TTTP
Traffic and Transport Theory and Practice
Journal for Traffic and Transport Research and Application
Volume 11 Number 1 • Banjaluka • July 2026 (1-84)
ISSN: 2490-3477 (Print) • 2490-3485 (Online)
UDC: 656

ERIH PLUS
EUROPEAN REFERENCE INDEX FOR THE HUMANITIES AND SOCIAL SCIENCES
www.tttp-au.com
APEIRON

TTTP
Traffic and Transport Theory and Practice
Journal for Traffic and Transport Research and Application

Published by ..... Pan-European University ''Apeiron'' Banja Luka, Bosnia and Hercegovina
Person Responsible for the Publisher ..... Darko Uremović *(Bosnia and Hercegovina)*
Editor of University Publications ..... Aleksandra Vidović *(Bosnia and Hercegovina)*

Lectors ..... Mirela Simić, Tanja Aničić
Web Design ..... Marko Milovanović
Printed by ..... Markos, Banja Luka
Printed in 300 copies

The TTTP Journal is an international scientific journal published in English language with both electronic and printed versions.

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

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Traffic and Transport Theory and Practice (TTTP) Journal is registered with the Ministry of Science and Technology of the Republic of Srpska by serial registration code 07.06/053-19/2016-1, date 07. 03. 2016. Traffic and Transport Theory and Practice (TTTP) Journal (ISSN 2490-3477-Print, 2490-3485 (Online) is an international journal published two time a year. Annual subscription is 30 EUR

Indexed in: LICENSE AGREEMENT, 3.22.12. EBSCO Publishing Inc., Current Abstracts
Google scholar.google.com
ERIHPLUS erihplus.nsd.no
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crossref crossref.org

UDC: 656
COBISS.RS-ID 6892568

ISSN: 2490-3477 (Print)
2490-3485 (Online)

Traffic and Transport Theory and Practice

Journal for Traffic and Transport Research and Application

*BOSNIA AND HERZEGOVINA / BANJA LUKA / **JULY 2026** / VOLUME **11**/ NUMBER **1** (1-84)*
http://www.tttp-au.com

Contents

From the Editor

Dear readers,

It is my pleasure to present the 16th printed and electronic edition of the journal Traffic and Transport Theory and Practice – TTTP, featuring 10 peer-reviewed articles in the field of traffic and transport engineering. This time, we have the opportunity to present a selection of the best papers presented at the Second International „Safe-Urban-Mobile" Conference. Rigorous reviews by distinguished international and domestic experts have contributed to the growing visibility of the journal and the scientific conference, resulting in a high level of quality in this issue.

Among other topics, we draw attention to a model for regulating traffic at two-lane roundabouts through legal and technical regulatory measures. New criteria for determining damage resulting from traffic accidents are also presented. This issue places particular focus on road safety, especially regarding the implementation of Directive 2008/96/EC. It also includes an article by authors from the medical profession addressing the harmful consequences of traffic in urban environments. Sustainable urban mobility, quality of life in cities, and electronic micromobility are among the thematic areas covered in this edition.

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

DOI: 10.7251/JTTTP2601005S
UDC: 625.739:656.11.021(497.6)

ORIGINAL SCIENTIFIC PAPER

Assessment of critical headway estimation methods across multiple unsignalized intersections

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Recived: December 2, 2025
Revised: May 3, 2026
Accepted: May 29, 2026

Abstract: Driver behavior under local conditions has a significant influence on the value of accepted headways required for performing minor maneuvers. In operational analyses and the design of unsignalized intersections, driver behavior is quantified through the value of the critical headway. It is assumed that the critical headway represents the shortest headway that a driver is willing to accept. Since it is not possible to measure the critical headway directly from field observations, measurement results are processed using application software and mathematical tools. To determine the critical headway at three priority intersections in the urban area of the city of Doboj, six different methods were applied: Harders', Logit, Lag, Raff's, Wu's, and the Maximum Likelihood method. In order to identify which of the applied methods provides the best solution for the analyzed intersections, a comparative analysis was conducted between the theoretically obtained capacity values and the actual measured capacity value. The Lag method was the most suitable for intersection I_1, the Maximum Likelihood method was chosen for intersection I_2, while the Raff method was selected for intersection I_3.

Keywords: critical headway estimation, unsignalized intersection

INTRODUCTION

Since the early stages of Traffic Flow Theory, many studies have aimed to define procedures for analyzing the capacity of roads, streets, and intersections, as well as identifying influencing factors. The first research efforts in this field date back to the early 1930s, when capacity studies of uninterrupted road segments were conducted for the first time. The capacity of roads, intersections, and other elements of the roadway and street network continues to be a highly relevant topic that motivates extensive scientific research. The findings of such studies are used to develop procedures and models for the calculation of various components of the road and street network. Although established procedures exist for the capacity analysis of most of these elements, all models and procedures are still being refined and improved through new research and mathematical modeling efforts. In engineering practice, capacity estimation for unsignalized intersections is most commonly performed using the procedures defined in the Highway Capacity Manual (HCM). The HCM represents the most widely cited manual for capacity analysis within the roadway and street network.

When estimating the capacity of unsignalized intersections, one of the traffic flow parameters that most strongly influences both capacity and level of service is the critical headway. The critical headway represents the mathematically determined minimum headway in the major stream that allows a vehicle from the minor stream to complete its maneuver. In theory, it is assumed that the critical headway is smaller than any accepted headway and greater than any rejected headway. Since drivers will accept all headways greater than their critical headway, this value cannot be measured directly at the observed intersections [1]. Therefore, accepted and rejected headways must be extracted and statistically processed so that they can be used in the calculation of intersection capacity and level of service.

The value of the critical headway depends on objective factors, such as the technical and operational characteristics of vehicles and the geometric features of intersections. However, in addition to objective factors, the value of the critical headway equally depends on

the driver's subjective assessment and behavior in such traffic situations. Specifically, drivers on the minor approaches of priority intersections assess the value of the headways in the conflicting major streams and choose the headway they perceive as suitable for performing the minor maneuver. In the case of poor judgment, the driver may impede vehicles in the major stream, and in extreme situations this may lead to conflicts or traffic accidents.

Although the HCM provides recommended headway values that can be used under various conditions, more accurate and precise values of the critical headway can be obtained through field observations that account for the specific local conditions of a given area [2]. In this way, calibration is performed by adapting the input parameters to real traffic conditions at the intersections, ensuring that the theoretical models more accurately reflect actual traffic operations [3]. Due to the inability to directly measure the critical headway at every intersection under analysis, numerous methods and procedures have been developed for its estimation.

METHODOLOGY

For the purposes of this research, it was necessary to conduct measurements of the parameters used to determine the capacity and level of service of unsignalized intersections under real traffic conditions. Such studies are very rare in Bosnia and Herzegovina and the broader region, even though the HCM methodology recommends local measurements as the most reliable approach for defining traffic flow parameter values. For this study, the observation of headways in the major stream was conducted at three unsignalized intersections in Doboj, namely:

- The intersection of Sveti Sava Street, Miloš Obilić Street, King Aleksandar Street, and Vidovdanska Street (marked as I_1 in the paper);
- The intersection of Vasilije Ostroški Street and King Aleksandar Street (I_2);
- The intersection of Vojvoda Stepa Street and King Dragutin Street (I_3).

For the estimation of the critical headway, six different methods were applied, namely: Harders', Logit, Lag, Raff's, Wu's, and the Maximum Likelihood method.

Raff's method

The earliest method for estimating the value of critical headway is based on the research conducted in [4]. Raff's method involves the empirical distribution of the functions of accepted gaps $F_a(t)$ and rejected gaps $F_r(t)$. According to his conclusions, the critical headway (t_c) is a function of t at the points where the functions $1\text{-}F_r(t)$ and $F_a(t)$ intersect. When the sum of the cumulative probabilities of accepted gaps and rejected gaps is equal to 1, then the headway of t is equal to the critical headway t_c. This means that the number of rejected gaps greater than the critical gap is equal to the number of accepted gaps lower than the critical gap.

$$F_a(t) = 1 - F_r(t) \quad (1)$$

Later, Miller [5] provided some mathematical explanations of this method and stated that the results of estimating the critical gap are directly related to flow rate at approaches. This method was previously used in many countries due to its ease of application, such as in Germany [6].

Harders' method

Harders [7] developed a method for estimating t_c, which was often used in Germany. The largest number of performed procedures for capacity calculation in Germany is still based on his method of estimating the values of t_c and t_f. In Harders' procedure, lags are not used in the sample observed. The time scale is divided into intervals of equal length, e.g. Δt = 0.5 [s], and the center of each interval i is denoted as t_i. For each vehicle in a minor-stream queue, it is necessary to measure all the gaps from the major stream available to the driver and record the accepted gaps. Based on all the above, it is necessary to calculate the following values:

- N_i - the number of all measured gaps of i, which are available to minor-stream drivers
- A_i – the number of accepted gaps of i
- $a_i = A_i/N_i$

By plotting the value of a_i in the center of each interval t_i, a curve is obtained that represents $F_c(t)$, i.e. the function of critical gaps. On the other hand, there is no mathematical concept or further proof that $a_i = f(t_i)$ nor that a real curve of critical gaps $F_c(t)$ is thus obtained.

2.3 Maximum likelihood method

The maximum likelihood method for estimating the critical headway was developed in the early 1970s by Miller and Pretty [5, 8]. This method for estimating the critical headway is most accurately explained in [9]. The maximum likelihood method is based on the fact that the value of critical headway is between the largest rejected gap and the accepted gap. The following parameters are used to estimate the critical headway using this method [10]:

- y_i - the logarithm of the gap accepted by the i^{th} driver
- x_i – the logarithm of the largest gap rejected by the i^{th} driver, x_i=0 if no gap is rejected
- μ – the logarithm distribution mean of individual critical gaps of drivers
- σ^2 – the logarithm distribution variance of individual critical gaps of drivers
- $f(\,)$ - probability density function for normal distribution
- $F(\,)$ - cumulative distribution function for normal distribution

The average value of critical headway t_c and the variance s^2 can be calculated as follows:

$$t_c = e^{\mu+0,5\sigma^2} \tag{2}$$

$$s^2 = t_c^2(e^{\sigma^2} - 1) \tag{3}$$

Wu's method

Wu [11] presented a new model for estimating critical headways at unsignalized intersections (Probability equilibrium method). The theoretical background of the model is the probability equilibrium between the accepted and rejected gaps. The author states that in addition to a good theoretical background, the new model has other positive features such as robust results, independence from any assumptions before applying the model, the ability to use all relevant gaps. The advantage is also the possibility of obtaining the empirical probability distribution function of critical headways directly, as well as a simple calculation procedure without iteration. This method is defined by the following mathematical expression:

$$\mathrm{F_{tc}}(\mathrm{t}) = \frac{\mathrm{F_a}(\mathrm{t})}{\mathrm{F_a}(\mathrm{t}) + 1 - \mathrm{F_r}(\mathrm{t})} = 1 - \frac{1 - \mathrm{F_r}(\mathrm{t})}{\mathrm{F_a}(\mathrm{t}) + 1 - \mathrm{F_r}(\mathrm{t})} \tag{4}$$

Logit method

The Logit method uses the negative logarithm of likelihood function. Logit is basically a linear regression model with a mathematical form as shown in the following expression:

$$\mathrm{P} = \frac{1}{1 + \mathrm{e}^{-(\beta_0 + \beta_1 \mathrm{x})}} \tag{5}$$

where P is the probability of gap acceptance, β_0 and β_1 are regression coefficients, and x is the length of the gap. The critical headway can be estimated by solving the expression above for x by assigning a value from 0.5 to P, i.e. the probability is 50% that the gap will be accepted. This model is often used to check the influence of different independent variables on the critical headway, such as waiting time, average speed, etc.

The lag method

This method is based on the lag in the major stream, that is, the time between the arrival of a vehicle in the minor stream and the arrival of a vehicle in the major stream. It assumes homogeneous drivers and independence of minor-stream arrivals from traffic conditions in the major stream [12]. The underlying premise is that the probability of accepting a lag t is equal to the probability that the driver's critical headway is smaller than t, meaning that the critical headway lies between the largest rejected and the accepted lag. Therefore, it can be stated that:

$$P_{a,lag} = F_c(\mathrm{t}) \tag{6}$$

For this method, it is necessary to measure all intervals, both accepted and rejected. A scale of W segments of size Δt (e.g., Δt = 1 s) is then formed, and for each segment i the following values are analyzed:

N_i = the number of observed lags within the interval i

A_i = the number of accepted lags within the interval i

$a_i = A_i/N_i$

If it is assumed that the value t_1 represents the center of interval i, then:

$$F_c(\mathrm{t}_i) = a_i \tag{7}$$

which represents an approximation of the cumulative distribution function of the critical headways. The mean critical headway in that case is:

$$t_c = \sum_{i=1}^{W} t_i \cdot \left[F_c(\mathrm{t}_i) - \mathrm{F}_c(\mathrm{t}_{i-1})\right] \tag{8}$$

where W is the number of intervals of size Δt.

Comparative analysis of methods for critical headway estimation

To determine which of the applied methods provides the most realistic estimate of the critical headway, a comparison was made between the measured field capacity values and the theoretical capacity values, i.e., the capacity values obtained based on critical headways calculated using different methods. For the comparative analysis of the mentioned capacity values, the method developed and presented in [13, 14, 15] was applied, which requires determining the values of the field capacity and the conflicting flow rate. For the purpose of defining these two parameters, only headways observed in queues consisting of at least three vehicles were considered. The field capacity is obtained as the ratio between the number of vehicles in the queue and the time elapsed from the moment the first vehicle in the queue reaches the stop line to the moment the last vehicle in the queue reaches the stop line, during which all vehicles in the queue use the same headway in the conflicting stream [14]. During the same observation period, the conflicting flow rate is calculated using *Equation (9)*:

$$\text{Conflicting flow rate} = \frac{\mathrm{n}}{\mathrm{t_n} - \mathrm{t_0}} \tag{9}$$

where:

- n is the number of vehicles in the conflicting stream, including the vehicle that passed immediately after the last vehicle from the queue on the minor approach,
- t_n is the arrival time of the nth vehicle from the conflicting stream in front of the minor approach,
- t_0 is the arrival time of the first vehicle from the queue at the stop line.

On the other hand, for the capacity calculation based on the obtained critical headway values, the model defined in [16] was applied. Afterwards, a scatter plot was created in MATLAB using the values of the field capacity and the conflicting flow rate.

RESEARCH RESULTS

Table 1 presents the calculated critical headway values obtained using the previously mentioned methods.

Critical headway values equal to zero in the table correspond to situations in which the applied method did not produce results. Such cases occur due to an insufficient number of collected observations, i.e., accepted and rejected headways/lags. The primary reason for this issue in the case of the right turn maneuver from the minor approach is that this movement has the smallest number of conflicting streams compared to all other minor maneuvers. In addition, the traffic volume in the conflicting streams for this maneuver was relatively low, allowing most drivers to complete the right turn from the minor approach unimpeded. Therefore, within this comparative analysis of methods, in such cases the critical headway and follow-up headway values recommended in [16] were adjusted to local conditions.

For comparison of the previously mentioned capacity values, it was necessary to determine the field capacity and conflicting flow values based on the procedure described in the Methodology section. When it comes to the observed minor roads at intersections I_1 and

Table 1. Calculated critical headway values at the three unsignalized intersections

Method	Intersection						
	I_1			I_2		I_3	
	Through traffic on minor	Right turn from minor	Left turn from minor	Right turn from minor	Left turn from minor	Right turn from minor	Left turn from minor
Lag	7,20	0,00	8,17	0,00	9,00	6,83	10,66
Harders	6,84	0,00	7,75	6,64	7,23	0,00	7,56
Logit	6,24	0,00	6,83	5,93	7,13	0,00	7,08
Raff	6,22	0,00	7,50	6,15	6,65	6,00	6,85
Wu	6,40	0,00	7,07	6,19	6,01	6,49	6,97
MLM	5,58	4,71	7,12	5,85	6,33	4,27	6,46

Table 2. Adjusted recommended values of critical headway and follow-up headway in the HCM manual

Intersection	Parameters	Through traffic on the minor road	Right turn from the minor road	Left turn from the minor road
I_1	Critical headway	6.53	6.21	7.10
	Follow-up headway	4.03	3.31	3.50
I_2	Critical headway	-	5.54	5.53
	Follow-up headway	-	3.34	3.62
I_3	Critical headway	-	6.23	6.42
	Follow-up headway	-	3.33	3.52

Table 3. Descriptive statistics for the follow-up headway

Intersection	Maneuver	Arithmetic Mean	Standard Deviation	Variance	Minimum	Median	Maximum
I_1	Through traffic on the minor road	3.55	0.90	0.82	2.02	3.34	5.53
	Right turn from the minor road	3.26	0.65	0.43	1.81	3.42	4.57
	Left turn from the minor road	4.18	0.69	0.47	3.69	4.18	4.66
I_2	Left turn from the minor road	3.33	0.87	0.75	1.61	3.13	5.72
	Right turn from the minor road	3.71	0.69	0.47	2.46	3.61	5.48
I_3	Left turn from the minor road	4.26	0.84	0.70	2.58	4.23	6.13
	Right turn from the minor road	3.44	0.74	0.55	2.17	3.52	4.94

I_3, it was impossible to find a sufficient number of waiting queues with at least three vehicles performing the same minor maneuver for the calculation of field capacity and conflicting flow. The main reason for this impossibility is that all minor maneuvers share a single lane at the analyzed minor roads at the intersections. Therefore, for these two intersections, data were extracted for the calculation of field capacity and conflicting flow in situations where at least three vehicles performed the same or different maneuvers to enter the center of the intersection. On the other hand, intersection I_2 has separate minor roads for left and right turns, so it was possible to identify traffic situations where at least three vehicles performed the same movement maneuver to enter the center of the intersection.

For the purposes of calculating the theoretical capacity based on the HCM model, the values of conflicting flows for each maneuver at the observed unsignalized intersections were determined. Additionally, the values of follow-up headways were calculated separately for each maneuver, and are presented in *Table 3.*

Considering the previously described case at intersections I_1 and I_3, which refers to data extraction when at least three vehicles form a queue, the capacity of the shared traffic lane was calculated for these two intersections and used in further analysis. On the other hand, due to the physically separated minor roads at intersection I_2, the capacities for left and right turns from the minor road were calculated separately at this intersection.

Due to the specific geometric characteristics of intersection I_2, modifications were made to the original equation for calculating the capacity of the left turn movement from the minor approach, as defined in [16]. More precisely, the adjustment primarily concerns the exclusion of the left turn flow from the major approach ($2v_4$) from the equation used to calculate the conflicting flow for the left turn from the minor approach. This modification was introduced because vehicles turning left from the major approach use a separate, physically divided lane located in front of the lane used by vehicles turning left from the minor approach. In addition, vehicles turning left from the major approach decelerate before executing the maneuver due to higher priority vehicles approaching from the opposite direction. As a result, vehicles turning left from the minor approach can perform their maneuver unimpeded. The adjusted equation for calculating the capacity of the left turn from the minor approach, adopted as a consequence of neglecting the influence of the left turn from the major approach, is given as $c_{m,7} = c_{p,7}$ (i.e., the movement capacity is equal to the potential capacity).

In MATLAB, a scatter plot was created with points determined by the field capacity values (labeled as Field Q in *Figures 1*, *2, 3*, and *4*) and conflicting flow values (labeled as CF in *Figures 1*, *2, 3*, and *4*). In some cases, there were significant variations in the field capacity values, which is quite common in field measurements [14]. For this reason, a smoothing technique based on the moving average method was applied to reduce the variations in the data. In this way, the exponential model was adjusted to the field data and compared with the theoretical capacity values. After applying the aforementioned method, the field capacity values are labeled as Field Qm, while the exponential curve, i.e., the model, is labeled as Fit in *Figures 1, 2, 3,* and *4*.

The values on the *x*-axis represent the conflicting flows determined for each maneuver at the analyzed intersections, while the values on the *y*-axis represent the capacities estimated based on the critical headways obtained using different methods. The best method for calculating the critical headway is the one that yields the theoretical capacity value closest to the field capacity value for the same conflicting flow value.

Based on *Figure 1*, it can be observed that the theoretical capacity value obtained using the Lag method is the closest to the field capacity value at intersection I_1.

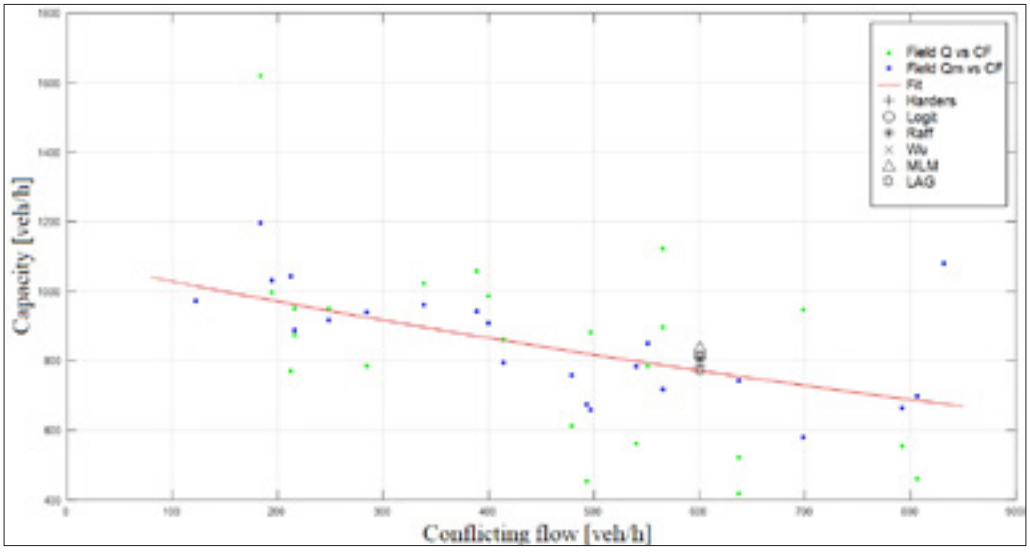

Figure 1. Comparative analysis of methods at intersection I_1

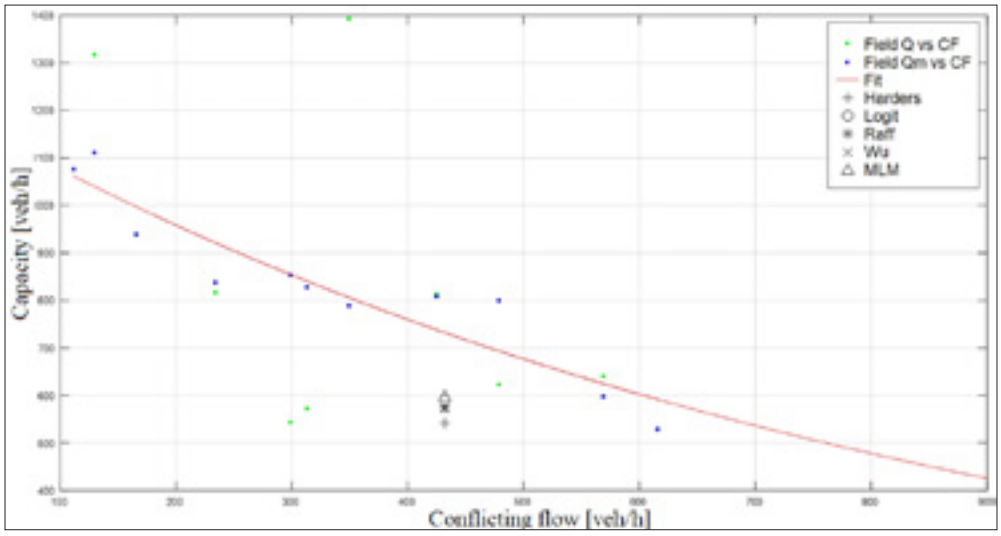

Figure 2. Comparative analysis of methods for right turn from the minor road at intersection I_2

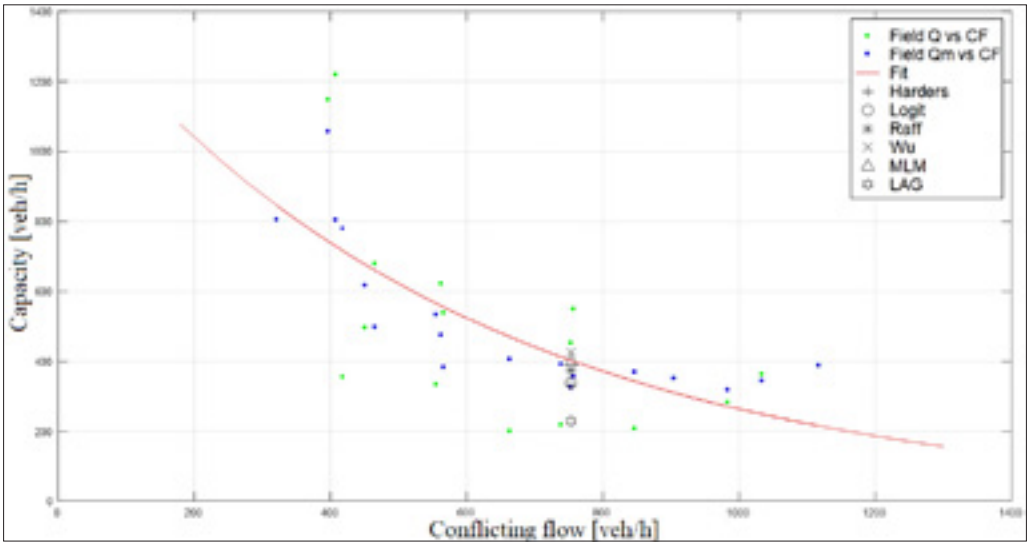

Figure 3. Comparative analysis of methods for left turn from the minor road at intersection I_2

The Lag method showed the best results at intersection I_1, as it is particularly effective in practice for urban four-leg intersections with complex traffic patterns, lacking dedicated turning lanes from the minor roads in the observed case, and featuring high variability in driver behavior caused by a mix of driver types (novice, elderly, professional, etc.).

Figure 2 shows that the theoretical capacity values are quite distant from the exponential model at intersection I_2. The reason lies in the calculated follow-up headway, which is higher than the recommended value due to the specific radius on the road designed for right turns. Since the HCM model, on which the theoretical capacity values are based, does not consider the radius to be one of the influencing factors on capacity, these theoretical capacity values are far from the actual capacity values. Through a comparative analysis of theoretical capacity values calculated in this way, it can be established that the Maximum Likelihood method is the most suitable for right turns from the minor road.

