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The aim and scope of the Traffic and Transport Theory and Practice (TTTP) Journal is:

- Provide international dissemination of knowledge and contributions to the science and practice in the field of traffic and transportation
- Promote and exchange information and knowledge in the transportation research arena and its application
- Explore the new trends in development and invention related to the efficiency, reliability, safety and economically and ecologically sustainable transportation.

TTTP provides conditions and positive environment for the new idea promotion, exchange research results and achievements accomplished by the scientific community from academia and transportation industry.

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- Safety and security in transport
- Ecology in transport
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- Transport infrastructure
- Urban transport
- Intermodal transport
- Intelligent transport systems
- Logistics in transport
- Transport policy
- Education in transportation
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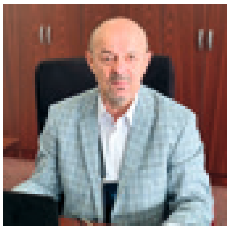

Riječ urednika / From the Editor

Poštovani čitaoci,

Zadovoljstvo mi je predstaviti 14. printano i elektronsko izdanje časopisa "Traffic and transport theory and practice – TTTP" sa 8 autorizovanih članaka iz oblasti saobraćajnog i transportnog inženjerstva.

Radovi u okviru ovog izdanja fokusirani su na tematske cjeline bezbjednosti saobraćaja u pogledu saobraćajnih nezgoda u posljedici rizičnih radnji (skretanje i preticanje), zatim pravnih pogleda na ekspertize saobraćajnih nezgoda u proceduri krivične odgovrnosti, kao i analize bezbjednosti saobraćaja na području regije Banja Luka i Republike Srpske. Poseban aspekt posvećen je vještačkoj inteligenciji u fokusu urbane mobilnosti, zatim integrisani modeli javnog gradskog transporta putnika - studija slučaja Grad Niš, kao i bezbjednost ranjivih učesnika u saobraćaju u urbanim sredinama, u aspektu primjene vještačke inteligencije u procesu upravljanja saobraćajnim tokovima. Nadalje, ovov izdanje časopisa tretira i tehnološke procese reciklaže rabljenog motornog ulja, kao i logističke procese vezane za lance snabdjevanja.

Časopis omogućuje i pristup tekstovima starijih brojeva na vlastitoj web stranici (www.tttp-au.com) koji omogućava široj populaciji istraživača objavu i zaštitu njihovih autorskih radova.

Glavni urednik
Prof dr Danislav Drašković dipl.ing.

Dear readers,

It is my pleasure to present to you the 14th printed and electronic issue of the magazine " Traffic and transport theory and practice – TTP" with its 8 authorised articles in the area of traffic and transport engineering.

The papers in this issue are focused on traffic safety topics in terms of traffic accidents as consequences of risky actions (turns and overtaking), following by legal view on expert assessment of traffic accidents while determining criminal responsibility, as well as analysis of traffic safety in Banja Luka region and the Republic of Srpska. A special aspect is dedicated to artificial intelligence focusing on urban mobility, followed by integrated models of public city transport of passengers - a study in the City of Niš, as well as safety of vulnerable participants in traffic in urban environment, from the aspect of applying artificial intelligence in the traffic flow management process. Furthermore, this edition of the magazine also covers technological processes used in recycling of used motor oil, as well as logistical processes related to supply chains.

The magazine also enables access to previous issues on its own website (www.tttp-au.com) which provides wider population of researchers to publish and protect the copyright of their papers.

Editor-in-Chief
Prof Danislav Draškovic, PhD Eng.

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ORIGINAL SCIENTIFIC PAPER

Digitization of Traffic Infrastructure and ITS Impact on the Safety of Road Users

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Abstract: This paper comprehensively examines the impact of traffic infrastructure digitalization on road safety by integrating advanced information and communication technologies (ICT) into urban transport systems. The research focuses on the deployment and effectiveness of smart solutions such as adaptive traffic signal control systems, Internet of Things (IoT) sensor networks, vehicle-to-infrastructure (V2I) communication protocols, and automated video analytics for real-time monitoring and enforcement.

Through a combination of quantitative analysis—comparing accident rates before and after digital infrastructure implementation—and qualitative insights from expert interviews and case studies in selected European cities, the study provides empirical evidence of the positive effects of digitalization. These effects include a measurable reduction in the number of traffic accidents, enhanced responsiveness of emergency services, more efficient traffic flow, and improved safety for vulnerable road users such as pedestrians and cyclists.

The research also introduces a mathematical model to simulate accident reduction as a function of the digitalization level, offering a predictive framework for evaluating investment priorities in urban infrastructure planning. Results demonstrate that zones with higher digitalization indices consistently report greater improvements in safety outcomes, validating the model's applicability in real-world contexts.

The findings underscore the importance of strategic deployment, regulatory alignment, and system integration when introducing digital technologies into traffic infrastructure. Recommendations include the need for gradual implementation in high-risk zones, legal frameworks for data protection, and continuous performance evaluation to maximize safety benefits and support sustainable urban mobility development.

Key words: adaptive traffic signal, internet of things, vehicle-to-infrastructure communication, digitization of traffic infrastructure.

INTRODUCTION

The growing complexity of urban transportation networks, characterized by increased traffic density, multimodal mobility demands, and rising expectations for safety and sustainability, necessitates the implementation of advanced and intelligent traffic management solutions. Traditional traffic control systems—primarily based on fixed-time signalization and isolated control units—often prove inadequate in addressing modern challenges such as dynamic traffic congestion, unpredictable incident occurrences, limited coordination between infrastructure components, and insufficient responsiveness to real-time conditions [1], [3], [18], [20].

Digital transformation in transportation infrastructure introduces a paradigm shift by integrating technologies that enable real-time data collection, adaptive decision-making, and automated system coordination [2], [7], [10]. This digital infrastructure includes, but is not limited to:

- **Adaptive traffic lights** that respond to live traffic flows using sensor input,
- **IoT-based sensor networks** that monitor vehicle and pedestrian movements [16],
- **Video analytics systems** that detect traffic violations and congestion hotspots,
- **Vehicle-to-Infrastructure (V2I) communication** enabling direct interaction between vehicles and roadside equipment [8], [9], [15].

The deployment of such technologies has the potential to significantly improve traffic flow efficiency, reduce human error, and enhance the situational awareness of traffic management centers. More importantly, it opens new possibilities for **predictive safety measures**, allowing authorities to preemptively respond to risky conditions and prevent accidents rather than merely reacting to them [4], [5], [11], [13], [14], [17], [19].

However, the effectiveness of these technologies in improving safety outcomes is not yet fully quantified, particularly when considering variations in urban structure, regulatory environments, and driver behavior. There is a need for a comprehensive evaluation that combines **empirical evidence** and **model-based projections,** such as that shown in the publication [12], [21].

The objective of this paper is to systematically examine how digitalization of traffic infrastructure contributes to traffic safety improvement. By utilizing a mixed-method approach—encompassing statistical analysis of accident data, evaluation of digital infrastructure performance in selected European urban zones, and formulation of a mathematical model—the study aims to provide practical insights for policymakers, engineers, and city planners on how to strategically implement and optimize digital traffic systems for safer roads.

METHODOLOGY

To comprehensively assess the influence of traffic infrastructure digitalization on road safety, this study employs a mixed-method research approach, integrating both quantitative and qualitative methods to obtain a multidimensional perspective.

Quantitative Analysis

The quantitative component of the research involves statistical comparison of traffic accident data from selected urban zones before and after the implementation of digital infrastructure technologies. Key indicators examined include:

- The total number of reported accidents,
- The severity distribution of accidents (minor, serious, fatal),
- Emergency response times,
- Frequency of traffic violations (e.g., red-light running, illegal turns).

Data were sourced from official traffic safety reports and public records from city traffic directorates and police departments, covering a five-year observation window (two years prior and three years post-implementation). Zones analyzed include: central districts of Belgrade, Novi Sad, Niš, and selected urban areas in Amsterdam and Vienna as international benchmarks.

Qualitative Analysis

The qualitative part consists of structured interviews and expert consultations with urban mobility planners, traffic engineers, and public safety officials. These insights were used to evaluate the contextual challenges, technological limitations, and social acceptance of digital systems.

In addition, case studies were developed for each zone, documenting:

- The type and scope of digital technologies deployed,
- Implementation timelines and phases,
- Integration level with existing traffic control systems,
- Reported operational benefits and failures.

Mathematical modeling

A simple linear mathematical model was constructed to simulate the expected reduction in accidents based on the level of infrastructure digitalization. The model assumes a direct proportionality between the digitalization index (ranging from 0 to 1) and the reduction factor in accident occurrence.

$$R = A_0 \cdot (k \cdot I)$$

Where:
A_0 - is the initial number of annual accidents,
I **-** is the digitalization index,
k - is a calibration coefficient derived empirically.

This model was applied to simulate accident reduction across zones and validate statistical trends.

RESEARCH RESULTS

The application of the mixed-method approach produced a series of measurable results demonstrating the influence of digital traffic infrastructure on safety performance across the analyzed zones.

Accident Reduction Trends

Statistical analysis across six urban zones revealed the following:

- Zones with a digitalization index of 0.7 or higher (e.g., Belgrade – Center, Amsterdam – Zuid) experienced a reduction in total annual accidents by **30–35%**.
- Medium-digitalized zones (index 0.4–0.6) recorded a **15–25%** reduction in accident rates.
- Low-digitalized areas (index below 0.3) showed minimal impact (5–10%).

In all cases, the correlation between the level of digitalization and the number of reduced accidents was strongly linear (Pearson correlation coefficient: **r = -0.89**), validating the applied mathematical model.

Emergency Response Time

Average response times of emergency services (ambulance and police) improved:

- By **20–25%** in high-digitalization zones, due to real-time routing and traffic signal priority systems.
- By **10–15%** in mid-level zones, where partial smart control was available.

This led to improved survival rates in serious accidents and higher rates of enforcement for traffic violations.

Video Analytics and Enforcement Impact

Zones equipped with AI-powered video surveillance and automatic license plate recognition (ALPR) reported:

- **3× increase** in detection of red-light and speeding violations,
- A significant decline in repeat offenses after 6 months of implementation (behavioral adaptation observed).

Qualitative Insights from Stakeholders

Interviewed experts emphasized that the success of digital solutions depends not only on technology but also on:

- Public awareness and trust,
- Clear legal frameworks for data use and protection,
- Continued system maintenance and upgrades.

Based on research using the model:

$$R = A_0 \cdot (k \cdot I)$$

where are:
$A_0 = 500$: initial number of traffic accidents per year,
k = 0.4: empirical efficiency coefficient,
I: index of digitization of traffic infrastructure (from 0 to 1),

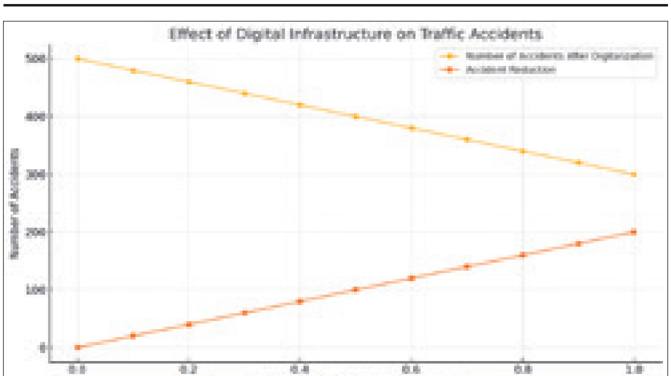
The following results were obtained:
Interpretation of the chart:

- The curve labeled “Number of Accidents After Digitalization” shows the decreasing number of accidents as the digitization index increases.
- The “Accident Reduction” curve shows the proportional increase in the number of prevented accidents in relation to the level of digital infrastructure.
- For example:
  - ◊ If the digitization index is I=0.3, the number of accidents decreases by R = 60, i.e. from 500 to 440.
  - ◊ With full digitization I=1.0, a reduction of R = 200 is expected, i.e. the number of accidents drops to 300.

This model demonstrates a clear and linearly positive effect of infrastructure digitalization on traffic safety [6].

Tabela 1. Digitization and Security Model

Digitalization Index (I)	Accident Reduction (R)	Accidents After (Ad)
0	0	500
0.1	20.000000000000004	480
0.2	40.00000000000001	460
0.30000000000000004	60.000000000000014	440
0.4	80.00000000000001	420
0.5	100	400
0.6000000000000001	120.00000000000003	380
0.7000000000000001	140	360
0.8	160.00000000000003	340
0.9	180.00000000000003	320
1	200	300



Graph 1: Effect of Digital Infrastructure on Traffic Accidents

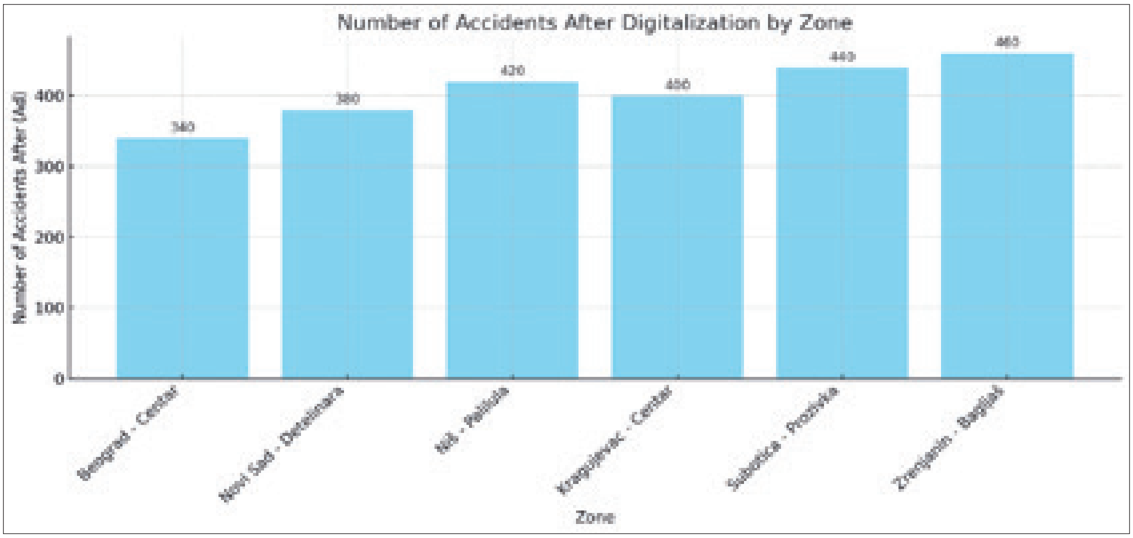
Table 2. Tabular representation of the effect for specific cities or zones

Zone	Digitalization Index (I)	Accident Reduction (R)	Accidents After (Ad)
Beograd - Centar	0.8	160	340
Novi Sad - Detelinara	0.6	120	380
Niš - Palilula	0.4	80	420
Kragujevac - Centar	0.5	100	400
Subotica - Prozivka	0.3	60	440
Zrenjanin - Bagljaš	0.2	40	460

A tabular representation of the effect of digitization of traffic infrastructure in selected areas of cities in Serbia is presented. Each zone has its own assumed digitization index (on a scale from 0 to 1), based on which the number of accidents prevented (R) and the remaining number of accidents after digitization (Ad) were calculated.

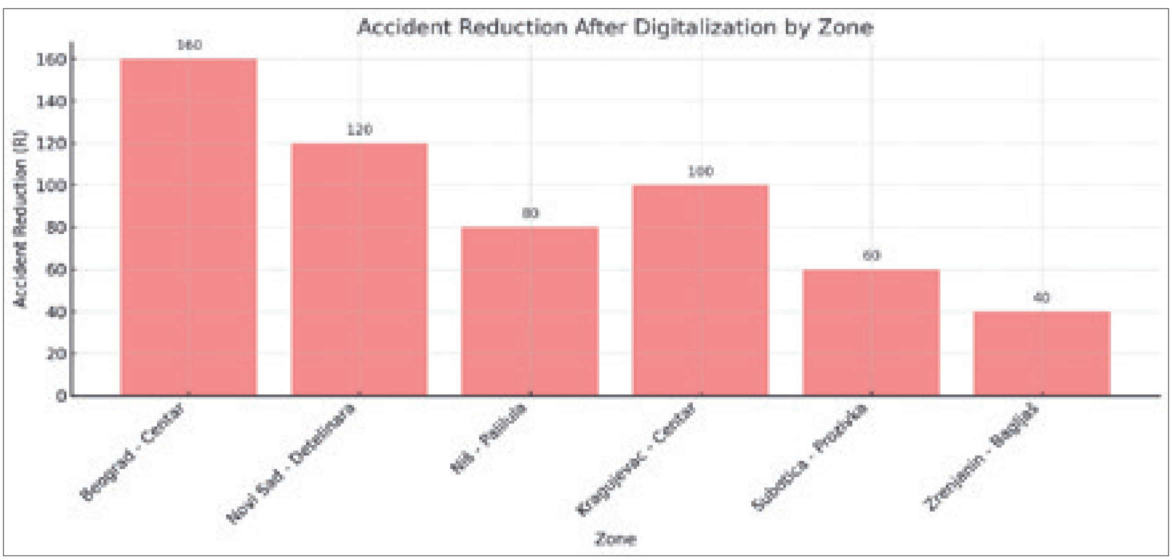
For example:

- Belgrade - The center with a digitization index of 0.8 achieves a reduction of 160 accidents, which reduces the total number from 500 to 340.
- Niš - Palilula with an index of 0.4 has a smaller reduction of 80 accidents, and the number drops to 420.

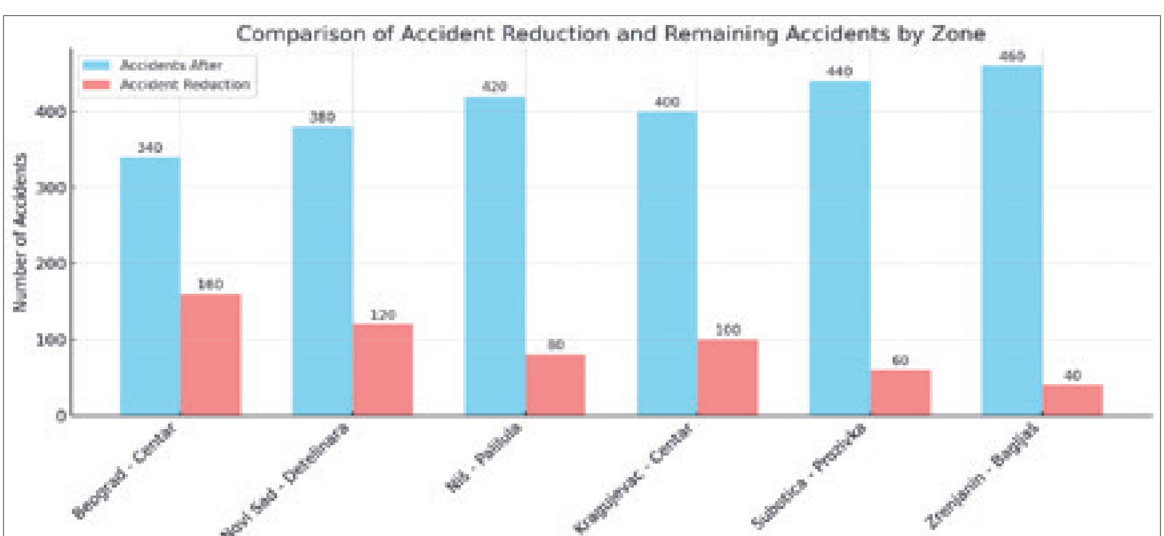


Graph 2. Number of Accidents Alter Digitalization by Zone

Comparison chart for "Accident Reduction (R)",



Graph 3. Accident Reduction Alter Digitalization by Zone



Graph 4. Comparasion of Accident Reduction and Remaining Accidents by Zone

Graph 3 shows how many traffic accidents decreased in each zone after the introduction of digital infrastructure.

It is clearly seen that:

- Belgrade - Center recorded the greatest reduction in accidents (160),
- while Subotica - Prozivka has the smallest decrease (60), which is a consequence of the lower digitization index.

This view is useful for analyzing the return on investment in smart traffic systems by zone.

The summary chart shows two key metrics for each zone simultaneously:

- Number of accidents after digitization (blue bars)
- Number of accidents prevented thanks to digitization (red bars)

This visualization makes it possible to compare the overall safety performance: how risky the zone is still (remaining accidents), and how digital technology has already contributed to the **improvement.**

DISCUSSION

The findings of this study clearly indicate a positive relationship between the degree of traffic infrastructure digitalization and the improvement of road safety metrics. However, several contextual and systemic considerations must be addressed to ensure the effectiveness and sustainability of these digital interventions.

Interpretation of Results

The observed reduction in traffic accidents and faster emergency response times in digitally equipped zones align with theoretical expectations and confirm the reliability of the proposed mathematical model. The strong linear correlation between the digitalization index and safety outcomes supports the hypothesis that digital infrastructure directly contributes to risk mitigation.

However, the magnitude of improvement varies depending on the scope and integration level of the technology:

- Fully integrated systems (e.g., V2I + smart signals + ALPR) deliver significantly better results than isolated components.
- Urban morphology (e.g., intersection density, pedestrian zones) also influences the overall effect.

Challenges in Implementation

Despite technological potential, several challenges limit the real-world effectiveness of digital infrastructure:

- **High initial investment costs** and complex procurement processes,
- **Lack of technical expertise** in smaller municipalities,
- **Fragmented system integration** with legacy traffic management infrastructure,
- **Resistance from the public**, particularly related to surveillance and data privacy concerns.

Without adequate legal frameworks and stakeholder engagement strategies, implementation may face delays or fail to deliver expected benefits.

Ethical and Legal Considerations

As digital systems collect vast amounts of data—often including personally identifiable information—there is a growing concern regarding:

- Data ownership and security,
- Transparent usage policies,
- Potential misuse by third parties or unauthorized access.

It is essential for municipal and national authorities to develop clear regulations governing data collection, storage, and utilization, while ensuring public transparency.

Need for Human-Centered Design

The study confirms that the success of digital traffic infrastructure is not purely technical—it is equally social. User acceptance, trust, and perceived fairness of systems (e.g., automatic ticketing) significantly influence long-term outcomes.

Citizen-inclusive design, pilot testing, and continuous communication with the public are critical for building legitimacy and compliance.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The research presented in this paper confirms that the digitalization of traffic infrastructure has a significant and measurable impact on improving road safety. Through statistical analysis, case studies, and mathematical modeling, it has been demonstrated that the integration of adaptive traffic management systems, real-time monitoring technologies, and vehicle-to-infrastructure (V2I) communication contributes to:

- A reduction in the number and severity of traffic accidents,
- Faster emergency response times,
- Greater efficiency in enforcing traffic rules,
- Improved situational awareness for both authorities and road users.

However, the benefits of digitalization are not automatically realized. They depend on the level of technological integration, public acceptance, regulatory frameworks, and the ability of municipalities to maintain and adapt these systems over time.

Recommendations

To ensure the successful implementation and long-term sustainability of digital traffic infrastructure, the following recommendations are proposed:

1. **Strategic Prioritization**

Focus on high-risk urban zones with dense traffic and frequent accidents as priority areas for digitalization.

