 meters from a high-traffic boulevard and approximately 15 to 20 meters from nearby residential buildings. It also monitors pollution from industrial facilities located roughly 600 to 700 meters away.

The station measures the concentrations of the following pollutants: Ozone (O_3), Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), Carbon monoxide (CO), Particulate matter PM10, Particulate matter PM2.5

This strategic placement allows the station to capture both traffic-related and industrial pollution, making it a crucial point for assessing urban air quality and public health risks in the region.

Table 1. Limit Values for the Protection of Human Health (NO_2)

Pollutant	*Period*	*Permitted Exceedances per year*	*Limit Value*	*Threshold*
NO_2	1 hour	18	200 µg/m³	
	1 year	0	40 µg/m³	
	3 consecutive hours			400 µg/m

During the construction of a kindergarten in the schoolyard—on the site where the school's central heating boiler room was previously located—the boiler room was relocated and is now positioned only a few meters from the Tetovo air quality monitoring station. This raises concerns about the accuracy and reliability of the station's data, as it no longer meets the fundamental criteria for proper siting.

The location of an air quality monitoring station is a critical factor, and several criteria must be satisfied for the data to be considered valid. According to both international and national standards, a monitoring station: (i) must be placed at least 10 meters away from the edge of the sidewalk; (ii) and at least 25 meters away from the nearest intersection; (iii) measuring instruments must be positioned within the breathing zone, typically between 1.5 to 4 meters in height, and in some cases, up to 8 meters; (iv) most importantly, there must be no direct pollution sources near the station.

In the case of the Tetovo station, several of these parameters are not met. The presence of a large construction site and a boiler room located only a few meters from the station violates these guidelines. This situation is deemed unacceptable, as it compromises the representativeness and scientific validity of the recorded air quality data Although the monitoring station does not meet the basic criteria required to function as a reliable air quality monitoring site, the Ministry of Environment and Physical Planning has stated that it has no intention of relocating the station.

The average annual concentration of NO_2 was recorded in Tetovo are displayed on Figure 2.

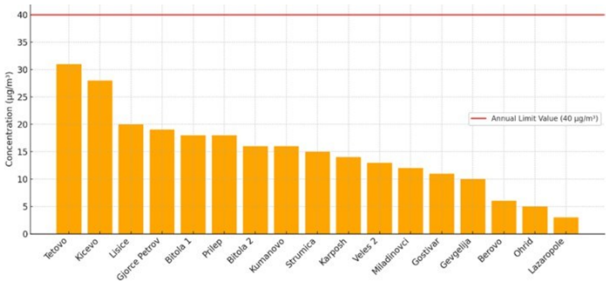

Figure 2. Average Annual Concentrations of NO_2

As shown in Figure 2, the highest average annual concentration of NO_2 was recorded in Tetovo, reaching 26.61 µg/m³.

Regarding its toxicity, NO_2 is four times more toxic than NO. Its harmful effects become more pronounced at higher concentrations and with long-term exposure. The toxicity of nitrogen oxides also increases with rising temperatures. When polluted air is inhaled, nitrogen oxides (NO and NO_2) easily penetrate the human lungs due to their low solubility in water.

Exposure to NO_2 has been strongly linked to an increase in cardiovascular and respiratory diseases in humans. In addition to its effects on human health, nitrogen oxides also negatively impact vegetation, inhibiting growth and damaging plant tissues.

As shown in Graph 3, the highest annual average concentration of nitrogen dioxide (NO_2) was recorded in Tetovo, reaching 26.61 µg/m³.

Regarding its toxicity, NO_2 is approximately four times more toxic than nitric oxide (NO). The harmful effects of nitrogen oxides become more pronounced at higher concentrations and with long-term exposure. Additionally, toxicity increases with rising temperatures. Due to their low solubility in water, nitrogen oxides (NO and NO_2) can easily penetrate deep into the human lungs upon inhalation of polluted air.

Exposure to NO_2 has been strongly associated with an increased incidence of cardiovascular and respiratory diseases in humans. Furthermore, nitrogen oxides have harmful effects on vegetation, impairing plant growth and function by damaging leaf tissue and interfering with photosynthesis.