Figure 3 shows that for left turn from the minor road at the same intersection I_2, the Maximum Likelihood method provides the best results. The main reason for this lies in the favorably channeled intersection geometry, the small number of conflicting traffic flows, and the clearly defined movement directions, all of which contribute to stable and consistent driver behavior. These conditions align well with the fundamental assumptions of the Maximum Likelihood method.

Figure 4 shows that the Raff method is the best solution for intersection I_3. Geometric characteristics of this intersection, such as limited visibility, lack of dedicated lanes, and the presence of a "STOP" sign, collectively contribute to high variability in driver behavior, unpredictable decisions, and a greater number of rejected headways. These conditions make the Raff method suitable for calculating the critical headway, as it does not model driver logic but instead relies on actual observed driver behavior.

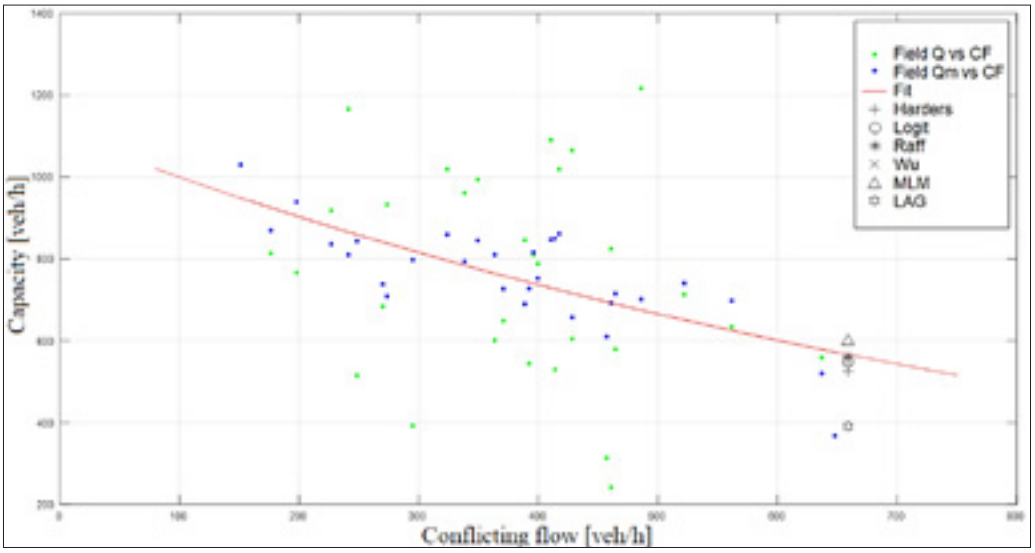

Figure 4. Comparative analysis of methods at intersection I_3

CONCLUSION

Practically all studies have shown that the capacity of unsignalized intersections largely depends on the critical headway. The value of the critical headway is influenced by vehicle characteristics, traffic conditions, and geometric features of the intersection, but also to a great extent by driver behavior. Driver behavior is shaped by numerous factors influenced by local conditions, habits, mentality, and similar influences. To properly analyze performance indicators of unsignalized intersections, it is essential to obtain reliable estimates of the critical headway for each maneuver. Variations in driver behavior therefore have a substantial impact on capacity, level of service, and overall traffic safety. Inaccurately estimated critical headway values for unsignalized intersections may lead to a misleading representation of traffic conditions and the performance of the traffic network.

As a result of the aforementioned variations in critical headway values, applying the same method can lead to differences in the calculated capacity at unsignalized intersections. Therefore, using recommended critical headway values derived for one country may lead to incorrect decisions when applied in another. For this reason, a comparative analysis of six different methods for estimating the critical headway was conducted in this study, with the aim of verifying the theoretically obtained values. The Lag method was the most suitable for intersection I_1, the Maximum Likelihood method was chosen for intersection I_2, while the Raff method was selected for intersection I_3.

Comprehensive research findings indicate an undeniable need for conducting local measurements of key parameters used in the capacity calculation of unsignalized intersections, in order to ensure that the obtained results are more relevant and applicable. It is expected that the research results will, in subsequent steps, initiate further research to be implemented in procedures for calculating capacity and service levels, and also encourage other researchers to conduct similar studies in other local environments.

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DOI: 10.7251/JTTTP2601013A
UDC: 656.1.08:656.11.021(497.6RS)

ORIGINAL SCIENTIFIC PAPER

Impact of traffic safety law amendments on fatal road traffic injuries in the Republic of Srpska: a before–after analysis

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Recived: April 20, 2026
Revised: June 7, 2026
Accepted: June 26, 2026

Abstract: Road traffic injuries remain a major contributor to premature mortality, especially in low- and middle-income countries. This study quantified the burden of premature mortality attributable to road traffic injuries in the Republic of Srpska by calculating Years of Life Lost (YLL) and Potential Years of Life Lost (PYLL), and assessed changes following the 2021 amendments to traffic safety legislation. A quasi-experimental before–after design compared the periods 2011–2020 and 2021–2024. Mortality data were sourced from official demographic statistics and analysed using descriptive and inferential statistical methods. The results indicate a substantial decline in premature mortality. The mean number of road traffic deaths decreased by 27.9%, while YLL and PYLL were reduced by approximately 70%. Reductions occurred across all age groups, with the most pronounced decline among individuals aged 15-24 years and among vulnerable road users, particularly pedestrians and bicyclists. The Haddon matrix was used as the primary analytical framework, organizing findings across pre-crash, crash, and post-crash phases. The observed changes were primarily associated with system-level interventions in the pre-crash phase, particularly legislative and enforcement measures. Improvements in crash and post-crash determinants also likely contributed to reduced mortality. In conclusion, the reduction in premature mortality observed after 2021 is temporally associated with legislative amendments and aligns with a broader system-based road safety framework rather than isolated policy measures. Further research is warranted to quantify the contribution of individual interventions and to assess long-term trends.

Keywords: Road traffic injuries; premature mortality; Years of Life Lost (YLL); Potential Years of Life Lost (PYLL; Haddon matrix

INTRODUCTION

Road traffic injuries represent a leading cause of premature mortality and disability worldwide, posing a significant challenge to public health and development. According to the World Health Organization, approximately 1.19 million individuals die each year as a result of road traffic crashes. Additionally, tens of millions experience non-fatal injuries that frequently result in long-term disability (WHO, 2023). These injuries disproportionately affect low- and middle-income countries and predominantly occur among younger, economically active populations, resulting in considerable social and economic consequences (WHO, 2023; Murray et al., 2020). Beyond immediate human suffering, road traffic crashes impose a substantial burden on health systems, families, and national economies. Injuries frequently require extended medical treatment and rehabilitation, leading to reduced productivity and enduring social costs. As a result, traffic injuries are increasingly analysed using population health metrics that encompass both mortality counts and

the broader effects of premature mortality (GBD, 2019; Collaborators, 2020).

Traditional mortality indicators quantify the number of deaths but fail to consider the age at death or the potential years of life lost due to premature mortality. To address this limitation, epidemiological research frequently utilises measures such as Potential Years of Life Lost (PYLL) and Years of Life Lost (YLL). PYLL estimates premature mortality using a predefined age threshold, such as 65 or 75 years. In contrast, YLL is calculated using standard life expectancy, representing the total number of years individuals would have lived had they reached the expected lifespan (Gardner & Sanborn, 1990; Romeder & McWhinnie, 1977; WHO, 2010; Murray et al., 2012). The YLL indicator is a core component of the Global Burden of Disease (GBD) framework and the World Health Organization Global Health Estimates methodology. In this approach, YLL is determined by multiplying the number of deaths by the standard life expectancy remaining at the age of death. This method places greater emphasis on deaths at younger ages, providing a more comprehensive assessment of the societal burden of premature mortality (Murray et al., 2012; WHO, 2023).

Road traffic deaths constitute a leading cause of mortality worldwide, particularly in low- and middle-income countries (LMICs), where more than 90% of fatalities occur. The burden is especially pronounced among vulnerable road users and young adults, notably those aged 15–29 years (WHO, 2023; Karkee & Lee, 2016; Konlan & Hayford, 2022). Given the disproportionate impact on adolescents and young adults, the use of YLL and PYLL indicators is highly pertinent in traffic safety research. These measures facilitate the identification of age groups most affected by premature mortality and inform the development of targeted prevention strategies and policy interventions (Elvik & Vaa, 2004; GBD 2019 Injuries Collaborators, 2020; World Health Organization, 2023).

Although global road safety has improved, the burden of road traffic injuries remains unevenly distributed across regions. In Europe, road traffic mortality has decreased significantly in recent decades, attributable to enhanced road infrastructure, vehicle safety standards, and comprehensive prevention policies. Nevertheless, countries in South-Eastern Europe and the Western Balkans continue to report higher mortality rates than the European Union average (European Commission, 2023; World Health Organization, 2023; European Transport Safety Council, 2022). Multiple studies have identified persistent challenges in these regions, including disparities in road safety policies, infrastructure quality, enforcement of traffic regulations, and emergency response systems (World Health Organization, 2023; European Transport Safety Council, 2022; European Commission, 2023).

In Bosnia and Herzegovina, particularly within the Republic of Srpska, road traffic injuries continue to be a significant cause of premature mortality and constitute a major public health concern (World Health Organization, 2023). While official statistics consistently report the number of traffic-related deaths and injuries, comprehensive analyses of premature mortality, using indicators such as PYLL and YLL, remain limited (Romeder & McWhinnie, 1977; GBD, 2019; Injuries Collaborators, 2020). Employing these indicators enables a more thorough understanding of the societal impact of traffic-related deaths by quantifying the loss of potential life years, especially among youth. Assessing premature mortality through YLL and PYLL can provide valuable insights for public health planning and road safety policy development in the Republic of Srpska, while also enhancing understanding of the burden of traffic injuries in the Western Balkan region (World Health Organization, 2023; European Commission, 2023; European Transport Safety Council, 2022; WHO Regional Office for Europe, 2019). This study aimed to evaluate the burden of premature mortality attributable to road traffic injuries in the Republic of Srpska using PYLL and YLL indicators. and YLL indicators.

Road traffic safety in Bosnia and Herzegovina is governed by a multi-level legal framework. At the state level, the Law on the Basics of Road Traffic Safety in Bosnia and Herzegovina establishes general rules for road user behaviour and specifies key safety measures, including seat belt use, helmet requirements, speed limits, and alcohol restrictions (Parlamentarna skupština Bosne i Hercegovine).

At the entity level, the Law on Traffic Safety of the Republic of Srpska regulates the implementation, enforcement, and organisation of the road safety system. This includes defining institutional responsibilities, monitoring mechanisms, and inspection procedures (Narodna skupština Republike Srpske, 2011, 2021).

The 2021 amendments to the entity-level law introduced stricter enforcement measures, enhanced monitoring of safety indicators, and improved coordination of road safety activities. These legislative changes establish a critical policy context for evaluating subsequent changes in road traffic mortality in the Republic of Srpska.

The analysis examines two distinct periods, 2011–2020 and 2021–2024, to assess temporal trends. This division corresponds to the 2021 amendments, which serve as the primary intervention of interest. The pre-intervention period reflects the regulatory framework established by the original 2011 law, facilitating a contextual interpretation of changes in mortality patterns (Narodna skupština Republike Srpske, 2011; Narodna skupština Republike Srpske, 2021). Accordingly, this study aims to assess changes in road traffic mortality following the implementation of legislative amendments, situating these changes within a broader system-level context.

METHODOLOGY

Study design and data sources

A retrospective, quasi-experimental (before–and–after) epidemiological study design was employed to assess changes in road traffic mortality and premature mortality in the Republic of Srpska.

Mortality data were obtained from official demographic statistics published by the Statistical Office of the Republic of Srpska for the period 2011–2024. Road traffic deaths were classified according to the International Classification of Diseases, Tenth Revision (ICD-10), within the transport accidents category (codes V00–V99). The study period was divided into two intervals: a pre-intervention period (2011–2020) and a post-intervention period (2021–2024), corresponding to the implementation of traffic safety policy measures. Mortality data were analysed by age group. Population data required to calculate mortality rates were also obtained from official demographic sources. This design enabled both a descriptive analysis of mortality trends over time and a comparative assessment of changes between the pre- and post-intervention periods.

Age-specific analysis

Mortality data were stratified into the following age groups: 0–4, 5–14, 15–24, 25–34, 35–44, and 45 years and older. Age-specific mortality rates were calculated per 100,000 population based on available demographic data. For grouped data, midpoint values were applied to estimate the average age at death within each category.

Potential Years of Life Lost (PYLL)

Potential Years of Life Lost (PYLL) were calculated using a fixed cut-off age of 75 years. For each age group, the midpoint of the interval was used to approximate the average age at death because individual-level data were unavailable. The total PYLL was determined as follows:

$$PYLL = \sum_{i=1}^{n}(L - a_i) \cdot d_i \quad (1)$$

where L represents the cut-off age (75 years), a_i is the midpoint of the age group, and d_i is the number of deaths in each age group. For the open-ended age group (45+ years), a midpoint of 65 years was assumed to approximate the average age at death. This approach was adopted to ensure consistent estimation of PYLL given the lack of more detailed age-specific data.

Years of Life Lost (YLL)

Years of Life Lost (YLL) were calculated according to the Global Burden of Disease (GBD) methodology, applying a standard life expectancy of 86.02 years. The midpoint of each age group served to estimate the average age at death. The total YLL was determined as follows:

$$YLL = \sum_{i=1}^{n}(LE - a_i) \cdot d_i \quad (2)$$

where LE represents the standard life expectancy (86.02 years), a_i is the midpoint of the age group, and d_i is the number of deaths in each age group. For the open-ended age group (45+ years), a midpoint of 65 years was assumed to approximate the average age at death.

Haddon matrix

The Haddon matrix served as a conceptual framework for interpreting injury prevention across temporal phases and system components. The matrix integrates the epidemiological triad of host, agent, and environment with the temporal sequence of pre-event, event, and post-event phases, thereby enabling a structured analysis of risk factors and intervention points (Sommers, 2006; Bonilla-Escobar & Gutiérrez, 2014; Hosking et al., 2011). The framework enables the classification of preventive strategies into primary, secondary, and tertiary levels and has been widely adopted in public health due to its systematic and adaptable approach to injury prevention (Sommers, 2006; Cabral et al., 2021). In this study, the Haddon matrix was used to interpret changes in road traffic mortality and premature mortality burden, as measured by years of life lost (YLL) and potential years of life lost (PYLL), by classifying findings into pre-crash, crash, and post-crash phases.

Data analysis

Data analysis was performed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Descriptive statistics, mortality rate calculations, and the estimation of potential years of life lost (PYLL) and years of life lost (YLL) indicators were conducted using standard spreadsheet functions. A linear trend for the 2011–2019 period was estimated using the FORECAST.LINEAR function in Excel to generate expected values, which were compared with observed mortality data for the period 2020–2024. Deviations from the projected trend were used to assess changes in mortality patterns over time. Differences between study periods were assessed using independent samples t-tests. Statistical significance was defined as $p < 0.05$, with $p < 0.001$ indicating a high level of statistical significance. Effect size was evaluated using Cohen's d, with values of 0.2, 0.5, and 0.8 interpreted as small, medium, and large, respectively.

Ethical considerations

This study was based on aggregated, publicly available data and did not involve individual-level information. Therefore, ethical approval was not required.

RESULTS

The mean number of road traffic deaths declined from 103.6 (SD = 15.0) in 2011–2020 to 74.8 (SD = 4.1) in 2021–

2024, representing a reduction of approximately 27.9%. This difference was statistically significant (t = 5.57, p < 0.001), indicating a very large effect size (Cohen's d = 2.18) (Table 1).

Table 1. Road traffic deaths across the study period

Period	Mean number of deaths	SD
2011-2020	103.6	15.0
2021-2024	74.8	4.1

Note: t = 5.57, p < 0.001; Cohen's d = 2.18

Figure 1 presents the trend in road traffic deaths from 2021 to 2024, compared with the expected linear trend derived from the 2011–2020 period. Observed mortality closely aligned with the expected trend prior to 2020; however, a marked divergence became evident thereafter. From 2020 onward, the number of deaths consistently remained below projected values, indicating a substantial reduction in mortality beyond the expected trend. The most pronounced decline occurred between 2020 and 2022, followed by stabilisation at a lower level through 2024.

From 2011 to 2020, individuals aged 15–24 years had the highest age-specific mortality rate (15.2 per 100,000 population). Mortality rates among individuals aged ≥25 years remained relatively stable, ranging from 8.9 to 9.7 per 100,000. The overall mortality rate during this period was 8.9 per 100,000, while rates in younger age groups consistently remained below 2 per 100,000. Between 2021 and 2024, the highest mortality rate was observed in the 25–34 age group, at approximately 10 per 100,000. Mortality rates in other age groups ranged from 6 to 8 per 100,000, with an overall rate of approximately 7 per 100,000. No road deaths were recorded among individuals aged 0–4 years.

Figure 2. Shows that mortality rates declined across all age groups between the two periods. The largest reductions were observed in the 15–24 age group (approximately 50%) and the 35–44 age group (approximately 30%). Moderate decreases of around 20% were observed in the 5–14 and 45+ age groups, as well as in the total population. The 25–34 age group experienced the smallest change, with a reduction of approximately 2%.

Road traffic deaths declined across all categories of road users, as indicated by mean values over the study period. The most substantial relative decreases occurred among bicyclists (−54.5%) and pedestrians (−48.4%). Passengers experienced moderate reductions (−24.4%), whereas drivers (−17.2%) and motorcyclists (−12.8%) saw smaller decreases. However, drivers continue to represent the largest group affected in absolute numbers.

Figure 3 presents the distribution of potential years of life lost (PYLL) across age groups for the periods 2011–2020 and 2021–2024. PYLL decreased substantially in all age groups. Individuals aged 15–24 years consistently experienced the highest burden of premature mortality,

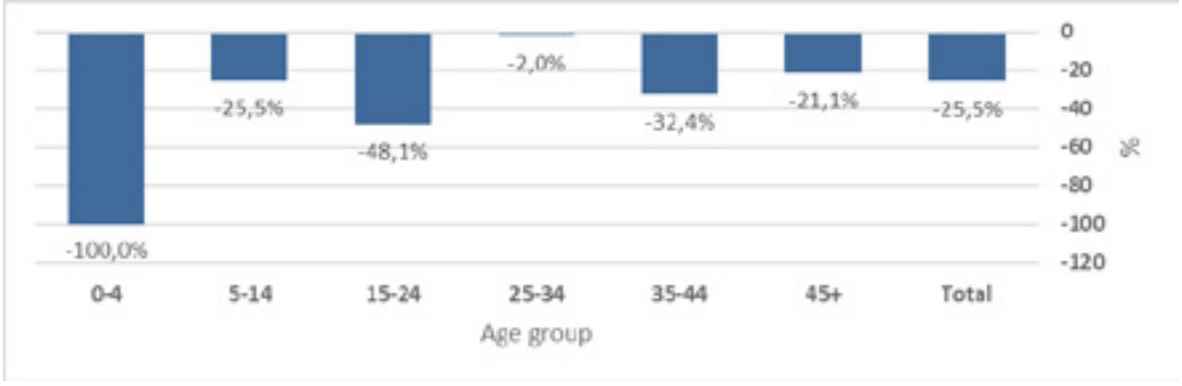

Figure 1. Percentage change in mortality rate by age group (2011-2020 vs 2021-2024)

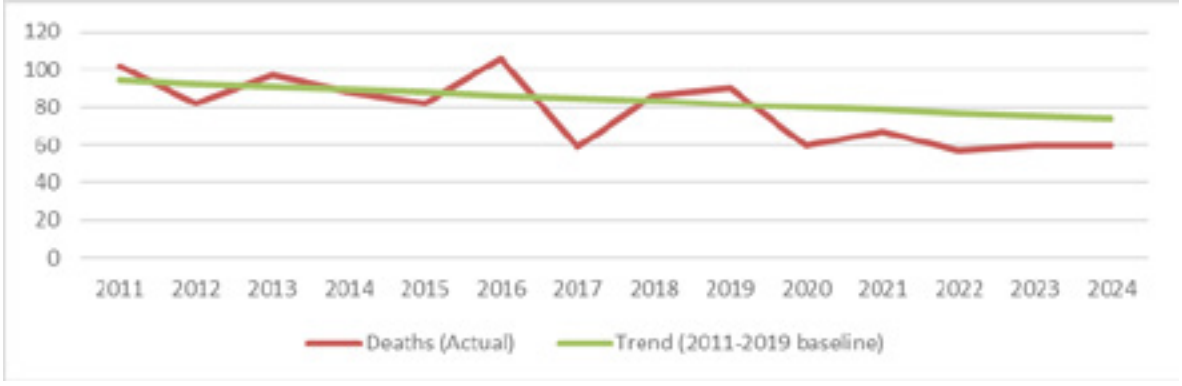

Figure 2. Trend in road traffic deaths and expected linear trend based on the 2011–2019 baseline

Table 2. Change in the mean number of road traffic deaths by road user categories across the study period

Road users	Period		% Change
	2021-2024	2011-2020	
Drivers	33.3	40.2	-17.2
Passengers	15.5	20.5	-24.4
Bicyclists	3.0	6.6	-54.5
Motorcyclists and moped drivers	7.5	8.6	-12.8
Pedestrians	11.3	21.9	-48.4
Others	4.0	5.8	-31.0

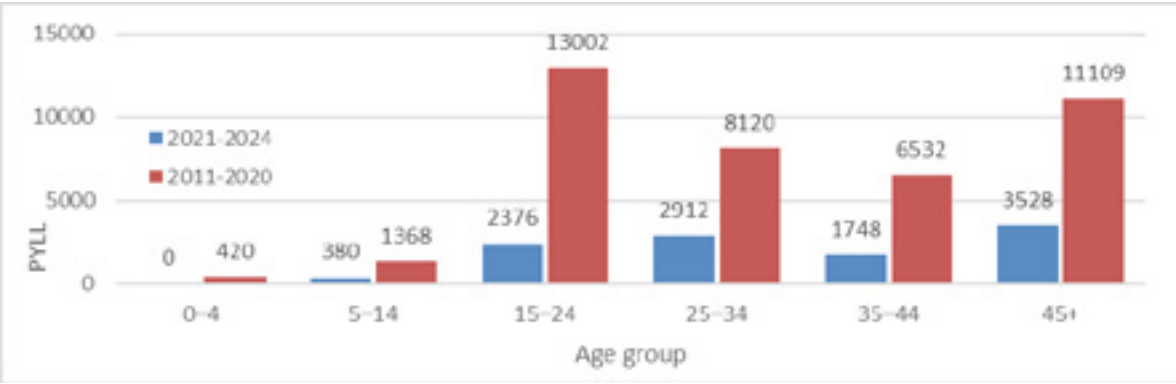

Figure 3. PYLL by age group in two periods (2011–2020 vs 2021–2024)

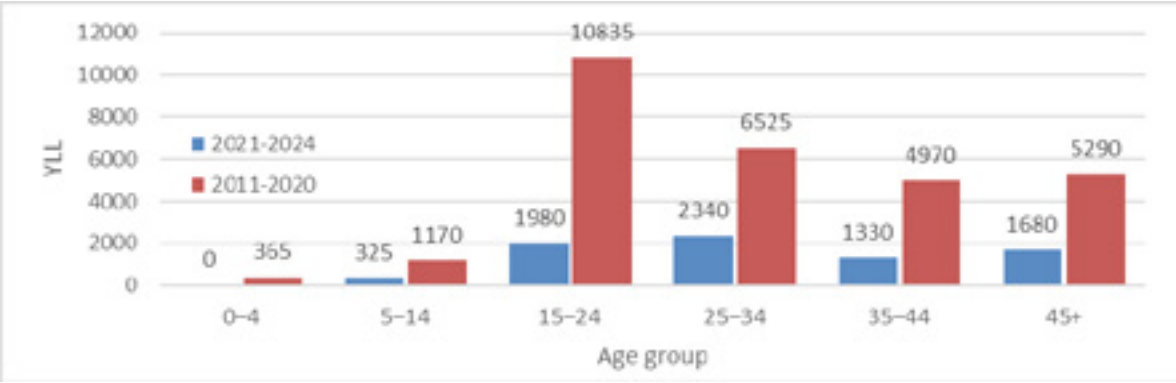

Figure 4. YLL by age group in two periods (2011–2020 vs 2021–2024)

followed by those aged 25–34 years and individuals aged 45 years and older.

Despite the overall decline, younger populations continued to account for a disproportionate share of total PYLL. The 15–24 age group experienced the most pronounced reduction, indicating a significant decrease in early deaths. Nevertheless, this group remained the largest contributor to premature mortality in both periods. Figure 4 illustrates the distribution of years of life lost (YLL) across age groups for the periods 2011–2020 and 2021–2024. In the more recent period, YLL decreased markedly across all age groups. The greatest burden of premature mortality was consistently observed among individuals aged 15–24 years, followed by the 25–34 and 45+ age groups.

Although older age groups experienced the highest number of deaths, younger populations contributed more substantially to total YLL because each death resulted in more years lost. The most pronounced decline in YLL occurred in the 15–24 age group, reflecting a significant reduction in early mortality. Nevertheless, this group continues to represent the largest contributor to the overall burden of premature mortality. These findings, based on PYLL, are consistent with the YLL analysis, which further confirms the substantial burden of premature mortality among younger populations.