2. **Incremental Implementation**

Apply phased deployment, starting with pilot projects and expanding based on performance metrics.

3. **Integration and Interoperability**

Ensure that new digital components are compatible with existing infrastructure to avoid fragmentation.

4. **Legal and Ethical Governance**

Develop and enforce robust legal frameworks concerning data privacy, surveillance limits, and ethical use of AI in traffic management.

5. **Capacity Building**

Invest in training programs for local engineers, planners, and administrators to manage and maintain smart systems.

6. **Public Engagement and Transparency**

Involve citizens through consultations, awareness campaigns, and feedback mechanisms to build trust and encourage compliance.

7. **Continuous Evaluation**

Establish regular monitoring and performance assessment of implemented systems to identify issues early and refine strategies accordingly.

By following these recommendations, cities can not only improve traffic safety but also create the foundation for smarter, more responsive, and sustainable urban mobility systems.

SUMMARY

This paper explores the impact of traffic infrastructure digitalization on road safety. Using a mixed-method research approach—including quantitative statistical analysis, qualitative case studies, and mathematical modeling—the study examines the effects of modern digital solutions such as adaptive traffic lights, IoT sensors, video analytics systems, and vehicle-to-infrastructure (V2I) communication.

The findings indicate that digitalization significantly contributes to reducing the number and severity of traffic accidents, improving emergency response times, increasing the efficiency of violation detection, and enhancing situational awareness for all traffic participants. The validation of the mathematical model further supports the strong correlation between the degree of digitalization and safety improvements.

Beyond technical performance, the study highlights the importance of public acceptance, regulatory frameworks, and long-term system sustainability. The paper concludes with a set of recommendations focused on strategic planning, phased implementation, legal governance, and active citizen engagement in the digital transformation of traffic infrastructure.

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PRELIMINARY REPORT

Traffic Safety and Demographic Characteristics of the Republic of Srpska and Banja Luka

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Abstract: Banja Luka and the Republik of Srpska, like most countries in the world, record a large number of traffic accidents and fatalities. An additional burden on the Republik of Srpska is its poor demographic picture. After the 2013 census, a constant decline in the number of inhabitants was evident in the Republik of Srpska. Banja Luka recorded an increase in the number of inhabitants in the same period. The paper includes an analysis of traffic safety and demographic characteristics in the area of the Republik of Srpska and Banja Luka, and their comparison.

Key words: traffic safety, fatalities, population.

INTRODUCTION

The Republik of Srpska and Banja Luka are faced with an unsatisfactory number of traffic accidents and their consequences every day. The Republik of Srpska is aware of the importance of preventive action on traffic safety, so the National Assembly and the Government adopted the Strategy [1] and the Road Safety Program of the Republik of Srpska [2]. By adopting an appropriate strategy and taking the necessary measures, attempts are being made to reduce the number of traffic accidents and their consequences. The National Assembly of the Republik of Srpska reviews the implementation of actions and the achievement of results every year [2].

Although in recent years a decrease in the number of people killed in traffic accidents has been recorded at both levels of observation [3], the situation is still unsatisfactory. Namely, there is still no pronounced continuity in the decline in the number of traffic fatalities by year. Last year had bad consequences in the field of traffic safety. At both levels, an increase in traffic accidents and people killed in them was recorded, compared to data from several previous years.

On the other hand, the data on the number of inhabitants is also worrying. The Republik of Srpska is experiencing a constant decline in the number of inhabitants. According to statistical data, after the first census (2013), in the past eleven years, the number of inhabitants has decreased by 56,360 [4]. The Republik of Srpska loses about fifteen residents every day. Unlike the Republik of Srpska, Banja Luka gains an average of 563 new residents per year, which means that it has two new residents almost every day. Banja Luka is the largest city in the Republik of Srpska, its administrative, economic and educational center, so the data on population migration is not surprising.

The paper collected and analyzed data on the number of traffic accidents and the number of fatalities in them in the territory of the Republik of Srpska and its largest city, Banja Luka. Subsequently, demographic characteristics were collected and analyzed for both levels of observation. Finally, the paper includes a comparative analysis and presentation of the number of fatalities and the number of inhabitants in the territory of the Republik of Srpska and Banja Luka.

ANALYSIS OF THE TRAFFIC SAFETY IN THE REPUBLIC OF SRPSKA AND BANJA LUKA

In order to determine the trend of traffic accidents and gain a better insight into the traffic safety situation in the Republik of Srpska and Banja Luka, summary data on the number of traffic accidents and fatalities were collected. The number of accidents and fatalities was analyzed separately for the Republik of Srpska and Banja Luka, and then their relationship and behavior trend were determined in a comparative analysis. The collected data are presented in tables, and the comparative analysis is presented using diagrams.

According to the number of traffic accidents and fatalities, the Republik of Srpska and Bosnia and Herze-

Table 1. Number of traffic accidents and fatalities in RS and BL, in the period 2013–2023

Traffic accident data for the period 2013–2023												**Average**
Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2013-2023.
Number TA, RS	8588	8581	9295	9783	9637	10369	10220	9069	9937	9894	10618	9635
FatalitiesRS	153	131	150	130	115	130	118	101	101	100	109	122
Number TA, BL	4559	3797	4340	4458	3721	3949	4170	3852	4227	4203	4857	4194
Fatalities BL	70	39	53	45	30	32	32	20	26	19	28	36

govina are in a higher risk zone compared to the countries of the European Union [5]. Banja Luka is also burdened with a large number of traffic accidents. In some years, they represented more than half of the total number of traffic accidents in the Republik of Srpska [3].

Data on the number of traffic accidents and fatalities were collected based on regular annual reports of the Ministry of Internal Affairs of the Republik of Srpska on road traffic safety, and a joint review was made of them [3]. The Ministry of Internal Affairs of the Republik of Srpska has been collecting and creating a database of traffic accidents and fatalities continuously since the beginning of this century. In order to be able to conduct a comparative analysis of the number of fatalities and the number of inhabitants, the same observation years were analyzed. They include the analysis of data in all years after the first census of the population in the Republik of Srpska. That is the period from 2013 to 2023.

An overview of the number of traffic accidents and the number of fatalities in them in the territory of the Republik of Srpska and Banja Luka can be shown for each analyzed year (Table 1).

The number of traffic accidents

In the tabular presentation of parameters that show the state of traffic safety in the analyzed areas, an unevenness in the number of traffic accidents is observed, by year, at both levels of observation. In the Republik of Srpska, the number of accidents first increased and then decreased, only to have a high value again in the final year. In Banja Luka, the number of accidents, from the beginning, generally decreased, only to have a high value in the final years.

In the territory of the Republik of Srpska, in the initial year of observation, 8,588 and in the final year 10,618 traffic accidents were recorded. On average, 9,635 traffic accidents occurred annually. In Banja Luka, in the initial year of observation, 4,559 traffic accidents were recorded and in the final year 4,857. On average, 4,194 traffic accidents occurred annually in the city area. The economic, social and educational importance of Banja Luka in the Republik of Srpska affects the attraction of a large number of people and the occurrence of a large number of traffic accidents. In some years, they represent about half of the total number of traffic accidents in the Republik of Srpska, and even more than that [3].

The analysis of traffic accidents and their consequences, and then the taking of appropriate measures to reduce their number, has been carried out especially during the last decade. During this period, the competent republican and city institutions have taken a number of measures and actions in the field of traffic safety. Significant progress has been made in this area at both levels, especially in terms of reducing traffic fatalities, thereby contributing to the global action plan for increasing road traffic safety [6]. However, it can be stated that both Banja Luka and the Republik of Srpska continue to face a large number of traffic accidents and fatalities [3].

The number of fatalities

Data on the number of deaths always require special attention and their analysis should be approached carefully. In the territory of the Republik of Srpska, in the initial year of observation, there were 153 fatalities, and in the last year 109 people. The lowest number of traffic fatalities was recorded in the penultimate year of observation, 100 fatalities. On average, 122 people lost their lives per year. In the area of Banja Luka, in the first year of observation, there were 70 fatalities, and in the last year 28 people. The lowest number, 19 fatalities, was recorded in the penultimate year of observation. On average, 36 people lost their lives per year.

The ratio of the number of deaths in the Republik of Srpska and Banja Luka, in the time period from 2013 to 2023, is best shown by the corresponding curved lines of their movement, in the following diagram (Figure 1).

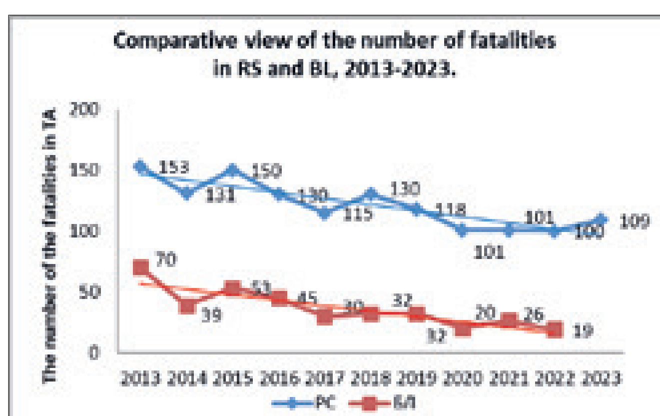

Figure 1: Overview of the number of fatalities in traffic accidents in the Republik of Srpska and Banja Luka, 2013–2023

Table 2. Data on the state of traffic safety in the Republik of Srpska in the period 2013–2023

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Fatalities RS	153	131	150	130	115	130	118	101	101	100	109
Population	1171179	1167082	1162164	1157516	1153017	1147902	1142495	1136274	1128309	1120236	1114819
Fatalities per 100 000 population	13	11	13	11	10	11	10	9	9	9	10

The line diagram shows a tendency of decreasing number of fatalities in traffic accidents in both areas, the Republik of Srpska and Banja Luka. However, a certain unevenness in behavior by age is also observed. Continuity in the decline in traffic accidents is not observed, there is still a pronounced deviation in values by year.

DEMOGRAPHIC CHARACTERISTICS OF THE REPUBLIC OF SRPSKA

In addition to the large number of traffic fatalities, a problem that Republik of Srpska has been struggling with throughout its existence is the continuous deterioration of its demographic picture [4]. Demographic data, data on population movements and changes, have only been kept more precisely since 2013, when the first and only population census was conducted in the territory of the Republik of Srpska. In the first census, the Republik of Srpska had a total population of 1,171,179. According to the Statistical Office, the population has been decreasing year by year. Last year (2023), the Republik of Srpska had a total population of 1,114,819.

In a period of eleven years, the Republik of Srpska has lost 56,360 inhabitants, which means that is becoming poorer by about fifteen inhabitants every day.

Although there are no statistical data on the number and movement of the population, from the moment of the establishment of the Republik of Srpska until the first census, the fact is that in those years, especially the post-war years, a large number of residents left the Republik of Srpska. Mostly, entire families left, who, due to difficult living conditions and in search of a better existence, went to various parts of the world.

Unfortunately, the exodus of residents from the Republic of Srpska, especially young people, has not stopped even today. A large number of educated young people, lacking work or dissatisfied with their status, are leaving abroad. The Republic of Srpska is thus losing its most productive residents in various segments.

THE PUBLIC RISK IN THE REPUBLIC OF SRPSKA AND BANJA LUKA

Based on the collected data on traffic accidents and the severity of their consequences (MUP RS), and using data from the Statistical Office of the Republik of Srpska on the number of inhabitants, it is possible to compare their relationship. A table can be presented with an overview of the number of people killed in traffic accidents, the number of inhabitants, as well as the public risk, i.e. the number of fatalities per 100,000 inhabitants, in the period between 2013 and 2023. After the first population census in the Republik of Srpska, and therefore also in Banja Luka, it became possible to compare data at these two levels of observation. Since traffic accidents in Banja Luka represent the largest share of the total number of traffic accidents in the Republik of Srpska [5], their consequences should be analyzed in detail.

Data on the number of inhabitants, fatalities and public risk are provided separately for the Republik of Srpska (Table 2) and Banja Luka (Table 3).

In the past eleven years, the Republik of Srpska has recorded a decline in the number of inhabitants, the number of fatalities, and the number of fatalities per 100,000 inhabitants. In the first year, 2013, the highest number of fatalities per 100,000 inhabitants was recorded, and it decreased in the following years.

In 2013, it was recorded 13 fatalities per 100,000 inhabitants, and by 2023, this number had decreased to 10 fatalities per 100,000 inhabitants. The analyzed data indicate that the number of fatalities per 100,000 inhabitants in the Republik of Srpska is still above the European average (significantly less than 10 fatalities/100,000 inhabitants) [7], and that it has only come closer to it in the three penultimate years of observation [8].

As for Banja Luka, in the past eleven years, an increase in the number of inhabitants has been recorded, and as in the Republik of Srpska, a decrease in the total number fatalities and the number of fatalities per 100,000 inhabitants has been recorded.

In the first year of observation, 2013, the highest

Table 3. Data on the state of traffic safety in Banja Luka in the period 2013–2023

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Fatalities BL	70	39	53	45	30	32	32	20	26	19	28
Population	180056	180961	181956	182848	183557	184257	184843	185094	185075	185177	185684
Fatalities per 100 000 population	39	22	29	25	16	17	17	11	14	10	15

number of fatalities per 100,000 inhabitants was recorded, while in the year before last, the lowest number of fatalities was recorded. In 2013, it was recorded 39 fatalities per 100,000 inhabitants, and by 2022, that number had decreased to 10 people fatalities per 100,000 inhabitants. However, the number of fatalities per 100,000 inhabitants in Banja Luka recorded an increase in fatalities in 2023. At that time, it was recorded 15 fatalities per 100,000 inhabitants, which is significantly higher than the European and national averages [8].

ANALYSIS OF DEMOGRAPHIC CHARACTERISTICS AND PUBLIC RISK

Demographic characteristics

Based on the collected data, different demographic characteristics are observed in the area of the Republik of Srpska and Banja Luka. The relationship between the population trends in the Republika Srpska and Banja Luka can be shown in a line diagram (Figure 2).

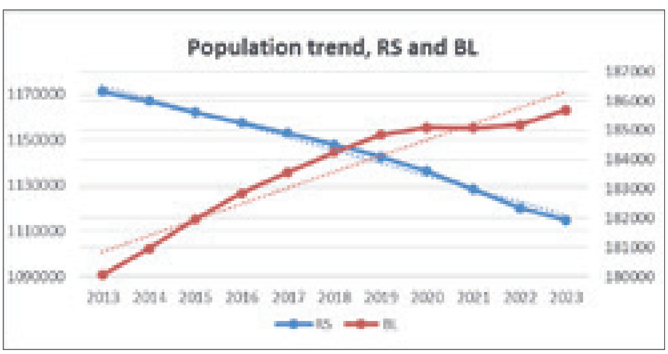

Figure 2: Overview of population in the Republik of Srpska and Banja Luka, 2013–2023

The line diagram shows the decreasing character of the curve showing the number of inhabitants in the Republik of Srpska and the opposite, increasing character of the curve showing the number of inhabitants in Banja Luka.

While the Republik of Srpska is struggling with the decrease in the number of inhabitants, Banja Luka is recording its increase. The decrease in the number of inhabitants in the Republik of Srpska has an almost linear character. The curve showing the increase in the number of inhabitants in Banja Luka initially has an approximately linear shape, but in recent years it has deviated from this and shown a downward bend, which indicates a smaller influx of inhabitants in those years.

Public risk comparison

One of the most relevant indicators of the security situation in an area is the number of fatalities per 100,000 inhabitants. The ratio of the number of fatalities per 100,000 inhabitants in the Republik of Srpska and Banja Luka can best be shown using a line diagram (Figure 3).

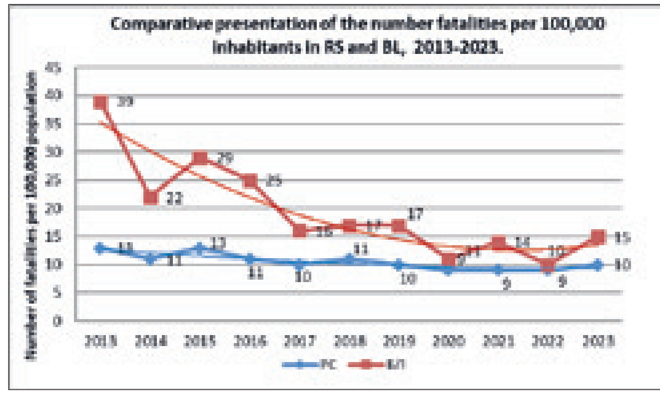

Figure 3. Overview of the number of fatalities per 100,000 inhabitants in RS and BL, period: 2013–2023.

The diagram shows a decreasing character of both lines. Regardless of the different behavior in terms of population in the Republik of Srpska and Banja Luka, a decrease in the number of fatalities in traffic accidents and the number of fatalities per 100,000 population was recorded at both levels.

Banja Luka, which at the beginning of the analyzed period (2013) had a very high number of fatalities per 100,000 inhabitants (39), has been recording a faster trend of decreasing this value. It could be said that some of the city's goals, planned by the development strategy, have been achieved [9]. However, it is noticeable that there is no continuity in the decrease of this value, where significant unevenness can be observed by year. In particular, the last year has recorded a deterioration of public risk in traffic, and 15 fatalities per 100,000 inhabitants have been recorded there.

The Republik of Srpska has lower values of public risk in traffic and a more pronounced continuity in the decline in the number of fatalities per 100,000 inhabitants.

CONCLUSION

The paper analyzes the behavior of traffic accidents, population movement, and the number of people killed in traffic accidents in the Republik of Srpska and Banja Luka area over the last eleven years.

During that period, the population was constantly decreasing in the Republik of Srpska and increasing in Banja Luka. In both areas of observation, there was an uneven trend in the number of traffic accidents, and a decrease in the number of people killed in them and the number of fatalities per 100,000 inhabitants.

Despite the increase in the level of traffic safety in the Republik of Srpska and Banja Luka, the situation is still not satisfactory. With an appropriate strategy and taking the necessary measures, at both levels of observation, the number of fatalities has decreased, but the set goals have not yet been achieved. The number of fatalities is still higher than the European average.

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Bezbjednost saobraćaja i demografske karakteristike Republike Srpske i Banje Luke

Apstrakt: Banja Luka i Republika Srpska, kao i većina svjetskih zemalja, bilježe veliki broj saobraćajnih nezgoda i lica poginulih u njima. Dodatno opterećenje Republike Srpske je njena loša demografska slika. Nakon popisa stanovništva, 2013. godine, u Republici Srpskoj je evidentno konstantno opadanje broja stanovnika. Banja Luka je u istom periodu bilježila porast broja stanovnika.

Rad obuhvata analizu bezbjednosti saobraćaja i demografskih karakteristika na području Republike Srpske i Banje Luke, te njihovo međusobno poređenje.

Ključne riječi: bezbjednost saobraćaja, poginula lica, broj stanovnika.

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PRELIMINARY REPORT

Criminal Procedure Principles of Traffic-Technical Expertise

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Abstract: Traffic accidents are an everyday occurrence in modern society and usually occur when a vehicle collides with another vehicle, pedestrian, animals, road debris or other immovable obstacles, such as a tree, pole or building. Traffic accidents very often result in minor and serious injuries, participants' disability, death or minor/major property damage, as well as financial costs of both society and individuals involved in the events during and after the traffic accident. There are numerous causes that contribute to the risk of collisions, i.e. traffic accidents, including vehicle design, driving speed, appearance, i.e. road condition, road environment, driving skills of traffic participants, alcohol or drug use by the participants, as well as their behavior, especially other participants driving obstructions, speeding and street racing.
Expertise is a procedural action that is undertaken by a Court or the Prosecutor's Office order, with the fulfillment of the conditions prescribed by law. Expertise involves the engagement of special experts, whose obligation is to examine the expertise subjects that have been handed over to them in accordance with the rules of their scientific field, technical knowledge, skills or artistic orientation, and then provide their expert findings and opinion.
Traffic-technical expertise is a special type of expertise which analyzes the material elements from the case file and conducts a detailed analysis of the traffic accident course. In this regard, the expert examination determines the manner in which the traffic accident occurred, the position of the vehicles at the time of the accident, the speed of the vehicles involved in the accident, the location of the collision and the position of the vehicles immediately before the collision. In order to establish the above facts, it is necessary to state all the findings that were collected through analysis, including some of the basic data if the expert analyzed it: who was driving, what were the weather or traffic conditions at the accident scene, etc.

Keywords: traffic accident, vehicle, expert, expert examination, traffic-technical expert examination, criminal procedure.

INTRODUCTORY REMARKS

Traffic accidents are an everyday occurrence in modern society and usually occur when a vehicle collides with another vehicle, pedestrian, animals, road debris or other immovable obstacles, such as a tree, pole or building. Traffic accidents very often result in minor and serious injuries, participants' disability, death or minor/major property damage, as well as financial costs of both society and individuals involved in the events during and after the traffic accident. There are numerous causes that contribute to the risk of collisions, i.e. traffic accidents, including vehicle design, driving speed, appearance, i.e. road condition, road environment, driving skills of traffic participants, alcohol or drug use by the participants, as well as their behavior, especially other participants driving obstructions, speeding and street racing.

A traffic accident is quite often the result of driver's error that leads to the creation of a dangerous situation. On the other hand, in a certain number of cases, a dangerous situation can be a consequence of sudden and unpredictable changes on the road, and when analyzing a traffic accident and consequently prosecuting criminal acts which endanger public traffic, it is important to conduct a comprehensive analysis of the traffic accident and avoid possible errors that occur due to direct and indirect reasons. The direct or immediate reasons for errors in traffic accident analyses are the following: superficial facts establishing, rashly conclusions making, formalism, subjectivism, ignorance, disinterest and inattention, and intentional concealment of certain knowledge caused by interests[1]. Indirect reasons for errors for traffic accidents analysis are: the lack of work standards and the required level of quality, the lack of a

[1] Istvan Bodolo, (2007), The use of software for simulating traffic accidents in expertise, Gazette of the Bar Association of Vojvodina 79, No. 7-8, p. 252.

requirement to explain the attitudes in the findings, the lack of an efficient social control mechanism and possible sanctions, and the unfavorable state of the judicial system in terms of motivation, personnel selection, organization and financial stability[2].

Direct or immediate reasons for errors in traffic accident analyses can originate from both the competent court and other participants in the criminal proceedings themselves. Thus, by failing to assess each piece of evidence individually and to relate them to each other, as well as by failing to assess the findings and opinions of traffic experts in terms of meeting the criteria for the completeness of the expert opinion and the obligation of expert research in relation to the causes of the traffic accident, the court violates the right to a fair trial, namely the right to a reasoned court decision, and the violation of the principle *in dubio pro reo*, which certainly leads to an absolutely essential violation of criminal proceedings, which is reflected in the lack of reasons for decisive facts. The consequence of such court action is reflected in the violation of the participants in the traffic accident's rights, as well as in the unfounded protection of a legal entity as a road manager.

A traffic expert who makes a finding and opinion based on a time-space analysis of a traffic accident that does not include all potential causes of the traffic accident, acts contrary to the principles of completeness and mandatory expert research.