III. 1. Pollution Pricing to Achieve Emission Reductions

Also known as congestion charges, this aims to ease traffic and reduce pollution by discouraging unnecessary trips and encouraging drivers to use alternative routes, travel during off-peak hours, switch to public transport, or share rides (including taxis) with others. Effectively implementing congestion pricing is essential for the sustainable development of urban transport systems. The fees charged for driving on busy city roads reduce greenhouse gas emissions and improve air quality, while also generating much-needed funding for transit systems that many people rely on for their daily commutes.

Congestion charges can improve the environment in several ways. First, they reduce vehicle kilometres travelled, thereby lowering fuel consumption and pollutant emissions. Second, they decrease stop-and-go traffic, cutting fuel use and emissions caused by frequent acceleration and deceleration. Third, reduced traffic in urban areas creates a more liveable environment, pedestrian-friendly spaces, and less noise pollution. While researchers have long predicted the environmental benefits of pricing, evidence of these impacts is visible in cities around the world where congestion charges have been implemented.

III. 2. Intelligent Traffic Management Systems (ITMS)

An Intelligent Transportation System provides a framework for integrating data from various sources, including real-time traffic cameras, GPS, and road sensors. This system allows traffic controllers to monitor road conditions, predict traffic patterns, and make quick adjustments. ITMS combines cutting-edge information and communication technologies used in traffic to enhance control, enforcement, safety, efficiency, and sustainability of transportation networks, reduce congestion, and improve driver experiences.

Benefits:

- The traffic system becomes efficient and safe through the use of information, communication, and control technologies.
- Speed cameras lead to fewer fatalities, improved congestion, and better environmental factors.
- Travel time is reduced and better managed across the entire city.
- Integration of vehicle systems with mobile communications and advanced mapping technology leads to reduced fuel consumption and lower harmful emissions.
- Electronic ticketing enables faster and easier public transportation use.
- Providing online information about buses and trains creates better-informed passengers and operators.
- Assisting drivers in finding parking spaces helps minimize congestion and pollution.

III. 3. Promotion of Public Transportation

Greater use of public transport services over individual car use is one of the best ways to reduce emissions and help protect the environment. Many cities have successfully managed to cut CO_2 emissions by up to 50 percent by reducing or limiting private car traffic. To make public urban transport a true alternative to private car traffic, it must offer rational, comfortable, fast, and regular service on appropriately chosen routes that cover the city's territory and connect important urban destinations. Travel time and comfort are crucial factors—often the main reasons people choose public transport over private vehicles. Successful public transport is essential for any strategy aiming to reduce emissions in the transport sector. It is a public good that benefits transport efficiency, pollution reduction, the local and national economy, and social inclusion. To make public transport an attractive and everyday choice for residents, cities must design services well and overcome both physical and cultural barriers. High-quality public transport services are reliable, frequent, fast, comfortable, accessible, and safe—and importantly, they should serve routes with sufficient demand.

III.4. Electric and Low-Emission Vehicles (EVs)

Battery electric vehicles have zero exhaust emissions, which makes them better for our environment than gasoline, diesel, or hybrid vehicles, especially in terms of improving air quality and reducing the health impacts of vehicle pollution. Research shows that even when EVs are charged from today's electricity grid, they still produce lower life-cycle emissions than comparable gasoline or hybrid vehicles. More importantly, as the electricity grid becomes cleaner, so do electric vehicles. EVs are the key technology for decarbonizing road transport, a sector that accounts for about one-sixth of global emissions. Ambitious policies remain crucial for the growth of EV markets worldwide.

III.5. Dedicated Cycling and Pedestrian Infrastructure

Most existing analyses of urban road transport performance do not adequately assess the impact of walking and cycling measures on pollution. Instead, they often focus solely on motor vehicle transport performance or exclude pedestrians and cyclists, or consider them as disruptions to vehicle traffic.

Promoting cycling supports physical activity but also reduces car trips and pollution, benefiting residents with cleaner air overall. Bicycle infrastructure calms traffic in residential neighbourhoods and reduces congestion on major roads, fuel consumption, air pollution, and more.

Positioning cycling as a form of transport is key to its adoption in North Macedonia, where it is mostly viewed as a recreational activity. By providing numerous protected bike lanes and simple usage improvements, such as green waves at traffic lights, more commuters will begin to see bicycles as a viable mode of transport, shifting from a form of exercise to a part of everyday life.