DISCUSSION

The results of this study offer significant insights into the mechanisms responsible for the reduction in road traffic mortality in the Republic of Srpska. Road traffic injuries are recognised as preventable events arising from the interplay of human, vehicle, environmental, and system-level factors (WHO, 2023). Following the 2021 amendments to traffic safety legislation, a substantial reduction

Table 3. Haddon matrix of road traffic injury determinants across pre-crash, crash, and post-crash phases

Phase	Human (host)	Vehicle / Equipment (Agent)	Physical Environment	System / Social Environment
Pre-crash	Speeding, alcohol/drug use, fatigue, distraction, risky pedestrian behaviour	Vehicle roadworthiness, brakes, tyres, lights, high-visibility equipment (e.g., reflective vests), and regulation of e-scooters and similar vehicles	Black spots, lighting, road surface conditions, traffic signage, pedestrian crossings, "Zone 30", hazardous road locations	Amendments to the 2021 law; mandatory monitoring of safety indicators; reporting to the Government; annual road inspection plans; road safety audits and inspections; local road safety councils; police enforcement and sanctions
Crash	Use of seat belts/helmets, body positioning, driver and passenger behaviour at the moment of impact	Passive vehicle safety, vehicle structure, airbags, fire risk	Guardrails, crash barriers, forgiving roadsides, road geometry, intersection design features influencing impact severity	Safe System approach, design standards, crash investigation and identification of corrective measures
Post-crash	Age distribution of victims, post-trauma survival	Vehicle extrication conditions, risk of fuel leakage or fire, accessibility for rescue teams	Access to the crash site, distance to the hospital, response time, and rural accessibility	Police, fire services, and emergency medical services; "golden hour" concept; the 2025–2034 strategy notes that helicopter emergency medical service is not yet established as a regular service; planned strengthening of emergency response capacity (Vlada Republike Srpske, 2023)

in both road traffic mortality and premature mortality burden was observed. The mean number of deaths declined by 27.9%, and both years of life lost (YLL) and potential years of life lost (PYLL) decreased by approximately 70%, demonstrating a notable reduction in premature mortality.

Within the Haddon matrix framework, the most pronounced effects were identified in the pre-crash phase, particularly within the system and social environment domains. The 2021 legislative amendments resulted in strengthened enforcement, enhanced monitoring, and improved institutional coordination.

The largest reductions were observed among individuals aged 15–24 years, a demographic typically associated with higher risk behaviours. These findings indicate that system-level interventions, such as stricter enforcement and regulatory measures, may have influenced road user behaviour and contributed to a reduction in the number of crashes. This interpretation aligns with previous evidence demonstrating that legislative and enforcement strategies are among the most effective approaches to reducing traffic injuries (WHO, 2023; Goel et al., 2024).

Improvements in crash-phase determinants may have contributed to a reduction in injury severity. The substantial decline in YLL observed in this study indicates improved survivability. These findings suggest that factors such as increased use of protective equipment, advancements in vehicle safety, and improvements in road infrastructure may have reduced the severity of injuries. Although these variables were not directly measured, the magnitude of YLL reduction supports the interpretation that crash outcomes became less fatal over time. In the post-crash phase, survival outcomes depend on the responsiveness of emergency medical services, access to trauma care, and the overall capacity of the healthcare system.

The continued decline and stabilisation of mortality in the later period suggest that improvements in emergency response and trauma care may have contributed to increased survival following road traffic injuries. The concept of the "golden hour" further underscores the importance of timely medical intervention in reducing fatal outcomes (WHO, 2023). The observed reduction in premature mortality is most appropriately interpreted as the result of coordinated improvements across all phases of the Haddon matrix (Table 3).

These findings indicate that the 2021 legislative amendments may have catalysed broader system-level changes, particularly in the pre-crash phase, while further improvements in crash- and post-crash determinants contributed to the overall decline in mortality. From a systems perspective, these results are consistent with the Safe System approach, which emphasises that road safety outcomes result from interactions among multiple components, including legislation, enforcement, infrastructure, vehicle safety, and post-crash care.

Official mortality statistics may underestimate the true burden of road traffic injuries. Previous research has demonstrated that reliance on a single data source can lead to underreporting, underscoring the importance of integrated and triangulated data systems (Mitra et al., 2021; Gutierrez et al., 2022). Additionally, this study relied on aggregated data, which limited the assessment of individual-level risk factors and causal relationships. The Haddon matrix was used as a conceptual framework for interpretation and does not establish causality. Overall, the findings support a comprehensive, system-based approach to road safety, in which coordinated interventions across multiple domains are essential for achieving sustained reductions in mortality. These results have significant implications for policy development, particularly in middle-income settings, where strengthening legislative frameworks and enforcement mechanisms may yield substantial public health benefits.

CONCLUSION

This study demonstrates a substantial reduction in road traffic mortality and premature mortality burden in the Republic of Srpska following the 2021 amendments to traffic safety legislation. Significant declines in years of life lost (YLL) and potential years of life lost (PYLL) across all age groups indicate that these improvements reflect broader system-level changes rather than effects limited to specific populations. The findings support a multifactorial interpretation of road safety, consistent with a system-based approach in which legislative measures, enforcement, infrastructure improvements, and post-crash care collectively contribute to reducing mortality. The application of the Haddon matrix further emphasises the importance of coordinated interventions across the pre-crash, crash, and post-crash phases.

Overall, the observed reduction in premature mortality is epidemiologically consistent with a comprehensive road safety framework rather than isolated policy measures, highlighting the importance of sustained, system-wide interventions. However, as the Haddon matrix was applied as a conceptual framework, causal relationships cannot be established. Future research using more robust analytical designs is needed to quantify the contribution of specific interventions and to assess long-term trends in road traffic mortality.

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DOI: 10.7251/JTTTP2601020U
UDC: 656.074:639.33]:330.101.547

ORIGINAL SCIENTIFIC PAPER

Transport costs in road transport as a determinant of macroeconomic price trends

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Recived: May 12, 2026
Revised: June 5, 2026
Accepted: June 26, 2026

Abstract: Road transport plays a central role in supply chains; without efficient logistics, domestic and international markets cannot function smoothly. Transport and logistics costs affect final prices because changes in service tariffs and energy inputs are transmitted into production and distribution costs. This paper examines how road transport costs influence macroeconomic price formation through supply-and-demand mechanisms, focusing on the effects of fuel prices and demand for transport and logistics services on transport-related price dynamics. The study uses monthly and quarterly secondary data from official sources: the Agency for Statistics of Bosnia and Herzegovina (BHAS), the Statistical Office of the Republic of Srpska (RZS RS), the International Road Transport Union (IRU), Eurostat, and BIHAMK. Data were analysed using descriptive statistics, correlation analysis, and a simple regression model (implemented in Excel) to assess the intensity and direction of the relationship between fuel prices and the Consumer Price Index (CPI). Results indicate a statistically significant relationship between fuel prices and CPI movements, while several logistics variables could not be fully examined due to limitations in data availability and inconsistent time frequencies. Multiple regression was not applied for the same reasons. The model explains 55.6% of CPI variability ($R^2 = 0.556$), highlighting transport costs as an important channel in macroeconomic price dynamics and motivating further empirical research with longer, frequency-aligned logistics series.

Keywords: CPI, PPI, road transport, transport costs, international economics

JEL Classification: E31, R41, R48, C32, F14

INTRODUCTION

The subject of this research is the impact of road transport—with a particular emphasis on transport costs, the efficiency and effectiveness of logistics processes, and the economic factors that shape the capacity of the transport services market—on the formation of macroeconomic prices through supply and demand mechanisms. The main research problem concerns how changes in transport costs are associated with price formation at the macroeconomic level. There is an inseparable link between fluctuations in fuel prices, the costs of transport services and logistics, and their impact on total production and distribution costs. When firms are unable to reduce other categories of expenses, increases in the prices of input components may be transmitted into higher prices of final goods or services. However, the existing literature provides insufficient insight into the effects of road transport on macroeconomic prices in economies such as Bosnia and Herzegovina, particularly through the transmission of fuel-related costs.

This paper examines the effects of road transport on market prices of goods and services, with the influence of transport costs being particularly pronounced in international trade, where logistics and cross-border goods flows directly affect competitiveness and price formation on the global market. Additionally, modern logistics systems are characterized by increasing demands for faster delivery, route optimization, greater reliability, and the reduction of operational delays. These factors, together with regulatory frameworks and administrative border barriers, affect the overall efficiency of the transport sector and can lead to fluctuations in supply, which in turn

influence inflationary pressures and price stability. Although numerous international studies analyse the impact of fuel prices on inflation, very few examine this relationship in the context of transport costs in Bosnia and Herzegovina. Although global supply and demand mechanisms shape prices, in small open economies such as Bosnia and Herzegovina the effects of transport costs are more pronounced due to greater import dependence. The literature contains almost no empirical research examining the transmission of road transport costs to macroeconomic prices in Bosnia and Herzegovina.

In the context of globally integrated markets, any disruption in the supply chain has the potential to spill over into macroeconomic developments, particularly in smaller and open economies. One of the key objectives of this paper is to determine how transport, logistics, and road freight influence price movements at the macroeconomic level and contribute to inflationary processes. In this context, the paper has a multidisciplinary character as it integrates transport sciences, logistics management, and macroeconomics. Their mutual synergy shapes economic developments not only within a single national economy but also at the global level, where transport costs represent a key factor of competitiveness and price stability.

The following sections of the paper present the previous research, methodology, results, discussion, and concluding considerations.

PREVIOUS RESEARCH

The literature review is structured into two thematic segments: (1) logistics- and cost-related mechanisms, and (2) the impact of transport inputs on international trade and prices.

Forecasting demand and price movements has always played an important role in business operations. By taking all relevant factors into account, predictive accounting enables the anticipation of financial trends and market dynamics (M. Aleksić, 2015). These foundations form the basis for the application of predictive methods in economic analysis, as timely assessment of changes in demand and costs reduces risk and enhances strategic decision-making. Forecasting models serve as a framework for anticipating the dynamics of economic cycles (M. Landika, 2022). Such models are often integrated into predictive accounting, enabling the formulation of hypotheses about cost transmission along the supply chain and the quantification of their impact on price formation.

The frequency of delivery, just like delivery speed, can serve as a source of competitive advantage (A. Y. Ha, 2003). Increasing the frequency and reliability of deliveries improves the level of service and reduces inventory costs along the supply chain, which directly affects prices and profitability. Faster and more frequent deliveries reduce the inventory held by the buyer (A. Y. Ha, 2003). In this context, transport prices become a key managerial lever: transport costs affect the price, sales volume, and profit of participants in the supply chain (V. Mamonov and V. Poluektov, 2020). Therefore, transport cost management policies are directly linked to a company's financial outcomes, as the management of transport expenses determines profitability within the supply chain (V. Mamonov and V. Poluektov, 2020). In parallel with this, customer requirements reshape the design of logistics systems: customers demand fast and reliable delivery, which directly influences logistics systems. Under such conditions, logistics becomes a crucial factor for both financial and operational efficiency (E. Demir A. S., 2022). Additionally, fuel price volatility and rising transport costs affect international trade, trade flows, and import/export prices, highlighting the need to view transport inputs as determinants of macroeconomic price movements and competitiveness.

Overall, the reviewed studies provide theoretical and empirical background for formulating hypotheses H1a–H1c on cost transmission, delivery performance, and demand-driven transport pricing; however, the expected sign and magnitude of these relationships remain an empirical question in the context of Bosnia and Herzegovina. The broader literature also shows that road freight and logistics costs cannot be reduced to fuel prices alone, because total cost structures additionally depend on transport prices charged to shippers, delivery reliability, the value of time, and cross-border delays, which justifies the inclusion of indicators such as transport price per kilometre, waiting times, and service reliability where such data are available.

Numerous studies in the field of international economics indicate that volatility in fuel prices and transport costs affects international trade, trade flows, and import/export prices. Researchers Hummels and Schaur, in their 2013 study *"Time as a Trade Barrier"*, examine the effect of fuel prices on international trade and export prices. They demonstrate in detail that higher levels of transport costs (including fuel costs) increase export prices and reduce the volume of international trade. Transport costs—particularly fuel price fluctuations—significantly affect international trade flows and export competitiveness, especially in open economies (Hummels & Schaur, 2013). The relationship between fuel prices and international trade has also been examined by numerous scholars, among whom Behar and Venables stand out. In their study entitled *"Transport Costs and International Trade"*, they argue that increases and fluctuations in transport costs reshape the structure of international trade and influence the geographic distribution of trade flows. Fuel price volatility is transmitted through transport costs directly into import and export prices, shaping global trade patterns (Behar & Venables, 2011).

Despite the extensive international literature on the impact of fuel prices on inflation, there are no studies

that simultaneously examine logistics costs, demand for transport services, and macroeconomic prices in the context of Bosnia and Herzegovina. This paper partially fills that gap. At the same time, the international literature generally points to a positive transmission mechanism, whereby higher transport and fuel costs increase trade costs, producer prices, and, eventually, consumer prices. In contrast, the present short-sample result for Bosnia and Herzegovina indicates a statistically significant but negative diesel–CPI relationship, suggesting that the domestic finding should be interpreted as context-specific and short-horizon rather than as a direct contradiction of the broader international evidence.

THE MARKET RELATIONSHIP BETWEEN SUPPLY AND DEMAND

Macroeconomic supply and demand mechanisms operate in a very straightforward manner. The greater the supply in the market, the lower the prices, and vice versa. The same applies from the perspective of demand: when demand for a product increases, its price rises, and when demand decreases, the price falls. When demand exceeds supply, prices increase until equilibrium is reached (N. Lipovec, 2013). Macroeconomic equilibrium occurs at the point where supply and demand "meet," that is, where consumers are willing to pay a certain price for a product and producers are willing to supply the required quantity of goods at that same price. When discussing prices, it is important to note that the prices of individual markets and products are not as simple as the basic supply-and-demand relationship suggests, as they depend on additional factors such as product or service quality, brand, consumer utility, and the availability of substitutes. The supply of a product depends on price, production costs, and the organization of the market (N. Lipovec, 2013). In addition to demand as the primary factor determining market prices, prices are also influenced by operating and production costs, as well as by the prices of all input and output components.

The influence of supplier bargaining power is particularly pronounced in the process of forming the prices of final products. Suppliers with stronger market positions have the ability to drive increases in input prices, given that, as stated by Alpha Capitalis, supplier power is determined by the strength of suppliers and their ability to raise the prices of products or services (Alpha Capitalis, 2017).

If supplier prices begin to fluctuate—such as in the case of transport and logistics—we can expect corresponding fluctuations in the prices of other final goods and services, especially those that depend on transport and logistics. From the perspective of international business and international trade, increases in fuel prices negatively affect export volumes and international trade activity.

The structure of the market influences competitiveness and shapes price dynamics (M. Tomić, 2022). Depending on the number of competitors, the extent of their market share, and the possibilities for product differentiation, different patterns of firm behaviour emerge, which directly affect final prices. In highly competitive markets, companies are forced to maintain lower prices in order to retain consumers, whereas in sectors with fewer suppliers, their bargaining power increases, raising their ability to elevate the prices of products or services.

LOGISTICS IN TRANSPORT AS A FACTOR OF LOW-PRICE COMPETITIVENESS STRATEGY

The optimization of logistics processes reduces overall costs. By optimizing routes and logistics operations, fuel consumption, transport time, and total costs are significantly reduced, which directly increases the efficiency and competitiveness of logistics systems (Prasetyo, 2023). **T**he stability and speed of delivery increase market competitiveness. In the article *"The Role of Logistics in Economic Growth and Global Competitiveness,"* the authors emphasize that logistics performance—including delivery reliability and speed—enhances the competitiveness of economies and improves market efficiency, as higher logistics sub-indices contribute to better goods flow and more stable supply (Bugarčić, 2023).

In modern international markets and business environments, transport logistics is no longer merely an operational function but has evolved into a key strategic instrument that enables companies to remain competitive through low-price strategies. With efficient management of transport processes, it is possible to reduce overall operating costs, accelerate the flow of goods and delivery times, thereby strengthening a company's market position — particularly in markets where price plays a crucial competitive role. The analysis of logistics strategy thus becomes a central component in understanding how companies can achieve stable and competitive prices in both domestic and international markets.

Fuel costs, which represent a key component of logistics expenses, influence the formation of final prices. Transport prices fluctuate the most in relation to fuel prices. If transport prices increase due to higher transport costs, final product prices will also rise—unless market participants find alternative ways, such as reducing production or labour costs, to remain competitive through low-price strategies.

Logistics infrastructure and transport capacity affect the efficiency of market flows. The quality of logistics infrastructure directly influences national competitiveness. Logistics infrastructure, delivery speed, and stable fuel prices are directly linked to low prices and international competitiveness. Conversely, inefficient transport and logistics systems, as well as administrative and bureaucratic barriers, significantly increase transport costs

and thus directly affect competitiveness.The integration of logistics and market strategy strengthens the ability of companies to offer lower prices.

RESEARCH METHODOLOGY

The study employed statistical methods that enabled a clearer understanding of the relationship between transport variables and macroeconomic price movements. First, basic descriptive statistics were conducted to provide an overview of the data—average values, ranges, deviations, and similar indicators. This helped us observe the behaviour of the variables and identify any potential irregularities.

Next, a correlation analysis was conducted with the aim of determining the extent of the relationship between fuel prices and total transport costs, as well as between changes in transport and the movements of the CPI and PPI indices. This analysis served as a solid foundation for the subsequent models.

The main analytical method used in this research was simple linear regression, through which the relationship between fuel prices and movements in the CPI index was examined. In the present model, diesel prices were used as a proxy for transport costs because they were the only frequency-consistent indicator available for the observed period. However, diesel captures only one component of the total logistics cost structure and does not fully reflect operational efficiency, service prices, delivery reliability, or border-related delays. The short time series (n = 22) limits the stability of the regression estimates, particularly the sign and magnitude of the coefficient β□. Multiple regression could not be applied due to the lack of longer time series, inconsistent data frequencies, and the absence of key logistics variables (such as transport price per kilometre, border-crossing waiting times, and delivery reliability indicators). Because of the different frequency levels (monthly CPI and fuel prices versus quarterly logistics series), it was not possible to construct a unified regression specification, as this would compromise the validity of the estimates. For these reasons, descriptive statistics, correlation analysis, and the simple regression model were used as the primary methodological framework for assessing the empirical association between transport-related costs and price movements. Future research should extend the observation period beyond 2024–2025 and incorporate additional logistics indicators in order to improve model specification, reduce omitted-variable bias, and provide a more comprehensive assessment of the transmission mechanism from transport and logistics to consumer prices.

This methodological approach enabled a clearer assessment of the actual contribution of road transport to changes in prices at the macroeconomic level. By including data from international institutions (IRU, Eurostat), a broader insight into the dynamics of transport costs in the international environment was obtained.

RESEARCH OBJECTIVES AND HYPOTHESES

The aim of this research is to identify the key transport-related factors that have a direct or indirect influence on the formation of final product or service prices at the macroeconomic level. One of the ultimate objectives is to determine the actual contribution of road transport to the dynamics of supply, demand, and inflationary movements. In this context, the paper seeks to answer the following questions:

1. In what way do transport costs influence the formation of producer prices?
2. Do changes in logistics—specifically those related to transport time, delivery reliability, and capacity—affect the market supply of products (which, according to macroeconomic principles, consequently influences product prices)?
3. To what extent do fuel prices and depreciation influence the price of transport services?
4. Does the increase in demand for transport services influence inflation?

In accordance with the previously stated research questions, one main hypothesis and four auxiliary hypotheses are proposed:

Main hypothesis:

H1: Road transport costs have a statistically significant contribution to the formation of macroeconomic prices through supply and demand mechanisms. In this study, fuel (diesel) prices are used as a proxy for transport costs due to data limitations.

Auxiliary hypotheses:

H1a: An increase in fuel prices raises total transport costs, which ultimately leads to higher prices of final products at the macroeconomic level.

H1b: Shorter delivery times and greater delivery reliability have a positive effect on reducing the prices of final products and services through macroeconomic mechanisms that increase market supply.

H1c: The increase in demand for transport services has a direct impact on the rise in transport prices, which in turn negatively affects the prices of final goods or services, implying their growth.

For the purposes of this research, secondary data were used, including: the volume of road transport, kilometres driven by freight vehicles, fuel prices, transport costs, the share of fuel in total operating costs, indicators of changes in transport volume, and infrastructure load. The data were collected from the following institutions/web locations: BHAS – Transport 2024 (BiH) (Agency for Statistics of Bosnia and Herzegovina (BHAS), 2025), RZS RS- Road Transport (Q2 2024) (Statistical Office of the Republic of Srpska, 2024), IRU – Foreign Trade Chamber

of Bosnia and Herzegovina (Foreign Trade Chamber of Bosnia and Herzegovina, 2026), BIHAMK – Fuel prices in BiH (BIHAMK, 2026), Costs of road transport– EU vs. BiH (2025) (Logistika.ba, 2025), Eurostat – Transport overview (Eurostat, 2026).

Based on the review of sources and the collected data, the research employed the following dependent and independent variables:

- Dependent variables – CPI – Consumer Price Index (BiH), PPI – Producer Prices
- Independent variables – diesel and gasoline prices (IRU/BIHAMK), ZTransportCost (Logistika.ba), Fightwork (RZS RS/BHAS), Km-Driven – kilometres driven by freight vehicles (RZS RS), InfrastructureIndex – number of vehicles (BHAS/Eurostat), AdminBarriers – border-crossing waiting times (Logistika.ba)

Although logistics variables (t-km, km-driven, administrative barriers) were included in the research framework, limitations in the duration and frequency of the time series did not allow their use in the regression model.

RESULTS OF THE RESEARCH

Table 1. provides a monthly overview of the CPI and diesel prices, allowing us to describe their movements over the observed period. Several phases can be observed in which diesel prices change ahead of, or alongside, changes in the CPI; however, given the short sample and potential lag effects, this descriptive pattern should not be interpreted as a stable transmission mechanism. In periods of stable or declining diesel prices, CPI still shows an upward trend, suggesting that other inflation drivers were present during 2024–2025.

Seasonal oscillations are also possible (e.g., higher fuel demand in certain months), but the overall picture remains the same: changes in diesel prices generally move in line with changes in the CPI, at least partially. This overview served as a motivation to further quantify the relationship through correlation and regression analysis, in order to determine how much of the CPI movement can be explained by transport-related variables. However, the subsequent correlation and regression results for 2024–2025 indicate a negative association between diesel prices and the CPI in this short sample, suggesting that descriptive co-movement patterns should be interpreted with caution.

In short, Table 1 provides a descriptive snapshot that confirms there is a foundation for deeper analysis.

Table 1. Monthly Data: CPI and Diesel Prices

Period	CPI (index)	Diesel (EUR/L, proxy)
2024-01	132.198	1.28
2024-02	132.859	1.28
2024-03	133.258	1.39
2024-04	133.391	1.36
2024-05	133.124	1.43
2024-06	132.459	1.36
2024-07	132.459	1.34
2024-08	133.121	1.34
2024-09	133.254	1.30
2024-10	133.521	1.26
2024-11	134.055	1.20
2024-12	134.591	1.24
2025-01	136.475	1.26
2025-02	137.431	1.29
2025-03	137.431	1.28
2025-04	137.843	1.22
2025-05	138.119	1.15
2025-06	138.533	1.14
2025-07	138.810	1.21
2025-08	138.532	1.21
2025-09	138.809	1.19
2025-10	139.365	1.19

Source: authors

Note: The CPI index is presented on the base '2015 = 100' (according to BHAS methodology).

Table 2. presents the basic descriptive indicators for the observed monthly CPI and diesel price data. This statistics overview provides insight into the average values, variability, and range of the data over the period. Based on the displayed values, it can be seen that the CPI shows relatively stable movement, without major fluctuations, while diesel prices exhibit somewhat more pronounced variability, which is expected given the volatility of the fuel market.

The standard deviation shows that fluctuations in diesel prices are greater compared to the CPI, confirming that fuel is far more sensitive to short-term changes. The minimum and maximum values further indicate the range within which both variables moved. This descriptive analysis served as an important first step, as it provides an overview of the basic structure of the data and helps facilitate the interpretation of later analyses, such as correlation and regression.

Table 2. Descriptive Statistics (Monthly)

Variable	Count	Mean	Std. dev.	Min	25%	50%	75%	Max
CPI	22.000	135.438	2.627	132.198	133.156	134.323	138.050	139.365
Diesel (EUR/L)	22.000	1.269	0.078	1.140	1.210	1.270	1.330	1.430

Source: authors

Table 3. presents the results of the correlation analysis between the CPI index and diesel prices. The obtained correlation coefficient indicates a strong and statistically significant relationship between the CPI and diesel prices; however, the negative sign ($r = -0.746$) suggests that, in the observed sample, higher diesel prices are associated with lower CPI values. This inverse association should not be interpreted as evidence that fuel costs reduce inflation. Rather, it most likely reflects the specific short-run structure of the sample, in which diesel prices broadly normalized after earlier energy-market disturbances while the CPI continued to increase under the influence of other price components, including food prices, regulated prices, and imported cost pressures. In addition, CPI adjustment is typically slower than fuel-price adjustment, so contemporaneous monthly data may capture different phases of the transmission process. For these reasons, the negative sign is better interpreted as a short-horizon empirical pattern than as a stable structural relationship. Although this relationship is not perfect, the value of the coefficient suggests that there is a statistically significant connection, confirming that diesel, as a key input component in transport, plays a role in shaping the broader price structure. This analysis served as a basis for further examination within the regression model.

Table 3. Correlation Between CPI and Diesel Prices

Pair	Correlation (r)
CPI vs Diesel (proxy)	-0.746

Source: authors

The correlation is statistically significant at the level of $p < 0.01$.

Table 4. presents the results of the simple regression model in which the CPI is the dependent variable, while the diesel price is used as the independent variable. The coefficient estimates show that diesel prices are statistically associated with CPI movements, confirming the existence of a linear relationship between these two variables in the observed sample. The R^2 value indicates that part of the variability in the CPI can be explained by changes in diesel prices. However, because the estimated slope is negative and the model is intentionally parsimonious (short sample, no controls), the results should be interpreted as evidence of association rather than a definitive cost-push transmission mechanism.

The coefficient β_1 is statistically significant at the $p < 0.01$ level, and the 95% confidence interval does not include zero, which confirms the existence of a linear relationship.

The negative coefficient should not be interpreted as evidence that higher diesel prices lower consumer prices. A more plausible interpretation is that the result reflects the short time series, the period of diesel-price normalization in 2024–2025, and the omission of other inflation drivers that continued to push the CPI upward even as fuel prices softened. These include food prices, administered or regulated price components, exchange-rate pass-through, and broader imported inflation pressures. In addition, the CPI is a composite index that usually adjusts with a lag relative to energy prices, which means that a contemporaneous regression may identify an inverse short-run co-movement rather than the full cost-push transmission mechanism. For these reasons, the estimated coefficient should be interpreted with caution and as a context-specific short-run result.

Table 5. presents the quarterly indicators of road transport volume in the Republic of Srpska. It is evident that in both observed quarters the index values are below the base level, indicating a reduced volume of transport activities compared to the previous year. Despite slight oscillations, the data show that infrastructure load remains stable. These indicators are important because a decrease in transport volume may signal a decline in economic activity or changes in market structure, which may subsequently be reflected in macroeconomic developments.