A prosecutor who, during the investigation phase, fails to specify the order for the traffic expert to conduct an expert examination regarding the analysis of all potential causes of the traffic accident, as well as a prosecutor who fails to supervise the work of authorized officials during the traffic accident investigation, produces negative consequences in the criminal procedure in terms of the completeness of the expert examination and the violation of the participants' rights.

Omissions by the defense attorney during the main trial phase, and above all those relating to the quality of the cross-examination of the traffic experts and the determination of the decisive facts on which the expert's finding and opinion are based, lead to a violation of the defendant's rights.

Improper behavior of the police officials during the traffic accident investigation can cause a large number of negative consequences in cases of public traffic endangerment[3].

Much has been written about the causes of traffic accidents, and in the literature, the causes of traffic accidents[4] can most often be divided into: 1. direct causes (errors/omissions), which can include: a suddenly created danger on the road, an inappropriate/incorrect assessment of the traffic situation, inattention/distraction, an inappropriate/incorrect maneuver or driving style, a sudden vehicle failure or hidden road defects, a collision in the communication of traffic participants and 'force majeure' (impact of a stone, bird, animal); 2. indirect causes, which most often include: alcohol and other intoxicants, insufficient knowledge and skills for driving a motor vehicle, aggressive driving - showing road rage, road and traffic equipment deficiencies, shortcomings in the vehicle construction and active safety elements, driver fatigue and other unfavorable psychophysical conditions, high and inappropriate speed and improper and irregular movement/driving, etc.; 3. contributing causes (certain conditions and circumstances), which can be: weather and climate conditions, physical defects (poor eyesight, nervous disorders, chronic diseases), psychological causes related to perception, understanding, decision-making and taking reactions, driving a vehicle with risks taking, driver's physical and physiological busyness and the participants' inadaptation to the traffic characteristics[5].

EXPERTISE IN TRAFFIC ACCIDENTS

The concept and subject of expert opinion

Expert opinion is a procedural action in which an expert, as a person who possesses special scientific or professional knowledge and skills, applies his knowledge, skills and methods to the facts that are the subject of expertise[6].

Expert opinion is a procedural action that is undertaken by order of a court or a prosecutor, in compliance with the conditions prescribed by law and by which special experts, i.e. experts, are engaged to examine the objects of expert opinion submitted to them in accordance with the rules of their scientific field, technical knowledge, skills or artistic orientation, and then provide their expert findings and opinions[7].

Within the definition of the meaning of the term expertise, there are several historical phases in which expertise is defined in different ways.

According to the theories that define expertise as a mixed investigation, expertise is not an independent evidentiary action. Expertise is most often carried out during the investigation process, during which an expert[8] appears. According to the authors who consider the expertise to be a scientific judgment, it is not evidence that the judicial panel will appreciate, like all other evidence, adhering to the prin-

[2] Ibid.

[3] Ljubinko Mitrovic, (2008), *Police Law – Internal Affairs Law*, Banja Luka, Defense Center for Security, Sociological and Criminological Research, p. 5-8.

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[6] Hajrija Sijercic-Colic, (2005), *Criminal Procedural Law*, Sarajevo, Faculty of Law, p. 332.

[7] Hajrija Sijercic-Colic et. al., (2005), *Commentaries on the Law on criminal/criminal procedure in Bosnia and Herzegovina*, book III, Sarajevo, Council of Europe and European Commission, p. 283.

[8] Snežana Sokovic, (1990), Expert testimony as evidence in criminal proceedings (doctoral dissertation, Faculty of Law Kragujevac, p. 44.

ciple of free judicial conviction, but a scientific judgment, that is, a decision that is always mandatory for the court. The understanding of expertise as a scientific judgment, that is, the expert as *iudex facti*, originates from the positive and anthropological school of Criminal Law[9].

One group of theorists' views expertise as a way of verifying evidence, denying it the property of an independent means of evidence and interpreting it as a form for verifying other evidence. According to this understanding, expert testimony is not a means of evidence, but, as the objects of expert testimony are usually other material evidence, it represents only a way of verifying that evidence[10].

There are also understandings according to which expertise is defined as a means of evidence *sui generis* since, depending on the specific situation, it can be designated as testimony, judicial assistance and as a scientific judgment[11].

The reasons for expertise are generally classified into three groups, namely: communication of general views of science and practice, concrete procedural facts and special knowledge of the issue[12].

Expertise is determined as a means of evidence and has two phases, namely:

1. disclosure of facts important for the procedure (expert report) and
2. giving an opinion on those facts (expert opinion).

The expertise cannot refer to legal issues, and the subject of the expert opinion can only be an important fact, the determination or evaluation of which requires the application of special professional knowledge possessed by the expert[13].

The concept of an expert

An expert is a person who, by the authority of his professional knowledge and/or skill in the field of a certain science or technique, at the request of the criminal procedure body, gives a written or oral finding and opinion on the existence or non-existence of facts that are established in the criminal proceedings, and who, as necessary, and based on the existence and/or non-existence of those facts, draws a certain conclusion[14].

An expert in criminal proceedings is any person who, on the order of the criminal proceedings authority and based on his special expertise in a certain area, performs the necessary research, according to the rules of a special professional discipline and according to the provisions of the Law on Criminal Procedure[15].

An expert is also a natural or legal person who is invited by a court decision to give his findings and opinion on the defined circumstances of the expert examination. Consequently, the expert should assist the criminal procedure authority exclusively in establishing the facts, and never when deciding on the application of the legal norm[16].

An important characteristic of every expert, that is, what is mostly his *differentia specifica*, or so-called the 'essential requirement' in relation to all other criminal procedure subjects, is precisely his expertise. For this reason, an expert can only be designated as a person who possesses special, extra-legal, i.e. professional knowledge needed to solve a specific criminal matter[17].

Although the demarcations of expertise stages, as well as their specific content, are conditioned by the specifically applied special professional methodology, which process theory cannot go into in detail, this should not be the reason for almost complete theoretical ignoring of this issue with important practical consequences[18].

The competences of a traffic-technical expert include, for example, the following activities and possible answers to the following questions, namely:

- determination of the technical condition of the motor vehicle, its individual parts, assemblies, and mechanisms,
- determining the conditions, causes and moment of occurrence of the traffic accident,
- determination of the causal link between the malfunction of the motor vehicle and the resulting traffic accident,
- determination of the mechanism of occurrence and course of the traffic accident,
- determining of the motor vehicle speed up to the moment of the traffic accident - what was the significance of speeding for the traffic accident,
- determining the braking and complete stopping distance at a given driving speed, type, condition and profile of the road,
- what was the significance of the traffic accident in violation of the driving rules from the Law on the Basics of Road Traffic Safety in Bosnia and Herzegovina, the Rulebook on Dimensions, Total Masses and Basic Load of Vehicles and on the basic conditions that must be fulfilled by devices and equipment on vehicles in road traffic, Rulebook on Road Traffic Signs, etc.
- determination of the causal link between the vehicle malfunctioning and the traffic accident,
- determining the cause of the collision, drifting, overturning of the motor vehicle and other conditions traffic and road situations with the aim of

[9] Ibid.

[10] Sijercic-Colic et al., *Commentaries on the Law on Penal/Criminal Procedure in Bosnia and Herzegovina*, book III, p. 283.

[11] Sokovic, Expert testimony as evidence in criminal proceedings, p. 54.

[12] Sijercic-Colic et al., *Comments on the Law on Penal/Criminal Procedure in Bosnia and Herzegovina*, book III, p. 283.

[13] Ljubinko Mitrovic, (2014), Means of evidence in misdemeanor proceedings, *Expert Journal, from the field of theory and practice of expert testimony in Bosnia and Herzegovina*, no. 1, p. 29-36.

[14] Sijercic-Colic et al., *Commentaries on the Law on Penal/Criminal Procedure in Bosnia and Herzegovina*, book III, p. 283.

[15] Sokovic,Expertise as evidence in criminal proceedings, p. 176.

[16] Sijercic-Colic, *Law on Criminal Procedure* p. 331.

[17] Sokovic, Expertise as evidence in criminal proceedings, p. 158.

[18] Ibid.

determining the violation of technical norms from the Law on the Basics of Traffic Safety on Roads in Bosnia and Herzegovina and other normative acts on safe driving,
- is there a causal connection between the malfunction of the motor vehicle, the condition of the road and the traffic accident,
- which parts of the vehicle hit the obstacle and
- how the driver had to act from a technical point of view in a given situation in order to ensure safe driving[19].

Findings and opinion of the expert

The expertise procedure depends on the type of expertise, but in any case, it has three phases, namely: introductory, operative and concluding.

In the introductory phase, procedural issues are resolved and a kind of preparation for operational work is carried out. In this phase, the invited expert first familiarizes with the legal norms that regulate expertise as an act of proving. Furthermore, in this phase, the expert is called and familiarized with the criminal case and the expert task. After that, the expert is handed the material to be expertized with all the accompanying documentation (expertise order, copies of the investigation report, etc.). In the same way, the expert gets to know the subject of the expertise and the questions to which he/she provides answers[20]. Also, the expert is invited to, for example, examine and consider the expertise subject carefully, then to state everything he/she observes and determines, and to express his/her opinion objectively and in accordance with the rules of science and skill[21].

The expertise is directly performed in the so-called operational phase. This phase is carried out by the expert personally, by applying methods and means in accordance with the profession and adhering to the strictly set requirements of the requester (customer) of the expertise[22]. Therefore, expertise is performed by an expert applying professional knowledge and methods, and adhering to the expertise order, in the sense that experts only perform what the prosecutor or the court ordered him/her to do[23].

The operative phase is expert work according to the order (request) for an expertise, and it depends on the expertise subject itself. It can refer to looking at certain objects or files and asking for the necessary clarifications, then proposing to produce evidence or obtain objects or data that are important for giving findings and opinions[24].

The final phase of the expertise refers to giving findings and opinions. Along with the findings and opinion, the expert submits working material, sketches and notes to the criminal procedure authority that ordered the expertise[25]. At the same time, the authority of criminal proceedings in the same expertise subject can request a finding from one expert, and an opinion from another[26].

Expert's finding *(visum repertum)* and opinion *(parere)* make up his testimony, and they must be based on verified facts and presented precisely and clearly. In the finding the expert states everything he/she observed and discovered, the methods he/she applied, and in his/her opinion - the conclusions he/she came to in the process of establishing the facts. In doing so, the expert must always explain on the basis of which facts he/she drew conclusions and gave an opinion, and which rules of science or skill he/she used[27].

Based on all performed actions necessary for expert research, the expert gives his/her findings and opinion. In the findings and opinion, the existence or non-existence of the facts for which the expertise was ordered, based on which the expert draws conclusions and gives his opinion, is established. The entire procedural action, i.e. determination of expertise, expert research, formulation of findings and opinions, and verbal or written communication of such findings makes an expertise a special means of evidence. The finding and opinion obtained in such a procedural action constitute evidence, independent, original, indirect or immediate, depending on the specific situation[28].

The report describes in detail the subject of the expertise subject, in the state in which the specific subject was submitted for expertise. The first is necessary for several reasons, the most important of which are the possibility of identification and possible irregularities in securing the delivered item[29].

The expert's findings and opinions constitute evidence, and as such have their place in criminal proceedings only if they reveal new facts. However, this is not possible just by 'opinion', not even in the sense of reasoning. On the other hand, the finding and the opinion are logically and organically interconnected, that is, the finding represents the foundation, the support, the argument for the 'opinion'. The finding is the subject of 'opinion'. If there is none of finding - there is none of opinion[30].

The written structure of the expert testimony in the form of an introductory part, findings and opinion (conclusion) must be based on something, and that is the expert's finding. There are special cases when the expert testimony consists only of findings or only opinions. The finding

[19] Vladimir Vodinelic, (1986), *Traffic criminology: methodology for traffic accidents processing on roads, water and air*, Belgrade, Contemporary administration, p. 329.

[20] Sijercic-Colic et al., *Comments on the Law on Penal/Criminal Procedure in Bosnia and Herzegovina,* book III, p. 297.

[21] Hajrija Sijercic-Colic, Law on *Criminal Procedure,* p. 334.

[22] Sijercic-Colic et al., *Comments on the Law on Penal/Criminal Procedure in Bosnia and Herzegovina,* book III, p. 297.

[23] Sijercic-Colic, Criminal Procedure Law, p. 334.

[24] Sijercic-Colic et al., *Comments on the Law on Penal/Criminal Procedure in Bosnia and Herzegovina*, book III, p. 297.

[25] Sijercic-Colic, *Law on Criminal procedure*, p. 335.

[26] Sijercic-Colic et al., *Comments on the Law on Penal/Criminal procedure in Bosnia and Herzegovina, book* III, p. 297.

[27] Ibid.

[28] Sokovic, *Expert testimony as evidence in criminal proceedings*, p. 221.

[29] Sijercic-Colic et al., *Comments on the Law on Penal/criminal Procedure in Bosnia and Herzegovina*, book III, p. 303.

[30] Sokovic, *Expert testimony as evidence in criminal proceedings*, p. 222.

and opinion of the expert must refer to the *expertise subject*, specified in the competent authority's order for expertise, as well as to the questions raised. Otherwise, the expert's testimony has no procedural value in a specific criminal case and cannot be used as evidence in the proceedings.

The introductory part of the expert report should contain information about the authority that ordered the expertise, with the official number and date of issuance of the expertise order, its brief content (general information about the expertise subject, the questions asked, etc., the conditions under which the report was conducted, etc.). Expertise finding is the second part of the expert report or the dispositive (descriptive) part. As far as the content is concerned, it must be a direct reflection of what the expert established by examining (analyzing) the expertise subject. In that part of the record, the expert should state everything he/she observed during the examination (analysis), which is relevant in connection with the tasks received from the criminal procedure authorities.

In accordance with the provisions of the Law on Criminal/Penal Procedure, the expert is obliged to carefully consider the object or objects of the expertise and accurately state everything he/she observes and finds (establishes). Report formulation must be such that, in terms of important facts, they give the most accurate picture of expertise subject, without any generalizations. If the expert was unable to determine the true factual situation by examining the expertise subject, this unreliability should be highlighted without hesitation. It follows from the above that the finding of an expertise is a statement of a set of facts required for the opinion of an expert. The findings primarily include the facts that the expert discovered, noticed, found and selected, but also other facts that were established by the criminal procedure authority or that were established and found by another expert. This certainly means that the expert must also take the facts from the file as the basis of his findings, where observation and finding does not require special professional knowledge.

The question of whether there have been any changes and consequences and which ones, why and what possible impact they might have on the course and outcome of the expert examination, is one of the main questions to which the expert must answer. Specifying and describing of the expertise subject must be done in such a way that it enables its identification[31].

Traffic-technical expertise

In order to carry out and produce a traffic-technical expertise, it is necessary to perform a detailed analysis of all material elements from the case file and perform their comparative analysis. In order for the expert to be able to draw correct conclusions about the possible manner of traffic accident occurrence, it is necessary to first analyze the place where the accident occurred, the time of occurrence, atmospheric conditions and the possibility of safe traffic at the scene of the accident. The stated facts represent the basic data related to the traffic accident, they are in the file and are an indispensable part of the expert's findings and opinion. Apart from the basic data about the traffic accident, which are already in the court files, the findings and opinion are mandatory parts of the expert report.

In the traffic-technical expertise, the criminal procedure authority may encounter the problem of marking the most important questions to which the expert should answer. Marking the most important questions to which the criminal procedure body requires an answer from the expert implies not only the ordinary logic of the criminal procedure body, but also a deeper knowledge of the problems of traffic-technical expertise, that is, the methods and procedures that are applied within it. The criminal procedure body can hire an expert advisor for this, who will, if necessary, clarify the possible problems and direct him to the most important questions and answers he/she expects from the expert[32].

The analysis of a traffic accident implies the determination, calculation and analysis of material elements that can be obtained from the evidence collected during the investigation of a traffic accident. Such analyzes enable an objective assessment of the situation at the time of the traffic accident or the situation that possibly preceded the traffic accident in a relatively short period of time. A qualitative analysis of the collected data related to the occurrence of a traffic accident provides data related to the place and time of the occurrence of the traffic accident, i.e. a shorter time interval immediately before the accident, but it does not give us reliable data about the longer period that preceded the accident, i.e. the moment when the danger occurred, i.e. when the traffic situation required the action of one of the traffic participants[33].

On the basis of a complex investigation of all the accident causes in the forensic examination procedure, the indictment can be correctly defined and, in the light of the assessment of all the presented evidence, a fair judicial decision can be made. This also applies to cases where the indictment is brought only against the persons who are the main culprits of the accident or only against the surviving participant of the accident, because in the decision-making process the contribution of other elements of the system (the contribution of the victim) is evaluated, which is important for determining the punishment type and amount.

The action of individual elements of the vehicle - driver - road - environment (V-D-R-E) system, which are important for defining the course and dynamics of a traffic

[31] Dusko Modly, (2007), *Contemporary criminal theories*, Sarajevo, Faculty of Criminal Sciences, p. 56.

[32] Dragan Radosavljevic, (2012), Traffic-technical expertise, expert and expert advisor through the new Criminal Procedure Law in the Republic of Serbia, in: Proceedings: XI Symposium - *Analysis of traffic accidents and insurance fraud*. TSG (Traffic Safety Group) Serbia, Zlatibor, p 1-12.

[33] Nenad Markovic & Dusko Pesic, (2012), Dangerous situation and occurrence of traffic accidents, in: Proceedings: XI Symposium - *Analysis of traffic accidents and insurance fraud*. TSG (Traffic Safety Group) Serbia, Zlatibor, p. 51-60.

accident[34], is expressed to the greatest extent in the phase preceding the accident. In order to define and evaluate the action of these elements in an expertise, by analyzing the material factors produced in the accident (traces, damage, injuries) and witness statements, one should also be well acquainted with the basic elements of driving quality. During the expertise, driving quality is assessed by analyzing the driver's actions and behavior in all phases of a traffic accident. Such an analysis can only be performed by a traffic expert who knows all the factors of safe driving conditioned by the action of the V-D-R-E system.

As part of a traffic and technical expertise findings, it is necessary to determine the necessary elements for conducting an analysis of the course of a traffic accident by analyzing the material elements from the file. Namely, the manner of the accident, the collision position, the speeds of the accident participants, the collision location and the position of the vehicle immediately before the collision should be determined. To establish the above facts, it is necessary to state all the findings that were reached through the analysis, including some of the basic data if the expert analyzed them: who was driving, what were the weather conditions at the accident scene, what were the traffic conditions, etc[35].

During the investigation of the accident, the expert uses certain graph-analytical procedures to calculate the basic parameters in order to provide answers to the following questions based on them, namely:

a) what was the driving speed of the accident participants before the dangerous situation occurred,

b) at the time of the dangerous situation, were the drivers driving their vehicles at the permitted speed (if it was limited) and at a safe speed for the situation that happened before the danger occurred,

c) did the participants in the accident before the collision react to the danger in appropriate manner

d) did the participants in the accident have the technical ability to avoid a collision by braking in appropriate time?

If the collision occurred while the car was moving at an equally slow speed (braking), the expert is also asked to answer the following question: Was there a possibility to avoid the collision without braking, with or without turning?

In cases of accidents when the danger was created suddenly, in situations that the driver could not foresee, the court asks for an answer to the question: At what speed (conditionally safe speed) should the car be driven in order to avoid the collision by braking, by stopping the car before reaching the place of the collision (some experts wrongly equate this speed with safe speed for the situation that existed before the sudden danger occurred)[36]?

When performing a traffic-technical expertise, the expert is given a court file for study, which contains:

- investigative documentation (record, scene sketch, photo documentation, etc.),
- data on accident participants and injured persons,
- data on vehicles and their technical condition,
- road and weather data,
- records of the participants' and witnesses' hearing about the accident and
- other material data and evidence about the traffic accident[37].

Every traffic accident can be viewed as one event resulting from the action of several different factors, some of which may be accidental. That is why every collision between vehicles or a vehicle and a pedestrian (every traffic accident), has its own specific characteristics, characteristic only for that case, which separate it from other analogous events[38].

The place of the traffic accident is an important element for the traffic accident analysis and the application of temporal or spatial criteria. The dangerous situation in the area of the traffic accident is a key factor in the occurrence of a traffic accident, which represents a traffic-technical issue. At the same time, the cause of the traffic accident results from it, which is a legal issue[39].

Determination of the technical causation of a traffic accident is the competence of an expert, while the determination of causation in the sense of Criminal Law falls under the competence of the court. The circumstance that the driver's actions (behavior) in the process of driving a motor vehicle caused certain technical results (vehicle sliding from the road, drifting, overturning, and so on) is conditioned by technical causal connection. If the same action of the driver, which is contrary to the provisions of the Law on Traffic Safety, caused socially dangerous consequences described in the Criminal Law - carried out intentionally or unintentionally, in such a case the causal connection between the driver's actions and the occurrence of the consequences has a criminal character, not an accidental one, and becomes one of the essential features of the criminal act.

In order to solve the question of causality, the method of thought elimination (hypothetical elimination) is applied. Its essence is that from the set of antecedents (predecessors), which are supposed to have a causal meaning, the action that interests the examiner is excluded (abstracted)

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[34] Milan Vujanic & Tijana Ivanisevic, (2015), Time-space analysis of a traffic accident, Journal of Expertise, in the field of theory and practice of expert witnessing in Bosnia and Herzegovina, No. 2, p. 161-167.

[35] Marković & Pesic, Dangerous situation and the occurrence of a traffic accident, p. 52.

[36] Miodrag Tojagic, (2015), *Road Traffic Safety*, Brcko, European University, p. 251.

[37] Radoslav Dragac, (2009), Time-spatial analysis of a traffic accident in the preparation of findings and opinions of experts, in: Proceedings: VII *Symposium - On traffic-technical expertise and damage assessment*, TSG (Traffic Safety Group) Serbia. Vrnjacka Banja, p. 351-367.

[38] Vodinelic, *Traffic crime*, p. 332-335.

[39] Milan Bane Stevovic, (2012), Delineation of legal and traffic-technical issues in a dangerous situation, in: Proceedings: XI *Symposium - Expert examination of traffic accidents and insurance fraud*. TSG (Traffic Safety Group) Serbia, Zlatibor, p. 32-37.

in the mind (e.g. the actual driving speed). If it turns out that the event would not have occurred or would have occurred in a different course than the real one, this means that this action appears as a necessary condition (cause) of the event (traffic accident) and is in the causal nexus. If it is shown that the event would have occurred as it did without that action, then it is assumed that there is no causal connection between that action and the event[40].

In practice, it happens that the court asks the traffic expert whether the driver could or could not foresee the obstacle (danger)? The expert may only be asked a question about the technical moment of the danger occurrence (real obstacles). The expert will determine the time when the suspension arm broke, the causes of that phenomenon, whether the failure was invisible or could be noticed, when and in what way, whether the driver could have noticed it in time, and the like. However, the legal moment when the driver is obliged to notice the technical malfunction of his motor vehicle and take appropriate steps to prevent a traffic accident must be determined by the court, based on the totality of all the evidence obtained. The expert examines what measures the driver should have taken if this requires the knowledge of a specialist. Determination of the moment when the driver had the technical ability to prevent a traffic accident also falls within the competence of a traffic expert. However, the determination of the moment when the driver had to and could foresee the occurrence of a traffic accident falls exclusively within the court jurisdiction. The court's analysis refers to the subjective characteristics and driver conditions. The expert opinion helps the court to obtain the necessary and comprehensive information about the traffic situation (visibility, condition of the road) and the condition of the vehicle in order to determine whether the driver had the opportunity in the specific situation (and at what time) to foresee the probable occurrence of a traffic accident in the event that he/she acted contrary to the norms of the Law on Traffic Safety[41].