IV. Conclusion

Transport sector is one of the main sources of air pollution, especially in urban areas where vehicle concentration is high and alternative, environmentally friendly modes of transport are poorly developed or not used at all. This paper presents an analysis of the air quality situation in North Macedonia, with an emphasis on the city of Tetovo. The level of pollution caused by traffic is alarming, with a high presence of PM10 and NO_2, which are very harmful to human health. This level of air pollution is not only the result of fuel combustion but also the mechanical abrasive processes of brakes and tires. This confirms the fact that there is a great and urgent need for comprehensive and integrated traffic management measures, which include: introduction of congestion pricing, development of Intelligent Traffic Management Systems (ITMS), promotion of public transport, adoption of electric vehicles, encouragement of cycling and walking as alternative transportation solutions.

There are many good examples worldwide where such measures have shown excellent results. These should be considered, especially when it's clear that their implementation has not only reduced pollution but also improved the quality of life in major cities. An outstanding example is London, which has introduced an Ultra Low Emission Zone (ULEZ). The results of its implementation demonstrate that such outcomes are also achievable in our context with well-crafted traffic policies.

Therefore, it is clear that the state, together with local authorities, the professional public, and citizens, as part of one functional system, must develop a long-term strategy for sustainable traffic planning. This will enable not only a reduction in pollution but also an improvement in the quality of life for the population.

References

[1] Mustafai, M., & Mustafai, E. *Traffic as a cause of air pollution in Tetovo city and proposed measures to reduce CO_2 emissions.* TEC Journal. ISSN: 2303-5854 (print), e-ISSN: 2303-5900 (online).

[2] Ministry of Environment and Physical Planning of the Republic of North Macedonia (MoEPP), (June 2023). *Quality of the Environment in the Republic of Macedonia – Annual Report 2022.* Skopje.

[3] Lindov, Prof. Dr. Osman. (January 2017). *Ecological Engineering in the Field of Transport* (Doctoral Studies, 3rd cycle). Faculty of Transport and Communications, Sarajevo.

[4] Lindov, Prof. Dr. Osman. (2016). *Transport and Environment.* Faculty of Transport and Communications, Sarajevo.

[5] https://www.uisk.ba/en/journal-tec/item/155-x?utm

[6] https://www.sciencedirect.com/science/article/abs/pii/S221067072030216X

[7] https://www.moepp.gov.mk/sites/default/files/alfa/reports/2023_vkupengodisen_final.pdf

[8] https://www.burnhamnationwide.com/final-review-blog/bike-infrastructure-key-to-healthier-cities-reduced-emissions

[9] https://kunakair.com/air-pollution-from-transport/

ATTACHMENTS:
Student presentations

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Green Urban Transport Solutions

IDENTIFICATION OF HAZARDOUS LOCATIONS ON THE REGIONAL ROAD NETWORK THROUGH THE APPLICATION OF INTELLIGENT TRANSPORT SYSTEMS (ITS) TECHNOLOGIES: AN ANALYTICAL APPROACH.

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Introduction

- The identification of hazardous locations on the regional road network is crucial for traffic safety, directly impacting accident prevention and road security. The application of Intelligent Transport Systems (ITS) offers significant opportunities for improving the detection and analysis of high-risk points and optimizing road infrastructure.
- ITS technologies, including sensors, cameras, and radars, enable real-time monitoring of road conditions, incidents, traffic density, and violations. This data is processed using Big Data algorithms, allowing for the identification of dangerous locations and providing recommendations for intervention.
- Proactive identification of high crash-risk locations is an important approach in road safety and traffic management. It involves analyzing patterns of road accidents, traffic flow, weather conditions, and other contributing factors to identify locations that are prone to accidents before they occur. This enables authorities to take preventive actions to reduce crashes and improve safety.

Data and Obstacles

- This study will focus on analyzing the regional road network of Bitola – Prilep located in the Pelagonia region, with amounts to approx. 43km of length. After exclusion of urban sections, the length is approx.35 km. The road is an integral part of Corridor 10-D and holdssignificant importance for the country, providing a range of transportand economic benefits.
- The roadway section is a two-way road, single-lane-per-directionpaved route, characterized by gentle curves and gradients, currentlyundergoing construction activities.