Table 5. Quarterly Indicators of Road Transport (RS)

Quarter	Freight t-km (index 2023=100)	KmDriven (index 2023=100)
2024Q2	83.0	98.6
2024Q3	75.5	99.4

Source: authors

These data additionally limit the possibility of testing H1b and H1c, as only two quarters do not allow for the construction of a valid regression model.

Table 4. Regression Results, CPI= β0+ β1*Diesel

Parameter	Estimate (β)	SE(β)	t	Note
β0 (Intercept)	167.358	6.390	26.19	
β1 (Diesel, EUR/L)	-25.152	5.026	-5.00	
R^2	0.556			n = 22

Source: authors

RESULTS DISCUSSION

During the writing of this paper, one main hypothesis and three auxiliary hypotheses were formulated. The following section presents a discussion of the results in relation to the proposed hypotheses. H1: Road transport costs have a statistically significant contribution to the formation of macroeconomic prices through supply and demand mechanisms.

H1: In the model CPI = $\beta_0 + \beta_1 \cdot$Diesel, our coefficient β_1 shows how the CPI moves in relation to changes in diesel prices. In the sample of 22 observations, $R^2 = 0.556$ means that the model explains a substantial part of CPI movements. If β_1 is statistically significant, we can conclude that changes in diesel prices, as one of the main components of road transport costs, influence consumer prices.

H1a is not supported in the observed sample: although the relationship between diesel prices and CPI is statistically significant, the estimated coefficient is negative ($\beta_1 < 0$), which is opposite to the expected cost-push effect; therefore, H1a is not confirmed for 2024–2025 and should be interpreted with caution given the short time series and potential lag/omitted-variable effects.

H1a: We would expect a positive coefficient sign (a cost-push effect), but in our sample β_1 is negative. This finding differs from the dominant pattern in international studies, where higher fuel and transport costs are usually associated with rising trade costs, higher producer prices, and inflationary pressure. A deeper interpretation suggests that the negative coefficient is not economically counterintuitive once the structure of the observed period is taken into account. First, diesel prices in 2024–2025 partly reflected a normalization phase after earlier energy-market disruptions, whereas the CPI continued to rise due to broader inflationary pressures that are not fully captured by fuel prices alone. Second, CPI is a composite indicator and often reacts more slowly than fuel prices, so monthly contemporaneous estimates may capture asynchronous adjustment rather than the true direction of medium-run transmission. Third, diesel is only a proxy for transport costs and does not fully reflect service pricing, logistics bottlenecks, border delays, or the pricing behaviour of firms. Finally, the model does not include other relevant inflation determinants such as food prices, regulated prices, or exchange-rate effects, which may dominate CPI dynamics in a short sample. Therefore, the negative sign should be interpreted as a short-run, context-specific, and partially incomplete estimate rather than as evidence against the broader cost-transmission mechanism. To obtain stronger confirmation of H1a, the time period should be extended and additional variables included, such as food prices, regulated prices, and the exchange rate.

The H1b and H1c hypotheses could not be quantitatively tested due to the lack of longer and frequency-aligned logistics time series (€ / km, waiting times, t-km).

H1b: Shorter delivery times and greater delivery reliability would theoretically be expected to have a positive effect on reducing prices through increased market supply. The quarterly t-km indicators in the Republic of Srpska are lower in Q2 and Q3 2024, indicating a lower volume of transport and reduced pressure on supply. Over a longer period, the expected relationship would be the opposite, as higher t-km values signal more efficient logistics flows and potentially lower prices. For a formal test of H1b, longer and consistent quarterly time series are required (e.g., CPI/PPI ~ diesel + t-km + km-driven).

H1c: Theoretically, an increase in the demand for transport services raises transport prices, which negatively affects the final prices of goods and services. However, H1c could not be quantitatively tested because time series data for transport price per kilometre (€ / km), border-crossing waiting times, and delivery reliability are not available in a sufficiently long and frequency-aligned form. Including these variables would expand the model beyond fuel costs alone and would likely explain a larger portion of the variance in the CPI, because logistics performance depends not only on energy inputs but also on time, reliability, and service pricing. Their omission should therefore be treated as an important limitation of the current specification and a key avenue for future research.

The obtained findings have implications not only for the domestic economy but also for international trade flows, given that transport costs represent a key element of export competitiveness. Overall, the results confirm the existence of a partial transmission mechanism through which fuel costs affect macroeconomic prices, while logistics-related factors remain unassessed due to limitations in data availability. From a policy perspective, these findings suggest three priorities. First, economic authorities and statistical institutions should improve the regular collection of transport and logistics indicators—especially transport prices per kilometre, border-crossing waiting times, and delivery reliability—in order to support evidence-based inflation and competitiveness analysis. Second, transport and trade policy should focus on reducing administrative and border-related delays, since time losses in logistics can raise effective transport costs even when fuel prices are stable or declining. Third, firms and sectoral regulators should treat transport cost management as part of wider price-stability policy, because better route planning, more reliable delivery systems, and lower operational bottlenecks can reduce cost pressures transmitted to final prices.

SCIENTIFIC CONTRIBUTION AND RECOMMENDATIONS FOR FURTHER RESEARCH

Within the conducted research, one main hypothesis and a set of auxiliary hypotheses were defined, guiding the analytical approach and the methodological framework of the study. The obtained results provide additional insight into the degree and direction of the influence of road transport, logistics, and fuel costs on macroeconomic price movements and international trade, highlighting the interconnectedness of logistics and transport with final prices in both the international and domestic economy. This paper represents one of the rare empirical attempts to quantify the relationship between fuel costs and the CPI in Bosnia and Herzegovina using official monthly data.

For this reason, the paper highlights the scientific contribution of the conducted analyses and identifies areas that open the door to new research studies and projects aimed at fully understanding the mechanisms underlying the proposed hypotheses. The paper fills a gap in the literature identified in previous research, as it is the first to integrate transport variables, logistics constraints, and CPI movements for Bosnia and Herzegovina.

The obtained results confirm that logistics and transport costs have a direct and dynamic influence on the formation of macroeconomic prices, which makes this paper an important contribution to understanding their interaction with market supply-and-demand mechanisms. Although some of the hypotheses were only partially confirmed, the analyses also indicated the presence of factors whose effects are more subtle or time-lagged, which further highlights the complexity of the relationship between logistics variables and price movements. The key contribution of the paper is the empirical confirmation of transport costs as a determinant of macroeconomic prices in Bosnia and Herzegovina. In practical terms, this means that policy aimed at price stability should not be limited to traditional macroeconomic instruments alone, but should also include measures that improve transport efficiency, lower border frictions, and strengthen logistics performance. More efficient transport systems can support both domestic price stability and external trade competitiveness.

CONCLUSION

The aim of this research is to examine the impact of road transport—with particular emphasis on transport and logistics costs in terms of efficiency—on the formation of macroeconomic prices and prices on international markets through supply and demand mechanisms. In international economics, where supply chains are longer and more complex, changes in transport costs exert an even stronger inflationary effect, which further confirms the relevance of this research.

The research confirms that road transport costs make a statistically significant contribution to macroeconomic price formation through supply-and-demand mechanisms. However, in the observed sample the expected cost-push channel from higher fuel prices to higher consumer prices (H1a) is not supported, because the estimated relationship between diesel prices and the CPI is statistically significant but negative. To verify hypothesis H1b — which states that *"shorter delivery times and greater delivery reliability have a positive effect on reducing the prices of final products and services through macroeconomic mechanisms that increase market supply"* — longer and frequency-aligned time series are required; therefore, this hypothesis remains untested.

Hypothesis H1c referred to the impact of increasing demand for transport services on the rise in transport prices and, consequently, on macroeconomic prices of final products. However, its full empirical verification could not be carried out. The reasons for this lie in the lack of time series for key variables (time series for transport prices per kilometre and border-crossing waiting times), and the variables reflecting transport demand were not available in sufficient scope (they covered only a short period—two quarters). For this reason, it was not possible to construct a regression model that would validly estimate the effect of rising demand on increases in transport and final prices.

Status of hypotheses

- H1: confirmed (statistically significant association between diesel prices and CPI)
- H1a: not supported (estimated coefficient is negative, opposite to the expected cost-push effect)
- H1b: not tested (insufficient time series / frequency mismatch)
- H1c: not tested (no time series for transport price per km and border-crossing waiting times)

Overall, the results confirm that fuel costs represent a key transmission channel through which road transport affects macroeconomic prices in Bosnia and Herzegovina. However, unlike the dominant pattern reported in international studies, the short-sample result for Bosnia and Herzegovina indicates a negative diesel–CPI association. This inverse relationship should not be interpreted as evidence that higher diesel prices reduce inflation; rather, it is more plausibly explained by the short observation period, lagged CPI adjustment, post-crisis diesel-price normalization, and the omission of other inflation drivers that remained active during 2024–2025. The result should therefore be interpreted cautiously as a short-run and context-dependent outcome rather than as evidence against the broader positive cost-transmission mechanism documented in the literature.

In future research, it would be useful to expand the available data, particularly those related to transport prices and border-crossing delays, so that the hypotheses can be fully tested. It would also be valuable to include

longer time series and additional logistics indicators, as this would provide a clearer picture of how transport and logistics influence price movements. In particular, future work should incorporate indicators such as transport price per kilometre (€ / km), freight volume (t-km), kilometres driven, border-crossing waiting times, and delivery reliability wherever such data become available in frequency-aligned form. These variables would allow logistics to be measured more comprehensively than through diesel prices alone and would improve the explanatory power and economic interpretation of the model. These steps would contribute to more reliable analyses and a deeper understanding of the relationships that were only partially confirmed in this study. Future research should focus on extending the observation period beyond 2024–2025 and collecting longer, frequency-aligned logistics time series (€ / km, t-km, waiting times), which would enable the construction of multiple regression models, more robust testing of lagged effects, and the full verification of the auxiliary hypotheses. From a policy standpoint, the findings also indicate that improving logistics statistics, reducing border and administrative delays, and promoting more efficient transport operations could support both inflation monitoring and competitiveness policy in Bosnia and Herzegovina.

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DOI: 10.7251/JTTTP2601029K
UDC: 005.334:368.2.026.4(497.11)

REVIEW SCIENTIFIC PAPER

Unified Criteria for Damage Assessment – Theoretical Models, Methodological Framework and Application in Contemporary Practice

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Recived: March 6, 2026
Revised: June 15, 2026
Accepted: June 26, 2026

Abstract: Damage assessment represents a crucial component of legal, economic, technical, and insurance procedures; however, contemporary practice still demonstrates significant inconsistencies in assessment criteria, methodologies, and interpretation of results. Different sectors—including judicial systems, insurance, transportation, industry, construction, and digital security—apply their own assessment models that are frequently incompatible with one another, leading to inconsistent decisions, legal disputes, and reduced legal certainty.

The objective of this paper is to develop the concept of a unified interdisciplinary framework for damage assessment based on universal principles of objectivity, measurability, reproducibility, and transparency. The study examines existing damage assessment approaches through a comparative methodological analysis encompassing quantitative models (econometric, statistical, and engineering approaches), qualitative models (expert assessments, legal standards, and normative frameworks), and hybrid models integrating numerical and descriptive parameters.

Particular attention is devoted to identifying key variables influencing the final assessment outcome, including direct costs, indirect losses, loss of profit, temporal factors, escalation risk, and intangible effects. Based on this analysis, a universal assessment model is proposed that integrates standardized weighting coefficients and a multiparametric evaluation matrix.

The proposed framework consists of three levels of assessment: basic assessment (quantification of immediate damage), extended assessment (analysis of secondary consequences), and strategic assessment (long-term effects and risk projections). This structure enables the systematic application of unified criteria across different domains while preserving the specificity of individual cases. The principal contribution of the study lies in defining methodological guidelines that support the standardization of expert evaluations, reduce assessor subjectivity, and enhance the reliability of findings in judicial, administrative, and commercial proceedings.

The results indicate that implementing unified criteria significantly improves legal certainty, procedural efficiency, and cross-sector compatibility of assessments. It is concluded that methodological standardization of damage assessment represents a necessary step toward establishing a transparent and internationally harmonized system for evaluating harmful events, particularly in the context of globalization and digitalized economies. The paper also provides recommendations for institutional implementation of the proposed model through regulatory standards, professional protocols, and specialized training of assessors.

Keywords: damage assessment, standardization of criteria, evaluation methodology, interdisciplinary model, legal certainty, loss quantification.

INTRODUCTION

Damage assessment represents one of the fundamental elements of contemporary legal, economic, technical, and insurance systems, as its accuracy directly influences decision-making processes in judicial, administrative, and commercial proceedings. In modern societies characterized by rapid technological development, globalization of markets, increasing interdependence of economic activities, and the digital transformation of business processes, the need for reliable and standardized damage assessment methodologies has become increasingly important. Previous studies in the fields of economics, law, valuation theory, and risk management have emphasized the necessity of objective and transparent assessment procedures capable of producing consistent and reproducible results [1], [3], [5], [16].

Despite significant advancements in assessment methodologies, contemporary practice remains characterized by considerable fragmentation of approaches. Different sectors—including insurance, transportation, industry, construction, environmental protection, and digital security—have developed their own assessment frameworks based on specific disciplinary perspectives and evaluation criteria. Consequently, similar damage events may produce substantially different assessment outcomes depending on the methodology applied, resulting in inconsistencies, legal disputes, increased transaction costs, and reduced legal certainty [1].

Traditional damage assessment models primarily focus on direct financial losses and material consequences. Although such approaches are suitable for evaluating immediate economic impacts, they frequently neglect broader dimensions of damage, including temporal effects, uncertainty factors, escalation risks, reputational consequences, social impacts, and other intangible losses. Modern risk management theory emphasizes that harmful events should be analyzed not only through their immediate consequences but also through their long-term effects and potential future implications [3], [4], [5].

The increasing complexity of socio-economic systems further highlights the limitations of conventional assessment models. Industrial accidents, environmental disasters, cyberattacks, transportation disruptions, and large-scale infrastructure failures often generate interconnected consequences that extend beyond direct material damage. Such events produce cascading effects across multiple sectors, requiring comprehensive assessment methodologies capable of integrating economic, legal, technical, and social dimensions into a single analytical framework [11], [12], [17].

Another important challenge concerns the assessment of intangible damage. While direct material losses can generally be quantified using established financial methods, intangible effects such as reputational harm, psychological consequences, loss of public confidence, and diminished market position remain difficult to evaluate objectively. Existing approaches often rely on expert judgment and qualitative evaluations, introducing significant levels of subjectivity into the assessment process [8], [14], [21].

The lack of universally accepted standards also presents a significant obstacle to the comparability of assessment results. International organizations and professional bodies have increasingly advocated the adoption of standardized procedures and harmonized assessment criteria. Frameworks such as ISO 31000, ISO/IEC 31010, and International Valuation Standards provide valuable guidance for risk assessment and valuation activities; however, they do not offer a fully integrated methodology capable of encompassing all relevant dimensions of damage assessment [3], [16], [22].

In response to these challenges, this paper aims to:

- systematize existing theoretical and methodological approaches to damage assessment;
- identify the principal limitations of contemporary assessment models;
- develop a unified interdisciplinary framework for damage assessment;
- propose a multiparametric model integrating quantitative, qualitative, temporal, and stochastic components;
- establish methodological foundations for the standardization of assessment procedures across different sectors.

The central hypothesis of this research is that it is possible to develop a universal damage assessment model capable of standardizing evaluation procedures without compromising the specific characteristics of individual cases. Such a model should integrate direct and indirect losses, risk factors, temporal dynamics, and intangible consequences into a coherent analytical framework applicable across diverse domains.

The scientific contribution of this study lies in the integration of economic, legal, engineering, and risk-management perspectives into a unified assessment methodology. Furthermore, the proposed model introduces temporal and stochastic dimensions into the evaluation process and develops a structured framework for incorporating intangible losses, thereby addressing several limitations of existing approaches [5], [9], [11].

The remainder of the paper is organized as follows. Section 2 reviews previous research and existing damage assessment models. Section 3 presents the research methodology and analytical framework. Section 4 introduces the proposed unified damage assessment model and demonstrates its practical application through an illustrative example. Finally, Section 5 discusses the principal findings and presents conclusions and recommendations for future research and institutional implementation.

REVIEW OF PREVIOUS RESEARCH AND DAMAGE ASSESSMENT MODELS

Economic Models of Damage Assessment

Within economic theory, damage assessment has traditionally been based on the principles of financial compensation, value maximization, and efficient resource allocation. Classical economic approaches evaluate damage through direct financial losses and measurable economic consequences. Widely used methods include Cost–Benefit Analysis (CBA), Net Present Value (NPV), Discounted Cash Flow (DCF) analysis, and opportunity-cost assessment. These methods enable the quantification of direct and indirect losses and provide a structured framework for economic decision-making [2], [10], [13].

Modern economic studies emphasize the importance of incorporating future cash flows, uncertainty factors, and long-term economic consequences into damage assessment models. Disaster economics and risk-based valuation methodologies have further expanded traditional approaches by considering the broader economic impacts of catastrophic events and systemic disruptions [6], [17].

Despite their practical usefulness, economic models exhibit significant limitations. Their primary weakness lies in the tendency to focus predominantly on monetary indicators while neglecting social, environmental, reputational, and psychological consequences. Consequently, purely economic approaches often underestimate the total impact of harmful events and fail to capture the full spectrum of damage experienced by affected stakeholders [8], [13].

Legal and Normative Approaches

Legal systems traditionally assess damage through the principles of compensation, causation, proportionality, and fairness. In most jurisdictions, damage is classified into actual loss and loss of profit, with compensation determined according to the specific circumstances of each case. Courts frequently rely on expert opinions and professional evaluations to establish the extent and monetary value of damage [1], [16].

Legal scholars have long emphasized that the purpose of damage compensation is not only to restore financial equilibrium but also to preserve legal certainty and public confidence in the justice system. However, substantial differences often exist among jurisdictions regarding assessment criteria, compensation limits, evidentiary standards, and methods for evaluating non-material losses.

One of the principal shortcomings of legal approaches is their dependence on expert judgment. Since experts may apply different methodologies, assumptions, and evaluation criteria, similar cases can result in significantly different compensation outcomes. This variability introduces subjectivity into the assessment process and may lead to inconsistent judicial decisions, particularly in complex commercial, environmental, and technological disputes [1], [16].

Engineering and Technical Approaches

Engineering damage assessment methodologies focus primarily on the physical consequences of harmful events. These approaches are widely applied in transportation systems, civil engineering, industrial facilities, energy infrastructure, and manufacturing processes. Assessment techniques typically involve reliability analysis, life-cycle analysis, structural integrity evaluation, failure analysis, and maintenance-cost estimation [7], [15], [18].

Reliability engineering provides a rigorous framework for quantifying technical losses by analyzing system performance, failure probabilities, and recovery costs. Such approaches are particularly valuable in industries where operational continuity and safety are critical. Engineering models often achieve a high level of precision because they rely on measurable technical parameters and objective performance indicators [15].

Nevertheless, technical approaches are generally limited to the engineering domain and rarely incorporate broader economic, legal, social, or reputational consequences. As a result, while they provide accurate estimates of physical damage and restoration costs, they may significantly underestimate the total impact of harmful events on organizations and society [9], [15].

Risk-Based Assessment Models

Recent developments in risk management theory have introduced probabilistic and stochastic dimensions into damage assessment. Risk-based models consider damage as a function of both the probability of occurrence and the severity of consequences. This perspective allows decision-makers to evaluate not only realized losses but also potential future impacts and escalation scenarios [4], [5], [11].

International standards such as ISO 31000 and ISO/IEC 31010 have significantly contributed to the development of systematic risk assessment methodologies. These frameworks emphasize the identification, analysis, evaluation, and treatment of risks across organizational and societal contexts [3], [22].

Risk-based approaches offer several advantages, including the incorporation of uncertainty, dynamic modeling of harmful events, and support for preventive decision-making. However, many existing risk assessment frameworks do not provide detailed methodologies for converting risk indicators into comprehensive damage estimates. Consequently, there remains a gap between risk analysis and practical damage quantification [4], [11], [12].

Hybrid and Interdisciplinary Models

Recognizing the limitations of single-discipline approaches, recent research has increasingly focused on hybrid and interdisciplinary assessment frameworks. These models combine quantitative and qualitative methods in order to provide a more comprehensive evaluation of harmful events [8], [11].

Multi-Criteria Decision Analysis (MCDA), the Analytic Hierarchy Process (AHP), fuzzy logic systems, and integrated risk-assessment frameworks have become widely used tools for incorporating subjective factors into formal analytical models. Such methods enable decision-makers to evaluate multiple dimensions simultaneously and to assign relative importance to different assessment criteria [8], [14], [19], [20].

Hybrid models are particularly valuable in situations involving uncertainty, incomplete information, and conflicting stakeholder interests. They provide greater flexibility than traditional methods and facilitate the integration of economic, legal, technical, and social perspectives into a single evaluation framework.

Despite considerable progress, no universally accepted model currently exists that integrates all relevant dimensions of damage assessment while maintaining methodological consistency, transparency, and practical applicability across different sectors. This limitation continues to represent one of the most significant challenges in the field [11], [14].

Identification of the Research Gap

The review of existing literature reveals several persistent shortcomings in contemporary damage assessment methodologies:

- fragmentation of assessment approaches across sectors and disciplines;
- insufficient integration of quantitative and qualitative variables;
- inadequate consideration of temporal dynamics and long-term effects;
- limited incorporation of uncertainty and escalation risks;
- absence of standardized weighting coefficients and evaluation matrices;
- difficulties in quantifying intangible and reputational losses;
- lack of a universally applicable interdisciplinary assessment framework.

These limitations demonstrate the need for the development of a unified methodology capable of integrating economic, legal, engineering, and risk-management perspectives into a coherent and standardized assessment system. Addressing this research gap constitutes the primary motivation for the development of the unified damage assessment model proposed in this paper.

The following section presents the methodological framework employed in developing the proposed model and explains the procedures used for identifying variables, constructing the analytical structure, and validating the conceptual framework.

RESEARCH METHODOLOGY

Research Design

This study employs an interdisciplinary and integrative research approach designed to develop a unified framework for damage assessment. The methodological concept combines qualitative and quantitative analytical techniques with the objective of identifying the essential dimensions of damage assessment and integrating them into a comprehensive evaluation model.

The research design is based on five sequential phases:

1. Systematic review and classification of existing damage assessment models;
2. Identification of key variables influencing damage evaluation;
3. Development of a conceptual and mathematical assessment framework;
4. Construction of a multiparametric evaluation model;
5. Theoretical and illustrative validation of the proposed framework.

This approach enables the combination of deductive reasoning, derived from established theoretical principles, and inductive reasoning, based on the comparative analysis of existing methodologies. The integration of these approaches provides a robust foundation for developing a model that can be applied across different professional and institutional contexts.

Data Sources

The study is primarily based on secondary data sources obtained from scientific literature, professional publications, international standards, and institutional guidelines. The analyzed sources include:

- scientific articles in economics, law, engineering, and risk management;
- international standards and regulatory frameworks (ISO 31000, ISO/IEC 31010, International Valuation Standards);
- OECD and European Commission methodological guidelines;
- expert reports and professional valuation procedures;
- case studies from transportation, insurance, industrial, environmental, and digital-security sectors;
- publications addressing risk analysis, multicriteria decision-making, and damage quantification methodologies.

The use of secondary sources is appropriate because the objective of the research is conceptual model development rather than empirical testing. Existing scientific

knowledge provides sufficient theoretical foundations for identifying common principles and methodological gaps in contemporary damage assessment practices.

Research Methods

Several complementary research methods were applied throughout the study.

Comparative Analysis

Comparative analysis was used to evaluate similarities and differences among existing assessment models. Particular attention was devoted to identifying:

- assessment criteria;
- evaluation procedures;
- treatment of uncertainty;
- incorporation of qualitative factors;
- applicability across different sectors.

The comparative approach enabled the identification of methodological strengths and weaknesses associated with each model category.

Descriptive Analysis

Descriptive analysis was employed to classify and characterize the principal components of damage assessment systems. This method facilitated the systematic organization of concepts, variables, and methodological approaches found in the literature.

Synthesis Method

The synthesis method was applied to integrate findings from different scientific disciplines into a coherent analytical framework. Through synthesis, economic, legal, engineering, and risk-management perspectives were combined to establish the foundation of the proposed unified model.

Modeling Method

Modeling represents the central methodological component of the study. Based on identified variables and relationships, a multiparametric assessment model was developed that incorporates quantitative, qualitative, temporal, and stochastic dimensions of damage.

Identification and Classification of Variables

A critical stage in the research process involved identifying variables that significantly influence damage assessment outcomes.

The analysis revealed four primary categories of variables:

Quantitative Variables

Quantitative variables represent directly measurable economic consequences and include:

- direct financial losses;
- repair and restoration costs;
- indirect economic losses;
- loss of profit;
- operational interruption costs.

These variables can generally be expressed in monetary terms and constitute the traditional basis of damage assessment.

Temporal Variables

Temporal variables capture the dynamic nature of harmful events and include:

- duration of damage consequences;
- recovery period;
- delay-related impacts;
- escalation over time.

The inclusion of temporal factors enables the assessment of long-term consequences rather than limiting evaluation to immediate losses.

Risk Variables

Risk variables reflect uncertainty and future developments associated with harmful events. These variables include:

- probability of escalation;
- uncertainty of outcomes;
- vulnerability of affected systems;
- exposure to additional losses.

The incorporation of risk variables allows the model to account for potential future consequences and supports proactive decision-making.

Qualitative Variables

Qualitative variables encompass effects that cannot be directly measured through conventional financial indicators. These include:

- reputational damage;
- psychological consequences;
- social impacts;
- institutional credibility losses;
- public trust deterioration.

Although more difficult to quantify, such variables often represent a significant portion of the overall impact of harmful events.

Development of the Unified Assessment Model

Following the identification and classification of variables, a unified assessment model was developed based on a multiparametric structure.

The model integrates four fundamental dimensions:

- economic dimension;
- temporal dimension;
- risk dimension;
- qualitative dimension.

Unlike traditional approaches that focus exclusively on direct financial losses, the proposed framework considers damage as a dynamic phenomenon influenced by multiple interacting factors.