The criminal responsibility of the driver for not applying the safe driving measures, provided in the regulations on traffic safety, occurs only from the moment he/she notices the obstacle or was obliged and could have foreseen its appearance. The driver's criminal responsibility for measures taken or not taken arises only from the moment when his/her obligation to respond to the danger arose.

It can be safely concluded that the key moment for determining liability is the moment of danger. In relation to it, the emergence of the traffic participant's obligation to react to the danger and be responsible for the resulting consequences is always determined. It is the duty of the court to determine: the moment of the danger occurrence and the moment when the driver was obliged to take measures to prevent the traffic accident[42].

[40] Vodinelic, *Traffic crime*, p. 345.

[41] Vodinelic, *Traffic crime*, p. 345.

[42] Ibid.

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PRELIMINARY REPORT

Integration of the public transport system using the example of the Niš Administrative District

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Abstrakt: Public (regional) transport, which is carried out between territorial units of one or more neighboring administrative districts in the Republic of Serbia, is based on the concept of deregulation and relies mainly on one means of transport – the bus. It is a system of intercity and municipal timetables, i.e. bus lines operated by private bus operators. On the other hand, these public transport services are not considered communal activities, they are not subsidized and are provided by private operators in accordance with commercial interests.
This paper investigates the public transport system on the territory of the Niš Administrative District. The research focus is on analyzing the current state of the system, identifying key challenges and problems, assessing public transport needs and developing recommendations for improving the system. The aim of this research is to provide a comprehensive insight into the current state of public transport in the Republic of Serbia and to identify opportunities for improvement in order to meet the needs of the population, improve mobility and contribute to the economic development of the region.
The research includes discussions on topics such as deregulation, reliance on one mode of transport and integration of public transport. The analysis provides deeper considerations of the challenges facing the system and possible strategies for addressing them.
Based on the collected data, analysis and conclusions, this paper will offer relevant recommendations for improving the public transport system and contribute to improving the quality of services, efficiency and accessibility for service users.

Key words: integration, public transport, administrative districts, mobility.

INTRODUCTION

Public passenger transport between neighboring municipalities has all the characteristics of public transport system, while its organization operates according to the rules of classic intercity transport. Therefore, carriers register timetables, define prices and ticket systems, determine the traffic regime at their own discretion - complete deregulation. There is increasing public pressure to influence the quality of municipal public urban transport services, on the one hand, and the multiple interest of the authorities to make the public transport system as economical and efficient as possible, so that it has created a need for legal regulation of the public transport services market in Serbia. Therefore, some systems have experienced significant changes in the way of organization and management over the last decade, which were inspired by current developments in the EU.

The way of organization and management of the public transport system varies significantly from country to country, and even from city to city. There are many influential factors: the way in which national and local authorities entrust the service; the way in which public transport financing is organized; the nature of the relationship between the authorities and the operator and the manner in which this relationship is established; the ownership and structure of the operator; the use of the principle of competition, etc. The management of such public transport encompasses all activities and processes necessary for the efficient management of public urban passenger transport. This includes planning, organisation, monitoring and control of all resources in order to provide the safest and highest quality services for passengers. Planning and organisation are key aspects of the management of public regional transport. The aim is to achieve optimal use of resources and to ensure that public urban transport is accessible and reliable for all users. Planning and organisation are continuously adapted to changes, needs and demands of passengers, as well as to conditions observed during monitoring and control systems. A particular challenge is posed by developing countries, where the process of uncontrolled urban sprawl and the influx of rural population is still present, which leads to the development of industry, rising standards, mobility and population movement, as well as an increase in motorization, whose position has been increasingly favored over other modes of transport in recent years.

Vuchic (2005) explains three key problems faced by public transport systems in developing countries:

- *Avoidance of public transport obligations* – private companies, concerned about their economic efficiency and profits, avoid public transport services in poor areas and areas of low population density. They also avoid suburban lines, as well as transport in the evenings and on weekends.
- *Unfair competition* – financially stronger companies eliminate competition in their area through pricing policies, and then use their monopoly positions to increase profits (the price of the service increases, while the quality and quantity decrease).
- *Decreased efficiency* – uncontrolled competition has created duplicated and uncoordinated services on many lines, which is not an efficient way of providing services. Passengers are forced to make multiple transfers, wait longer for transportation, pay different prices for the same routes with different carriers, and have difficulty obtaining information about the transportation itself.

One of the consequences of the deregulated system, characteristic of bus modes of transport, is the so-called "on route competition" where carriers compete with each other to take on passengers along the route. This type of competition is especially present on profitable routes with high passenger flows, while the negative effects on traffic safety, the environment and the quality of service are immeasurable.

EU TRANSPORT POLICY

The European Union's transport policy is a set of strategies, objectives and measures aimed at improving the efficiency, sustainability and competitiveness of the transport system in the European Union. It covers all modes of transport, including road, rail, air and waterborne transport. It is implemented through cooperation and coordination between the European Commission, the Member States and other relevant stakeholders in the transport sector. The European Union's transport policy is defined as a set of measures, policies and regulations aimed at improving the efficiency, safety, sustainability and competitiveness of the transport sector within the European Union (Đorđević, 2023). The main objectives include improving infrastructure, increasing energy efficiency, reducing emissions of harmful gases, encouraging sustainable mobility, improving economic competitiveness, reducing pollution and improving the quality of life, connecting and integrating European regions, as well as creating jobs and economic growth. The European Union plays a key role in transport policy by enacting legislation, setting standards, providing financial support, promoting innovation and research, and supporting international cooperation in the transport sector. The European Commission is responsible for developing and implementing transport policy, while member states have a role in implementing regulations and measures at national level.

EU White paper

The EU White Paper, which adopted the comprehensive Transport 2050 strategy in 2011, states that a greater share of public transport in the modal split of travel, combined with minimum service obligations by the competent authorities, will enable an increase in the density and frequency of services, thus creating the basis for generating different models of public transport, primarily integrated ones (Višković, 2024).

Also, the basic objectives are defined as safe, efficient and high-quality passenger transport services through limited/regulated competition, while taking into account factors of social development, environmental development and regional development or providing special tariff conditions to certain groups of passengers such as pensioners, students and pupils, etc.

The objectives of the EU White Paper are to present the current state and challenges facing the European Union in the economic, social, political, legal and security domains, the book defines key problems through analysis and research and can provide recommendations for improvement in each of the above areas. The aim is to use this book as a guide for making informed decisions and improving the situation in the EU. The White Paper research methodology is based on careful collection of data from relevant sources, such as the latest reports, case studies and statistical data. For each area of analysis, different data collection methods were used, including quantitative and qualitative methods.

The structure of the EU White Paper has the following parts: introduction, overview, challenges, recommendations and conclusion. In the first part, i.e. the introduction, readers will be introduced to the objectives of the book, the research methodology and the general structure. This is followed by a state of play that analyses in detail the economic indicators, social situation, politics, law and security in the EU. In the third part, the book will focus on the challenges in each of the above areas and provide recommendations for improvement. Finally, the main conclusions are summarized and the importance of further actions for the further development of the EU is highlighted.

PUBLIC TRANSPORT SYSTEM INTEGRATION

Public transport system integration is a strategy that aims to make it easier for public transport users to move efficiently between different modes of transport within the same city, region or urban area. This integration allows passengers to switch from one mode of transport to another without too much complication and without the need for multiple tickets or tickets from different carriers. An integrated public transport system aims to provide better connectivity, convenience and efficiency for passengers. Public transport system integration has many benefits, including reducing traffic congestion, improving accessibility and reducing air pollution. It provides passengers with greater mobility and ease of use of public transport, making sustainable transport more attractive and efficient.

Figure 1. Integration of urban and local passenger transport (source: https://constructive-voices.com/connecting-the-city-vancouvers-success-with-public-transit-and-urban-integration)

Public transport system integration typically involves several key elements:

1. *Intermodality* - This involves connecting different modes of transport, such as buses, trams, trains, subways, bicycles and pedestrian routes, to allow passengers to easily transfer from one mode of transport to another. This is often achieved by installing transfer stations where different modes of transport meet.
2. *Single ticket* - An integrated system typically uses a single ticket or smart card that allows passengers to pay for their journey without the need for multiple different tickets. This ticket can be used on all modes of transport within the system.
3. *Single timetable* - System integration also involves coordinating the timetables of different transport operators to reduce waiting times at transfer points. Passengers should be able to easily transfer from one mode of transport to another without long waits.
4. *Price coordination* - For the system to be attractive to users, the price of transportation should be competitive and easy to understand. An integrated system often includes price coordination between different carriers to provide affordable rides.
5. *Information system* - A good integrated system should provide passengers with accurate information about different routes, departure times, transfers and other details to facilitate trip planning.

The main goal in article (Kłos, et al., 2021) is to propose a model for integration of different transport services which could support those who intend to travel in the decision-making process. Therefore, the parameters of a model of urban sharing services were identified and classified. The parameters discussed in the paper with reference to an extensive literature review describe how individual sharing services are functioning. What has also been identified is the location-specific factors as well as those related to the potential area of operation which affect the integration with public transport.

In public transport (PT) operations planning, timetable synchronization is a useful strategy to reduce inter-route or inter-modal passenger transfer waiting time and provide a well-connected service. This paper (Chen, et al., 2017) addresses the integrated PT timetable synchronization with vehicle scheduling problem for a given PT network. A new bi-objective integer programming model is developed for the problem.

Growth of towns is a result of citizen's social and physical division. Urban planners and scientists have increased the number of links between urban transport and urban development. Public transport has been in the focus of attention as a sustainable and environmentally sensitive transport that brings environmental benefit and possibility to serve mobility needs of citizens without private cars and reduces social division. Burinskienė, et al. (2011) identifies the main factors that affect the use of public transport in town: land use planning; local government policy; extent of economic resources; implementation of modern technologies; social tendencies. Analysis of the scientific literature has revealed four main models of towns of sustainable urban forms: neo-traditional development, urban restrictions, compact town and ecological town.

Analysis of the number of passengers between Niš and neighborhood municipalities

According to the 2022 census, the population of the City of Niš was approximately 249.501, while the population of the settlement itself was approximately 178.976, making Niš the third largest city in Serbia (after Belgrade and Novi Sad). The average population density in the City of Niš is 300 inhabitants/km^2. The population of the City of Niš is an important indicator for measuring the population size of this area.

The Niš Administrative District consists of several settlements: Aleksinac, Svrljig, Merošina, Ražanj, Doljevac, Gadžin Han and City of Niš.

Figure 2. Municipalities in the Niš Administrative District

All of these municipalities have a developed network of urban or intercity lines, which residents of these municipalities can use daily. Public transport in the Niš District plays a key role in maintaining the mobility of residents and connecting different settlements. For this reason, it is important to investigate the current state of public transport and identify the problems that accompany it. The overview of public transport in the Niš District includes the various modes of transport available to citizens. This includes buses, taxi services and suburban transport. Each of these modes of transport has its own characteristics and role in meeting the needs of passengers.

Local public transport between the city of Niš and its neighboring municipalities is a system of intercity departures - bus lines, on which private transport operators operate. These lines are not subsidized and are maintained according to a regime defined exclusively by the transport operator in accordance with operating costs. In order to more realistically view and analyze the local public transport system between the city of Niš and other neighboring municipalities within the Niš Administrative District, data obtained from the most dominant transport operator in this area - „Niš Ekspres", were taken into account. The data obtained refer to the number of single and monthly tickets sold between Niš and neighboring settlements/municipalities. The months of October (2023) and May (2024) were defined as characteristic time periods. Five directions - corridors were taken into account: Niš-Gadžin Han, Niš-Aleksinac, Niš-Merošina, Niš-Svrljig and Niš-Doljevac.

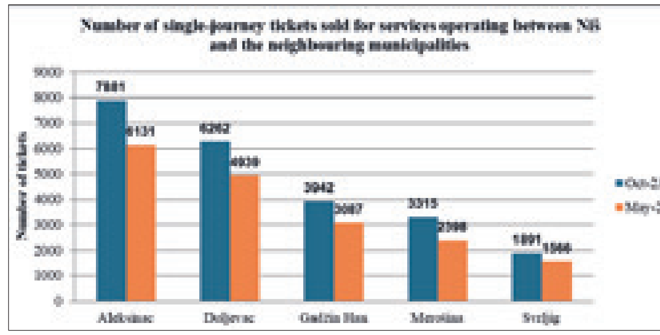

Chart 1. Analysis of the number of trips made between Niš and neighboring municipalities based on the sale of individual tickets (source: Niš ekspres)

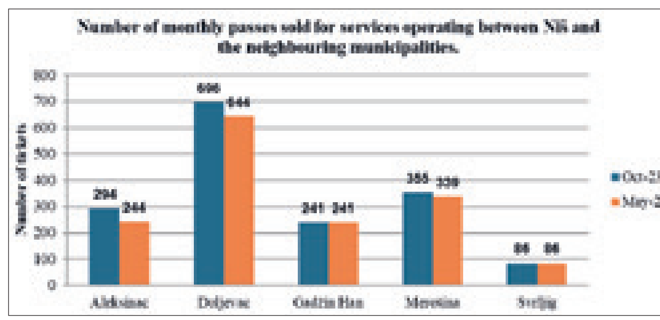

Chart 2. Comparative overview of monthly ticket sales for October 2023 and May 2024 by defined routes (source: Niš Ekspres)

By analyzing the submitted data on the number of monthly and individual tickets sold, it can be concluded that in the local transport system, on the routes between Niš and some of the neighboring municipalities, slightly more than 1,500 residents use a monthly ticket. If we multiply this number by a minimum of two rides during the day, this is about 3,000 passengers/rides in one day. About 20,000 individual tickets are sold on a monthly basis, which is about 600 to 700 passengers/rides in one day. Therefore, based only on the most dominant sample, we arrive at the data that more than 3,700 passengers/rides are realized daily in the local (regional) public transport system in the Niš Administrative District. The Niš-Aleksinac and Niš-Doljevac corridors are the largest in this system in terms of the number of transported passengers, but also in terms of the number of inhabitants and the development of the public transport network.

The municipality of Doljevac is the second largest in the Niš Administrative District and the number of monthly tickets is three times larger than the municipality of Aleksinac. This data shows that public transport on this corridor is more accessible and more adapted to the daily needs of the local population.

However, it is characteristic that the municipality of Doljevac also borders the municipality of Žitorađa and the city of Leskovac, which territorially belong to the Toplica and Jablanica districts, respectively. Passenger movements within and between these territories do not have a classic inter-city character, but arise as a consequence of daily existential migrations of residents (employees, students, retired people, etc.).

A similar specificity applies to the municipality of Merošina, which is located between the city of Niš and the municipality of Prokuplje. The number of tickets sold (single and monthly) in the municipality of Merošina has decreased significantly in recent years as a result of special scheduled transport that is organized not only for the transport of students to the "Jastrebački Partizani Primary School" but also for the transport of workers. Taking into account the previous analysis of the Niš Administrative District based on the data obtained from the most dominant local road transport company - Niš ekspres, characteristic points were observed for all corridors included, i.e. settlements located along the edge of the zone reached by the JGPP (Figure 3). These settlements are located at a distance of one to three kilometers from the defined border, and since they belong to a neighboring municipality, they are not part of the public transport system.

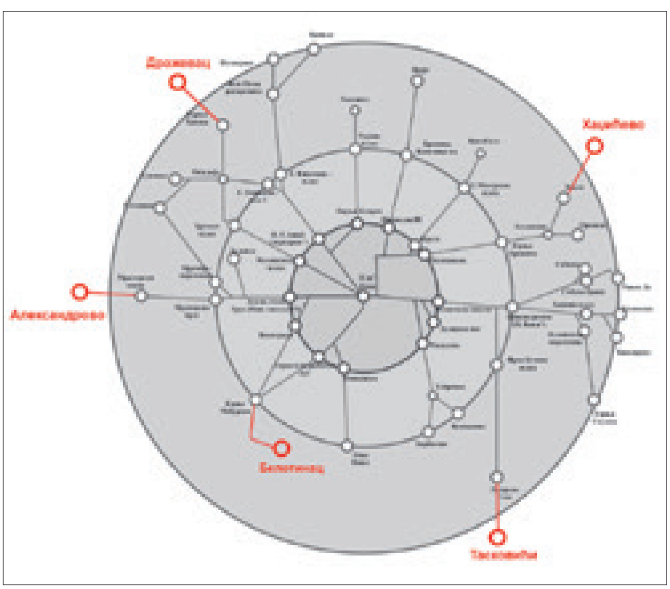

Figure 3. Position of the first settlements located along the edge of the PT zones in Niš

In the direction of Aleksinac, the residents of the village of Draževac are only 3 km away from the subsidized public transportation, and they do not have a quality network of intercity departures. The village of Belotinac, on the other hand, has a certain network of departures that is adapted to basic needs, namely going to work and school, which, in accordance with the population, results in a slightly higher frequency of travel compared to similar examples from neighboring corridors. Only from these characteristic, border points, 70 to 90 passengers/rides are realized daily (Table 1).

Table 1. Data on the volume of ticket sales from/to settlements along the edge of the PT zone in Niš

Settlement	Month	Distance from the PT Service area boundary	Monthly passes	Single tickets
Draževac	October -23	3 km	4	6
	May - 24		4	8
Hađžićevo	October -23	1.6 km	6	2
	May - 24		6	6
Aleksandrovo	October -23	1 km	3	62
	May - 24		3	25
Taskovići	October -23	1.3 km	0	191
	May - 24		0	123
Belotinac	October -23	1.4 km	36	337
	May - 24		34	310

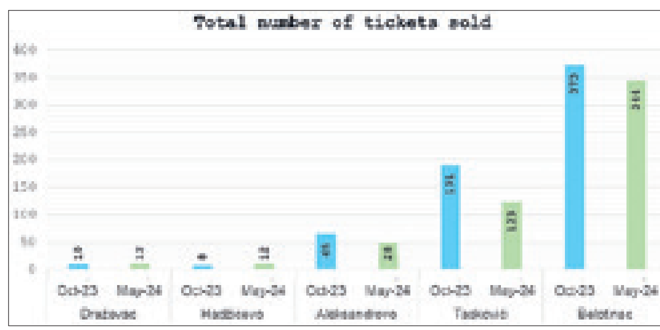

Chart 3. Total number of tickets sold from/to settlements along the edge of the PT zone in Niš

CRITICAL POINTS FOR IMPROVING THE PUBLIC TRANSPORT SYSTEM IN THE NIŠ ADMINISTRATIVE DISTRICT

Daily migrations of the local population within the territory of the Niš Administrative District are realized in several mutually uncoordinated and independent ways that may represent an obstacle to the further development and improvement of public transport in the Niš District:

1. By using intercity and municipal bus lines maintained by private car carriers,
2. By the model of special scheduled transport,
3. Individual transport by passenger car,
4. By alternative modes that rely on the passenger car - sharing of transport and travel costs,
5. By illegal modes of transport - scheduled taxis and van transport.

Individual transport by passenger car

The main advantage of a passenger car is its flexibility and accessibility. Public transport may never be able to match the flexibility of a passenger car, but appropriate measures can be taken to strengthen its competitiveness. Practice has shown that the greatest influence on system users when choosing a mode of transport is the price policy (fuel price, parking price and supply, ticket prices).

In other words, public transport must be a more accessible and economically viable means of transport than a passenger car from the user's perspective, otherwise:

- A transfer of a part of users to a passenger car occurs;
- Illegal forms of public transport that are basically based on a passenger car, such as regular taxis and the so-called van transport, develop.

Within the Niš Administrative District, in the last ten years alone, the number of registered passenger cars has increased by 28.8 %, while the number of residents living in this area has decreased by 8.6 %. It is symptomatic that the most devastated municipalities in the district have the largest increase in the number of registered cars (Chart 4). The municipality of Gadžin Han lost slightly more than 8.000 residents in the period between the two censuses, which is a decrease of 30.3 %. At the same time, there are 267 more registered passenger cars. This fact speaks in favor of the state of public transport in the devastated areas.

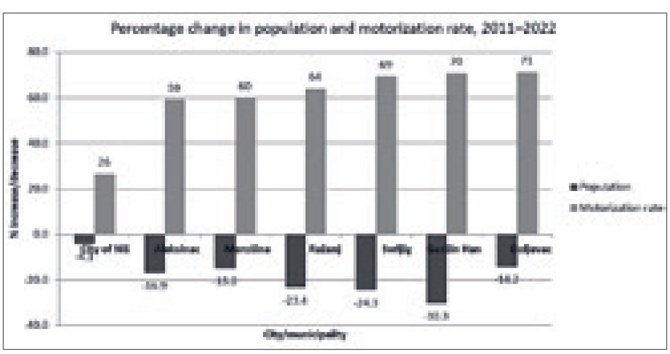

Chart 4. Comparative overview of changes in the number of inhabitants and the degree of motorization in the Niš Administrative District in the period 2011-2022

Sharing of transport and travel costs

When it comes to alternative modes, sharing transportation and travel costs is very popular among employees who join forces to go to work together in one passenger car. The habits created in this way should be used wisely, integrating transportation sharing into the regional transport system and stimulating the use of green vehicles.

If we take the example of the Niš Administrative District, whose seat is the City of Niš, which has organized public urban and suburban transportation, transportation sharing is particularly attractive to citizens who live in settlements of neighboring municipalities, but are on the very border of the PT zone (Figure 8). For example, in the direction of Aleksinac, the last settlement reached by the PT is Gornja Trnava and the price of a monthly ticket for workers on the Niš-Gornja Trnava route is 4410,00 RSD (I+II+III zone). The next settlement is the village of Draževac, which belongs to the municipality of Aleksinac and is only 3 km away from Gornja Trnava. Depending on the road transport company that provides intercity transport through the settlement of Draževac, the difference in the price of a monthly worker's ticket on the Niš-Draževac route, compared to Niš-Gornja Trnava, can be up to three times higher.

The main difference is that the price of a monthly ticket for the Niš-Gornja Trnava route is subsidized within the PT system in Niš. The price of a monthly ticket Niš-Draževac is formed on the basis of the real operating costs of the road transport company that provides intercity transport on this route.

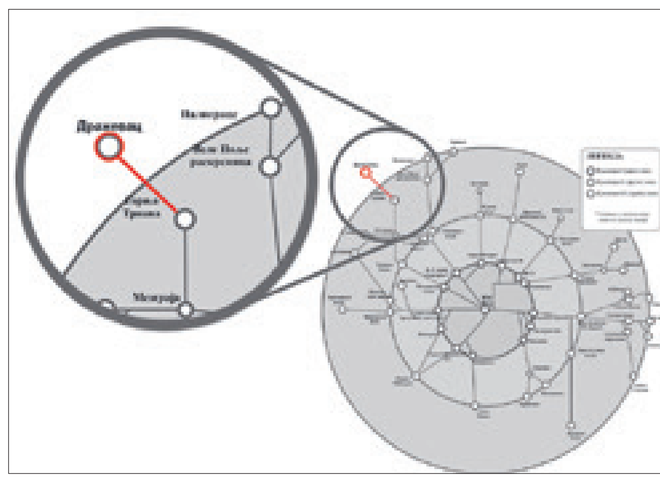

Figure 4. Position of the village of Draževac in relation to Gornja Trnava – the border of the third zone of the PT in Niš

Given that Niš is a university city, one of the characteristic situations when it comes to students and high school students is that their parents often opt for renting an apartment rather than purchasing a monthly ticket for a specific local route because the price ratio is of the same order of magnitude.