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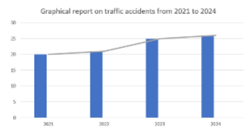
Traffic Accident Data Analysis

- Based on the collected accident data for the period from 2021 to 2025, the following analysis has been conducted, categorized by type of accident, couse of an accident and nature of consequences.
- A year-on-year increase in the number of traffic accidents can be observed from 2021 to 2024. The year 2024 recorded the highest number of traffic accidents, with a total of 26 accidents, compared to 2021, which had 20 accidents. This is most clearly illustrated in the following diagram (Figure 2):



The processed data are official data obtained from the MIA Bitola and SIA Prilep

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PESTLE Analysis

- This framework helps in identifying key areas for intervention and improving road safety strategies.

PESTLE analysis

P Political	E Economic	S Social	T Technological	L Legal	E Environmental
• Support from the government and local authorities for road safety-related projects. • European standards and regulations for transport safety.	• Financial feasibility of implementing ITS systems. •Opportunities for obtaining grants from the EU and international institutions. • Reduction of economic losses due to traffic accidents.	• Improving safety for residents and passengers. • Reducing the number of accidents and casualties. • Raising awareness among drivers through notification and control systems.	•Implementation of smart traffic lights and traffic monitoring systems. • Introduction of road condition detection systems (humidity, ice, fog). • Use of GPS and IoT devices for better traffic management.	• Obligations for maintenance and technical integrity of ITS systems. • Compliance with European standards for smart transport. • Regulations for the use of ITS systems in traffic.	• Reducing pollution through traffic optimization. • Using solar energy to operate ITS devices. • Protecting nature by reducing traffic incidents with wild animals.

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Proactive Identification

- There are established methods that help detect, prioritise and treat high crash-risk sites based solely on prior crash history.
- The road safety check types are:
  - road safety impact assessments
  - road safety audits
  - road safety inspections
  - road assessment programmes

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Road Safety Impact Assessment

- Road safety impact assessment is conducted for infrastructure projects at the initial planning stage before the infrastructure project is approved. It indicates the road safety considerations which contribute to the selection of the proposed solution and provides all relevant information necessary for a cost-benefit analysis of the different options assessed.

Road Safety Audit

- A road safety audit is defined as a formal and independent technical check of a road scheme design and construction, to identify any unsafe features or potential hazards and to provide recommendations for rectifying them during all stages, from planning to early operation.

Road Safety Inspection

- The PIARC Road Safety Inspection Guideline for Safety Checks of Existing Roads (2012a) defines a road safety inspection (RSI) as a systematic, on-site review of an existing road with the aim of identifying hazardous conditions, faults and deficiencies that may lead to serious crash outcomes.

Road Assessment For Safety Infrastructure

- The proactive approach has been extended with a method that takes a quantified approach to the inspection of existing roads and road designs. Although several approaches exist, the most commonly applied is the Road Assessment Programme (RAP).

- RAPs take the concept of road safety audit and inspection a step further by estimating the risk (based on likelihood and severity) for different road sections based on road and roadside characteristics.

ITS Technology

- Traffic Management Systems (TMS) are a key component of Intelligent Transportation Systems (ITS), which utilize advanced technologies for monitoring, controlling, and optimizing traffic flows in real time.

- These systems include the integration of cameras, sensors, traffic lights, and other devices, which work together to provide efficient traffic management and improve the safety and flow of vehicles.

Sensors and Cameras for Traffic Monitoring

- Sensors are installed on roadways to monitor vehicle speeds, their density, and other important parameters. Sensors and cameras for traffic monitoring are placed on roads to track the speeds of vehicles, their density, and other crucial factors.

Traffic Forecasting and Driver Information

- Traffic forecasting uses historical and real-time data to predict road conditions, congestion, and accidents. Information is shared via signs, apps, or vehicle systems, including alerts on accidents, weather, and road hazards.

Traffic Accident and Emergency Situation Control

- When a traffic accident or other emergency situation occurs, information from sensors and cameras is used for quick detection and identification of the issue. ITS systems can redirect traffic, activate warning signs, or block lanes to allow for intervention by emergency services.

Conclusion

- Improving road safety requires both reactive and proactive approaches, with Intelligent Transportation Systems (ITS) playing a key role through real-time monitoring, predictive analytics, and emergency coordination.

- The Bitola–Prilep road study highlights the value of structured safety evaluations and ITS technologies in reducing accidents and optimizing traffic flow. Integrating data-driven strategies, proactive assessments, and advanced technologies leads to safer road networks and more efficient traffic management.