The model is based on weighted aggregation, where each component contributes proportionally to the final assessment outcome. Weighting coefficients may be determined through expert judgment, multicriteria decision-making methods, statistical calibration, or institutional standards.

This structure provides:

- methodological flexibility;

- sectoral adaptability;
- transparency of evaluation procedures;
- comparability of assessment outcomes.

Validation Procedure

Because the study focuses on conceptual model development, validation was conducted through two complementary approaches.

Theoretical Validation

Theoretical validation involved examining:

- consistency with established scientific theories;
- compatibility with international standards;
- methodological coherence;
- completeness of included variables.

The proposed framework was compared with existing economic, legal, engineering, and risk-based models to ensure that all relevant dimensions of damage assessment were adequately represented.

Illustrative Validation

Illustrative validation was performed through hypothetical scenarios designed to demonstrate the operational logic of the model.

The simulation-based approach enabled:

- testing of variable interactions;
- examination of weighting effects;
- assessment of model behavior under different conditions;
- preliminary verification of practical applicability.

Although illustrative validation does not replace empirical testing, it provides an important initial evaluation of model functionality.

Research Limitations

Several limitations should be acknowledged.

First, the research relies predominantly on secondary data and theoretical sources. Second, the proposed model has not yet been empirically tested using a large sample of real-world cases. Third, weighting coefficients have not been statistically calibrated and therefore remain subject to future refinement. Finally, qualitative variables continue to require expert judgment, which may introduce a degree of subjectivity into the assessment process.

These limitations should be viewed as opportunities for further development rather than weaknesses of the conceptual framework itself.

Future Research Directions

Future research should focus on:

- empirical validation using real assessment cases;
- statistical calibration of weighting coefficients;
- development of software tools supporting automated assessment procedures;
- application of artificial intelligence and machine-learning techniques for model optimization;
- integration of the framework into regulatory and institutional assessment systems;
- development of international standards for unified damage assessment.

The completion of these research activities would significantly contribute to the practical implementation and broader acceptance of the proposed methodology.

The following section presents the Unified Damage Assessment Model, including its conceptual structure, mathematical formulation, evaluation matrix, and illustrative application.

UNIFIED DAMAGE ASSESSMENT MODEL

Conceptual Framework of the Model

The proposed Unified Damage Assessment Model is based on the integration of deterministic and stochastic components of damage evaluation. Unlike traditional approaches that treat damage as a simple function of direct costs, the proposed framework considers damage as a dynamic phenomenon influenced by multiple interdependent variables.

The model integrates four principal dimensions:

- Economic dimension;
- Temporal dimension;
- Risk dimension;
- Intangible impact dimension.

This approach enables a comprehensive assessment of harmful events by simultaneously considering direct and indirect consequences, future uncertainties, and non-material effects.

The conceptual structure of the model is founded on three assessment levels:

Level I – Basic Assessment

This level quantifies direct and immediately measurable damage.

It includes:

- direct financial losses;
- repair and replacement costs;
- operational interruption expenses.

The objective of this level is to establish the minimum measurable value of damage.

Level II – Extended Assessment

This level incorporates secondary consequences resulting from the harmful event.

These include:

- indirect economic losses;
- loss of profit;
- business interruption effects;
- supply-chain disruptions.

The purpose of this level is to evaluate the broader economic implications of damage.

Level III – Strategic Assessment

The strategic level focuses on long-term and systemic consequences.

It includes:

- escalation risks;
- future uncertainty;
- reputational damage;
- social and institutional impacts.

This level provides decision-makers with information regarding long-term sustainability and strategic consequences.

The integration of these three levels allows a comprehensive and multidimensional evaluation process.

Mathematical Formulation of the Model

Based on the identified variables, the following general damage assessment function is proposed:

$$D=\sum_{i=1}^{n} w_i X_i+\sum_{j=1}^{m} \alpha_j R_j+\beta T+\gamma I \quad (1)$$

where:
D - represents the total assessed damage,
X_i - denotes direct and indirect damage components,
w_i - represents weighting coefficients,
R_j - denotes risk-related factors,
a_j - represents risk influence coefficients,
T - is the temporal factor,
β - is the temporal coefficient,
I - is the intangible damage index, and
γ - is the coefficient of intangible impact.

The first term represents measurable economic losses, the second term incorporates risk-related effects, while the final two terms introduce temporal and intangible dimensions into the assessment process.

The proposed formulation enables flexible adaptation to different sectors while preserving methodological consistency.

Incorporating the Temporal Dimension

One of the most significant limitations of conventional assessment approaches is the treatment of damage as a static quantity.

In reality, many harmful events produce consequences that evolve over time.

To address this limitation, damage growth is modeled using an exponential function:

$$D(t)=D_0 e^{rt} \quad (2)$$

where:
$D(t)$ - represents the value of damage at time t,
D_0 - is the initial damage value,
r - is the escalation rate, and
t - denotes elapsed time.

This formulation is particularly relevant in:

- judicial proceedings involving delayed compensation;
- industrial accidents;
- infrastructure failures;
- environmental incidents;
- prolonged business interruptions.

The temporal component enables the assessment of cumulative effects and future losses that may emerge long after the initial harmful event.

Intangible Damage Index

The quantification of intangible losses remains one of the most challenging issues in contemporary assessment practice.

Examples include:

- reputational damage;
- psychological consequences;
- loss of public confidence;
- deterioration of institutional credibility;
- market-position losses.

To address this issue, an Intangible Damage Index (IDI) is proposed:

$$I=\sum_{k=1}^{p} \lambda_k y_k \quad (3)$$

where:
I - represents the intangible damage index,
y_k - denotes qualitative indicators, and
λ_k - weighting coefficients determined through expert evaluation or multicriteria analysis.

The index transforms qualitative effects into measurable assessment parameters while preserving analytical transparency.

Weighting coefficients may be established through:

- Analytic Hierarchy Process (AHP);
- Delphi expert methods;
- multicriteria decision analysis;
- institutional assessment standards.

$$D=\sum_{i=1}^{n} w_i X_i+\sum_{j=1}^{m} \alpha_j R_j+\beta T+\gamma \sum_{k=1}^{p} \lambda_k y_k \quad (4)$$

Equation (4) represents the expanded form of the Unified Damage Assessment Model. In this formulation, total damage is expressed as a function of direct and indirect economic losses, risk-related factors, temporal effects, and intangible consequences. The integration of the Intangible Damage Index into the model enables the inclusion of qualitative impacts that are traditionally difficult to quantify, thereby providing a more comprehensive and realistic assessment of harmful events. The model is sufficiently flexible to be adapted to different sectors, including legal, insurance, transportation, industrial, and public administration applications.

$$D_{\text{total}}(t)=\left(\sum_{i=1}^{n} w_i X_i+\sum_{j=1}^{m} \alpha_j R_j+\beta T+\gamma \sum_{k=1}^{p} \lambda_k y_k\right) e^{rt} \quad (5)$$

Equation (5) presents the dynamic version of the Unified Damage Assessment Model by incorporating the temporal escalation factor. This formulation assumes that the consequences of a harmful event may increase over time due to delayed recovery, operational disruptions, legal disputes, market reactions, or other cumulative effects. The exponential term enables the simulation of damage growth and provides a framework for evaluating long-term consequences and future risks. Consequently, the model supports not only retrospective assessment of realized losses but also prospective analysis of potential damage development under different scenarios.

The transition from Equation (4) to Equation (5) transforms the model from a static assessment framework into a dynamic decision-support tool, enabling both current damage evaluation and future impact forecasting. This represents one of the principal methodological contributions of the proposed unified assessment approach.

The mathematical framework combines concepts from risk analysis, multicriteria decision-making, and integrated assessment methodologies reported in contemporary scientific literature [3], [5], [8], [9], [14].

Unified Damage Assessment Matrix

To facilitate practical implementation, a standardized evaluation matrix is proposed.

Table 1. Unified Damage Assessment Matrix

Component	Quantitative Value	Weight	Total Contribution
Direct Damage	X_1	w_1	w_1X_1
Indirect Losses	X_2	w_2	w_2X_2
Loss of Profit	X_3	w_3	w_3X_3
Time Factor	T	β	βT
Escalation Risk	R	α	αR
Intangible Damage	I	γ	γI

The matrix provides a transparent framework for evaluating the contribution of each component to the total damage value and facilitates standardization across different sectors.

Distribution of Weighted Components

Figure 1 illustrates the relative influence of individual assessment components within the proposed model.

The distribution demonstrates that direct material damage remains the dominant assessment component. However, indirect losses, temporal effects, risk factors, and intangible impacts collectively account for a substantial proportion of total damage, highlighting the importance of adopting a multidimensional assessment framework.

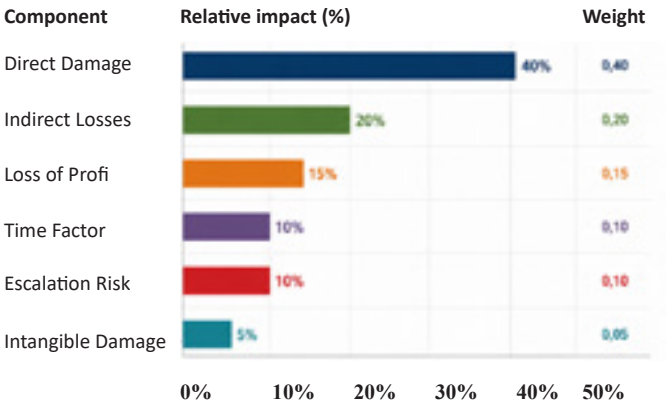

Figure 1. Distribution of weighted components in the Unified Damage Assessment Model

Illustrative Application of the Model

To demonstrate the practical application of the proposed framework, consider a transportation accident involving the following parameters: Direct damage: €10,000; Indirect losses: €5,000; Loss of profit: €3,000; Time factor: 1.2; Escalation risk: 0.3; Intangible damage: €2,000.

Assuming the following weights: $w_1 = 0.40$; $w_2 = 0.20$; $w_3 = 0.15$; $\beta = 0.10$; $\alpha = 0.10$; $\gamma = 0.05$ the assessment becomes:

$D = 0.4(10000) + 0.2(5000) + 0.15(3000) + 0.1(1.2) + 0.1(0.3) + 0.05(2000) = 5550.15$

The example demonstrates how the model integrates multiple dimensions into a single transparent and reproducible assessment outcome.

Comparative Analysis of Existing and Proposed Models

Table 2. Comparative Analysis of Damage Assessment Models

Model	Advantages	Limitations
Classical Financial Models	Simple and widely applicable	Ignore intangible effects
Legal Assessment Models	Normatively grounded	Subjective and inconsistent
Engineering Models	Highly precise	Limited to technical systems
Risk-Based Models	Include uncertainty	Difficult to quantify total damage
Proposed Unified Model	Integrated, flexible, interdisciplinary	Requires standardization and calibration

The comparison indicates that the proposed framework overcomes several limitations of existing approaches by integrating economic, legal, technical, temporal, and risk-related dimensions within a single methodological structure.

CONCLUSION

Damage assessment represents one of the most important components of contemporary legal, economic, technical, and insurance systems. The quality and accuracy of assessment procedures directly influence decision-making processes, legal certainty, financial compensation, resource allocation, and the overall effectiveness of judicial, administrative, and commercial proceedings. As modern societies become increasingly interconnected and technologically complex, the need for objective, transparent, and standardized damage assessment methodologies becomes progressively more significant.

The review of existing literature and assessment practices demonstrates that contemporary damage evaluation remains characterized by substantial methodological fragmentation. Economic, legal, engineering, and risk-management disciplines have developed independent approaches tailored to their specific objectives and professional requirements. Although these approaches provide valuable analytical tools within their respective domains, they frequently fail to capture the multidimensional nature of damage and often produce inconsistent assessment outcomes. Similar harmful events may therefore receive substantially different evaluations depending on the methodology applied, resulting in reduced comparability, increased uncertainty, and potential legal disputes.

The findings of this study indicate that traditional assessment models exhibit several important limitations. Most existing methodologies focus primarily on direct financial losses while paying insufficient attention to indirect consequences, temporal dynamics, escalation risks, and intangible impacts. Furthermore, many assessment procedures continue to rely heavily on expert judgment without providing standardized mechanisms for integrating qualitative and quantitative factors into a unified analytical framework. These shortcomings reduce transparency and may introduce a significant degree of subjectivity into the evaluation process.

To address these limitations, this paper proposed a Unified Damage Assessment Model that integrates economic, legal, technical, and risk-management perspectives into a single methodological framework. The proposed model combines measurable economic losses, probabilistic risk factors, temporal effects, and intangible consequences through a multiparametric mathematical structure. Unlike conventional approaches, the model recognizes damage as a dynamic phenomenon whose overall impact extends beyond immediate material losses.

The principal scientific contributions of this research can be summarized as follows:

- development of a comprehensive multiparametric damage assessment model;
- integration of quantitative, qualitative, temporal, and stochastic variables into a unified framework;
- introduction of a dynamic temporal component capable of modeling damage escalation over time;
- development of an Intangible Damage Index for the evaluation of non-material consequences;
- establishment of a standardized assessment matrix suitable for application across different sectors;
- creation of methodological foundations for future standardization of assessment procedures.

The proposed framework offers several practical advantages. First, it improves transparency by explicitly defining assessment variables and weighting mechanisms. Second, it enhances objectivity through the systematic incorporation of measurable and qualitative indicators. Third, it increases reproducibility by providing a structured methodology that can be consistently applied by different assessors. Finally, it facilitates cross-sector comparability by integrating multiple dimensions of damage into a common evaluation structure.

From an institutional perspective, the implementation of unified assessment criteria could significantly contribute to improving legal certainty, reducing inconsistencies in expert evaluations, enhancing the quality of judicial and administrative decision-making, and supporting the harmonization of professional assessment practices. Such benefits are particularly important in the context of increasingly complex economic activities, digital transformation, environmental risks, and globalized business operations.

Despite its contributions, the study is subject to certain limitations. The proposed model has been developed primarily on the basis of theoretical analysis and secondary data sources and has not yet undergone large-scale empirical validation. In addition, weighting coefficients and qualitative indicators require further calibration through statistical analysis and expert consensus-building processes. Consequently, the model should be regarded as a conceptual and methodological foundation rather than a finalized operational standard.

Future research should therefore focus on empirical testing of the model using real-world damage assessment cases from different sectors. Additional studies may explore the application of machine-learning algorithms and artificial intelligence techniques for optimizing weighting coefficients, improving predictive accuracy, and supporting automated assessment procedures. Further development may also include the creation of specialized software platforms and decision-support systems based on the proposed framework.

In conclusion, the results of this research suggest that the standardization of damage assessment methodologies represents a necessary step toward establishing a transparent, objective, and internationally harmonized

system for evaluating harmful events. The proposed Unified Damage Assessment Model provides a scientifically grounded foundation for achieving this objective and offers a promising direction for future academic research, professional practice, and institutional implementation in the field of damage assessment.

Acknowledgement

The authors declare that no external funding was received for this research. The views expressed in this paper are solely those of the authors and do not necessarily reflect the positions of any affiliated institutions.

Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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DOI: 10.7251/JTTTP2601039I
UDC: 656.11.021:656.1.08(4-672EU)

REVIEW SCIENTIFIC PAPER

Analysis of Factors Influencing the Knowledge of International Transport Documentation Among Professional Drivers and Dispatchers

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Recived: February 26, 2026
Revised: May 11, 2026
Accepted: May 29, 2026

Abstract: This paper analyzes the level of knowledge of international transport documentation among professional drivers and dispatchers in Serbia, with a focus on the CMR, CEMT, EUR.1, and TIR documents. The research was conducted on a sample of 177 respondents through an online survey, and the collected data were processed using descriptive statistics and one-way ANOVA analysis. The results show that professional drivers are significantly more familiar with documentation used in operational transport, while dispatchers possess better knowledge of administrative and customs-related documentation. Statistically significant differences were recorded based on job position, gender, age, level of education, and driver's license category. The findings indicate the need for targeted training and harmonization of knowledge among employees in international road transport to reduce the likelihood of administrative errors and improve the efficiency and compliance of transport processes.

Keywords: international road transport; transport documentation; CMR Convention; TIR Convention; customs procedures; cross-border transport

INTRODUCTION

Numerous international and non-governmental organizations in Europe play a key role in regulating and standardizing international transport. Among them are the International Chamber of Commerce (ICC), the International Air Transport Association (IATA), the International Union of Railways (UIC), the International Road Transport Union (IRU), the World Customs Organization (WCO), the World Trade Organization (WTO), and many others. These organizations not only define standards and procedures for the international transport of goods but also develop and distribute forms and documents used globally. Such documentation enables the proper, safe, and lawful transport of goods across national borders, facilitating the work of drivers, freight forwarders, and other participants in the transport chain [1].

Knowledge and proper use of international transport documents are essential for every professional driver and dispatcher. Drivers must always have complete documentation with them to avoid potential issues during the trip, especially during customs checks and inspections. In addition, it is necessary to be informed beforehand about the laws, rules, and procedures of the countries through which the transport route passes, in order to ensure compliance with local and international regulations and avoid possible penalties [1].

Particular attention is required when transporting certain types of shipments, such as dangerous goods, whose transport is governed by strict legal regulations and specialized documentation. Unlike domestic road transport, international transport requires specific procedures and forms, which further highlights the need for detailed knowledge and practical preparedness of drivers and dispatchers [1], [22].

Given the complexity of international transport and the variety of required documentation, the aim of this research was to examine the level of knowledge professional drivers and dispatchers possess regarding key documents and procedures in international transport. The results of such research can highlight potential gaps in employee preparedness and serve as a foundation for developing targeted training programs.

International road transport represents the most logistically sensitive segment of the supply chain, and proper and accurate handling of documentation directly

affects transport duration, regulatory compliance, avoidance of fines, and prevention of administrative delays. A lack of knowledge among drivers and dispatchers can lead to increased operational costs, delivery delays, and safety risks, which underscores the importance of systematically examining their level of awareness.

The main objective of the research is to quantitatively determine the level of knowledge of international transport documentation among professional drivers and dispatchers, as well as to identify key factors (gender, age, education, work experience, driver's license category) that influence the degree of knowledge. A specific objective is to identify the areas in which the greatest deficiencies occur, in order to define recommendations for improving training and practices in international transport.

LITERATURE REVIEW

International road transport represents a complex logistical system in which documentation plays a key role in ensuring regulatory compliance and the smooth transport of goods across borders. Previous research emphasizes that effective management of documentation directly impacts transport efficiency, reducing delays, costs, and administrative risks [2,3]. Research papers in the field of international freight forwarding and transport law indicate that properly completed and applied documentation, such as CMR, TIR, or EUR.1, forms the basis for the lawful and safe execution of transport operations [4,5,6]

A significant portion of the literature focuses on the impact of the human factor on the accuracy and precision of administrative processes in transport. Studies indicate that levels of knowledge among employees vary depending on experience, education, professional role, and frequency of handling documentation [7,8]. It is particularly emphasized that professional drivers often possess better practical knowledge of the documents accompanying goods during transport, while dispatchers have more developed administrative knowledge. This highlights the need for integrated training models to reduce disparities in understanding procedures [9,10].

The literature also points to the rapid evolution of documentation toward digitalization, such as e-CMR and electronic customs procedures, which further increases the need for continuous employee training and development [11]. Numerous studies confirm that digital systems reduce administrative errors, accelerate the flow of information, and improve shipment tracking, but they require a high level of technical and procedural proficiency [12].

The literature review shows that knowledge gaps between drivers and dispatchers represent a global challenge and can be overcome through the implementation of standardized training programs that cover both the operational and administrative aspects of international transport. These findings underscore the importance of research focused on assessing employee knowledge, as well as the need for systematic improvement of educational content in the road transport sector [13,14,15].

RESEARCH METHODOLOGY

For the purposes of this research, a survey was created to examine the level of knowledge of professional drivers and dispatchers regarding international transport documentation. The study was conducted in the Republic of Serbia and involved a total of 177 respondents. The survey was created using the Google Forms platform and sent to the official email addresses of companies engaged in international transport. Participants received all relevant information about the study in the email, including a link to the online survey, and participation was voluntary and randomly selected [16,17,18,19].

The survey consisted of nine closed-ended questions covering the respondents' demographic characteristics, including gender, age, occupation, and work experience, as well as possession of a driver's license. A specific section of the questionnaire focused on assessing the respondents' level of knowledge regarding key documents and procedures in international transport.

The collected data were processed in Microsoft Excel, where initial data handling, verification, and validation were performed [20,21]. Subsequently, statistical analysis was conducted using IBM SPSS Statistics version 22, which enabled precise determination of the level of knowledge and potential differences between professional drivers and dispatchers.

The validity of the instrument was verified through internal consistency (Cronbach's α), while descriptive statistics and one-way ANOVA were applied in the statistical analysis to compare groups, with post hoc testing (Tukey HSD) used to identify specific differences between categories. This approach allows for more reliable conclusions regarding the impact of individual factors on the level of knowledge.

RESULTS

The study included 102 respondents, of which 57.6% were professional drivers and 42.4% were dispatchers. All professional drivers (100%) were male, while 72% of dispatchers were female and only 28% male. Regarding age, the largest proportion of professional drivers (41.2%) were between 36 and 45 years old, while the majority of dispatchers (64%) were up to 25 years old. Among professional drivers, 88.2% had completed high school as their highest level of education, whereas the majority of dispatchers (76%) had completed either undergraduate academic or vocational studies. In terms of driving license categories, 82.4% of drivers held a license for heavy vehicles, while 96% of dispatchers held

a license for passenger vehicles. Regarding work experience, the largest proportion of drivers (38.2%) had been working as professional drivers for 21 to 30 years, 32.4% for less than 10 years, and 29.4% for 11 to 20 years. The majority of dispatchers (76%) had been in their position for up to 10 years.

Analysis of Professional Drivers' and Dispatchers' Knowledge of Transport Documentation

In response to the question "What is CMR?", the largest proportion of professional drivers, 85.29%, answered correctly, indicating that CMR is the international consignment note for road transport of goods between signatory countries, while only 60% of dispatchers answered this question correctly. Dispatchers responded in a significantly higher percentage that they did not know the correct answer to the question (Fig. 1).

In response to the question "What is CEMT?", the largest proportion of professional drivers, 79.4%, as well as the largest proportion of dispatchers, 68%, answered correctly, stating that CEMT is a multilateral permit that authorizes a carrier from one member state to perform international road transport of goods between two (or more) member states, in compliance with specific technical and safety standards (Fig. 2).

In response to the question "What is EUR.1?", the largest proportion of dispatchers (72%) as well as the largest proportion of drivers (55.9%) answered correctly, stating that EUR.1 is a document indicating and certifying the preferential origin of goods (Fig. 3).

In response to the question "What is a TIR carnet?", the largest proportion of dispatchers (56%) and drivers (76.5%) answered that the carnet is used for the transport of goods, primarily by road, between two contracting parties of the TIR Convention or between two points within a participating country, as long as the goods pass through a third country during transport (Fig. 4).

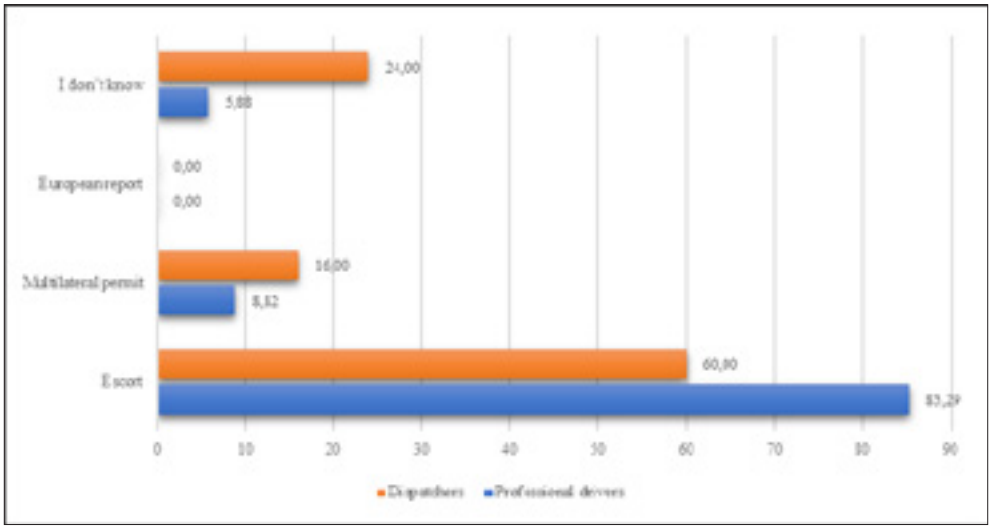

Figure 1. Response to the question "What is a CMR permit?"

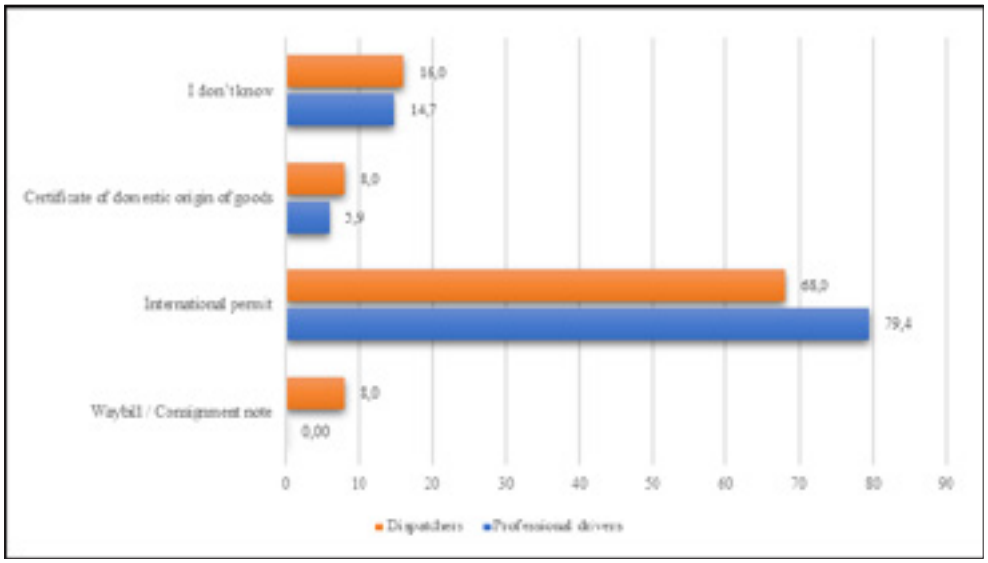

Figure 2. Response to the question "What is a CEMT permit?"