CONCLUSION

For many years, efforts have been made to improve the public urban and suburban transport system due to its key role in the social, economic and economic development of modern cities. The development of new, smart technologies has made public transport more accessible, transparent and comfortable. However, rapid urban development and its monocentric character are expanding the influence of cities to wider geographical areas, making the classic territorial division inadequate for the needs of public transport. Therefore, it is necessary for neighboring municipalities or municipalities within one district to join forces in order to jointly organize and operate public urban transport.

The paper examines the state of public transport in the Niš Administrative District and the general position of the city of Niš within the district itself. The legal framework regulating the public transport system in the Republic of Serbia is also reviewed and analyzed, and compared with examples from the European Union. The conclusion is that local (regional) public transport in the Niš Administrative District has the same character as suburban public transport that connects settlements with the narrower urban area. Therefore, it can be seen as public suburban transport in larger cities. And similarly to other municipal activities, local (regional) transport does not have standard economic characteristics and as such cannot function on a commercial basis.

The city of Niš has organized public urban and suburban transport, according to the public-private partnership model, but when its position is viewed from a geopolitical and socio-economic perspective, it can be concluded that it represents a regional center in a wider geographical area to which the local population gravitates.

Finally, critical points have been defined that need to be worked on in order to further improve the system of local, i.e. regional public transport, thus creating conditions for the implementation of a fully integrated system of local public transport on the territory of the Niš Administrative District.

Integration involves physical, i.e. network integration, then information, tariff and broader planning – the one that should be included in urban plans. In order to implement integration, there are a number of obstacles that need to be overcome in relation to the legal framework, political environment, business models of private road transport operators, the method of revenue distribution, but before that, focus on obstacles related to operational problems that are defined as key.

The next step is the association of municipalities and the joint performance of public transport, which is prescribed by the Law on Communal Activities. Two or more local self-government units may, by agreement, regulate the joint performance of communal activities, unless otherwise regulated by another special regulation.

If they determine the interest in the joint performance of communal activities, the municipal or city council of each local self-government unit makes a decision to prepare a feasibility study.

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PRELIMINARY REPORT

Urban Traffic Management Using Artificial Intelligence: A Sustainable Approach to Enhancing Urban Mobility

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Abstract: In modern cities, growing traffic volumes and limited infrastructure capacity lead to frequent congestion, increased emissions, and reduced quality of life. Traditional traffic management systems, based on fixed signal timings, often fail to adapt to real-time traffic dynamics. This paper presents how artificial intelligence (AI) can significantly enhance the efficiency and sustainability of urban traffic systems. By integrating data from sensors, cameras, and mobile devices with learning and forecasting algorithms, an intelligent system is developed to adjust traffic signals in real time. Simulation results show reduced waiting times, lower greenhouse gas emissions, and improved safety for all road users, including pedestrians and public transport. Special focus is placed on fairness and inclusive mobility, ensuring that technological advancement also addresses social equity. The proposed approach can be implemented across various urban environments without requiring extensive infrastructure changes.

Key words: Traffic management, AI, sustainability.

INTRODUCTION

Urban mobility is a cornerstone of sustainable development, with far-reaching implications for economic productivity, environmental sustainability, and social equity. Efficient transport systems facilitate commerce, reduce the cost of living, and enhance quality of life by enabling access to jobs, education, and essential services. However, as cities continue to expand and motorization rates rise, many urban areas are experiencing escalating congestion, deteriorating air quality, and growing spatial inequalities. The resulting strain on existing transport infrastructure is not only an operational challenge but also a policy imperative for achieving the Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action).

Traditional approaches to traffic management, primarily based on fixed signal timing plans and heuristic control strategies, are increasingly ill-suited for today's complex and dynamic urban environments. These legacy systems, often designed for more predictable traffic conditions, are unable to cope with the stochastic nature of modern mobility patterns shaped by ridesharing, logistics demand, public transport variability, and non-motorized transport. They also lack the adaptability needed to respond in real time to unforeseen events such as accidents, construction, weather disruptions, or special events. Consequently, cities reliant on outdated traffic systems face higher travel delays, increased vehicle emissions, and diminished roadway safety.

Moreover, the conventional design of traffic control systems has historically favored private vehicles, often at the expense of pedestrians, cyclists, and public transport users. This car-centric paradigm contributes to spatial inequality and environmental injustice, particularly in underserved communities where walking and transit are dominant modes of mobility. A shift toward inclusive, sustainable traffic management is therefore essential—not only to improve system efficiency, but also to ensure that urban mobility systems are equitable, resilient, and future-ready.

In this context, artificial intelligence (AI) emerges as a transformative tool with the potential to revolutionize urban traffic management. Leveraging the proliferation of real-time data from cameras, sensors, mobile applications, and connected vehicles, AI algorithms can detect traffic patterns, forecast congestion, and autonomously adjust traffic signal operations. Machine learning, reinforcement learning, and deep learning methods allow systems to "learn" optimal responses over time, enabling highly responsive, context-aware signal control. In contrast to static or semi-adaptive systems, AI-driven approaches can dynamically manage intersections, prioritize high-occupancy vehicles, and respond proactively to emerging disruptions.

This paper proposes a comprehensive AI-enhanced traffic signal management framework aimed at tackling the challenges of modern urban mobility. The framework integrates real-time data collection, predictive modeling, and adaptive signal control into a unified system capable of improving traffic flow, reducing environmental impact, and enhancing accessibility for vulnerable road users. A simulation-based evaluation is conducted in a model of a mid-sized European urban network to quantify the benefits and assess the equity implications of the proposed system. Through this research, we aim to demonstrate not only the technical viability of AI in traffic control, but also its capacity to support more inclusive and sustainable urban development.

LITERATURE REVIEW

Urban traffic management has long been a focal point for transportation engineers and city planners seeking to balance vehicle throughput with safety, accessibility, and environmental considerations. Over the past few decades, the field has transitioned from rule-based approaches to increasingly data-driven, automated, and intelligent systems. This evolution has been underpinned by advances in sensing technologies, computing power, and, more recently, artificial intelligence (AI) and machine learning (ML).

Traditional and Adaptive Signal Control Systems

Historically, traffic signals were managed using fixed-time control strategies, where signal phases followed predetermined schedules based on historical traffic volumes. While simple to implement, these systems were inherently rigid and unable to accommodate real-time fluctuations in traffic demand. This led to inefficiencies during non-peak periods or in response to unexpected events such as accidents, roadworks, or weather disruptions.

In the late 20th century, the introduction of Intelligent Transportation Systems (ITS) marked a significant step forward. Adaptive systems like SCATS (Sydney Coordinated Adaptive Traffic System) and SCOOT (Split Cycle Offset Optimization Technique) used embedded loop detectors and traffic sensors to adjust signal timings based on real-time vehicle counts and occupancy data. These systems introduced feedback loops into signal control and improved performance over static configurations, especially in urban grids (Papageorgiou et al., 2003).

However, SCATS and SCOOT relied on rule-based heuristics, often encoded by human engineers, and thus lacked the ability to "learn" from patterns or optimize across complex, dynamic networks. Their performance deteriorated under conditions not foreseen by their designers, prompting interest in more adaptive, autonomous control strategies.

Artificial Intelligence in Traffic Signal Control

With the rise of big data and AI, researchers began to explore machine learning models capable of autonomous learning and real-time decision-making. Reinforcement learning (RL), particularly Q-learning, emerged as a popular method for optimizing traffic signals by treating intersections as agents that learn to minimize cumulative traffic delay through trial-and-error (Wei et al., 2018; Michailidis et al., 2025). These agents use reward functions—such as minimizing queue lengths or wait times—to update signal policies dynamically.

More advanced models, such as Deep Q-Networks (DQN) and multi-agent reinforcement learning (MARL), enable coordinated learning across entire intersections, especially in dense urban grids (Kanis et al., 2021; Miletić et al., 2022). These frameworks allow adjacent intersections to share state information and jointly learn optimal control strategies, which is particularly valuable in preventing congestion spillbacks and optimizing corridor-level flow.

Supervised learning models have also been used to forecast traffic volumes and detect anomalies using historical and real-time data. Algorithms such as random forests, gradient boosting machines, and support vector machines (SVMs) have proven effective in short-term traffic prediction, particularly when integrated with weather and event data (Zhao et al., 2024). These models enable proactive signal adjustments before congestion becomes severe.

In parallel, deep learning techniques such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs) are increasingly applied to visual and sequential traffic data. CNNs are used for real-time vehicle detection and flow estimation from traffic cameras (Zhang et al., 2020), while RNNs model time-series data to predict future traffic states based on historical patterns.

Recent innovations such as SafeLight, proposed by Du et al. (2022), further refine RL systems by incorporating safety constraints (e.g., collision avoidance) directly into the reward structure, enhancing real-world applicability.

Multi-Intersection and Network-Level Optimization

While early AI applications focused on optimizing individual intersections, more recent developments emphasize network-wide control using multi-agent systems. These frameworks distribute control among intelligent agents located at each intersection, which collaborate to manage overall flow. Studies by Miletić et al. (2022) and Kolat et al. (2023) demonstrate that coordinated MARL systems improve green wave propagation, reduce bottlenecks, and lead to more balanced traffic distributions across large networks.

Federated learning and edge computing have also gained attention as strategies to scale AI control without centralizing sensitive data. By training models locally at each intersection and sharing only model parameters (not raw data), federated learning allows cities to preserve data privacy while improving system performance (Wang et al., 2022).

These decentralized AI architectures are especially relevant for cities with fragmented infrastructure or legal constraints on data centralization.

AI for Sustainable Urban Mobility

Beyond operational efficiency, AI-enhanced traffic management systems are increasingly evaluated for their environmental impact. Several studies have shown that adaptive signal control using AI significantly reduces fuel consumption, CO_2 emissions, and noise pollution by minimizing unnecessary stops and smoothing traffic flow (Chen et al., 2021; Eteifa et al., 2025).

For instance, Michailidis et al. (2025) review multiple RL applications and note consistent reductions in vehicular idle time and average travel delay. Zhao et al. (2024) further highlight the role of hybrid models that jointly optimize emissions, congestion, and transit performance using multi-objective reward functions.

Simulation studies suggest that emissions reductions of 30–40% are achievable when adaptive AI is deployed along major urban corridors, especially when integrated with transit signal priority and eco-driving algorithms.

Gaps and Future Directions

Despite these promising developments, several key gaps persist in the literature. First, many AI models remain confined to simulated environments, where variables are controlled and idealized. The leap to real-world implementation introduces complexities such as sensor noise, unpredictable driver behavior, and hardware failure—all of which are rarely modeled in academic studies (Chen et al., 2021; Shashi et al., 2021).

Second, there is limited research comparing the performance of AI traffic systems across diverse urban settings—such as compact historic cities versus sprawling metropolitan areas. The generalizability of results is therefore uncertain.

Third, while equity is increasingly mentioned in smart mobility literature, there is a lack of operational AI models that explicitly account for pedestrians, cyclists, elderly populations, or transit-reliant communities. Mitieka et al. (2023) argue for a broader inclusion of social sustainability metrics in AI traffic planning to ensure that smart systems do not unintentionally reinforce existing mobility disparities.

Future research should also explore hybrid AI architectures that combine supervised learning, RL, and optimization in real-time settings. Likewise, the development of explainable AI (XAI) and ethically-aligned frameworks will be essential for building public trust and regulatory acceptance.

METHODOLOGY

This study introduces an AI-based traffic signal system that learns how to manage intersections more efficiently. The model combines two core AI techniques:

- Supervised learning is used to predict traffic flow based on past data.
- Reinforcement learning allows the system to adjust signal timings in real time to improve performance.

The system uses live data from several sources:

- Traffic cameras to monitor congestion,
- Vehicle sensors at intersections,
- Mobile GPS data from navigation apps,
- Public transport feeds to track buses and trams.

A realistic city layout was simulated using the SUMO platform, representing a mid-sized European city. First, a traditional fixed-timing traffic system was tested. Then, the AI-based system was deployed on the same network. Key performance metrics—such as delay times, emissions, and public transport efficiency—were collected to compare the results.

RESULTS

The simulation produced compelling evidence that AI-driven traffic signal control systems can yield significant improvements across a range of urban mobility performance indicators. The average vehicle delay per intersection—a core measure of traffic flow efficiency—was reduced by 47%, decreasing from 72 seconds in the baseline scenario to just 38 seconds under the AI-managed regime. This reduction suggests a marked improvement in intersection throughput and reduced queuing, both of which contribute to smoother traffic conditions and lower travel time variability.

Environmental benefits were equally pronounced. CO_2 emissions per intersection declined by 35%, falling from 1,480 grams to 965 grams. This drop is largely attributable to the system's ability to minimize stop-and-go driving patterns, which are known to cause inefficient fuel consumption and elevated tailpipe emissions. By facilitating more continuous vehicle movement, the AI system helps reduce unnecessary acceleration and idling—both key contributors to urban air pollution and greenhouse gas output.

Pedestrian wait times at signalized crosswalks decreased by 30%, from 60 seconds to 42 seconds on average. This metric is particularly important from an inclusivity and walkability standpoint. Reducing pedestrian wait times enhances the experience of walking as a mode of transport and can encourage modal shift away from car dependency. It also has safety implications, as shorter wait times reduce the temptation for pedestrians to cross illegally or against signals.

Furthermore, bus travel time during peak hours improved by 22%, decreasing from 18 to 14 minutes across the observed network. This gain is the result of intelligent transit signal priority (TSP), which grants extended green phases or early green returns to buses approaching intersections, especially those running behind schedule. Improved bus reliability not only enhances passenger satisfaction but can also improve operational efficiency for transit agencies.

The following table summarizes the quantified improvements observed in the AI-controlled scenario:

Table 1. Quantified improvements in AI scenario

Metric	Traditional System	AI-Based System	Improvement
Vehicle Delay (s)	72	38	−47%
CO_2 Emissions (g/inter.)	1480	965	−35%
Pedestrian Wait Time (s)	60	42	−30%
Bus Travel Time (min)	18	14	−22%

In addition to these quantifiable gains, the simulation revealed meaningful equity-focused outcomes, which are often overlooked in traditional traffic performance assessments. The system was programmed to dynamically prioritize pedestrian signals in high-sensitivity zones such as school districts, hospital zones, and elderly care centers. This led to faster pedestrian clearance times in these areas, contributing to a safer and more accessible environment for vulnerable populations.

Another key feature was the prioritization of public transport equity. Buses running behind schedule were detected in real time via GPS feed integration and granted adaptive green phases at upcoming intersections. This led to fewer cumulative delays and improved on-time performance—an essential metric for retaining rider trust and encouraging public transport usage. The algorithm also considered headway restoration, helping maintain even spacing between buses to reduce bunching, a common issue in high-frequency corridors.

These outcomes underscore the AI system's ability to align operational efficiency with social goals such as accessibility, safety, and transit equity. Rather than treating efficiency and equity as trade-offs, the system demonstrates that with appropriate algorithm design, it is possible to simultaneously improve overall system performance and redistribute mobility benefits more fairly across user groups.

In conclusion, the AI-based traffic control framework outperformed the conventional system across all evaluated dimensions—mobility, emissions, safety, and fairness. These results provide a robust foundation for advocating broader implementation of intelligent traffic systems, particularly in rapidly urbanizing or transitionary cities where legacy infrastructure is under strain but major reconstruction is infeasible.

DISCUSSION

The findings of this study underscore the transformative role that artificial intelligence (AI) can play in modernizing urban traffic management systems. By enabling real-time data processing, adaptive signal control, and predictive decision-making, AI technologies offer an unprecedented ability to respond dynamically to the complexity of urban mobility. Unlike traditional systems that operate based on pre-defined schedules or historical averages, AI systems can learn continuously from current traffic conditions, adapting signal timings to reduce delays, minimize congestion, and enhance traffic flow resilience. This agility is critical in today's urban environments, where fluctuations in demand, unforeseen incidents, and changing mobility patterns render static control systems increasingly obsolete.

Importantly, this study demonstrates that AI integration need not be narrowly focused on efficiency metrics such as vehicle throughput or travel time. The inclusion of equity-aware features—such as prioritizing pedestrians, cyclists, and delayed public transport vehicles—challenges the long-standing dominance of the automobile in urban design. This shift is consistent with contemporary urban planning paradigms that emphasize multimodal accessibility, social inclusion, and environmental justice. AI, in this context, is not merely a tool for optimizing flows but a platform for rethinking whose mobility needs are prioritized and how urban space is allocated. By embedding fairness into the logic of traffic control, cities can move closer to achieving inclusive mobility systems that serve all residents, regardless of age, ability, or socioeconomic status.

Despite these promising results, several challenges must be acknowledged and addressed for AI-based traffic management systems to reach their full potential. First, the successful deployment of such systems hinges on the availability and quality of data. AI models require large volumes of high-resolution, real-time data to function effectively, including information on traffic volumes, vehicle speeds, pedestrian movements, and public transport operations. In cities lacking sufficient sensor infrastructure or where data is siloed across agencies, the performance of AI systems may be significantly constrained. Bridging this data gap requires not only technological investment but also strong institutional coordination and standardized data-sharing protocols.

Second, the integration of data from mobile phones, GPS devices, and surveillance cameras raises important ethical and legal concerns. The real-time collection and processing of location and behavioral data could infringe upon individual privacy if not carefully managed. Therefore, any city-wide implementation must be accompanied by robust data governance frameworks that ensure transparency, accountability, and data minimization. Anonymization techniques, encryption protocols, and explicit consent mechanisms should be integral components of any AI-driven mobility initiative. Moreover, public communication strategies are needed to inform citizens about how their data is used and to build trust in the system's safeguards.

Third, the so-called "black box" nature of many AI algorithms—particularly those involving deep learning or neural networks—can complicate efforts to ensure accountability and regulatory compliance. When decision-making processes are opaque or non-intuitive, it becomes difficult for operators, regulators, or the public to understand how and why certain traffic patterns are prioritized or modified. This lack of explainability can erode trust and pose challenges for post-incident evaluations or appeals. As such, there is a growing need for interpretable AI (XAI) models that offer greater transparency without compromising performance. The development and adoption of explainable machine learning tools should be a key research priority moving forward.

Fourth, the resilience of AI systems under stress conditions—such as natural disasters, cyberattacks, or sensor failures—remains a relatively underexplored area. While adaptive control can enhance flexibility under normal conditions, reliance on digital infrastructure makes the system vulnerable to disruptions. Redundancy planning, edge computing, and real-time system diagnostics must be incorporated into future AI traffic systems to ensure operational continuity and cybersecurity resilience. Pilot programs should simulate various failure scenarios to test system robustness and identify necessary safeguards.

In addition to technical and ethical considerations, social and organizational challenges must also be managed. AI traffic management systems require cross-sector collaboration between city governments, transport authorities, technology providers, and civil society. Institutional inertia, funding constraints, and lack of interdisciplinary capacity can slow adoption. Thus, capacity-building initiatives, training programs, and cross-departmental coordination mechanisms are essential for effective implementation.

Finally, the global applicability of AI traffic systems depends on their adaptability to different urban typologies. Cities vary widely in terms of traffic culture, infrastructure maturity, governance capacity, and mobility needs. What works in a densely populated European capital may not translate directly to a rapidly growing secondary city in the Global South. Contextual adaptation—guided by local data, participatory design processes, and culturally sensitive metrics—is necessary to ensure that AI systems do not reinforce existing inequalities or overlook local priorities.

In summary, while AI offers powerful tools to enhance the intelligence, efficiency, and fairness of urban traffic systems, its deployment must be thoughtfully designed and rigorously governed. The full realization of AI's potential in urban mobility hinges not only on technological innovation but also on ethical alignment, institutional readiness, and sustained public engagement.

CONCLUSION

This paper demonstrates that the integration of artificial intelligence (AI) into urban traffic signal systems can lead to transformative improvements in how cities manage mobility, sustainability, and equity. By leveraging real-time data and adaptive learning algorithms, AI systems can significantly reduce traffic delays, optimize signal phasing, and respond dynamically to unpredictable road conditions. The simulation results confirm that AI-enabled control not only enhances vehicle flow but also substantially reduces greenhouse gas emissions and improves accessibility for pedestrians and public transport users. These outcomes are critical in the broader context of urban sustainability, where transportation remains one of the most significant contributors to pollution, energy inefficiency, and social exclusion.

The proposed AI framework stands out for its ability to operate using existing infrastructure, making it a cost-effective and scalable solution suitable for cities at various stages of technological maturity. Its modular architecture allows for incremental adoption, from pilot corridors to city-wide deployments, without requiring disruptive overhauls. Moreover, the incorporation of equity-aware algorithms ensures that the benefits of improved traffic management extend beyond private vehicles to more vulnerable road users—such as pedestrians, cyclists, and transit riders—who are often underserved in traditional systems. In this way, AI-driven traffic management supports a more inclusive vision of urban development, aligned with global goals such as the UN's Sustainable Development Goal 11 (Sustainable Cities and Communities).

However, the path toward full-scale implementation is not without challenges. Ensuring the ethical use of AI in public infrastructure is paramount, particularly in terms of data privacy, algorithmic transparency, and accountability. Public trust must be cultivated through open communication, explainable AI models, and robust governance structures. Furthermore, technical limitations related to data coverage, system interoperability, and resilience in extreme traffic scenarios require further investigation and testing under real-world conditions.

Future research should prioritize large-scale, multi-jurisdictional pilot deployments that evaluate system performance in diverse urban contexts, from highly congested city centers to suburban and transitional areas. Integrating AI-based traffic systems with multimodal transport planning—encompassing walking, cycling, shared mobility, and public transit—will be essential to realize the full spectrum of sustainability benefits. Additionally, cross-disciplinary collaborations between engineers, urban planners, policymakers, and ethicists will be necessary to develop and institutionalize standards for safe, fair, and effective AI deployment in public spaces.

In conclusion, AI represents a strategic enabler for next-generation urban traffic systems. When thoughtfully implemented, it can not only optimize operational efficiency but also contribute meaningfully to the long-term resilience, inclusiveness, and ecological balance of modern cities. The convergence of AI and urban mobility is no longer a futuristic ambition—it is an urgent imperative for cities navigating the twin pressures of population growth and climate change.

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PROFESSIONAL PAPER

Analysis of a Traffic Accident During Turn and Overtake - Case Study

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Abstract: Traffic accidents represent a significant safety challenge, and analyses in the Republic of Srpska show that one of the most common driver errors is improper overtaking and turning. These actions require high concentration, assessment of road conditions and correct decision-making, and their improper execution often leads to collision situations. Overtaking, in particular, is a complex action that includes numerous factors such as assessing speed, distance and the reactions of other road users.