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INTELLIGENT TRANSPORTATION SYSTEMS

Intelligent Transportation Systems for Sustainable Smart Cities

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Introduction

- Intelligent Transport Systems (ITS) have emerged as a revolutionary force in the rapidly evolving environment of modern transport. Fundamentally changing the way we move people and things. They combine cutting-edge technology, data analysis and communication, systems that aim to improve the efficiency of transport networks, safety and environmental friendliness.
- ITS uses cutting-edge information and communication technology to improve several areas of transportation, including traffic management, vehicle management, and public transportation systems. ITS seeks to alleviate traffic congestion, reduce travel times, improve safety, and limit environmental impacts using real-time data, sensor networks, and intelligent algorithms.
- The scope of ITS is extensive, covering a wide range of applications, including intelligent traffic signal systems, autonomous vehicle technology, dynamic route planning, electronic toll collection, and real-time public transport tracking. These advances not only improve everyday transportation for individuals, but also contribute to broader societal goals such as energy conservation, lower emissions and improved urban planning. With the ongoing acceleration of urbanization and the increasing demand for efficient transportation, ITS plays a key role in determining the future of mobility. Global governments, corporations, and researchers are allocating resources to implement ITS technologies to establish more intelligent, interconnected, and environmentally friendly transportation ecosystems.

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Table.1 Four pillars of a smart city (source)

Source: Compiled by the authors

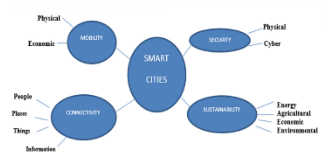

Table 2. Smart city model

Source: Compiled by the authors

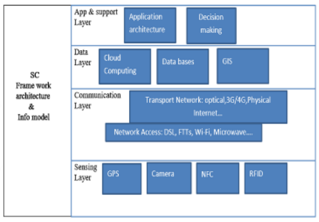

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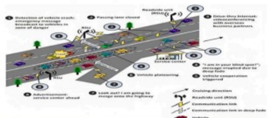
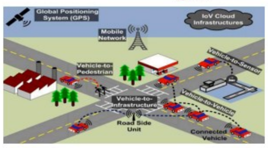
Fig. 3 and 4. Vehicle communication in smart cities and vehicle communication scenario and Table 6. How certain cities benefited from the implementation of ITS
Source: Compiled by the authors





	City	ITS Technology	Achievements
I.	Los Angeles, USA	*ITL *Traffic prediction *Mobility prediction	*Reduction of travel time by 16% and pauses at intersections by 12% *Reduction in GHG emission
1.	Montreal, Canada	*VANETs (V2P& V2I) *ITL *Cameras	*V2P could decrase the accidents rate by 60% *Reduction in fuel Consumption and CO_2 emission. *Fast emergency services
2.	Singapore, Singapore	*Traffic monitoring by real time data from sensors and cameras with the help of 5G	* Regular traffic flow. * Reduce congestion. *Established a goal of 36% Carbon emisson.
3.	Barcelona, Spain	*ITL *Smart Parking *Real time automsted traffic management	*Reduction in traffic congestion *Reduction in air pollution *Less idling time *Being carbon neutral by the year 2025
4.	Copenhagen, Denmark	*Smart parking *Traffic monitoring by real time data	

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Conclusion

- Intelligent Transport Systems (ITS) play a key role in shaping sustainable smart city strategies by revolutionizing transport efficiency, safety and connectivity. Through real-time data analysis, optimized traffic management, and improved public transportation, ITS enables cities to achieve reduced congestion, improved air quality, and efficient mobility solutions.
- By integrating advanced technologies and data-driven decision-making, ITS enables seamless travel, encourages sustainable modes of transportation, and promotes smarter resource allocation. As cities strive to build more sustainable and livable environments, ITS stands as a key enabler, shaping the future of urban transportation and paving the way for sustainable smart city strategies.