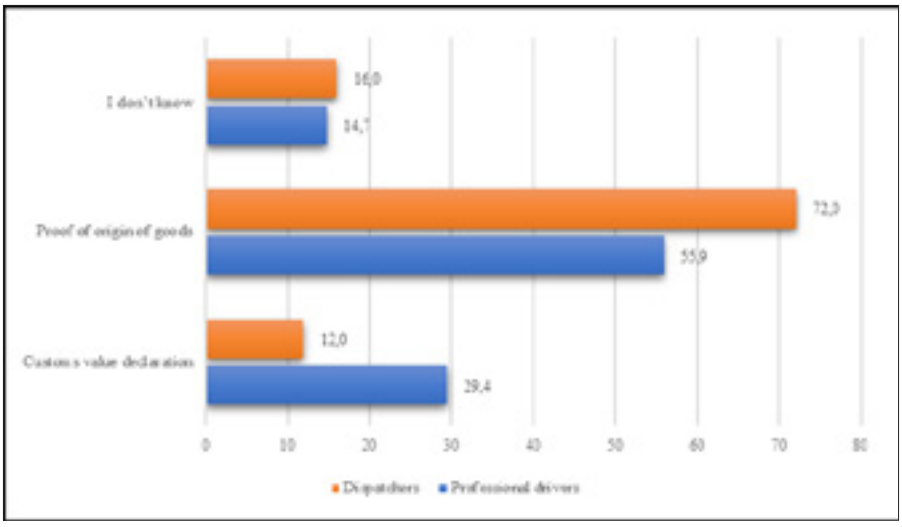

Figure 3. Response to the question „What is EUR.1?"

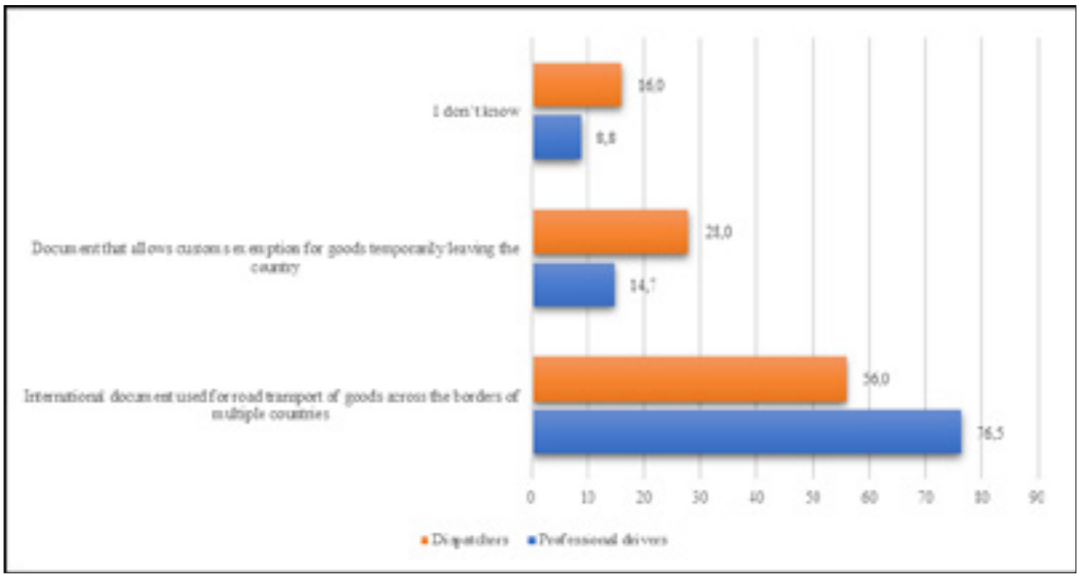

Figure 4. Response to the question „What is a TIR carnet?"

Impact of Respondents' Job Positions on Knowledge of Transport Documentation

A one-way analysis of variance (One-way ANOVA) was used to examine whether there is a statistically significant difference in the level of knowledge between the two groups of respondents—professional drivers and dispatchers. The results show that knowledge differs significantly between these groups with regard to the CMR, EUR.1, and TIR documents. Specifically, the One-way ANOVA results indicate a significant statistical difference between the two groups in knowledge of CMR ($F=16.670$; $p<0.005$), EUR.1 ($F=4.156$; $p=0.043$), and TIR ($F=7.023$; $p=0.009$) documents. These results may reflect the different nature of each profession's work and specific job tasks—drivers more frequently encounter certain documents in practice, while dispatchers have a broader administrative role that requires knowledge of other aspects of international transport. Overall, the analysis confirms that professional role significantly shapes the level of knowledge, highlighting the need for precisely targeted training to enhance the knowledge of both groups and contribute to more efficient and compliant transport operations.

Impact of Respondents' Gender on Knowledge of Transport Documentation

A one-way analysis of variance (One-way ANOVA) was applied to determine whether there are statistically significant differences in the level of knowledge between two groups of respondents, based on gender. The results show that gender has a statistically significant impact on knowledge of the CMR document ($F=7.132$; $p=0.008$), indicating that the level of knowledge differs between the two groups. This finding may point to differences in work experience, frequency of document use, or the representation of genders in certain segments of the transport industry. Although the analysis does not reveal the cause of the differences, it highlights that gender can be a factor influencing acquired knowledge of the CMR document. Accordingly, the results suggest the need for edu-

cational programs and training to be evenly adapted for all groups to ensure uniform awareness and competence, regardless of respondents' gender.

Impact of Respondents' Age on Knowledge of Transport Documentation

A one-way ANOVA was used to determine whether respondents' knowledge differs depending on their age. The analysis showed that age significantly affects knowledge of the CMR (F=6.640; p=0.000), CEMT (F=3.333; p=0.021), and TIR (F=29.002; p=0.000) documents, indicating that older and younger age groups differ statistically in their knowledge of these documents. These results suggest that age can be an important factor in acquiring and developing knowledge in the field of international transport. Older respondents have longer work experience and richer practical knowledge, which contributes to a better understanding of complex transport documentation. In contrast, younger respondents are in the early stages of their professional development and therefore possess less experience and a narrower scope of knowledge.

Impact of Respondents' Education on Knowledge of Transport Documentation

A one-way analysis of variance (One-way ANOVA) was applied to determine whether there are statistically significant differences in the level of knowledge between respondent groups based on their education level. The results indicate that education significantly affects knowledge of CMR (F=11.912; p=0.000), CEMT (F=3.716; p=0.013), EUR.1 (F=5.064; p=0.002), and TIR (F=9.836; p=0.000) documents. These findings clearly show that a higher level of education contributes to a better understanding of key international transport documentation. In other words, education is an important factor influencing respondents' ability to correctly know and use relevant documents in international transport, which can have a direct impact on the efficiency and accuracy of performing professional tasks in this field.

Impact of Driver's License Category on Knowledge of Transport Documentation

The results of the one-way analysis of variance (One-way ANOVA) show that the category of driver's license held by respondents has a statistically significant impact on their level of knowledge of certain international transport documents. It was found that knowledge of the CMR document differs depending on the license category (F=12.567; p=0.000), indicating that drivers with higher or more specialized license categories have a more informed understanding of this documentation. Significant differences were also observed in knowledge of CEMT permits (F=3.240; p=0.042) and TIR documents (F=12.642; p=0.000). These results suggest that the level of qualification and experience associated with specific driver's license categories can contribute to better knowledge of key documents in international transport.

DISCUSSION

In the conducted research, which included 177 respondents, clear differences were observed between professional drivers and dispatchers in terms of gender, age, education, and experience. Professional drivers, who make up 57.6% of the sample, are exclusively male and mostly belong to the 36–45 age group, indicating a more mature and experienced workforce. In contrast, dispatchers, accounting for 42.4% of respondents, are predominantly female (72%) and mostly under 25 years of age, suggesting that this profession is more attractive to younger individuals and often represents the early stages of a career. These differences are also reflected in the educational structure—while the majority of drivers (88.2%) have completed high school, the majority of dispatchers (76%) possess higher education, either undergraduate academic or vocational studies, indicating higher formal educational requirements for the dispatcher role.

Analysis of work experience further highlights the differences between these two groups. Professional drivers have significantly longer work experience, with the largest proportion (38.2%) having worked between 21 and 30 years, while the remainder have 11–20 years or less than 10 years of experience. In contrast, dispatchers are mostly at the beginning of their professional careers, with 76% having up to 10 years of experience. This profile suggests that the profession of a professional driver is stable and long-term, whereas the dispatcher role is more dynamic and open to entry by younger, more educated personnel. Overall, the results clearly indicate structured differences in career paths, job requirements, and demographic characteristics between these two workforce groups.

The research results reveal clear differences in the level of knowledge of key documents and procedures in international transport between professional drivers and dispatchers. In response to the question "What is CMR?", as many as 85.29% of professional drivers answered correctly, while only 60% of dispatchers demonstrated the same knowledge, with a significantly higher number of dispatchers indicating that they did not know the answer. This suggests that professional drivers, likely due to their direct experience in international transport, are more familiar with documentation related to the practical operational execution of transport. On the other hand, dispatchers, although administratively involved in organizing transport, show insufficient knowledge of certain fundamental documents, such as the CMR. A similar trend is observed for questions related to CEMT permits: 79.4% of drivers and 68% of dispatchers answered correctly, indicating relatively good knowledge in this area, but still with a slight advantage in favor of drivers.

For the remaining questions, the differences are less pronounced, or the advantage shifts to dispatchers. Regarding the EUR.1 document, which certifies the preferential origin of goods, 72% of dispatchers and 55.9% of drivers answered correctly, indicating that dispatchers have better knowledge in this area, likely due to their direct role in preparing export and import documentation. For the TIR carnet, drivers again demonstrated a higher level of knowledge (76.5%), while 56% of dispatchers answered correctly, which is expected, as the TIR procedure often involves the practical cross-border movement of goods that drivers handle on a daily basis. Overall, the pattern of results suggests that professional drivers are more familiar with documents related to the on-the-ground execution of international transport, whereas dispatchers show better knowledge of documents that are part of administrative and customs procedures, which logically aligns with the nature of their job responsibilities.

The research results indicate that various respondent characteristics, including job position, gender, age, education level, and driver's license category, have a significant impact on the level of knowledge of international transport documentation. A clear pattern was observed, showing that professional and sociodemographic differences shape the scope and quality of acquired knowledge. This is particularly important in the context of international road transport, where proper use of documentation directly affects the efficiency, safety, and legality of transport operations.

The greatest differences in the level of knowledge are observed between professional drivers and dispatchers. Respondents from these two groups differ significantly in their knowledge of CMR, EUR.1, and TIR documentation, which is expected given the specific nature of their job responsibilities. Drivers more frequently encounter documents related to the transport of goods in practice, while dispatchers take on a broader organizational and administrative role. This finding confirms that professional role critically shapes the type of knowledge acquired in everyday work.

Respondents' gender also proved to be a factor influencing the level of knowledge of the CMR document, which may reflect differences in gender representation in the transport sector, as well as differences in work experience and frequency of handling documentation. Although the analysis cannot determine the causes of these differences, the results suggest that educational programs and training should be designed to be equally accessible and adapted for all employees, regardless of gender.

Age represents another important parameter affecting knowledge of international documents. Older respondents, who possess greater professional experience, demonstrate a higher level of knowledge of CMR, CEMT, and TIR documentation compared to their younger colleagues. This finding indicates that a significant portion of knowledge in this sector is acquired through practice and long-term professional engagement, highlighting the importance of mentor-structured training and knowledge transfer to younger employees.

The impact of education further confirms that formally acquired knowledge plays an important role in understanding complex international procedures. Respondents with higher levels of education achieve better results in knowledge of CMR, CEMT, EUR.1, and TIR documentation, supporting the need to integrate content on international transport into formal educational programs and professional courses.

Finally, the category of driver's license was also identified as a factor influencing the level of knowledge. Respondents with higher or more specialized license categories demonstrate better awareness of key documents, which can be explained by the higher likelihood of these drivers being involved in international transport operations. This confirms that professional qualifications, together with experience, directly contribute to a better understanding and proper use of international documentation.

Overall, the findings clearly indicate that knowledge of international transport documentation is multilayered and influenced by a combination of experiential, educational, and professional factors. The identified differences highlight the need for systematic, targeted training programs that would raise the level of knowledge across all employee groups, thereby improving efficiency, accuracy, and professionalism in performing tasks within the international transport sector.

The differences between drivers and dispatchers can be explained by the distinct types of operational work: drivers handle documentation related to the transport of goods on a daily basis, while dispatchers primarily work in administrative settings, where documents are prepared but not applied directly in the field. This division of labor affects the selectivity of knowledge and highlights the need for integrated training programs in which both profiles become familiar with both the practical and administrative aspects of documentation.

CONCLUSIONS

The study included 102 respondents, of whom 57.6% were professional drivers and 42.4% were dispatchers. All drivers were male, while 72% of dispatchers were female. Professional drivers were most commonly aged 36–45, whereas dispatchers were mostly under 25. The majority of drivers (88.2%) had completed high school, while 76% of dispatchers held undergraduate academic or vocational degrees. Regarding driver's licenses, 82.4% of drivers had a license for heavy vehicles, and 96% of dispatchers had a license for passenger vehicles. The largest proportion of drivers (38.2%) had been in their

position for 21–30 years, while the majority of dispatchers (76%) had up to 10 years of experience.

In response to the question "What is CMR?", 85.3% of drivers and 60% of dispatchers answered correctly, while dispatchers more frequently indicated that they did not know. For "What is CEMT?", 79.4% of drivers and 68% of dispatchers answered correctly, and for "What is EUR.1?", 55.9% of drivers and 72% of dispatchers responded correctly. Regarding the TIR carnet, 76.5% of drivers and 56% of dispatchers answered correctly.

The professional role of respondents significantly affects the level of knowledge of international transport documents. The results show that professional drivers and dispatchers differ in their knowledge of CMR ($F=16.670$; $p<0.005$), EUR.1 ($F=4.156$; $p=0.043$), and TIR ($F=7.023$; $p=0.009$) documents. Drivers demonstrate better knowledge of documents used in everyday transport operations, while dispatchers have an advantage in administrative documentation, reflecting the different nature of the work and tasks of each group.

Respondents' gender shows a statistically significant impact on knowledge of the CMR document ($F=7.132$; $p=0.008$). This finding suggests that differences in experience, frequency of handling documentation, or gender representation in the transport sector may shape acquired knowledge. Although the analysis does not reveal the causes of these differences, it emphasizes the need for educational programs that are equally adapted for all genders.

Age significantly affects knowledge of the CMR ($F=6.640$; $p=0.000$), CEMT ($F=3.333$; $p=0.021$), and TIR ($F=29.002$; $p=0.000$) documents. Older and more experienced respondents demonstrate a higher level of knowledge, highlighting the importance of long-term practical experience in acquiring competencies in international transport. Younger respondents, who are at the beginning of their professional careers, have narrower knowledge and require additional training.

Education significantly affects knowledge of the CMR ($F=11.912$; $p=0.000$), CEMT ($F=3.716$; $p=0.013$), EUR.1 ($F=5.064$; $p=0.002$), and TIR ($F=9.836$; $p=0.000$) documents. A higher level of education enables better understanding of complex procedures and directly contributes to more efficient and accurate performance of professional tasks in international transport.

Finally, the category of the driver's license influences the level of knowledge of key documents. Significant differences were observed in knowledge of CMR ($F=12.567$; $p=0.000$), CEMT ($F=3.240$; $p=0.042$), and TIR ($F=12.642$; $p=0.000$) documents, with drivers holding higher or more specific license categories demonstrating better awareness and practical readiness in handling documentation.

The results indicate that companies in the international road transport sector should implement periodic training for drivers and dispatchers, particularly in areas where the greatest gaps were identified—knowledge of CMR, TIR, and CEMT documents. It is recommended to develop short e-learning modules, as well as practical workshops in which both employee profiles work with real examples of documentation. This approach would reduce the risk of administrative errors and increase the efficiency of the transport process.

A limitation of this research is that the sample was collected within companies operating in Serbia, so the results may not be fully generalizable to other countries. Additionally, the data are based on self-assessment by the respondents, which may lead to subjective deviations.

Future research could include comparisons between different countries in the region, analysis of understanding of specific procedures (e.g., insurance, customs control, phytosanitary documentation), as well as examining the effects of targeted training before and after the courses.

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DOI: 10.7251/JTTTP2601047D
UDC: 656.1.08:621.039.58

REVIEW SCIENTIFIC PAPER

Improving Traffic Safety at Two-Lane Roundabouts Through Legal and Technical Regulatory Measures

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Recived: June 8, 2026
Revised: June 15, 2026
Accepted: June 26, 2026

Abstract: The title of the paper reflects the traffic-related issues associated with two-lane roundabouts, from the perspective of the level of service and traffic safety. Particular focus is placed on establishing traffic rules in two-lane roundabouts and eliminating ambiguities regarding the right of way of vehicles when exiting the circulatory roadway.The research results enable a higher level of quality in the training of new drivers, as well as in the work of police and judicial-prosecutorial authorities, which will contribute to improving traffic safety in roundabouts. In addition to proposing amendments and supplements to the legal framework, the research findings also provide guidelines for the technical regulation of traffic in two-lane roundabouts.

Keywords: Roundabout, Level of service, Traffic safety

INTRODUCTION

In order to resolve ambiguities regarding the rules of vehicle entry, circulation, and exit within two-lane roundabouts, it is necessary to clearly prescribe or amend the existing regulations and, crucially, to establish the technical elements of traffic control to eliminate current dilemmas [1], [5],[6], [10], [11].

Roundabouts are designed and constructed for two fundamental reasons:

- Traffic calming in urban areas / safety aspect,
- Improving the intersection level of service (LOS) / increasing vehicle throughput.

From a traffic safety perspective, single-lane roundabouts—featuring a single traffic lane both within the circulatory roadway and at the approaches and exits—are the safest configuration. Specifically, the number of potential conflict points at these intersections is equal to the number of approaches, which is minimal compared to all other types of at-grade intersections.

However, there is an increasing number of two-lane roundabouts where traffic flows are not governed or regulated by clear legal, and in most cases, technical standards. Consequently, these issues directly affect driving schools during candidate training, police officers managing traffic control, insurance companies during the claims liquidation process, as well as court experts and judiciaries in identifying the root causes of traffic accidents. Therefore, it is essential to clearly define traffic rules in two-lane/multi-lane roundabouts based on robust legal and technical regulations [8], [9].

METHODOLOGY

The research methodology is based on a comparative analysis of traffic flows within the orthogonal projection of a conventional four-leg (crossroad) intersection and its subsequent transformation into a two-lane roundabout. A specific aspect of analyzing vehicle flows focuses on achieving a strategic objective: increasing the intersection level of service (LOS) compared to its previous configuration—either a three-leg or a four-leg intersection. Given that several distinct descriptive analyses of this problem exist, a specialized approach is required to integrate them into a cohesive whole, followed by a discussion that will ultimately utilize the scientific method of synthesis to establish traffic regulation rules for two-lane roundabouts.

The strategically set objectives relate to the speed of the traffic flow in the inner lane, which must not approach a breakdown flow state (stop-and-go regime). Since the highest concentration of vehicles is located in this lane, facilitating its continuous discharge is directly aimed at improving the level of service. In the context of the previous orthogonal projection of the intersection, traffic within the inner circulatory lane corresponds to "through" and "left-turning" vehicle flows, whereas traffic in the outer circulatory lane corresponds to "right-turning" and "through" vehicle flows.

ROUNDABOUTS

The assumption of proper vehicle maneuvering within a two-lane roundabout is based on the principle that both lanes can be utilized for through-movements, whereas the right lane is strictly used for right turns, and the left lane for left turns or U-turns. In this regard, three categories of conflict exist within a roundabout: merging, diverging, and crossing. If the right traffic lane were restricted exclusively to right turns, the safety aspect would be satisfactory; however, the intersection level of service would be significantly reduced [2], [3], [4], [7].

Conventional roundabouts are categorized as shown in Table 1.

Table 1. Types of Conventional Roundabouts

Intersection Type	Outer Diameter (m)	Function/Objective
Mini roundabout	12-24	Traffic calming
Compact roundabouts	24-30	Traffic calming
Standard single-lane roundabouts	30-45	Increasing vehicle throughput
Standard two-lane roundabouts	45-55	Increasing vehicle throughput

The focus of our research is on the standard two-lane roundabout, with an outer diameter ranging from 45 to 55 meters. Unlike a single-lane roundabout, this configuration generates a conflict within the right/outer circulatory lane in the exit zone, specifically when a vehicle is exiting from the left/inner circulatory lane while another vehicle in the right/outer circulatory lane continues its permitted and ongoing circulating movement.

Increasing the number of traffic lanes within roundabouts reduces traffic safety, primarily due to the emergence of conflicts at the roundabout exit lanes.

TRAFFIC RULES WITHIN A ROUNDABOUT

Traffic rules within a roundabout are established by legal regulations, as well as by vertical (traffic signs) and horizontal (road markings) traffic control devices. The described regulations in Bosnia and Herzegovina, as well as in the region, are vague and very often conflict with the actual traffic control devices installed at the intersection.

Article 50, Paragraph 3 of the Law on Basics of Road Traffic Safety of Bosnia and Herzegovina (ZoOBSBiH) imperatively obliges the driver of a vehicle:

(3) Before entering an intersection, a driver shall position the vehicle at a sufficient distance within the traffic lane through which they must pass the intersection.

From the aforementioned paragraph, it follows that the central dividing line within the circulatory roadway cannot be broken, and that this provision rules out the possibility of changing lanes within the circulation zone (which is also partially emphasized in Figure 1 – Traffic rules for vehicles within a two-lane roundabout).

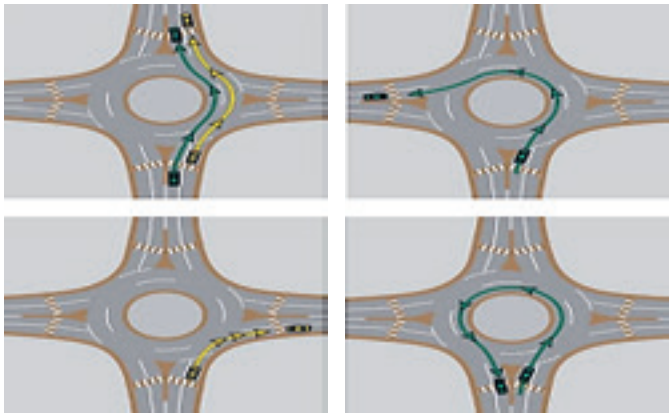
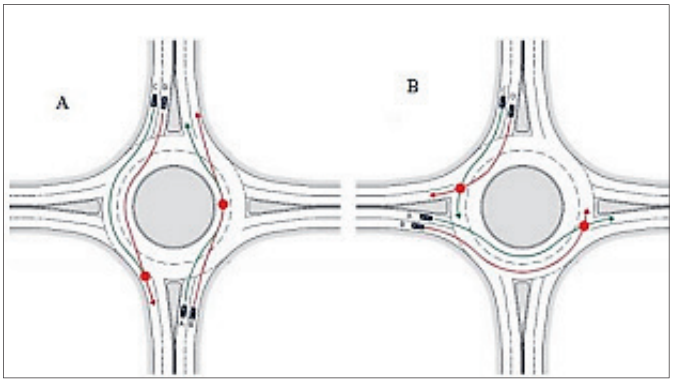


Figure 1. Traffic rules within a two-lane roundabout
Source: WSDOT2 , 2015

A specific safety issue arises when two vehicles simultaneously enter the roundabout from the same approach roadway (using both the left and right traffic lanes), as illustrated in detail in Figures 2A and 2B, and subsequently circulate within the circulation zone where the traffic lanes are divided by a broken longitudinal marking.



Figures 2. A and 2B. Conflicts caused by prohibited vehicle maneuvers within a roundabout

Source: Bastos Silva et al., 2014

In Figure 2A, the vehicle from the left approach lane properly enters the left/inner circulatory traffic lane and, intending to make a permitted exit at the second outlet, does so via the right exit lane, which is designated for traffic coming from the right/outer lane. In the second scenario on the same figure (Figure 2A), the vehicle from the right/outer lane performs a prohibited lane change into the left/inner traffic lane.

Figure 2B also illustrates two scenarios. In the first scenario, the vehicle from the left approach lane properly enters the left/inner traffic lane but makes a prohibited exit at the first outlet. In the second scenario, vehicles properly enter the circulatory roadway from the same approach, after which the vehicle in the right lane unlawfully continues its circulating movement past the second exit location. These specific conflict cases within the roundabout occur despite the proper initial entry of the vehicles from the same approach and direction into the circulatory roadway. However, once the described conflict situations arise, it becomes difficult to determine the previous direction of travel for both vehicles, which subsequently complicates proving the root cause of the traffic accident.

Article 50, Paragraph 4 of the ZoBSBiH clearly and unambiguously regulates the right-of-way priorities between vehicles entering the roundabout and vehicles that are already within the roundabout:

(4) When regulating traffic within a roundabout, traffic shall be regulated in such a manner that vehicles within the roundabout have the right-of-way.

The aforementioned provision eliminates any possible type of conflict between a vehicle from the left/inner traffic lane and a vehicle moving along the far-right traffic lane, provided that the latter vehicle had previously properly entered the roundabout (in compliance with the II-2 "Yield" sign), given that the conflict point between these vehicles is located within a very short distance traveled by the vehicle in the right/outer traffic lane (π/2 radians). In the event that these vehicles meet at the described conflict point within the right/outer traffic lane at the first exit—observed from the entry direction of the vehicle moving along the right/outer traffic lane—it can be characterized as a failure of the driver in the right/outer traffic lane to yield the right-of-way previously. This necessitates a specific method of traffic regulation.

Article 42, Paragraph 3 of the Law on Road Traffic Safety of Republika Srpska (ZoBSRS) additionally regulates the traffic of vehicles within a roundabout:

(3) A driver entering a multi-lane roundabout with a vehicle shall use the far-right lane to exit at the first and second outlets, unless otherwise regulated by a traffic sign.