The aim of this paper is to determine, through a temporal-spatial analysis, who and to what extent contributed to the occurrence of a traffic accident in a case where vehicles performed turning and overtaking actions. Special emphasis will be placed on whether these actions were permitted in the specific circumstances, as well as on determining the causal factors that led to the accident. The analysis will be conducted through a review of the traffic and technical expertise of this case, taking into account relevant traffic regulations, technical aspects and the behavior of the participants in the accident.

The results of this research can contribute to a better understanding of risk factors when performing overtaking and turning actions, and provide guidelines for improving traffic safety, both through improving regulations and by raising driver awareness of the risks associated with these maneuvers.

Keywords: expertise, traffic safety, vehicle operations.

INTRODUCTION

An estimated 1.19 million people died in road traffic accidents in 2021, a 5% decrease from 1.25 million deaths in 2010. More than half of United Nations Member States reduced the number of road deaths between 2010 and 2021. The modest overall decline in fatalities occurred despite the global vehicle fleet more than doubling, the road network expanding significantly, and the world population increasing by almost a billion people. This shows that efforts to improve road safety are yielding results, but they are still far from what is needed to achieve the goal of the United Nations Decade of Action for Road Safety 2021–2030, which envisages halving the number of deaths by 2030 (1).

In the period 2020-2024, 50,332 traffic accidents occurred on the territory of the Republic of Srpska, of which 460 were fatal, 11,198 were injured, and 38,674 were property damage.

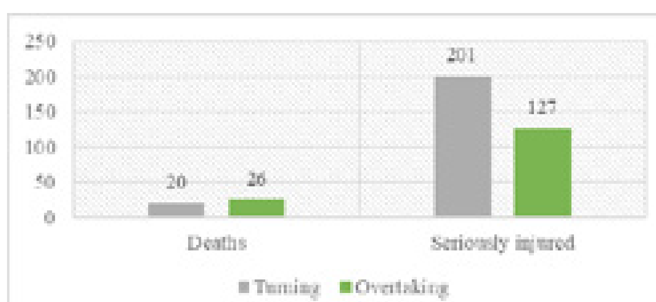


Chart 1. Overview of "Turning" and "Overtake" Errors Resulting in Traffic Accidents, Period 2020-2024

The graph shows the statistics of errors related to turning and overtaking in traffic accidents in the period from 2020 to 2024. In the category of fatalities, overtaking errors resulted in 26 cases, while turning was the cause of 20 cases. When it comes to serious bodily injuries, turning was the cause in 201 cases, which is significantly more compared to overtaking, which led to 127 cases. These data indicate that turning is a more common cause of serious injuries, while overtaking is slightly riskier in terms of fatalities.

The determination of liability has several important aspects. First of all, one of the key principles of both misdemeanor and criminal proceedings is to ensure a fair trial, which guarantees that innocent persons are not unjustly punished. In addition, the decision made in criminal proceedings may affect the civil process for compensation of damages. Although the civil court is not obliged to abide by the outcome of the misdemeanor proceedings, the burden of proof is often shifted from the injured party to the person who caused the damage. In contrast, in criminal proceedings, the liability established is binding on the civil court as to the existence of a criminal offence, but there is still the possibility of considering the contribution of the injured party, since civil liability covers a wider scope than criminal liability.

In order to accurately determine responsibility, it is necessary to conduct a detailed traffic and technical expertise, which allows for the analysis of the movement of participants in the traffic incident, the temporal and spatial examination of the event and the determination of relevant facts. After that, the relevant provisions of the Law on the Fundamentals of Traffic Safety in BiH, as well as other regulations regulating this area, are applied to the established circumstances.

LEGAL REGULATIONS REGARDING THE PERFORMANCE OF TURN AND OVERTAKE OPERATIONS

Overtaking is defined as passing another vehicle moving in the same lane and in the same direction. A driver who intends to overtake, turn, or perform any other action with a vehicle on the road must first ensure that he can do so without endangering other road users and property. In doing so, he is obliged to take into account the vehicle's position, direction, and speed.

Overtaking and passing are permitted only if this does not impede the normal movement of vehicles from the opposite direction and if there is sufficient space on the road for safe performance of the action. The driver may not overtake in situations where, due to the characteristics of the road, existing traffic conditions or technical characteristics of the vehicle, this would endanger other road users. Overtaking is usually carried out on the left side, except when the vehicle on the roadway takes a position that clearly indicates that it is turning left, in which case overtaking may be carried out on the right side. Also, a vehicle moving on rails installed in the middle of the roadway may not be overtaken on the left side, but exclusively on the right, if there is a special traffic lane for this.

A driver who notices that another vehicle is overtaking him from the left is obliged to move the vehicle to the right edge of the roadway in order to enable safe overtaking. He must not increase his speed while overtaking. If the roadway is too narrow or in poor condition, and overtaking is not possible without endangering traffic safety, the driver of the slower vehicle is obliged to move as far to the right as possible, and if that is not enough, to stop the vehicle in a suitable place to let faster vehicles pass.

There are clear situations in which overtaking is prohibited. A driver may not initiate overtaking of a convoy of vehicles, nor if the vehicle behind him has already initiated overtaking. He may also not initiate overtaking if the vehicle in front of him is preparing to overtake another vehicle or an obstacle on the road. Overtaking is also not permitted if the traffic lane he intends to overtake is not clear at a sufficient distance, as this could endanger safety or interfere with vehicles from the opposite direction. A driver may not initiate overtaking if, after completing the action, he would not be able to safely return to the original lane without endangering other road users. It is also prohibited to overtake using a lane intended for forced stopping of vehicles, directly in front of and in a tunnel with only one traffic lane in the direction of travel.

The overtaking driver is obliged to maintain a sufficient distance from the overtaking vehicle during this action, so as not to obstruct or endanger it. After overtaking is completed, as soon as possible and without obstructing other participants, the driver is obliged to return to the lane in which he was moving before starting the overtaking. On two-way roads, a driver may not overtake another vehicle in front of the top of a bend or on a curve when visibility is insufficient, unless there are several marked lanes intended for movement in the same direction.

Overtaking is also prohibited immediately in front of an intersection or at an intersection that does not have a roundabout, except in certain situations, such as overtaking a vehicle turning left from the right, overtaking a vehicle turning right without changing to the opposite lane, or when overtaking is carried out on a road with the right of way or when traffic at the intersection is regulated by traffic lights or signs of an authorized person. Also, overtaking immediately in front of or at a road crossing over a railway or tram line without a bumper or half-bumper is permitted only when traffic at the crossing is regulated by traffic lights.

A driver may not overtake another vehicle that is approaching a pedestrian crossing, crossing it, or has stopped to let pedestrians pass. Also, on roads with at least two lanes of traffic in the same direction, a driver may only change lanes to turn or park, while moving faster in one lane than in another is not considered overtaking.

Considering that in the expertise selected as a case study in this paper, the driver who performed the overtaking action was operating at a speed higher than the speed limit on the specified section. In addition to all of the above, the driver, when performing the overtaking action, must take into account the speed limit on the road he is driving on, and comply with it.

When it comes to turning, a driver turning right must do so from the far right lane along the edge of the road, unless traffic signs prescribe otherwise. A driver turning left must make the turn from the far left lane along the center line of the road, following an imaginary or marked arc connecting the two center lines of the side roads. If it is a one-way road, a left turn is made from the far left lane along the left edge of the road, unless otherwise indicated by a traffic sign.

For performing actions, it is of great importance to convince the driver, with the previously fulfilled condition that the action is permitted. The general observation time is between 0.50 and 1.16 seconds. To transfer the gaze from the road in front of the vehicle to the instrument panel, read a certain index and turn the gaze back to the road, a time of between 1.5 and 1.9 seconds is required (2).

EXPERTISE OF TRAFFIC ACCIDENTS IN WHICH DRIVERS PERFORM TURN AND OVERTAKE

As stated in the introductory part of the paper, we can see that overtaking and swerving are widely represented in traffic accidents. Given the frequency of traffic accidents of this type, it is possible that in these cases both actions are permitted, that one of them is not permitted, or that both are prohibited. Therefore, the expert opinions of the aforementioned traffic accidents require special attention, and this paper will present the expert opinion of a traffic accident in which both participants performed the aforementioned actions, which were permitted in the specific situation.

Participants in a traffic accident

The following people participated in the analyzed traffic accident:

- Golf 4 passenger car
- Golf 3 passenger car

Road and weather information

At the scene of the accident, the roadway is constructed of an asphalt pavement, 6.70 m wide, divided by a dashed dividing line into two traffic lanes, with the left traffic lane being 3.30 m wide. On the left side of the roadway, viewed from the indicated direction, there is a ditch 0.60 m wide, a grassy area 1.80 m wide, and a path intended for pedestrians 1.50 m wide. On the left side of the main road, there is a turn to the bakery parking lot. On the right side of the roadway, there is a sandy extension 3.00 m wide, which is connected to the installed elements of concrete cubes in the form of a wall that form the fence of the yard.

The speed limit for motor vehicles on the specified section of road is regulated by a traffic sign in a populated area at 50 km/h.

At the time of the traffic accident, as well as at the time of the investigation, it was night, the weather was cloudy, the roadway was dry, and the place was illuminated by street lights.

Vehicle data and vehicle damage

The inspection report does not list the damage to the vehicles involved in the collision, but only states that the vehicles sustained significant material damage.

From the photographs of the "Golf 4" vehicle, it is visible that the entire front part of the vehicle is damaged, with the front left end being slightly more pressed towards the middle of the vehicle than the front right part of the vehicle. On the "Golf 3" vehicle, the entire rear part of the vehicle is damaged in such a way that it is pressed towards the middle part of the vehicle.

Based on the damage to the colliding vehicles, it can be concluded that the front of the Golf 4 collided with the rear of the Golf 3.

Determining the location of the collision and the position of the accident participants

Based on the damage to the colliding vehicles, it can be concluded that the contact occurred between the front, slightly more to the left, part of the "Golf 4" vehicle and the rear part of the "Golf 3". At the time of the collision, the longitudinal axes of the colliding vehicles were almost parallel. After the contact, the "Golf 4" vehicle, as a vehicle with a significantly higher speed of movement, which means kinetic energy, continued to move in the direction of Banja Luka, turning to its right side and stopping after contact with the wall, while the "Golf 3" vehicle, as a result of the kinetic energy gained by the impact by the "Golf 4" vehicle, was thrown forward and to the left side with the vehicle rotating in an anti-clockwise direction.

Immediately before the accident, a passenger vehicle of the brand "Golf 3" was moving from the direction of Gradiška towards Banja Luka, and it can be concluded that it was in the phase of turning into a parking lot on the left side of the road, having moved completely into the left lane. At the same time, a passenger vehicle of the brand "Golf 4" was also moving from the direction of Gradiška towards Banja Luka, having moved completely into the left lane.

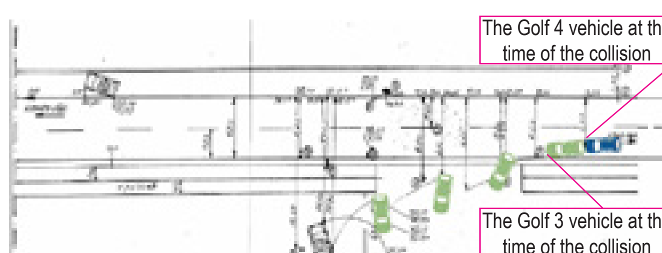


Figure 1. Vehicle Position at the Moment of the Collision

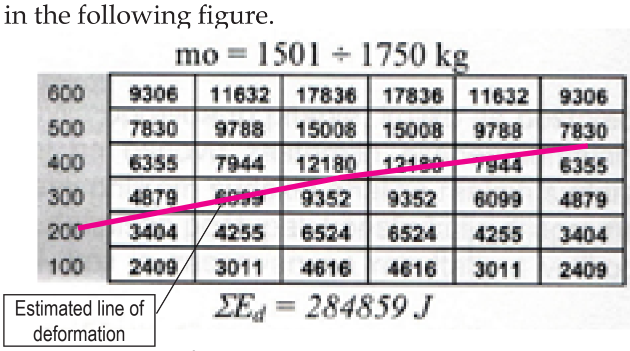
Determining the speed of the accident participants

Based on the data from Spis, it was not possible to determine the speed of the Golf 3 at the time of the collision. However, considering that the vehicle was in the process of turning into a parking space, which is usually done at lower speeds, its speed can be estimated with sufficient accuracy at 20 km/h.

The kinetic energy possessed by the passenger car "Golf 4" at the moment of contact was spent on the deformation of the vehicle during the collision, on the ejection of the vehicle "Golf 3" and on its movement to the point of stopping. The speed of the vehicle "Golf 4" immediately before the accident can be determined using the following physical equation:

$$\frac{m_{G4}\cdot V_{G4s}^2}{2} = m_{G4}\cdot b_{k1}\cdot S_{k1} + \frac{m_{G4}\cdot V_{G4d}^2}{2} + m_{G3}\cdot b_{G3z}\cdot S_{G3z} - \frac{m_{G3}\cdot V_{G3}^2}{2} + m_{G4}\cdot b_{kr}\cdot S_{k2} \quad (1)$$

The speed of the Golf 4 vehicle lost to deformation was determined using the energy raster diagram shown in the following figure.



mo = 1501 ÷ 1750 kg

600	9306	11632	17836	17836	11632	9306
500	7830	9788	15008	15008	9788	7830
400	6355	7944	12180	12180	7944	6355
300	4879	6099	9352	9352	6099	4879
200	3404	4255	6524	6524	4255	3404
100	2409	3011	4616	4616	3011	2409

$\Sigma E_d = 284859\ J$

Figure 2. Energy Layout Diagram

where is it,
E_{G4d} – deformation energy (86464 Nm),
K_{G4gp} – coefficient of the year of production (1999,1,038),
m_{G4} – mass of the vehicle ``Golf 4'' with driver and passengers (1540 kg).

Now we can calculate the speed of the Golf 4 at the time of the collision using the following formula.

$$V_{G4s} = \sqrt{V_{G4d}^2 + 2\cdot\frac{m_{G3}}{m_{G4}}\cdot b_{G3z}\cdot S_{G3z} - \frac{m_{G3}}{m_{G4}}\cdot V_{G3}^2 + 2\cdot b_{kr}\cdot S_{kr}} = 19{,}4\,\frac{m}{s} \approx 70\,\frac{km}{h} \quad (2)$$

where is it,
m_{G3} – mass of the "Golf 3" vehicle with passengers (1030 kg),
S_{G3z} – length of the skid marks of the "Golf 3" vehicle (34.00 m),
b_{G2z} – deceleration of the "Golf 3" vehicle along the drift tracks (4.00 m/s ^{2}),
V_{G3s} – speed of the vehicle "Golf 3" (20 km/h),
S_{kr} – the length of the path of the "Golf 4" vehicle after the collision (56.50 m),
b_{kr} – deceleration of the "Golf 4" vehicle on the road after the collision (1.0 m/s ^{2}),
t_3 – deceleration increase time (0.2 s).

Therefore, the speed of the "Golf 4" vehicle at the time of the collision was 70 km/h. The driver of the "Golf 4" vehicle, in his statement, among other things, states: " at that moment I tried to avoid contact with the vehicle but I failed and hit the rear of his vehicle with the front left side of my vehicle". The driver of the "Golf 4" vehicle does not state what action he was taking, but it could have been braking or swerving to the left or right. If the "Golf 4" vehicle was braked before the accident, then the speed of this vehicle immediately before the accident was greater than 70 km/h, but this cannot be determined based on the data from the Record. It should be noted here that even if the Golf 4 had been braked intensively, as a rule, no brake marks would have remained because this vehicle has an ABS braking system that has been standardly installed in Golf vehicles since 1996. Given this fact, the possibility cannot be ruled out that the Golf 4 had been braked after the collision, which would represent a normal driver reaction, and which would certainly affect the calculation of the speed of this vehicle, i.e. the speed would be greater than 70 km/h.

Temporal-spatial analysis of the course of a traffic accident

The time taken for the Golf 4 to avoid the dividing line to the point of contact was:

$$t_{G4iz} = 2{,}51\cdot\sqrt{\frac{B_p}{\mu_b\cdot g}} = 2{,}6\,s \quad (3)$$

where is it,
B_p – lateral displacement of the vehicle (2.7 m),

The evasive distance of the "Golf 4" vehicle from the dividing line to the point of contact was :

$$S_{G4izr} = V_{G4s}\cdot t_{G4iz} = 51{,}0\,m \quad (4)$$

Taking into account the collision position of the two vehicles, and "returning" the "Golf 3" vehicle back in the direction of movement it had at the time of the collision, I determined that the distance traveled by the "Golf 3" vehicle from the dividing line to the point of contact was approximately 25 m. The speed of the "Golf 3" vehicle at the beginning of the 25 m avoidance distance was:

$$V_{G30} = \sqrt{V_{G3s}^2 + 2\cdot b_{G3k}\cdot S_{G3kr}} = 12{,}5\,\frac{m}{s} \approx 45\,\frac{km}{h} \quad (5)$$

where is it,
b_{G3k} – deceleration of the vehicle "Golf 3" (2.5 m/s2),

S_{G3kr} – the path of movement of the "Golf 3" vehicle from the dividing line to the point of contact (25 m).

The travel time of the Golf 3 vehicle from the dividing line to the collision site was:

$$t_{G3kr} = \frac{V_{G30} - V_{G3s}}{b_{G3k}} = 2{,}78\ s \tag{6}$$

In a time of 2.78 s, the "Golf 4" vehicle traveled the following distance:

$$S_{G4iz} = V_{G4s} \cdot t_{G3kr} = 54{,}50\ m \tag{7}$$

The longitudinal distance between the rear of the "Golf 3" vehicle and the front of the "Golf 4" vehicle, at the moment the front of the "Golf 3" vehicle crossed the dividing line, was:

$$S_{uo} = S_{G4iz} - S_{G3kr} = 29{,}50\ m \tag{8}$$

Based on the analysis conducted above, it can be concluded that the drivers of the colliding vehicles began their left-hand swerve action within a very short time interval of 0.18 s, so it can be said that it was approximately simultaneous.

Now we will check whether the driver of the "Golf 4" vehicle had the conditions to safely perform the overtaking action. The overtaken vehicle, a "Golf 3" vehicle, was moving at a speed of 45 km/h immediately before starting the left turn. At the scene of the accident, the speed limit is 50 km/h. The driver may move at the maximum permitted speed only if the road conditions, visibility, clearness, atmospheric conditions, traffic density and other circumstances allow it. In all other cases, the driver is obliged to adjust the speed to the specified circumstances and move at a speed lower than the permitted speed. The driver may not move the vehicle at a speed higher than the permitted speed. In the specific case, the driver of the "Golf 4" vehicle could have undertaken the overtaking action by moving at a speed of up to 50 km/h. Now we will check what the overtaking distance and time would be if the "Golf 4" vehicle was moving at the permitted speed of 50 km /h:

$$S_{50pr} = \frac{V_{50} \cdot (L_{G3} + L_{G4} + L_3 + L_4)}{V_{50} - V_{G30}} = 580\ m \tag{9}$$

$$t_{50pr} = \frac{S_{50pr}}{V_{50}} = 42\ s \tag{10}$$

where is it,
V_{50} – permitted speed (50 km/h),
L_{G3} – length of the vehicle "Golf 3" (4.0 m),
L_{G4} – length of the vehicle "Golf 4" (4.0 m),
L_3 – distance between the vehicles "Golf 4" and "Golf 3" before the start of overtaking (25 m),
L_4 – distance between the vehicles "Golf 4" and "Golf 3" at the end of overtaking (25 m),

Therefore, the driver of the "Golf 4" could have overtaken at a speed of 50 km/h, which would have taken him 42 s to perform, and during that time the vehicle would have traveled a distance of 580 m. Objectively, given that this is a very busy road, it would be difficult to expect the left lane to be free for a length of 580 m and a time of 42 s. Summarizing the analysis conducted above, it was concluded that the main failure of the driver of the "Golf 4", which is directly related to the creation of a dangerous situation and the occurrence of a traffic accident, is reflected in the overtaking action at a speed of 70 km/h, which was 20 km/h higher than the permitted speed. These actions by the driver with the vehicle are most likely a consequence of the psychophysical state in which he was, or the degree of alcoholism.

When it comes to the driver of the "Golf 3" vehicle, the situation is as follows. When turning left, the actions that the driver should first perform are as follows:

- turn on the left turn signal,
- look ahead to check whether another vehicle is possibly moving towards the vehicle he is driving, which would mean that the left lane is not free,
- looks in the left side mirror and makes sure whether a vehicle moving behind his vehicle has already started overtaking, or has announced this action by giving the appropriate direction indicator,
- Start turning left, possibly by first shifting the transmission to a lower gear.

A driver turning left is required to drive the vehicle along an imaginary circular arc connecting the center line of the roadway and the center line of the side road. The time-space analysis showed that the driver of the "Golf 3" crossed the dividing line with the front left end of the vehicle 25 m before the point of contact, that is, that he made the left turn in such a way that he moved to the left lane before the point of the turn, with the intention of turning left from the left lane into the parking lot next to the roadway. If the driver of the "Golf 3" had made the left turn while driving the vehicle along an imaginary circular arc connecting the center line of the roadway and the center line of the side road, he would have been able to see the "Golf 4" in the rearview mirror, which would be in the left lane, at the beginning of the turn. Based on the above, the conclusion is that the driver of the "Golf 3" vehicle also made a certain mistake related to the occurrence of the traffic accident, which is reflected in the fact that he made the left turn, instead of moving along the circular arc connecting the dividing line of the roadway and the center line of the side road, by previously changing lanes to the left traffic lane from which he intended to make the left turn into the parking lot.

Based on the data from Spis, it was not possible to determine whether the drivers of the colliding vehicles announced the actions of turning, or overtaking, by giving the appropriate direction indicator and whether this was done in a timely manner.

CONCLUSION

The main fault of the driver of the "Golf 4", which is directly related to the creation of a dangerous situation and the occurrence of a traffic accident, is reflected in the overtaking action at a speed of 70 km/h, which was 20 km/h higher than the permitted speed. Such actions with the vehicle by the driver are most likely a consequence of the psychophysical state in which he was, or the degree of alcoholism.

The driver of the "Golf 3" vehicle made a certain error that was related to the occurrence of the traffic accident, which is reflected in the fact that, instead of moving along the circular arc connecting the dividing line of the roadway and the center line of the side road, he performed the action of turning left by previously aligning himself with the left traffic lane from which he intended to make a left turn into the parking lot.

The speed of the "Golf 4" vehicle at the time of the collision was 70 km/h. If the "Golf 4" vehicle was braked before the accident, then the speed of this vehicle immediately before the accident was greater than 70 km/h, but this could not be determined based on the data from the Spis.

Based on the data from Spis, it was not possible to determine the speed of the Golf 3 at the time of the collision. However, considering that the vehicle was in the phase of turning into a parking space, which is usually done at lower speeds, its speed can be estimated with sufficient accuracy at 20 km/h. The speed of the Golf 3 at the beginning of the evasive path was 45 km/h.