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Green Urban Transport Solutions

Gis based solutions for road network managment

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Introduction

- ***GIS*** *or* ***"Geographic Information System"*** *is a computer system that is capable of integrating, storing, organizing, analyzing and displaying geographic information.*
  - ***GIS*** is often used for the needs of marketing research, geology, construction, but also in all fields that use data related to maps. ***GIS*** science is often considered a subdiscipline of geography within the branch of technical geography. It is associated with various operations and numerous applications, relating to engineering, planning, management, transportation, insurance, telecommunications and business, as well as natural sciences such as forestry, ecology and Earth science.
  - ***GIS*** also provides the ability to link previously unrelated information, through the use of location as a "key index variable".

Maps and Software

- ***GIS applications*** include hardware and software systems. These applications may include cartographic data, photographic data, digital data, or tabular data.
- ***GIS maps*** can be used to display information about numbers and densities. With ***GIS technology***, researchers can also look at changes over time. They can use satellite data to study topics such as the advance and retreat of ice sheets in polar regions and how that coverage has changed over time.

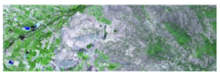

Figure 1: GIS Map

- The traditional form of ***GIS software***, first developed for mainframes and minicomputers, then for Unix workstations, and now for personal computers. Desktop ***GIS software*** provides a full suite of capabilities, although some programs are modularized with extensions that can be purchased separately.
- The ***GIS software*** industry encompasses a wide range of commercial and open source products that provide some or all of these capabilities across a variety of information technology architectures.

Figure 2: GIS Software

- Early server software focused specifically on web mapping, including only the output stage, but current server ***GIS*** provides the full suite of features.

Application in transport and modeling

- ***Geographic Information Systems*** have a wide range of applications in transportation, enabling better planning, management, and optimization of transportation systems. This includes using ***GIS tools*** to map roads, railways, public transportation, and other transportation networks. ***GIS*** is also used for traffic analysis, route optimization, fleet management, and transportation infrastructure planning.

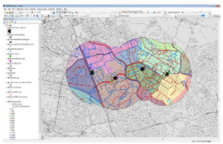

Figure 3

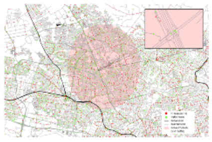

Figure 4

- Topographic data in a ***GIS platform*** can be converted into functional road models for large-scale traffic simulation. ***GIS*** helps to geocode road networks as vector layers with a set of attributes that helps to organize and spatially visualize the road network based on their characteristics.

Data analytics, road safety

- ***Spatial data*** can use accurate, real-time, and comprehensive information to inform transportation and infrastructure use. ***GIS*** delivers powerful spatial analytics for processing data from mobile phone GPS, public transit, and roadside sensors to create forecasts based on historical data, to support real-time route suggestions, to build long-term visualization tools for use by policymakers and transportation planners, regulatory or revenue-raising applications, and to actively manage the transportation network.

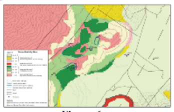

Figure 6

- ***Road safety*** applications include analyzing traffic accident data, sharing traffic accident risks, reporting pedestrian safety issues, and locating high-risk roads. ***GIS*** can analyze historical accident data, allowing authorities to find patterns and identify traffic accident hotspots

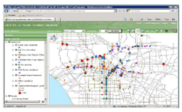

Figure 5

- ***GIS*** helps to assess, monitor and mitigate environmental problems and is useful in preparing Environmental Impact Statements or transportation infrastructure projects to include relevant information on risks, hazards and areas to be protected. ***GIS*** to know where transportation inventory is located and information about them. The process of managing infrastructure using ***GIS*** includes identifying assets, mapping them, and assessing their condition.

GIS in Macedonia

- Prilep has introduced the most modern and unique ***GIS system*** of its kind in Macedonia. With the help of a geo scanner and other sophisticated equipment, all underground installations can be detected up to 8 meters underground and it can be seen whether there is a burst pipe somewhere and whether there is water loss.
- Problems in the sewage system will also be detected with a camera that will be placed in the pipes. While other special detectors will be used to locate other underground installations so that they are not damaged while digging.

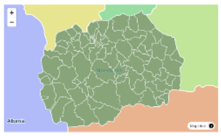

Figure 7

Conclusion and future work

- ***GIS*** is a powerful tool that allows users to analyze and visualize geographic data to understand patterns, relationships, and trends.Its applications are widespread, from urban planning and environmental management to logistics and disaster response, making it indispensable in many industries. Why is ***GIS*** indispensable? Because it unifies data, space, and time into one, and visually! A map often says more than a table.