Bearing in mind that a vehicle entering the roundabout from the right approach lane into the right/outer circulatory lane must exit the roundabout at the second outlet at the latest, it follows that a conflict with a vehicle from the left/inner lane can only occur at the first exit, at a distance of π/2 of the lane arc length. In the event that this vehicle continues its permitted circulating movement toward the second outlet and a conflict occurs with a vehicle from the left/inner lane during its exit phase from the roundabout, such a scenario can then be characterized as a failure of the driver in the right/outer traffic lane due to non-compliance with the obligation imposed by the II-2 regulatory sign at the intersection entry.

In order to enhance traffic safety within roundabouts, it is necessary to eliminate ambiguities through additional standardization, as well as legal and technical regulatory measures.

In practice, various and often conflicting expert opinions exist, such as:

1. According to the general traffic rules, specifically the right-hand rule, a vehicle from the left/inner lane changes its direction of travel and thereby "takes" the right-of-way from a vehicle in the right/outer circulatory lane that is not changing its direction of travel.
   This standpoint "mandates" stopping the traffic flow in the left/inner lane in order to "yield" the right-of-way to the vehicle in the right/outer circulatory lane, which subsequently:
   - Derogates the positions established by the designer when deciding on the construction of the roundabout, as it forces a halt on the permitted traffic flow in the left lane along its entire length, thereby degrading the intersection's level of service. The length of the inner traffic lane (2 π radians), with a radius of 10 meters, where the traffic flow is halted, amounts to:

$$L_{LT} = 2 \cdot 3.14 \cdot 10{,}00 = 62{,}8\ m \quad (1)$$

2. In addition to the obligations arising from the meaning of the II-2 traffic sign, a vehicle from the right/outer circulatory lane is obliged to yield the right-of-way for the exiting vehicle from the left/inner circulatory lane. This is intended to facilitate the intensive clearing of the inner lane and to increase the intersection's level of service, which will result in a significantly smaller impact in terms of occupying the surface of the right/outer lane along a roadway length of (π /2 radians), namely:

$$L_{DT} = 3.14/2 \cdot 12{,}50 = 19{,}62\ m \quad (2)$$

Bearing in mind the ratio between the calculated and saturated traffic lane lengths, it explicitly follows that it is more expedient to halt traffic in the right/outer lane and allow the left/inner lane to clear along its entire length.

CONCLUDING REMARKS

In order to eliminate the thoroughly described ambiguities, it is considered expedient to standardize and amend Article 42 of the ZoBSBiH by adding Paragraph (4).

Article 42, Paragraph (4) of the Law on Road Traffic Safety of Republika Srpska (ZoBSRS) additionally regulates the traffic of vehicles within a roundabout:

(4) A driver who has entered the roundabout into the outer/right lane and intends to exit at the second outlet shall yield the right-of-way at the first exit to vehicles from the inner traffic lane that have commenced or intend to execute an exit at the first outlet.

In this regard, there is a need for horizontal traffic markings within the roundabout to prevent lane changing or vehicle sorting inside the circulatory intersection, and to regulate the priorities previously elaborated.

Namely, it is necessary to design the central dividing line as a double line, specifically at the locations of permitted 'merging' or 'entry' into the roadway surface that has priority over other flows, as shown in more detail in Figure 3.

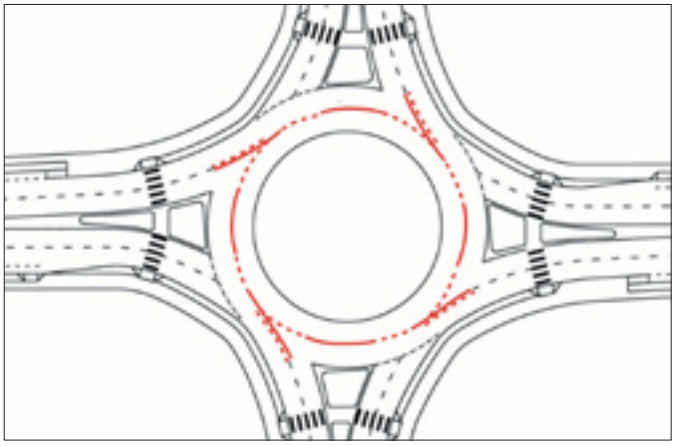


Figure 3. Proposed horizontal road markings at roundabouts in accordance with the suggested amendments to traffic rules within the circulatory zone

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DOI: 10.7251/JTTTP2601051A
UDC: 331.45:316.334.3(4-672EU)

REVIEW SCIENTIFIC PAPER

Multilevel Public Administration and Occupational Health and Safety (OHS) Governance in Sustainable and Mobile Urban Environments

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Recived: April 20, 2026
Revised: May 22, 2026
Accepted: May 29, 2026

Abstract: This paper examines the transformation of Occupational Health and Safety (OHS) governance driven by digitalization, labor mobility, and the expansion of non-standard employment. It argues that OHS has evolved from a narrow regulatory function into a core pillar of sustainable development and public health resilience. While the European Union has embedded OHS as a fundamental social right, many developing economies remain trapped in a "cycle of neglect," marked by weak regulatory capacity and high rates of workplace accidents. The study underscores the limitations of traditional command-and-control enforcement in fragmented labor markets shaped by platform work, subcontracting, and informal or bogus self-employment. These arrangements diffuse accountability and disproportionately expose vulnerable groups, particularly migrants and women, to occupational risks. The Pressures–Disorganization–Regulatory Failure (PDR) model is used to explain how such structural conditions contribute to adverse physical and mental health outcomes. The COVID-19 pandemic is identified as a catalyst for closer integration between OHS and public health surveillance, especially in dense urban settings. In response, emerging paradigms such as OSH 5.0 promote a human-centered, digitally enabled governance approach aligned with the UN Sustainable Development Goals and based on quadruple-helix collaboration among the state, industry, academia, and civil society. The paper concludes by proposing a strategic roadmap for Turkey, addressing the coexistence of advanced digital OHS systems and a large informal economy. Key recommendations include legal protections for migrant reporting, guidance-oriented inspections for SMEs, and the integration of health security indicators into Sustainable Urban Mobility Plans.

Keywords: OHS Governance, Multilevel Administration, OSH 5.0, Sustainable Urban Mobility, Public Health Resilience

INTRODUCTION

Occupational health and safety (OHS) remains a major global challenge, posing significant human, social, and economic costs. These burdens are most acute in developing economies, where weak regulatory capacity, low productivity, and poor working conditions amplify occupational risks (Chen et al., 2020). In contrast, the European Union has progressively institutionalized OHS as a core element of social policy since the 1950s, evolving from early debates on the "humanisation of work" to binding frameworks such as Directive 89/391/EEC. Today, EU OHS policy emphasizes mental health, sustainability, and decent work in response to green, digital, and demographic transitions, underpinned by tripartite governance involving governments, employers, and trade unions and framed as a social right within the European Pillar of Social Rights (Dörflinger & Tisch, 2023).

Safe and healthy work is increasingly recognized as a cornerstone of sustainable development and effective public governance in a rapidly changing world of work. OHS, and wellbeing underpin not only worker protection but also organizational performance, economic resilience, and social cohesion, requiring governance approaches that extend beyond compliance-based regulation toward integrated, multi-actor collaboration (Jain et al., 2024). Comparative evidence from developed countries including the United States, Japan, the United Kingdom, Germany, and Australia demonstrates that mature OHS systems combining strong enforcement with stakeholder participation have substantially reduced workplace accident mortality. These experiences highlight a persistent governance gap with developing

economies and have informed proposals for government-led, multi-subject collaborative governance models tailored to national institutional contexts, such as China, to improve regulatory effectiveness and OHS outcomes (Chen et al., 2020).

At the same time, labour market transformations associated with globalization, outsourcing, privatization, and non-standard employment have fragmented employment relationships and shifted health and safety risks from employers and states onto workers. Temporary, subcontracted, platform-based, informal, and migrant work arrangements are consistently linked to higher injury rates, poorer physical and mental health outcomes, and limited access to social protection, particularly in mobile and urban labour markets (Quinlan, 2025; Lippel et al., 2017). These dynamics weaken regulatory oversight and complicate enforcement across multilevel governance structures, where responsibilities are dispersed across public and private actors and along global supply chains (Dörflinger & Tisch, 2023).

The COVID-19 pandemic starkly exposed these vulnerabilities, demonstrating how weak OHS enforcement especially in essential, informal, and mobile sectors can accelerate disease transmission and overwhelm public health systems. In response, the literature increasingly conceptualizes OHS governance as an integral component of public health and environmental protection rather than a stand-alone regulatory function (Atima & Anioke, 2020). Integrated, risk-based, and outcome-oriented enforcement models that align labour regulation with public health surveillance are seen as critical for early detection of hazards, prevention of community-level spillovers, and reduction of health inequalities, consistent with the "healthy workplaces–healthy communities" perspective.

Informal, migrant, and other high-risk worker populations remain central challenges for urban OHS governance, as traditional enforcement mechanisms often fail in decentralized, mobile, and low-trust contexts. Scholars therefore emphasize adaptive strategies such as community-based monitoring, mobile inspections, trust-building measures, simplified reporting, and integrated data systems to extend protection to excluded workers (Atima & Anioke, 2020). The "cycle of neglect" identified by Jilcha and Kitaw (2016) illustrates how weak regulation, poor enforcement, low compliance, and underreporting mutually reinforce unsafe conditions, particularly in developing countries, underscoring the need for accountable and adaptive enforcement systems.

Recent evidence from the public sector further confirms these governance gaps. Studies from highly urbanized contexts, such as the Philippines, show that even where formal OHS legislation exists, implementation remains uneven due to limited institutional capacity, insufficient training, and weak accountability across governance levels (Abad, 2025). More broadly, the literature highlights that effective OHS governance depends not only on regulation but also on complementary strategies, including voluntary standards, corporate social responsibility and environmental, social, and governance initiatives, and rights-based approaches, while maintaining a strong role for the state in enforcement and coordination (Jain et al., 2024). Overall, the literature converges on the need for coordinated, multilevel OHS governance that integrates labour, public health, environmental, and urban policy objectives. Strengthening institutional capacity, aligning enforcement across governance levels, and addressing the needs of mobile and vulnerable workers are essential for ensuring safe and healthy work as a foundation of sustainable, inclusive, and resilient urban development.

EVIDENCE ON THE HEALTH EFFECTS OF NON-STANDARD / INFORMAL WORK

The literature indicates that non-standard and insecure work substantially heightens OHS risks by concentrating vulnerable groups, particularly migrants, women, young and older workers in low-paid, weakly regulated jobs marked by insecurity, irregular hours, and fragmented work organization. These risks are intensified by declining union representation, regulatory exclusions, and complex subcontracting and global supply chains that diffuse responsibility and strain enforcement. Employment insecurity increasingly affects both non-standard and permanent jobs, with overlapping work arrangements and demographic changes further amplifying risks and extending harm beyond workers to clients and the public. Despite extensive evidence, policy responses remain uneven, highlighting the need for stronger, better-resourced, and more inclusive multilevel OHS governance that integrates supply-chain accountability, social protection, and worker representation in mobile urban labour markets (Quinlan, 2025).

Informal work accounts for a large share of global employment around 61% of the workforce and is marked by the absence of formal contracts, OSH protections, and social security, particularly in developing and emerging economies. Informal workers face heightened exposure to physical, chemical, biological, and psychosocial hazards, compounded by unsafe workplaces, long hours, limited training, and restricted access to healthcare. Informal outsourcing by formal industries further shifts risks into unregulated settings, often extending harm to families and communities. The COVID-19 pandemic intensified these vulnerabilities, expanding informality and exposing its public health implications. Overall, the literature underscores the need for integrated occupational, public health, and social policies, alongside improved data and targeted interventions, to reduce risks and support safer, more sustainable informal work (Schulte et al., 2022).

Triangular/temporary agency work

Temporary and agency work consistently lead to elevated OHS risks, characterized by higher injury rates, greater exposure to physical and psychosocial hazards, and poorer mental health outcomes compared to permanent employment. According to Quinlan (2025), these risks are manifested through increased experiences of bullying, depression, and delayed return to work. These vulnerabilities are particularly acute for migrant, female, and inexperienced workers, who often face language barriers and economic pressures that make hazardous tasks seem like "risks worth taking" despite the inherent dangers (Hopkins, 2017; Cajander et al., 2023).

The Pressures–Disorganization–Regulatory failure (PDR) model explains how these risks are structurally embedded in triangular employment relationships. Economic instability creates pressures that discourage the reporting of hazards, while disorganization arises from mismatched placements, unfamiliarity with host worksites, and fragmented communication regarding training and supervision (Spillett et al., 2005; Underhill & Quinlan, 2011). This fragmentation is common in sectors like construction and hospitality, where the blurred lines of authority between staffing agencies and host firms often result in inadequate safety cultures and limited access to protective equipment (Gogelescu et al., 2021; Strauss-Raats & Adăscăliței, 2025).

Regulatory and governance gaps further exacerbate these dangers, as traditional OHS frameworks are often ill-equipped to handle multi-employer arrangements. Shared legal responsibility is frequently poorly defined or weakly enforced, leading to a "regulatory gap" where agencies and host employers shift blame rather than coordinating prevention (Strauss-Raats, 2019; Howard, 2016). For example, comparative studies of Ontario and Quebec reveal that while some systems offer better income replacement or shared liability, both struggle with underreporting and fragmented accountability (Lippel et al., 2011). Ultimately, addressing these vulnerabilities in modern urban labor markets requires stronger multilevel governance and clearer allocation of responsibility across all parties in the employment chain (Quinlan, 2025; Xu et al., 2025).

Home-based work

Home-based work (HBW) is a diverse and expanding component of urban labour markets, encompassing informal home production, formal telework, homecare, and platform-based gig work, each with distinct OHS and governance challenges. In low-income and informal settings, HBW is often invisible and unregulated, exposing workers and households to physical, chemical, and ergonomic hazards. In higher-income contexts, formal telework raises ergonomic and psychosocial risks, while platform-mediated home-based gig work is characterized by low pay, surveillance, weak dispute resolution, and limited OHS protection (Dong et al., 2025; Nilsson et al., 2021; Wagemann et al., 2024).

Access to HBW is highly unequal. The capacity to work from home is concentrated among higher-paid, better-educated urban workers in wealthier countries, while limited internet access, housing conditions, and job task requirements exclude many workers in low-income contexts. During crises such as COVID-19, these disparities amplified labour market and health inequalities, disproportionately harming young, poorly educated, temporary, and informal workers in countries with weaker social protection systems (Hall et al., 2023; Sánchez et al., 2020). HBW is frequently organized through subcontracting and temporary arrangements that fragment responsibility for OHS and shift risks into private homes. Cost-driven outsourcing, dispersed worksites, and weak enforcement contribute to poorer OHS outcomes across both high- and low-income settings, making HBW a critical governance challenge in sustainable and mobile urban economies (Quinlan, 2025).

Overall, the literature highlights the need for multilevel OHS and urban governance that recognizes the scale and diversity of HBW, extends labour and health protections into homes and digital platforms, addresses gendered care burdens, and better integrates housing, labour, and digital policies to ensure that home-based work supports both livelihoods and health.

Part-time work

Part-time work is often promoted as a means of improving work–life balance and supporting labour market participation, particularly for women. Evidence shows that voluntarily chosen part-time work can enhance work–life balance and job satisfaction, especially in gender-egalitarian contexts and when hours are substantially reduced, without necessarily increasing sickness absence at the organizational level (Beham et al., 2019; Jacobsen et al., 2023). In such settings, part-time employment can provide a stable and acceptable arrangement for combining paid work with care or study. However, the benefits of part-time work are unevenly distributed. Low-paid, marginal, or involuntary part-time jobs are associated with lower income, weaker job security, limited career progression, and long-term risks such as unemployment and disability retirement. Part-time work is strongly feminized and often reinforces gender inequalities by concentrating women in lower-status roles with reduced access to training, promotion, and pensions, while also sustaining traditional divisions of unpaid care (Booth & van Ours, 2010; Lyonette, 2015; Jacobsen et al., 2023).

From an OHS perspective, part-time work presents mixed outcomes. While reduced hours may lower some physical risks, part-time workers particularly in low-quality jobs are more exposed to unpredictable schedules, psychosocial stress, harassment, and economic insecurity. These patterns mirror broader challenges associated

with non-standard employment and point to the need for context-sensitive OHS and labour governance (Quinlan, 2025).Part-time work can be a sustainable and equitable employment form only when it is voluntary, adequately protected, and embedded in supportive welfare, gender, and employment regimes. Strengthening rights, job quality, and career opportunities for part-time workers is essential to prevent the reproduction of inequality and to realize the promised benefits of flexibility.

Dependent self-employment and subcontracting

Dependent self-employment occupies a regulatory "grey zone" between standard employment and genuine entrepreneurship and has become increasingly prevalent through outsourcing, subcontracting, and platform-based work. Workers are formally classified as self-employed but remain economically and organizationally dependent on one or a small number of clients, with limited autonomy over pricing, workload, or strategic decisions. This status raises significant concerns for job quality, social protection, and OHS governance, particularly in complex and mobile urban labor markets. Across the EU28, dependent self-employment is closely linked to worker misclassification, especially in the gig economy, where individuals lack multiple clients, hiring authority, or decision-making power. Williams and Lapeyre (2017) argue that addressing this gap requires reclassification mechanisms or hybrid protections, strengthened collective bargaining, and expanded social protection to ensure decent work. Evidence from the Netherlands shows that while dependency alone does not necessarily predict poor outcomes, involuntary entry into self-employment is associated with higher risks of dissatisfaction, low income, and financial insecurity (Kösters & Smits, 2021).

Firms increasingly rely on dependent self-employment to gain labor flexibility, shift risks, and evade employment protections, social contributions, and training obligations (Kautonen et al., 2021). Stricter employment protection legislation has been shown to increase transitions into dependent, rather than genuinely independent, self-employment (Román et al., 2011). High-risk sectors such as construction, logistics, care, finance, and platform delivery illustrate how subcontracting chains intensify precarity and unpaid work (Böheim & Muehlberger, 2006; Moore & Newsome, 2018). This fragmentation weakens regulatory oversight and elevates injury risks, making dependent self-employment a central challenge for multilevel OHS governance and accountability (Quinlan, 2025).

Bogus/undeclared work and the informal sector

Bogus self-employment, undeclared work, and informality represent a critical challenge for global OHS. These work forms frequently exist in a "gray zone" between formal and informal sectors, making them difficult to regulate in mobile urban environments. Research indicates that while these arrangements can serve as survival strategies for vulnerable populations, they are systematically associated with poorer physical and mental health, long hours, and low pay (Davidescu et al., 2024; Van Den Berg & Baum, 2024). The risks of informality are particularly concentrated in dispersed or home-based sectors such as construction, hospitality, retail, and platform courier work. In these areas, the formal/informal dichotomy often obscures deeper exploitation; for instance, digital platform couriers may face "super-exploitation" regardless of whether they are labeled as independent contractors or employees (Novianto, 2025). This precariousness is exacerbated by the lack of workers' compensation, tax evasion such as envelope wages, and a total absence of regulatory oversight, which is a widespread issue in both developing economies and high-income countries (Tairova, 2023; Quinlan, 2025).

Addressing these OHS vulnerabilities requires a move away from purely repressive or punitive measures toward "high-road" strategies. Effective governance must focus on formalization incentives, such as simplifying business registration and building trust in public institutions, rather than relying solely on labor inspections (Stasyuk et al., 2023). Furthermore, because dependent self-employment is often used to externalize costs along subcontracting chains, urban governance must look beyond traditional employer-employee contracts to address the blurred legal categories that leave workers unprotected. Ultimately, achieving sustainable development and decent work requires a nuanced policy approach. This involves balancing risk-based enforcement with enabling measures that make formal work accessible and attractive, ensuring that the most hazardous forms of non-standard employment do not continue to undermine unions, collective bargaining, and universal OHS standards (Quinlan, 2025).

MULTILEVEL PUBLIC ADMINISTRATION AND OHS GOVERNANCE IN MOBILE, SUSTAINABLE CITIES

Urban environments are becoming more digital, mobile, and sustainability-driven, which complicates how OHS is governed and enforced. Research links effective OHS to multi-level public administration, sustainable mobility planning, and smart-city agendas, but also shows persistent coordination and implementation gaps.

Multilevel Governance and OHS

Modern urban OHS governance is undergoing a transformative shift toward multilevel and polycentric arrangements. In dense, digitalized cities, OHS is no longer a standalone workplace issue but a core component of sustainable development and public health. Research indicates that while local governments are the primary

implementation hubs, they often face a under-cooperating on safety when acting independently. Centralized regulation and health-footprint models are essential to resolve this coordination failure and ensure stable intergovernmental cooperation (Li et al., 2020; Cevheribucak, 2024).

The current gold standard in advanced economies is a "multiple and differentiated" governance model. This approach features strong state leadership balanced by active collaboration between employers, unions, and social partners (Chen et al., 2020). Governance is effectively distributed across three distinct tiers:

- **National Level:** Establishing legal frameworks, standards, and alignment with Sustainable Development Goals (SDGs).
- **Regional/City Level:** Integrating safety into Sustainable Urban Mobility Plans (SUMPs) and coordinating context-specific enforcement (Mapar et al., 2017).
- **Organizational Level:** Managing internal safety systems, digital risk tools, and worker participation (Baghdadi, 2024).

A critical frontier in urban safety is the integration of OHS into broader infrastructure and mobility planning. Achieving Vision Zero requires cities to move beyond basic accident prevention to include "health security", addressing risk perception and contagion risks within mobility systems (Spadaro & Pirlone, 2021). By using systems-based frameworks like the Hierarchy of Hazard Controls(See Figure 1), urban planners can align transport safety with environmental and public health goals (McLeod & Curtis, 2020).

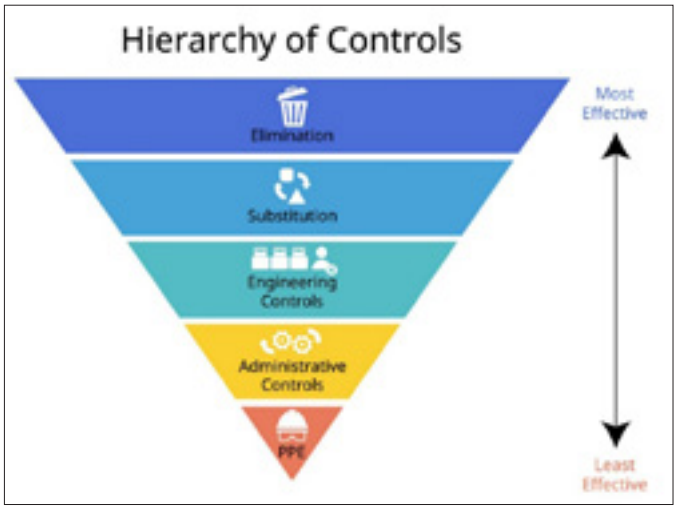

Figure 1. From OSH 4.0 to OSH 5.0: Bridging the Implementation Gap in Digital and Smart City Governance

OSH governance in the digital era is increasingly shaped by the interaction between traditional regulatory systems and rapid technological transformation. Effective OSH governance operates across international, regional, and national levels and depends on a complementary mix of hard law such as legislation, treaties, and ILO conventions and soft law, including voluntary standards, guidelines, and stakeholder agreements. While hard law provides legitimacy and enforceability, it often struggles to keep pace with digitalization and emerging psychosocial risks. Soft law, by contrast, enables flexibility and faster adaptation but lacks binding authority (Schulte et al., 2022).

The transition to Industry 4.0 has accelerated the emergence of OSH 4.0, where digital tools and data-driven systems can substantially improve safety performance and reduce accidents. However, digitalization also generates new risks, notably around data privacy and cybersecurity, blurred roles and accountability, and psychosocial hazards associated with intensified, platform-based, and algorithmically managed work (Akyıldız, 2023; Schulte et al., 2022). Despite these advances, a persistent implementation gap remains within Smart City and Industry 4.0 frameworks, where worker safety is often subordinated to efficiency, innovation, and productivity goals.

To address this gap, OSH 5.0- a human-centered, digitally enabled approach embedded in socio-technical systems and aligned with sustainable development is advocated. OSH 5.0 emphasizes quadruple-helix governance, bringing together public authorities, businesses, researchers, and citizens to ensure that technological innovation enhances, rather than undermines, worker health and safety. Within this framework, OSH innovation is positioned as a driver of all six pillars of sustainable development: economic, social, environmental, cultural, political, and technological rather than a narrow compliance function (Jilcha & Kitaw, 2017; Ávila-Gutiérrez et al., 2022).

Overall, the convergence of digital tools with cooperative, multilevel governance is critical for protecting an increasingly mobile, diverse, and digitally managed workforce. Adaptive OSH governance. Combining robust regulation, flexible voluntary instruments, and participatory governance models is essential for ensuring that smart cities and digital economies remain not only efficient, but also safe, inclusive, and sustainable.

OHS Governance: Standards, Participation, and Digital Transformation

A large-scale review of studies in the construction sector shows that research has focused primarily on occupational health and safety management systems (OHSMSs) implementation and management, while evidence on measurable benefits, performance, awareness, and barriers remains limited. Persistent challenges such as poor communication, inadequate training, weak safety culture, low PPE use, psychosocial strain, and insufficient legal compliance are compounded by a lack of reliable incident and organizational data, constraining

robust evaluation of OHSMS effectiveness. Nevertheless, international standards and management systems provide an important governance framework linking workplace risk control with sustainability, particularly in construction and infrastructure contexts (Kineber et al., 2023).

Public sector evidence underscores the importance of multilevel governance and localized implementation. Studies of urban government offices show generally high levels of OSH standards implementation, but with significant variation across governance levels and functional domains. City governments often translate standards into practice more effectively than national bodies, particularly in emergency preparedness and workplace safety, while gaps persist in OSH programs and support facilities at higher and intermediate levels. These findings emphasize the value of intergovernmental coordination and context-sensitive enforcement (Cagbaleño & Palic, 2025).

Digital transformation further reshapes OSH governance in public administration. Research from Swedish local governments demonstrates that digitalization can either strengthen or marginalize occupational health and safety, depending on managerial approach. Where Plan–Do–Check–Act (PDCA) cycles, risk assessment, and employee participation are embedded in digital change processes, OHS is reinforced; where technological determinism prevails, safety considerations are sidelined. This highlights leadership and adaptive management as critical determinants of safe digitalization (Asp et al., 2026).