FINAL CONSIDERATIONS

The paper is based on the need to analyze in detail critical actions in traffic that often lead to accidents, such as turning and overtaking. The introductory part of the paper emphasizes the importance of the topic in the context of increasingly frequent traffic accidents and the need for precise identification of the causes and circumstances that lead to them. The theoretical framework included a review of legal provisions, traffic rules, as well as previous studies and models of driver behavior in critical situations. The methodological approach is based on a case study, through the expertise of a specific traffic accident.

An analysis of the specific traffic accident concluded that the key factors that led to the collision were failure to comply with traffic regulations. The reconstruction of the event showed that the time intervals and speeds of both vehicles played a decisive role in the occurrence of the traffic accident. It was determined that the accident occurred due to overlapping actions – one was overtaking, while the other was turning.

Given the limitations of a single case as a data source, future research should include a larger number of similar traffic accidents in order to identify regularities and recurring patterns in driver behavior. It is desirable to include an analysis of the impact of factors such as weather conditions, lighting, road conditions and signal visibility. The use of advanced technologies, such as driving simulators and GPS data, could provide valuable insights into the real behavior of drivers in turning and overtaking situations. In addition, surveys and qualitative research among drivers of different categories could contribute to a better understanding of their decision-making in such situations. The goal of such research should be to formulate recommendations for improving regulations, training and infrastructure solutions in order to reduce risks and increase the safety of all road users. One of the important aspects when it comes to performing actions is persuasion. When we talk about turning, what the driver needs to do is to first make sure that the action can be performed without endangering other road users or property, taking into account the vehicle's position and direction and speed. Persuasion is usually performed using mirrors, inside and outside the vehicle, and it takes a certain amount of time , which is up to 1.9 seconds. Considering that in the above case study the time between the initiation of the actions was 0.18 s, the question arises as to what is an acceptable time between the initiation of the actions in question, and that the actions can be considered to have started simultaneously. The above question can serve as a basis for further research into this type of accident, as well as for improving the performance of traffic and technical expertise.

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PROFESSIONAL PAPER

Improving Supply Chain Efficiency Through Adequate Stacking of Bulk and Transport Packaging

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Abstract: The efficiency of logistics processes largely depends on the selection, sizing and stacking of aggregate and transport packaging. Properly organized packaging not only protects products but also directly affects the rationalization of space, the speed of manipulation and the reduction of costs in the supply chain. This paper analyzes the way in which standards and methods of stacking packaging units can improve operational efficiency. Through a theoretical review and analysis of practical examples, the role of palletization, modularity and optimal capacity utilization in the storage and transport process is discussed. The research confirms the hypothesis that adequate stacking of aggregate and transport packaging significantly reduces logistics costs and the time required for delivery, which directly contributes to improving supply chain performance.

Keywords: aggregate packaging, logistics, palletization, stacking, cost optimization.

LITERATURE REVIEW

The efficiency of the supply chain largely depends on the way packaging is designed and arranged within logistics units. Packaging is no longer just a protective wrapper, but an active and functional element of the logistics system, which affects costs, transport time, handling and storage. Modern packaging technologies strive to provide the highest possible process efficiency and product protection at minimal cost (Rodrigues & Han, 2003).

According to Han, Rodrigues and Han (2005), intelligent packaging must include functions that provide logistical support, such as storage condition indicators, integrated stability markings and optimized stacking systems. They point out that stacking of bulk and transport packaging can be viewed as a structured technical operation, which must be based on an analysis of stability, economy and space utilization.

Lim (2011) believes that packaging is becoming one of the essential resources of supply chain management, since it actively participates in the flow of goods, provides feedback and enables real-time system adaptation. In this context, the logistical potential of packaging must be included already in the design and simulation phase, and not only in the implementation phase.

Stilwell (1991) warns that improperly designed packaging not only leads to increased costs, but also to environmental consequences, including excessive material consumption and unnecessary burden on disposal systems. For this reason, packaging design must be accompanied by sustainability criteria, standardization, and software control of the composition.

Based on the above theoretical foundations, this paper aims to show how adequate stacking of aggregate and transport packaging can contribute to improving the overall efficiency of the supply chain. The research relies on simulations in the CAPE PACK software, and the analysis of the results is aimed at confirming the hypothesis that rational stacking design reduces the costs and time of logistics processes.

INTRODUCTION

Packaging plays a central role in the modern supply chain, where it no longer serves only as product protection, but has become a key factor in efficiency, cost rationalization and optimal use of logistics resources. Modern market needs have led to the design and functionality of packaging being viewed as an integral part of the logistics system, especially when it comes to bulk and transport packaging, which enables the organized handling and storage of larger quantities of goods in the loading, transport and distribution processes.

According to studies dealing with logistics engineering, optimally designed aggregate and transport packaging can contribute to reducing operating costs and time losses, and improve overall stability, safety and speed of delivery. Insufficiently adjusted dimensions, irregular shape and poor stacking of packaging units often lead to insufficient utilization of pallet, truck or warehouse capacity, which results in a higher number of transport rounds, higher energy consumption, increased handling time and additional financial costs.

Solutions are increasingly found in software support, with the CAPE PACK program being the most prominent in practice , designed for dimensioning, calculating and simulating the stacking of packaging within logistics units. By using this tool, it is possible to simulate the arrangement of packaging on pallets in advance, use the space in the truck and adapt the dimensions of the packaging to a specific logistics scenario. The paper presents three simulated cases, where the impact of different stacking methods on the total number of required pallets, load stability and the degree of transport utilization was analyzed. The results obtained indicate significant space savings and a reduction in logistical losses, which confirms the justification of a systematic approach to packaging design.

Starting from these assumptions, the aim of the paper is to show how adequate stacking of aggregate and transport packaging contributes to improving the efficiency of the supply chain. The research is based on the hypothesis that proper dimensioning and planned stacking of packaging units leads to a reduction in costs and time required for logistics operations. Practical examples, supported by simulation in the CAPE PACK program, provide a comprehensive insight into the importance of proper packaging organization in terms of overall supply efficiency.

Modern trends in logistics and packaging impose the need for the application of digital tools such as simulation software and multi-criteria decision-making models. Digitalization of packaging processes and optimization of packaging layout on pallets are becoming key elements for achieving efficiency in the supply chain.

In order to verify the hypothesis and apply the theoretical knowledge in practice, the paper analyzes the specific case of a company from Derventa that produces ketchup. Using the CAPE PACK simulation software, various packaging stacking configurations were examined, with the aim of determining the efficient layout in accordance with the characteristics of the product and the company's logistics resources. The research was conducted on the example of a company from Derventa that produces ketchup, where the methodological approach included the simulation of various layouts of bulk and transport packaging in the CAPE PACK software, in order to determine the efficient solution in terms of logistics capacity utilization.

Functions of bulk and transport packaging

Bulk and transport packaging represent an intermediate layer between primary packaging (which is in direct contact with the product) and the logistic units that are transported and stored. Their main function is to group multiple primary packaging units into units suitable for manipulation, loading, unloading and transport. In addition to physical protection, these types of packaging must provide stability during movement, efficient stacking within warehouses and means of transport, as well as reducing the number of individual operations during handling of goods.

Bulk packaging most often consists of cardboard boxes or crates in which multiple units of the same product are packed, resulting in packages that are easier to count, store, and transport. Transport packaging is a higher level, which includes grouping multiple bulk packages on a pallet, container, or other means of transport, with the aim of enabling rational use of space and reducing the possibility of damage during transport.

Proper sizing and stacking of bulk and transport packaging allows for full use of pallet space, load stability, and easy loading and unloading activities. Otherwise, incorrect dimensions and inappropriate package combinations lead to wasted space, increased pallet count, less stability, and higher distribution costs.

Additionally, one of the important goals of designing collective packaging is compatibility with means of transport, which is achieved through a modular design approach - the dimensions of collective packaging are adapted to the standard dimensions of Euro pallets and freight vehicles, in order to avoid unnecessary empty space. In this context, logistics packaging also becomes a strategic resource, as it allows for the reduction of costs per unit of product at all stages of movement through the supply chain.

METHODOLOGY

The research in this paper is focused on analyzing the impact of stacking of bulk and transport packaging on supply chain efficiency. The initial hypothesis is:

- Adequate stacking of bulk and transport packaging contributes to the optimization of costs and time in the logistics process.
- The goal was to determine to what extent the application of modern stacking methods, with the support of software simulation, can achieve better utilization of pallet and transport space, reduce the number of necessary manipulations, and reduce logistics costs.

Stacking methods and application of CAPE PACK software

The design of the layout of the aggregate and transport packaging is carried out using specialized software CAPE PACK, which allows the simulation of the package configuration according to input parameters such as dimensions, weight, number of boxes and transport restrictions. Using this tool, it is possible to visually and numerically compare multiple layouts and select the one that reduces costs and increases stability to the greatest extent.

As Esko (2015) points out, CAPE PACK provides the ability to create stacking models in several steps: defining primary packaging, generating layer layouts , simulating transportation, and analyzing key logistics indicators. Such an approach allows for optimal decisions to be made already at the packaging design stage.

The modular stacking methodology as an element of logistics cost management has also been confirmed in studies such as Han et al. (2005), which emphasize that packaging optimization must be based on digital simulation and transparency and sustainability criteria.

CAPE PACK enables the design and analysis of packaging systems by entering parameters related to primary packaging, such as length, width, height and weight, as well as the number of units per aggregate package. Based on this input data, the software calculates different possibilities for arranging boxes per layer and layers per pallet. The data input also includes restrictions related to maximum pallet height, cargo weight, handling method and logistics standards. An example of such an input is shown in ***Figure 1.***

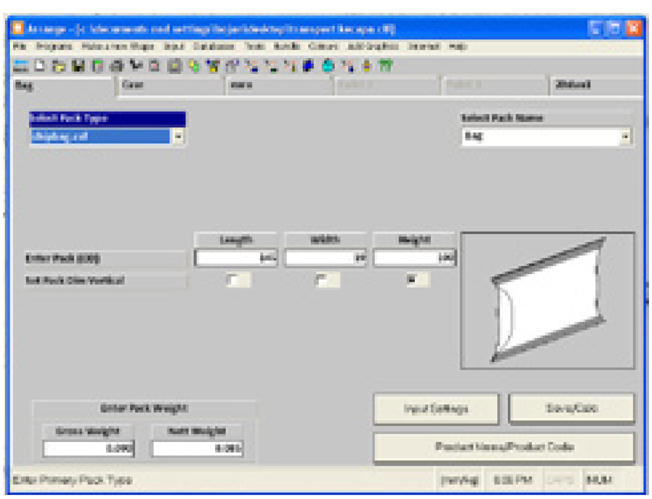

Figure 1. Data Entry for Primary Packaging

A company from Derventa produces and packages ketchup, and the problem arises from the need to deliver ketchup. Primary packaging is a bag containing ketchup. Secondary packaging serves to protect the primary packaging and, in addition, to perform other distribution functions of the packaging business. Secondary packaging is a cardboard box in which ketchup bags are placed. The company from Derventa uses a standard EURO 4 pallet. The boxes are placed manually on the pallet according to a predetermined layout.

The total length of the bag is 145 mm, the height is 100 mm, the thickness is 19-20 mm and the weight is 90 grams. The cardboard box used as collective packaging should contain 20 pieces of product already packed in primary packaging. The length of the cardboard box is 400 mm, the width is 140 mm, and the height is 105 mm. The standard EURO pallet has dimensions of 800x1200x150 mm, weighing 25 kg. The dimensions of the truck are 6500x2320x2350 mm.

Figure 2 shows a planar arrangement of box stacking, with boxes marked in yellow and unused pallet area in green. After calculation, a large amount of unused pallet area is observed, reaching as much as 12.5% of the pallet area. Here, the need arises to consider rearranging the arrangement of boxes in order to improve the pallet area utilization.

Figure 2. Box Laying Schedule on Pallet

After the program has been launched and the Arrange/ Design group selected, it is time to enter the necessary parameters to define the primary packaging, in this case a ketchup bag. The dimensions are indicated in the window: length, width and height. The bag dimensions are 145x100x20, and the mass is 0.09 kg. A standard EURO pallet with dimensions of 1200x800x150 mm, a maximum load capacity of 2000 kg, and a maximum load height of 1650 mm was selected.

After defining the input parameters, CAPE PACK automatically generates several different models of the arrangement of aggregate packaging on a pallet. Each of these models provides information on the number of boxes per layer, the number of layers per pallet, the total height and volume of the cargo, as well as the percentage of pallet area utilization. The resulting stacking arrangements and the arrangement of packaging are shown in the following figures.

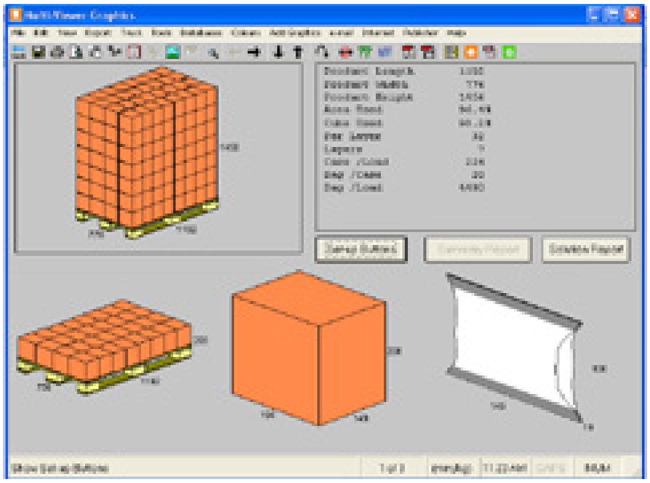

Figure 3. Packaging Arrangement for the 1st Case Found

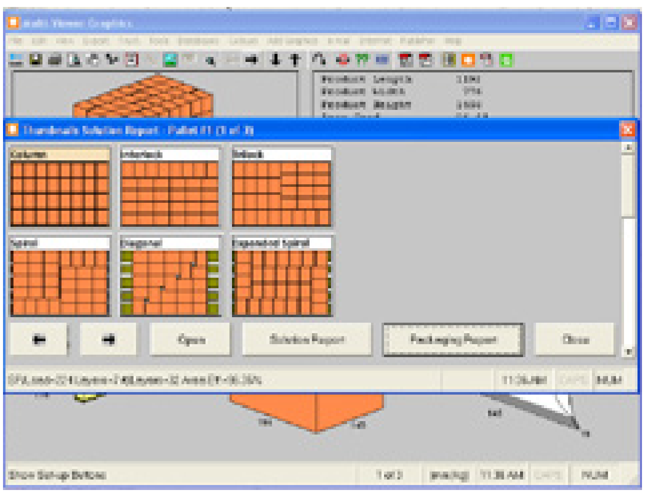

Figure 4. Laying Methods for the 1st Case Proposed

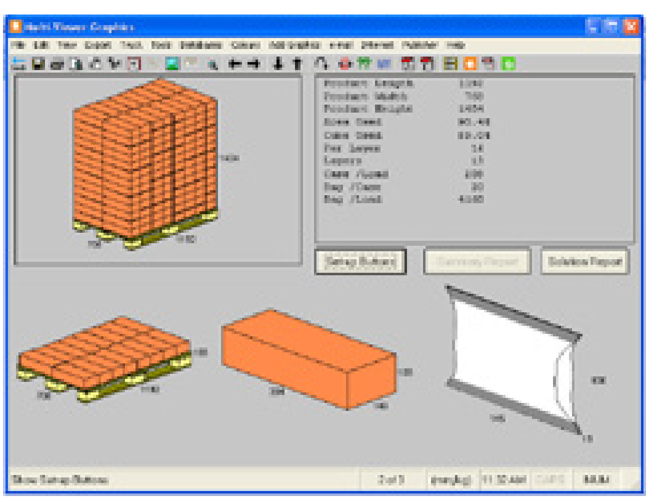

Figure 5. Laying Methods for the Proposed 2nd Case

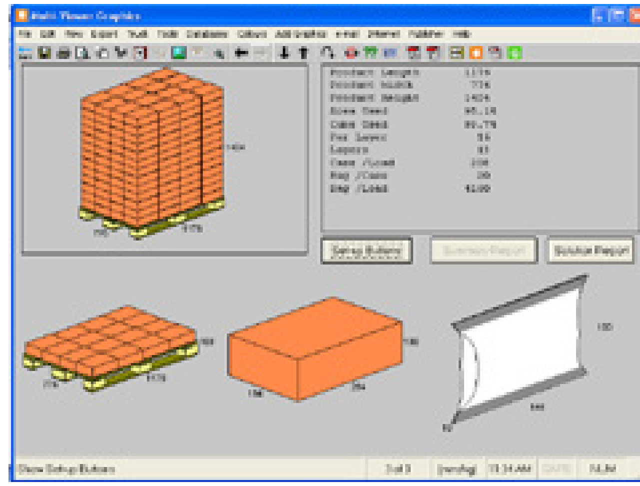

Figure 6. Packaging Arrangement for the 3rd Case Offered

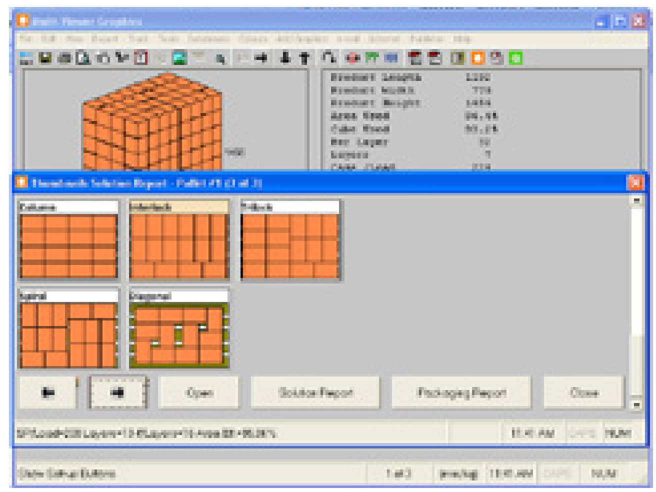

Figure 7. Laying Methods for the Proposed 3rd Case

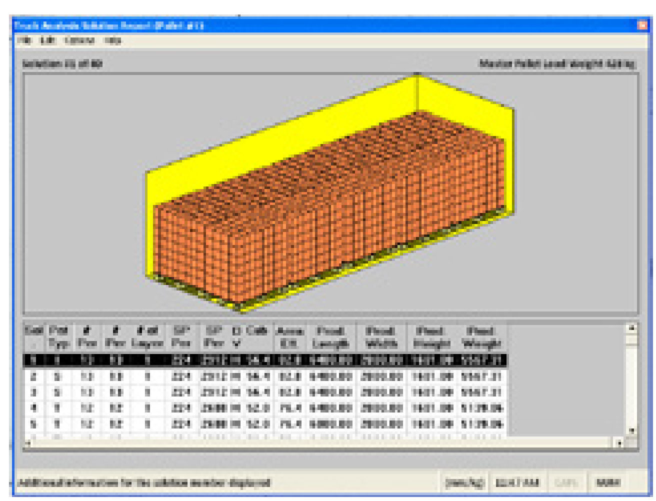

Figure 8. Pallet Arrangement in the Truck For Case 1

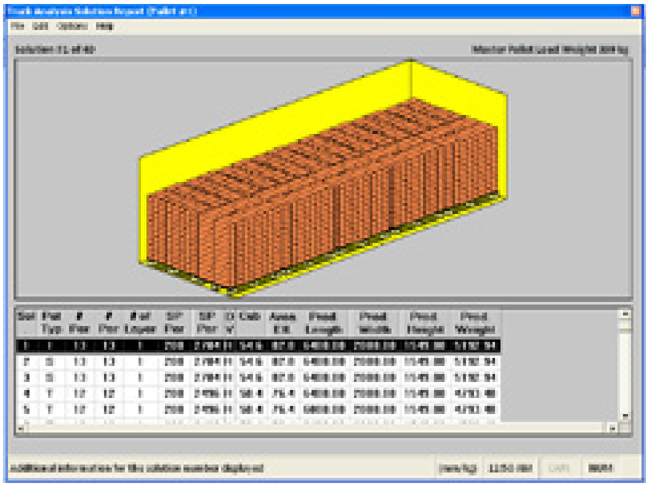

Figure 9. Pallet Arrangement in the Truck For Case 2

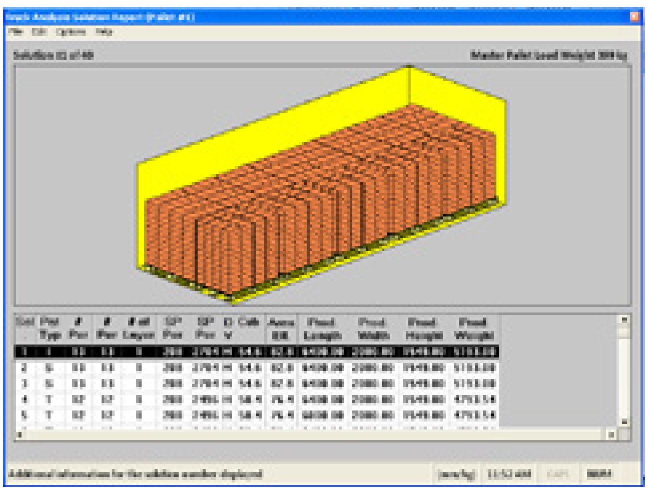

Figure 10. Pallet Arrangement in the Truck For Case 3

The results obtained are then compared and analyzed with the aim of selecting the most favorable variant. During the analysis, key criteria are observed: total pallet occupancy, cargo stability, logistical profitability and the number of pallets required to transport the same quantity of goods. The overall simulation results are shown in ***Table 1.*** The table presents parameters such as the number of boxes per pallet, number of layers, load height, percentage utilization of pallet area and the total number of pallets required for each simulated variant.

Table 1. Simulation Results

	Solution 1	Solution 2	Solution 3
Used pallet area, %	96.4	95.4	95.1
Used pallet volume, %	93.5	89.3	89.0
Products on a pallet, com	4480	4160	4160
Used truck area, %	82.8	82.8	82.8
Used truck volume, %	56.6	54.7	54.7
Pallet load capacity, kg	428	399	399

Based on a detailed analysis from the table, the model that shows the best ratio between utilization and stability was selected — that is, the model in which the number of boxes on the pallet is maximum, and stability and logistical functionality meet the criteria.

The simulation results show that even the smallest changes in the dimensions of the collective packaging or the way it is stacked can have a significant impact on the overall logistics efficiency. Software analysis, which allows visualization, comparison and measurable assessment of each layout, provides the basis for rational decision-making already at the packaging design stage. This leads to better space utilization, a reduction in the number of transport units, fewer manipulation operations and, ultimately, significant savings in distribution costs.

DISCUSSION OF RESULTS

The way in which bulk and transport packaging is organized within a logistics system has a significant impact on the overall efficiency of supply. Viewed through the prism of the arrangement of boxes on a pallet and in transport vehicles, rational stacking directly affects the number of pallets required, space utilization, load stability and the number of handling operations.

The simulation results, already presented in Table 1 and Figure 3, showed that different stacking models lead to significant differences in capacity utilization. The most optimal model achieves a pallet fill rate of more than 95%, which leads to a reduction in the number of pallets needed for the same volume of products. This means less transport, less fuel, less labor and shorter logistics processing times, but also less storage space.

In addition to reducing costs, the results also indicate a reduction in cargo processing time – whether loading, unloading or storage. Increased cargo stability, achieved by precise box arrangement, also reduces the risk of damage, which further reduces indirect costs in the supply chain. Through better planning and simulation, the need for excess protective material and improvised solutions in the transport phase is eliminated.

Applying a simulation approach, such as CAPE PACK, allows logistics managers to determine the most economical stacking model before production or shipment. This allows decisions to be made based on data, rather than assumptions or habit, which significantly improves the quality and reliability of logistics operations.

CONCLUSION

This paper analyzes the impact of stacking of bulk and transport packaging on costs and time in the supply chain, with the aim of determining to what extent a rationally designed layout can contribute to logistics efficiency. By applying simulation in the CAPE PACK software and comparing multiple stacking scenarios, data was obtained showing that proper dimensioning and configuration of packaging leads to a significant reduction in the number of pallets, greater utilization of space capacities and shorter duration of logistics operations.

Key results confirmed that the optimal arrangement of packaging units allows pallet fill rates above 95%, which directly reduces transport and handling requirements. In this way, the overall efficiency of the system is improved, and the costs associated with manipulation, storage and transport are reduced. In addition, the stability of the load increases transport safety and reduces the risk of product damage.

These findings enabled the verification of the initial hypothesis that adequate stacking of aggregate and transport packaging contributes to the optimization of costs and time in the logistics process . The confirmation of the hypothesis is based on quantitative and visual simulation results, as well as on the theoretical foundations of modern approaches in logistics and packaging design.

The paper highlights the need to view packaging as an integral part of supply chain management, not just as a means of protecting products. The application of simulation and optimization tools in the early design phase is a key step towards a more efficient, cheaper and more sustainable logistics system.

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PROFESSIONAL PAPER

Recycling of waste motor oils

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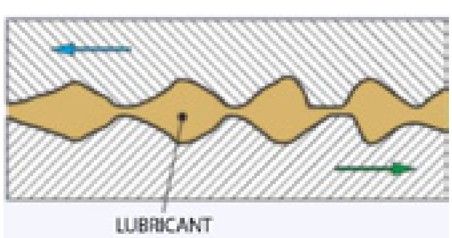
Abstract: During the use of motor oils, they lose their physical and chemical characteristics, their aging occurs and over time the oil becomes unusable and becomes waste motor oil.
After use, in addition to being harmful to the environment, waste oils pose a serious threat to human health.
In order to avoid the harmful effects of waste oils on humans and the environment, used oils must be disposed of appropriately.
The problem of waste motor oil can be solved in several ways: using waste motor oil as an energy source - incineration, recycling and disposal/disposal.
From an economic point of view and from the point of view of protecting the living environment, the recycling of waste motor oils has advantages over burning and disposal.
Recycling of waste motor oils is any procedure by which a new product is obtained through certain processing procedures, which enables the reuse of waste motor oils.

Keywords: lubricants, waste motor oil, disposal, recycling.

LUBRICANTS AND LUBRICATION

Lubricants are substances with specific physical and chemical characteristics that are used for lubrication.

Lubrication is the process of creating a protective layer of certain characteristics between the contact surfaces that are in mutual relative motion, in this way friction and wear of the contact surfaces is reduced.



Picture 1. lubrication

MOTOR OILS

Engine oil has the function of lubricant/lubrication in internal combustion engines. In addition to reducing friction and wear when operating an internal combustion engine, engine oil helps dissipate heat from heated engine parts and keeps engine assemblies clean.

In order for motor oil to be able to perform all the functions required of it, it must have appropriate characteristics, the most important of which are: stability at high operating temperatures, resistance to oxidation, be able to neutralize acidic compounds that are formed in motor oil as a result of fuel combustion, and have good anti-foaming and anti-corrosion properties. Engine oil acquires all the required characteristics in the production process when appropriate additives are added to it in certain quantities.

The base of motor oils is a base oil to which appropriate additives are added to improve the physicochemical and operational characteristics. According to the type of base oil used in production, motor oils are divided into: mineral, synthetic and semi-synthetic.

Mineral motor oils are produced from mineral base oils, which are obtained by distillation of crude oil. Mineral motor oils are primarily suitable for older vehicles or engines with less demanding technology. The main disadvantage of mineral motor oils is less protection at extreme temperatures and shorter replacement intervals compared to synthetic motor oils. They are the most represented on the market, and the reason for this is their favorable production price and availability.

Synthetic motor oils are obtained by adding additives to synthetic base oils. Synthetic base oils are produced by complex chemical-technological processes and have significantly better physical and chemical characteristics compared to mineral base oils. Synthetic motor oils have better characteristics at high and low temperatures, provide better engine protection and extend oil change intervals. They are suitable for modern, high-efficiency

Table 1. SAE J 300 classification of motor oils

SAE viscosity grade	Maximum viscosity (mPas) at low temperatures		Maximum pumpability temperature for viscosity 60,000 mPas	Kinematic viscosity (mm2/s) at 100 °C		HTHS viscosity (mPa.s) at 150 °C and shear rates of 106s-1
	max.	°C	°C	min.	max.	min.
0W	6200	-35	-40	3.8	-	-
5W	6600	-30	-35	3.8	-	-
10W	7000	-25	-30	4.1	-	-
15W	7000	-20	-25	5.6	-	-
20W	9500	-15	-20	5.6	<9.3	2.6
25W	13000	-10	-15	9.3	<12.5	2.9
20	-	-	-	12.5	<16.3	2.9 (0W-40, 5W-40, 10W-40)
30	-	-	-	12.5	<16.3	3.7 (15W-40, 20W-40, 25W-40, 40)
40	-	-	-	-	-	-
40	-	-	-	-	-	-
50	-	-	-	-	-	-
60	-	-	-	-	-	-

vehicles and engines operating in extreme operating conditions. Synthetic oils reduce engine wear in the long term and improve fuel efficiency.

Semi-synthetic motor oils, also known as partially synthetic oils, are a mixture of mineral and synthetic oils. Semi-synthetic motor oils provide better protection than mineral oils and are suitable for most modern vehicles. They have better resistance to oxidation, ensure better lubrication at higher temperatures and extend the life of the engine. They are a good choice for drivers looking for a compromise between price and quality.

Motor oils can be divided or classified according to several criteria, the most important classification of motor oils is by viscosity. The so-called SAE viscosity grades were introduced by the Society of Automotive Engineers. The viscosity gradation of motor oils is defined by the SAE J 300 standard. Two series of viscosity gradations of motor oils are defined, the gradation with the “W” mark and without the “W” mark. Oils marked “W” represent monograde oils for winter operating conditions (winter oils). Oils without the “W” mark are monograde oils for summer operating conditions (summer oils). By combining two viscosity gradations of oil, with and without the “W” mark, multigrade motor oils are obtained that satisfy both summer and winter operating conditions.

According to the type of engine in which they are used, engine oils are divided into oils for four-stroke engines, oils for two-stroke engines and oils for other engines.

During the use of motor oils, they lose their physical and chemical characteristics, their aging occurs and over time the oil becomes unusable and needs to be replaced with a new one.

Waste motor oil is any motor oil whose physical and chemical characteristics have changed during exploitation to such an extent that it is no longer suitable for the use for which it was originally intended.

After use, in addition to being harmful to the environment, waste oils pose a serious threat to human health, as they contain many toxic and carcinogenic substances such as heavy metals and polycyclic aromatic hydrocarbons.

Collection of waste motor oils

The first stage in solving the problem of waste motor oil is its collection. In order to evaluate the efficiency of waste motor oil collection, it is important to know what amount of waste motor oil is available for collection. The amount of waste motor oil available for collection is estimated based on the amount of fresh motor oil that is put on the market and it amounts to about 50% of its amount.

Solving the problem of waste motor oil

In order to avoid the harmful effects of waste oils on humans and the environment, used oils must be disposed of appropriately.

The problem of waste motor oil can be solved in several ways:

- using waste motor oil as an energy source - incineration,
- by recycling and
- disposal/disposal.

Recycling of waste motor oils

Recycling of waste motor oil in relation to incineration and disposal has a number of advantages, the most significant of which are:

- preservation of the environment,
- creation of new jobs,
- conservation of natural resources,
- energy conservation,
- reduction of health risks,
- contribution to technological progress i
- - economic benefit.

Preservation of the environment

One of the most significant advantages of recycling waste motor oil is its positive impact on the environment. The release of waste oils into the environment and their improper disposal leads to environmental contamination. Recycling waste oil contributes to the *preservation of the environment.*

Opening of new jobs

One of the advantages of recycling waste oil is the *creation of new jobs*. Recycling of waste motor oil is a process that requires the use of special equipment used for collection, processing and recycling. The recycling of waste motor oil will employ workers who will work on its packaging and manipulation, as well as in companies that recycle waste motor oil.

Conservation of natural resources

By reusing waste motor oils or by extending their life (extended replacement intervals), less raw material is used for their production. Today, the largest share of raw materials used for the production of lubricating oil comes from crude oil, which is extracted from oil fields and oil platforms. Crude oil is a non-renewable resource whose reserves are limited. The exploitation and refining of crude oil has a significant negative impact on the environment. By reusing waste oils, the amount of crude oil used for their production is reduced, which directly affects the *preservation of natural resources*.

Conservation of energy

The process of recycling waste motor oil involves filtering out impurities and contaminants, which can then be used as fuel in power plants, industrial boilers and other energy-intensive applications. By using this kind of energy, we can reduce our dependence on fossil fuels and contribute to a sustainable energy future and *energy conservation*. In addition, with appropriate preparation and control of the combustion process and processing of the resulting combustion products, waste motor oil can be used as an energy source for households and industrial needs.

Reduction of health risks

Improper disposal of waste motor oil can pose significant health risks to humans and animals. When waste motor oil enters the ground or water sources, it can release harmful toxins and chemicals. These toxins can enter the food chain, leading to health problems. Proper disposal and recycling of waste motor oil *reduces health risks* and ensures a safer environment for everyone.

Contributes to technological progress

Research and development of new engines or equipment that can use recycled motor oil must be used effectively and efficiently. As a result, it is a *contribution to the advancement of technology* that enables the reuse of waste motor oil.

Economic benefits

One of the advantages of recycling waste motor oil is the *economic benefit* it offers. The recycling industry creates jobs and contributes to the local and national economy. The recycling of waste motor oil creates opportunities for the installation and commissioning of facilities for recycling, processing and related industries.

Recycling of waste motor oils

Recycling of waste motor oils is any procedure by which a new product is obtained through certain processing procedures, which enables the reuse of waste motor oils.

The recycling process refers to the removal of impurities, partially and additives from waste motor oils, resulting in a base oil, which can be used as a raw material for the production of new lubricants and lubricating oils. The main problem of recycling waste motor oil, which has gone through the process of degradation during use, is its composition. Waste motor oil contains fractions of diesel and gasoline fuel that have entered the motor oil during the combustion process from the fuel combustion chamber, light hydrocarbons that result from the degradation of base oils, moisture/water that enters the motor oil from the atmosphere, sediments that form as a product of motor oil degradation (resin and asphalt) and additive residues.

The primary processing processes of waste motor oils are:

- deposition,
- filtration and
- dehydration and separation of the vapor phase.

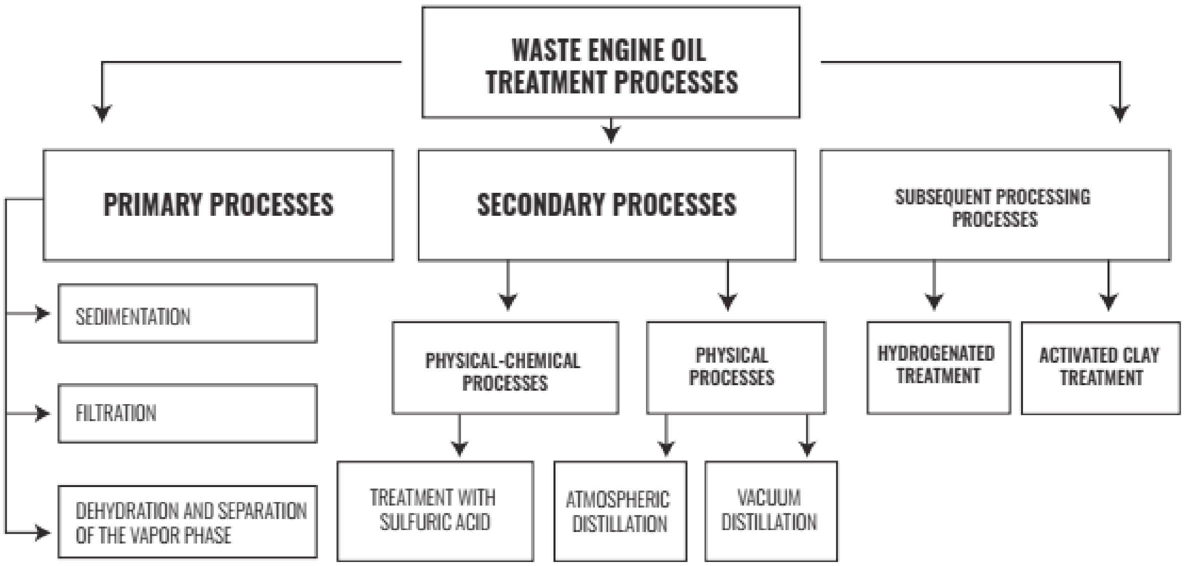
The processes of secondary processing of waste motor oils are:

- physical-chemical processes - treatment with sulfuric acid,
- physical processes:
    - ◊ atmospheric distillations to separate light diesel and gasoline fuel fractions and
    - ◊ vacuum distillation for the separation of fractions of base oils with the possibility of deasphalting the vacuum residue.

The processes of post-treatment of waste motor oils are:

- hydrogen treatment procedures i
- processing procedures with active clays for whitening.

Image 2. Schematic representation of the recycling of waste motor oils



Processes of primary treatment of waste motor oils

Sedimentation is an operation aimed at extracting water and sediment from waste motor oil. A certain amount of sediment and water is retained in the motor oil during exploitation due to the presence of dispersant additives in the oil. Deposits in engine oil are mainly a product of engine oil degradation during exploitation. The sedimentation process can be carried out in gravity separators that work on the principle of gravity and centrifugal separators that are more efficient and faster and that work on the principle of centrifugal force.

Mechanical impurities (metal filings, hardened degradation products of motor oils) are removed from waste motor oil by *filtration* using different types of filters. Filters can be ordinary mesh filters that remove larger-sized impurities from the oil, and fine filters with 150-250 μm pores of the filtration medium, which are used to remove micro and fine particles from waste motor oil.

In most cases, *vapor phase separation processes* take place at atmospheric pressure and at temperatures up to 180°C, which remove compounds with boiling points lower than the boiling point of diesel fuel from waste motor oil in addition to water.

Processes of secondary processing of waste motor oils

Sulfuric acid treatment procedure

Waste motor oil contains polar oxides, acidic compounds, residual additives, by-products of oil degradation, suspended particles and other substances that pollute it. The process of treating waste motor oil with sulfuric acid is based on mixing waste motor oil with sulfuric acid with the aim of removing harmful substances. As a result of the treatment of waste engine oil with sulfuric acid, acid tar is formed, while the hydrocarbon chains in the base oil in the engine oil do not degrade. In order to avoid reactions and processes of sulfonization and oxidation of the hydrocarbon chains of the base oil, the process must be conducted at a controlled temperature of 40 to 50°C. After the treatment of waste motor oil with sulfuric acid, the oil that remains after separating the acid tar is subjected to treatment with active clays. The role of active clay in the process is to absorb tiny drops of sulfuric acid that remain in the oil after treatment. After treatment with sulfuric acid and treatment with active clay, the obtained residue is subjected to vacuum distillation in order to divide the obtained residue into several fractions.

Processes for treating waste motor oil with sulfuric acid are economically more profitable (lower cost of the process) compared to other processes and are suitable for countries where a relatively small amount of waste motor oil is collected annually, up to several thousand tons. The negative side of this process is the formation of acid tar as a by-product of the treatment of waste engine oil with sulfuric acid, which is extremely dangerous and harmful to the environment.

If the motor oil in an internal combustion engine is replaced prematurely with a new, fresh motor oil, a significant amount of active additives remain in the oil that becomes waste motor oil, including dispersant additives that have not been used. If such an oil is to be refined with sulfuric acid and a good separation of the acid tar is to be achieved, a significantly larger amount of sulfuric acid is needed than when the dispersants in the oil have been used up. The solution to this problem is to destroy the active dispersant additives in the oil without changing the viscosity of the oil, which is achieved by thermal treatment of waste motor oil or flocculation with chemical means before treatment with sulfuric acid. The process of heat treatment is used more in practice, where care must be taken to ensure that the processes are conducted in as mild conditions as possible in order not to change the viscosity of the oil. The flocculation process is based on the contact of waste oil with the aqueous and organic phase with the aim of removing most of the dispersant and detergent additives from the oil. The aqueous phase contains chemical agents that destabilize the dispersed particles and react with the metals to form salts that are then deposited. The organic phase consists of a mixture of polar solvents for oil extraction that cause the precipitation of polar compounds, suspended particles and various oxidized substances.

Physical separation procedures

Distillation

In most waste motor oil recycling technologies, the first step is atmospheric distillation, which removes residual water, light hydrocarbons and other volatile compounds from the oil. The conditions for the separation of the vapor phase are mild, temperatures from 160 to 180°C and a pressure of about one bar or lower.

After separating the vapor phase by atmospheric distillation, vacuum distillation takes place in vacuum columns. In order to be able to separate the residual fraction of diesel fuel at the top of the column, it is necessary to construct the vacuum column properly, so that the passage time through the columns is as short as possible due to the very high temperature of the process.

In practice, vacuum distillation is often used in combination with TFE (Thin Film Evaporator). In these processes, the dehydrated oil is added at the top of the cylindrical column so that it flows down its walls, which are heated from the outside. In order for the oil to flow down the walls evenly and create a film of equal thickness in all places, rotating vanes are installed in the column, which enable regulation of the film thickness.

After distillation, it is necessary to remove the asphalt material from the vacuum residue by the process of deasphalting. The procedure is carried out by extraction with propane, butane or pentane. As a result, an oil phase with a large proportion of solvent is obtained, with which the extraction procedure is carried out and asphalt phases with a small proportion of solvent.

Final processing

Whitening clays

Treatment with adsorbents (bauxite, natural clay, charcoal) is still widely used, in some countries it is even growing due to the prohibition of oil refining with sulfuric acid. Adsorbents on their boundary surface bind molecules of dissolved substances from the solution, in this case particles of impurities in waste motor oil. The size of the adsorbent particles used is 0.25 - 0.50 mm.

The role of the adsorbent is to neutralize acids in acid-refined oils, unstable oxide and sulfur compounds and sulfuric acid residues. Adsorbents can also increase the oil's resistance to oxidation at high temperatures and color stability during storage.

Two methods of treatment with adsorbents are used, the first is filtering through filters containing the previously used adsorbent, and the current method is contact with clay.

When filtering through the filters, the waste motor oil passes through a medium on which an adsorbent has been applied. The main characteristics of this method are: long contact time (up to several hours), low temperature of the process, but high enough for the oil to be liquid. Adsorption efficiency is not constant, during the process it is difficult to ensure constant production quality, and the flow of oil through the adsorbent decreases over time.

When the oil comes into contact with the clay, the oil and the clay are continuously mixed and heated in a container for a certain time, and then separated by filtration. The characteristics of this method are: high temperature (150 - 330 °C) which enhances the catalytic effect of active clay, contact time of 15 - 30 minutes and uniform production quality.

Catalytic hydrogenation

For many years, catalytic hydrogenation has been considered an efficient refining process from the point of view of yield and quality of final products. The process consists of bringing oil fractions into contact with hydrogen at high pressure and temperature in the presence of a catalyst located on a suitable support. Catalytic hydrogenation, with the correct choice of catalyst and conditions in which the process takes place, can be applied to a wide range of products, from the lightest to the most difficult compounds. There are two basic reactions that take place:

- hydrorefining - which aims to remove sulfur, nitrogen and metals and hydrogenate olefinic and aromatic hydrocarbons and
- hydroconversion - with the aim of changing the structure of hydrocarbons by cracking and isomerization.

Saturated hydrocarbons are formed by these processes/reactions, and sulfur, oxygen and nitrogen are removed from waste motor oil.

There are a number of commercial processes that combine the above procedures and unite them in the process of recycling waste motor oils.

Thermal treatment of waste motor oil - incineration

Thermal treatment of waste motor oils means a procedure in which waste motor oils are used as energy sources. Thermal treatment of waste motor oils can be carried out in two ways:

- waste motor oil is only used as fuel or
- waste motor oil is mixed with some conventional fuel and the mixture is used as fuel

Waste motor oil consists of hydrocarbons, which makes it suitable for use as an energy source. Unlike heavy fuel oils, waste motor oil has a lower viscosity, so it can be injected into the combustion chamber at a temperature almost twice as low as the temperature at which fuel oils are injected into the combustion chamber, around 70 °C. In addition, waste motor oil is sufficiently fluid that it can be pumped and stored at a temperature of up to 10 °C, while heavy fuel oils must be heated to temperatures of 50 to 70 °C before pumping. Waste motor oil has a low sulfur content, which makes it competitive with other low-sulfur fuels.

The main disadvantage of the thermal treatment of waste motor oil is that it is necessary to reduce the emission of harmful substances in the flue gases produced by its combustion. In addition, before starting the combustion process, it is necessary to remove almost all metal particles from the waste engine oil, because otherwise there will be increased wear of injectors and pumps for manipulation and combustion. In addition, metal particles present in motor oil are also responsible for the formation of floating ash in flue gases.

Processes of thermal treatment of waste motor oils have found application in the cement industry, brickyards and asphalt production plants.

Harmful emissions from flue gases resulting from the burning of waste motor oil can be reduced by dedusting the flue gases, and dedusting can be carried out:

- mechanical methods - the principle of operation is based on gravitational, inertial or centrifugal forces,
- electrical methods - which ionize dust particles that are later collected on surfaces whose polarity is opposite to that of the dust particles,
- porous dust removers and
- hydraulic dust removers - which can work on three principles: washing with bubbles, sprinklers and in a venturi tube.

CONCLUSION

Due to their characteristics, waste motor oils are categorized as hazardous waste, which is why it is necessary to establish a system for their collection in order to minimize the amount of waste motor oils that ends up in the environment.

The problem of waste motor oil can be solved in several ways: using waste motor oil as an energy source - incineration, recycling and disposal/ disposal.

Recycling of waste motor oils is any procedure by which a new product is obtained through certain processing procedures, which enables the reuse of waste motor oils.

From an economic point of view and from the point of view of protecting the living environment, the recycling of waste motor oils has advantages over burning and disposal.

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The **Introduction** should provide a clear statement of the problem, the relevant literature on the subject, and the proposed approach or solution. It should be understandable to colleagues from a broad range of disciplines.

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[1] Zahavi Y. and Ryan, M. James. Stability of Travel Components Over Time. *Transportation Research Record*, 750 (1980), 70-75.

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Article in a Periodical [3]

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