Across governance levels, participatory approaches emerge as a key enabling factor. Multilevel, participatory interventions in municipalities improve psychosocial safety climate, leadership empowerment, and risk awareness, although effects on individual stress are limited and implementation is complex (Dalgaard et al., 2025). Broader public administration research similarly shows that stakeholder participation promotes preventive safety cultures and shifts governance from reactive to proactive risk management (Afiyah, 2023).

Finally, strong OSH governance in the public sector has clear economic and public health implications. Evidence from local administrations links weak OSH implementation to inefficient public spending, while improved safety culture reduces accidents, losses, and resource waste (Mohamed et al., 2022). In public health services, crises such as COVID-19 have exposed the consequences of inadequate OSH management, reinforcing the need to integrate occupational safety into public health policy and organizational resilience strategies (Adamopoulos et al., 2022). Collectively, there is a need of more holistic, data-informed, participatory, and digitally aware OSH governance models that align workplace safety with public health objectives and sustainable public administration (Akyıldız, 2023; Schulte, 2020).

A ROADMAP FOR MULTILEVEL OHS GOVERNANCE IN TURKEY'S RESILIENT CITIES

The governance of OHS in Turkey is at a transformative crossroads, driven by the pressures of rapid urbanization, post-pandemic recovery, and the digital shift toward Industry 4.0/5.0. While Turkey possesses a sophisticated legal framework (Law No. 6331) and advanced digital monitoring tools like İSG-KATİP, a significant implementation gap remains due to administrative fragmentation and a large informal economy

The Current Landscape: A Structural Paradox

Turkey's OHS environment is characterized by world-class digital architecture contrasted against chronic enforcement challenges in highly mobile urban settings.

- **Legal Strength:** As of January 1, 2026, OHS mandates cover all formal workplaces, regardless of size or risk level. Platforms like e-Nabız and İSG-KATİP offer potential for real-time tracking of occupational diseases (Çalış & Buyukakinci, 2019; Çabuk, 2025).
- **The "Invisible" Workforce:** including millions of refugees and migrants operates informally, remaining outside the reach of safety standards. Current enforcement relies heavily on punitive fines, which often drive these businesses further into the shadows (Yıldırım et al., 2022).
- **Sectoral Failures:** The construction industry, in particular, remains plagued by high accident rates and an immature inspection system that lacks the coordination necessary for meaningful reform (Yıldırım et al., 2022).

Integrated Urban Resilience & Mobility

Post-pandemic research in Istanbul highlights that sustainable city planning and public health are mutually reinforcing.

- **Healthy Urbanism:** Future resilience depends on "de-densifying" indoor spaces and integrating green infrastructure to mitigate contagion risks (Agboola, 2025). Successful responses require a balance of centralized decision-making and active local implementation (Ahsan, 2020).
- **Sustainable Urban Mobility Plans (SUMPs):** Transitioning from chronic congestion to sustainable mobility requires embedding health security indicators such as risk perception, crowding, and infection risk into transport planning (Spadaro & Pirlone, 2021).
- **Policy Translation:** Benchmarking successful models (like London's Mayor's Transport Strategy) requires "translating" international standards into Turkey's specific local institutional structure to overcome fragmented governance (Canıtez, 2020).

Strategic Roadmap for Turkey (2026–2033)

The proposed roadmap(See Table 1) advocates for a transition from a punitive culture to a protective, preventive one through a phased approach.

Table 1. The proposed roadmap for Turkey

Phase	Focus	Key Actions
Short Term (1–3 Yrs)	Alignment	Update regulations to integrate OHS 5.0 and SDGs; mandate health security indicators in all SUMPs .
Medium Term (3–7 Yrs)	Scaling	Establish a National–Metropolitan Coordination Platform; standardize OHS KPIs in all Public-Private Partnership (PPP) contracts (Canıtez, 2020).
Long Term (7+ Yrs)	Consolidation	Fully operationalize a digital OHS information system; use "health footprint" metrics to evaluate municipal performance .

Key Recommendations for Reform

- **The "Legal Firewall":** Establish a barrier preventing OHS data from being shared with migration authorities, ensuring that informal and migrant workers can report hazards without fear (Yıldırım et al., 2022).
- **Incentivized Compliance:** Shift to a "Guidance First" model for SMEs, offering financial incentives such as Social Security (SGK) premium discounts for workplaces with verified safety records.
- **Quadruple-Helix Collaboration:** Build alliances between public authorities, researchers, businesses, and citizens to increase the legitimacy of OHS measures (Agboola, 2025; Yıldırım et al., 2022).
- **Educational Mainstreaming:** Embed OHS and health security modules into university curricula (SDG 4) to support a preventive culture and future workforce skills (Kavouras et al., 2022).

DISCUSSION

The literature emphasizes that integrating OHS governance with public health is critical for sustainable, mobile urban environments, especially where informal, precarious, and non-standard work is prevalent. Fear of sanctions and job loss often suppresses reporting of unsafe conditions, allowing occupational hazards to spill over into wider public health risks such as disease outbreaks, environmental contamination, and gaps in surveillance. Shifting from purely punitive enforcement toward graduated, incentive-based compliance, supported by tools like amnesties, mobile training, and community safety champions can improve trust, extend regulatory reach, and enable incremental safety improvements without undermining livelihoods.

Contemporary OHS governance is increasingly multilevel and network-based, moving beyond command-and-control regulation toward orchestrated governance that combines legal rules with social dialogue, coordinated inspections, incentives, and information-based instruments. Evidence from Europe shows that strong vertical and horizontal coordination across EU, national, sectoral, and workplace levels is essential. Binding regulation provides the most durable impact, but its effectiveness depends on institutional capacity, while softer tools often struggle to translate into sustained workplace practice.

Broader transformations: digitalization, globalization, climate change, and the expansion of informal and platform work have fragmented labor markets and created new physical, psychosocial, and environmental risks, disproportionately affecting urban and climate-exposed workers. In response, scholars call for adaptive OHS frameworks aligned with the Decent Work agenda that integrate top-down regulation with bottom-up participation, link OHS data with public health surveillance, protect vulnerable and informal workers, and incorporate environmental and community health impacts into enforcement.

The provided text outlines a fundamental shift in OHS governance, moving from isolated "command-and-control" enforcement toward an orchestrated, multilevel model that integrates workplace safety with broader public health and urban sustainability. In modern, mobile urban environments, OHS is no longer just about preventing site-specific accidents; it is a critical component of community resilience. The literature highlights that when OHS is disconnected from public health, occupational hazards such as disease outbreaks or chemical leaks, remaining hidden due to workers' fear of reporting, thereby undermining national health surveillance (Schulte et al., 2022). To address this, a "four-pillar" strategy is proposed, emphasizing Institutional Capacity, Integrated Data, Enforcement Toolkits, and Inclusive Adaptability (Weber et al., 2023; Hasle et al., 2017).

A major barrier to effective OHS in urban contexts is the scale of the informal economy, where platform-based and migrant workers often avoid engaging with OHS systems out of fear that inspections may trigger immigration enforcement, rendering occupational risks largely invisible. To overcome this, the literature emphasizes the need for legal firewalls that explicitly separate OHS enforcement from immigration authorities, ensuring that all workers can report hazards and access protections without fear of retaliation or deportation (NIOH, 2022). In parallel, a shift from purely punitive regulation toward graduated compliance is recommended, whereby "guidance-first" approaches, temporary amnesty periods, and supportive inspections enable informal and small businesses to improve safety practices incrementally while preserving livelihoods, trust, and regulatory legitimacy.

The transition from traditional regulation to orchestrated governance represents a move toward "network-

based" regulation. Success depends on horizontal and vertical coordination from international frameworks (EU/ILO) to local municipal enforcement (Weber et al., 2023). In Turkey's context, this is reflected in the transition toward "OSH 5.0," which aligns safety standards with the UN Sustainable Development Goals (SDGs) and human-centered Industry 5.0 principles. The integration of OHS data with public health databases (such as Turkey's e-Nabız or İSG-KATİP) allows for the early detection of emerging threats. By sharing real-time metrics on workplace illness clusters, cities can trigger public health investigations before a localized hazard becomes a community-wide crisis.

While digitalization in Industry 4.0/5.0 reduces some physical risks, it introduces new psychosocial hazards, such as increased surveillance stress and cognitive workload. Furthermore, climate change acts as a "risk multiplier," where extreme heat and pollution disproportionately affect outdoor urban workers. A resilient governance framework must therefore be adaptive, integrating environmental health standards into OHS licensing and emergency preparedness. OHS in sustainable, mobile cities is most effective when it functions as a preventive public health strategy. By moving from "punishment to protection," and fostering "quadruple-helix" collaborations (government, business, researchers, and citizens), cities can build a safety culture that promotes social equity and long-term economic productivity (Hasle et al., 2017; Agboola, 2025; Schulte et al., 2022).

Overall, sustainable OHS outcomes in urban settings depend on strong institutional capacity, integrated data systems, inclusive enforcement strategies, and coordinated multilevel governance. When aligned with public health, OHS functions as a preventive policy tool that reduces community health risks, promotes social equity, and strengthens urban resilience.

CONCLUSION

The evolution of OHS from a narrow regulatory function to a pillar of sustainable urban governance is essential for protecting the modern, mobile workforce. As digitalization and informality fragment labor markets, traditional "command-and-control" models must be replaced by multilevel, orchestrated approaches that integrate workplace safety with public health, environmental standards, and urban mobility planning. The risks identified in the platform economy and "triangular" employment underscore the need for inclusive, adaptive strategies. In Turkey, bridging the "implementation gap" requires transitioning from punishment to protection by establishing legal firewalls for vulnerable workers and adopting "OSH 5.0" frameworks. Strengthening institutional capacity ensures that safety remains a driver of community wellbeing rather than a bureaucratic burden. Ultimately, the convergence of digital innovation and participatory governance is vital to ensuring that urban sustainability is never achieved at the expense of human dignity.

Taken together, the literature demonstrates that OHS in sustainable, mobile urban environments can no longer be treated as a discrete workplace issue. Effective protection depends on integrated, multilevel governance in which national frameworks aligned with the Sustainable Development Goals set clear standards, city and regional authorities are empowered to coordinate and implement them, and organizations embed robust OHS management systems into everyday practice. When inspections, data sharing, and corrective actions are coordinated across governance levels, OHS functions as a core element of preventive public health, ensuring that protecting workers simultaneously protects communities.

At the same time, significant implementation gaps persist. Smart city, digitalization, and mobility policies increasingly acknowledge safety, health, and epidemic risk as design criteria, yet worker-focused "smart OHS" and coherent intergovernmental coordination remain underdeveloped. These gaps are most visible in mobile, multi-employer urban labor markets, where temporary and agency workers face systematically higher risks due to economic pressures, fragmented responsibilities, and regulatory misfit between public rules and workplace realities. Addressing these challenges requires governance frameworks that explicitly account for labor mobility and non-standard employment. Clear allocation of duties between agencies, host employers, and regulators; stronger coordination across administrative levels; and meaningful participation and voice for temporary workers are essential. Combined with education, digital innovation, and inclusive enforcement strategies, such approaches enable OHS to support not only safer work but also broader goals of urban sustainability, equity, and resilience.

Acknowledgments

During the preparation of this manuscript, the authors used artificial intelligence–assisted tools to support the literature review process and facilitate efficient access to relevant sources. In addition, AI-based assistance was employed to enhance language refinement and clarity during the drafting and editing stages of the manuscript. The authors critically reviewed and edited all AI-assisted outputs and take full responsibility for the accuracy, integrity, and originality of the final publication.

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DOI: 10.7251/JTTTP2601061M
UDC: 656.132.025.6:629.038

PRELIMINARY REPORT

The eko2 line in belgrade as a contribution to the development of e-mobility in the city

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Recived: March 30, 2026
Revised: May 13, 2026
Accepted: May 29, 2026

Abstract: Buses powered by conventional fuel (diesel, CNG) are still the most common drive system in most cities of the world, including in Belgrade. The share of zero-emission buses, which primarily include electric-powered buses (E-bus), including the application of fuel cell and hydrogen technology, has a distinct upward trend in almost all developed cities of the EU and the world. Replacing conventional buses with zero-emission buses significantly contributes to the E-mobility strategy, which aims to decarbonize and reduce harmful gas emissions in cities originating from public transport vehicles. Electric buses have significantly higher energy efficiency compared to conventional buses, which is another reason for their use. The paper will present the environmental and energy effects of the use of electric buses in Belgrade on the EKO 2 line, which has been in operation since 2022, with an overview of the applied technology of E-bus, storing electricity, and charging infrastructure. At the end of the paper, a plan for the development of E-mobility of public transport in Belgrade is presented, which implies the introduction of a larger number of electric buses in the public transport system.

Keywords: E-mobility, E-bus, energy efficiency, ecology, development

INTRODUCTION

The transport sector takes an important place in meeting the needs of society in the transport of goods and passengers, but at the same time it is also a source of emissions of harmful gases and carbon dioxide as a result of the burning of fossil fuels. The use of fossil fuels is directly proportional to the industrial and economic development of a country, region or city [1]. In 2023, carbon dioxide (CO2) emissions originating from the transport sector amounted to 25% [2], as a result of the burning of fossil fuels, primarily oil derivatives, which is a share of about 57% of total oil consumption at the global level [3].

According to UITP data, in 2018 the share of diesel-powered buses in sales was around 80% [4], and in 2025 their share would be 15.6 % [5]. The system of public urban passenger transport is one of the most important functions of any city. Buses powered by diesel fuel are still the most represented drive system in most cities of the world, including in Belgrade, but with a constant trend of decreasing representation.

The use of fully electric buses for public urban transport should further reduce the level of emissions of harmful gases in cities, increase energy efficiency and contribute to the strategy of using zero-emission vehicles in cities, which is planned after 2050 [6,7]. The rapid development of battery technology and charging systems has contributed to the concept of electric buses being increasingly present in many cities since 2008, primarily in China, India, Europe, North and South America.

It can be considered that the concept of electric drive today has the greatest perspective for use in buses used in the public transport system, given that the performance of electric buses in terms of operational requirements (autonomy, transport capacity, charging time) has reached such a level that they can be a successful replacement for conventionally driven buses [8].

EU POSITION ON ELECTRIC MOBILITY IN PUBLIC TRANSPORT

In 2019, the European Union adopted Directive 2019/1161 (EU Directive 2019/1161) on clean vehicles (English: Clean Vehicle Directive), which in the sector of commercial vehicles (categories N2, N3, and M3) defines [9]:

- Zero-emission vehicles, which do not have internal combustion engines and whose CO2 emission does not exceed 1 g/kWh according to the criteria of EU Regulation 595/2009, i.e., 1 g/km according to the criteria of EU Regulation 715/2007. These vehicles include electric buses (with battery or supercapacitor), fuel cell buses, and trolleybuses when they work in autonomous mode and use electricity from the battery.
- Low-emission vehicles that use one of the alternative fuels defined by Directive 94/2014/EC.

These vehicles include hybrid-powered buses (Plug-in), standard hybrids, and CNG (compressed natural gas) buses.

According to the EU-Directive on clean vehicles 2019/1161, zero-emission vehicles represent an implementation strategy, so that from 2033, zero-emission buses (E-bus, fuel cells) should have absolute primacy in use in the public urban transport system of cities. According to the aforementioned Directive, all EU member states must, when procuring new buses, have a representation of buses with low and zero emissions according to the prescribed quota. For the period until 31.12.2025. year, the most developed EU countries (Germany, the Netherlands, Sweden...) had an obligation to purchase new buses with low and zero emissions, 44% of which 22% must be buses with zero emissions. EU member states that are less economically developed (Bulgaria, Romania, Croatia) had a set quota for the participation of buses with low and zero emissions between 28% and 32%.

As of January 1, 2026, the mentioned quotas have been increased by an average of 30% [9]. It is also important to mention the EU Directive 2014/94 [10], which refers to the use of alternative fuels in the transport sector, namely: Electricity, natural gas, biomethane, biofuels, hydrogen, synthetic diesel, liquefied petroleum gas, which should reduce the use of fossil fuels (diesel, gasoline) in the transport sector.

Tendencies of increasing use of zero-emission buses, which include electrically powered buses, trolleybuses and buses powered by fuel cells (fuel cells) and low emissions of harmful exhaust gases, which include CNG-powered buses, can be seen through the trend of the increase in the number of newly registered buses for public city transport for the EU 27 countries, i.e. for Norway, Iceland and Switzerland in 2023 and 2024. In 2023, the following were recorded: 6354 electric-powered buses, 4022 hybrid (diesel-electric) buses, 2883 CNG-powered buses, and 181 hydrogen-powered (fuel cell) buses, while the number of newly registered electric-powered buses in 2024 was 7779, which is an increase of 22.4% compared to 2023.

The growth trend of newly registered electric buses continued in 2025. Of the total of 12,165 newly registered E-buses, 11,605 were battery-powered, and 558 were fuel cell-powered. Compared to 2024, there was an increase of 56 % [5,11].

EXPERIENCES AND EFFECTS OF USING E-BUSES ON THE EKO 2 LINE IN BELGRADE

The public urban transport system in Belgrade has a total of 1481 rolling stock, of which the bus subsystem participates with 1289 vehicles in operation (about 87% of the total number of vehicles). Respectively, from the total number of buses that are in daily use, 516 buses belong to JKP GSP "Belgrade" and 773 buses belong to associations of private carriers [12]. Diesel-powered buses are the most prevalent and, as such, are one of the causes of urban pollution and exhaust gas emissions in Belgrade.

The main harmful emissions of IC engines using conventional fuel are: carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (CxHy), micro particles (PM10), smoke, and carbon dioxide (CO2) emissions. Starting from the fact that the buses of the city operator JKP GSP "Beograd" consumed about 14.1 million liters of Euro diesel and about 9.2 million kilograms of CNG (compressed natural gas) to achieve annual transport work in 2025 [13], leads to the conclusion that the effects of air pollution reduction in Belgrade can be significantly achieved by efficient energy and technical-technological management, as well as by successive renewal of the fleet with ecological vehicles with "zero" and low emission of exhaust gases in the bus subsystem of public city transport. In the area of Southeast Europe, the City of Belgrade is the leader in the implementation of the electric bus concept. A total of 15 E-buses from the Chinese manufacturer Higer are in operation on two city lines.

The first line, EKO 1 (Wolf Monument- Bellvil), on which only electric buses operate, was put into operation on September 1, 2016. year, while the second line EKO 2 (Dorcol / Sports center M.G. Muskatirović - Belgrade Waterfront) was put into traffic on January 24, 2022. year. The basic technical characteristics of E-bus (Figure 1) operating on the EKO 2 line are shown in Table 1.

Figure 1. E-bus Higer KLQ6125GEV3

Table 1. Technical characteristics E-bus Higer

Dimensions: length, width, height: 12.000x2.550x3.680 mm
Mass of empty vehicle: 12.120 kg
Number of places for sitting/ standing: 28/62
Number of doors: 3
Maximum speed: 70 km/h
Drive electric motor: Siemens 1DB2016 6NBO6 permanent magnet, central position
Max. power of the driving electric motor: 160/230 kW
Maximum torque: 2500 Nm
Drive controller: Siemens ELFA 3
Ultracapacitor: AOWEI
Capacity: 40 kWh
Charging time: 2-5 min

Figure 2. Route of the EKO2 line

Line EKO 2 is a typical city line. The average length of the line is 7.1 km, and the average transport speed is 13.8 km/h. The line connects the most attractive areas of the city: Belgrade on the water, Trg Slavija, Trg Republike, Kalemegdan, and Dorcol. 8 vehicles are operating on the line with an average arrival interval of 10 minutes [14].

The infrastructure (chargers) for fast charging of E-buses is installed at the terminus of the lines. The chargers are connected to the AC distribution network via

substations located in the immediate vicinity of the chargers. The high power of the charger enables the supercapacitor with a capacity of 40 kWh, which is built into the E-bus Higer, to be charged in just 2÷5 minutes. A view of the fast charger at the Dorcol terminus (Sports Center) is given in Figure 3. The basic characteristics of the charger are shown in Table 2.

Figure 3. Fast charger /Dorcol terminus/

Tabela 2. Technical characteristics of the charger

Input voltage .....3x380 V
Max.Power ..... 400 kW
Max.output voltage.....750 V DC
Charging efficiency 97%
Charger contact height .... 4.5-4.6 m

The introduction of E-buses into regular operation on the EKO 1 and EKO 2 lines in Belgrade is interesting for the analysis of the environmental effects compared to buses with other propulsion systems (diesel, KPG). In this sense, aspects of the impact on the environment of the immediate environment, where the vehicles are in operation (local level) can be analysed, which in the literature is called "Tank to Wheel-TTW" and the environmental impact on the wider environment, i.e. the region or the country, which is known as the analysis Well to Wheel-WTW. In the case of the TTW analysis, the propulsion system of electrically powered buses has no emissions: CO, NOx, CxHy, PM10, which makes them environmentally most suitable for working primarily on central city lines and traffic roads with the highest vehicle frequencies, thus contributing in the best way to reducing the impact of harmful exhaust gas emissions.

The environmental impact at the local level is minimal, considering that the only negative impact on the environment comes from the formation of microparticles and dust due to the contact of tires and the road, from the friction of brake linings, and the evaporation of working fluids (transmission lubricating oil, antifreeze, etc.), which can be ignored. The way electricity is produced and transmitted is essential when analyzing the environmental performance impacts of electric buses on a regional or national level, i.e., WTW analysis.

The analysis of WTW carbon dioxide emissions is important to understand and compare the level of emissions emitted by buses with different propulsion systems, including purely electric buses. The aspect of carbon dioxide emission that occurs during the electricity production phase is particularly important here, given that electricity is obtained from different sources [8,15].

The analysis WTW of CO2 emissions from electric buses is based on the fact that the production of electricity in the Republic of Serbia is predominantly from thermal power plants, with a representation of around 70%. The rest of the production comes from hydroelectric power plants, about 27%, and solar panels and wind generators, 3%. Given that the share of electricity production from thermal power plants is 70%, the standard CO2 emission factor (g/kWh) in electricity production is 774 g/kWh [8].

The results of measuring the average energy consumption for buses with different drive systems on the EKO 2 line are shown in Table 3.

Table 3. Energy consumption on the EKO2 line for buses with different drive system

Drive system	Average consumption (L/100 km)	Average consumption (kWh/km)	Average consumption (kg/100km)	Emissions CO2 (WtW) (g/km)
E-bus 12m, Higer KLQ6125 GEV3	-	1.15	-	952.4
Diesel bus 12m, Higer KLQ6129 GQ2 (Euro 6)	46.1	4.6	-	1394
CNG bus 12m (Euro 6)	-		47.0	1399

In the case of E- buses, the average consumption of electricity is 1.15 kWh/km [16], the CO2 emission (WTW), including transmission losses in the network, is 952.4 g/km [8,17]. Under the same operating conditions on the EKO2 line, the diesel-powered bus has a consumption of 46.1 l/100 km [18] and a CO2 emission (WTW) of 1394 g/km. A bus on CNG with an expected consumption of 47 kg/100 km [18] would achieve a CO2 emission (WTW) of 1399 g/km [17]. From this calculation, it can be concluded that the level of CO2 emission (WTW) is about 31.6% lower for an electric bus compared to a diesel bus, or 31.9% lower compared to a CNG bus. The "Tank to Wheel" (TTW) analysis of electric buses can be seen in the context of the environmental effect achieved by replacing buses using diesel fuel by quantifying the amount of pollutants that will not be emitted into the atmosphere as a result of vehicle substitution. In a specific example, one diesel-powered bus on the EKO2 line would have annual emissions of: 164.2 kg CO, 14.2 kg CxHy, 43.8 kg NOx, 1.09 kg PM10 [17].

Based on the data on power consumption on the EKO 2 line, it follows that the E-bus "Higer KLQ-6125GEV3" has more than 4 times higher energy efficiency than the diesel and CNG-powered buses. The high energy efficiency of electric-powered buses is a consequence of the greater degree of beneficial effect of the drive system inverter-electric motor (0.92÷0.95) compared to IC motors in buses with conventional drive, as well as the possibility of recuperating electrical energy

during the braking and deceleration phase. The effect of recuperation on the EKO2 line reaches up to 40% of the total energy consumed [16]. Electric buses have a significantly lower level of emitted noise. Compared to diesel-powered buses at a speed of 30 km/h, the emitted noise level of the E-bus is 8 dB lower. Compared to the KPG bus, the emitted noise level is lower by about 6 dB [8].

DIRECTIONS FOR FURTHER DEVELOPMENT OF E-MOBILITY IN THE PUBLIC TRANSPORT OF BELGRADE

An intense trend of increasing the number of electric buses in the public transport system of Belgrade is expected in 2027. As is known, the Republic of Serbia, i.e., the City of Belgrade, will host the World Exhibition EXPO 27. During the event, which will last from May 15 to August 15, 2027. Eight (8) lines will be established that will transport visitors from different parts of the city. It is planned that electric buses will operate on the lines. Table 4 shows the lines on which the E-bus will operate during the EXPO27 event [19].

Electric buses will be equipped with batteries with a large capacity of 420÷500 kWh and will be charged at the depot during the night with chargers with a power of 120÷150 kW. In addition to battery buses, buses with supercapacitors will be used as an electrical energy storage system, which will be charged at the terminus using 400 kW fast chargers. After the EXPO 2027 event, electric buses will be implemented in the existing bus subsystem of Belgrade. It is planned to replace diesel-powered buses with electric buses that will operate on central city lines such as lines 26, 27E, 35,... It is planned to establish new circular lines through New Belgrade, on which 25m long electric buses (Figure 4) will operate, with a capacity of 210 passengers, as well as new lines that will connect Block 20 with the EXPO exhibition complex.

The introduction of 90 new electric-powered buses into operation will result in a significant improvement in the environmental performance of the public transport system, which contributes to the sustainable development of the city's transport system as a whole.

CONCLUSION

The introduction of electric buses into the public transport system in Belgrade represents a significant qualitative shift from a technological and, especially, environmental point of view. JKP GSP "Beograd" represents a

Figure 4. Two-articulated E-bus, 25m

Tabela 5. Technical characteristics of 25m E-bus
- vehicle length: 25.0 m
- vehicle width: 2.55 m
- radius: max. 25 m
- powertrain: electric, synchronous motors, 2x160 kW
- passenger capacity: 210 passengers
- seats: 50
- places to stand: 160
- storage system: Ultracapacitor, 144 kWh
- charging strategy: fast, 400-600 kW

Tabela 4. Planned lines during EXPO 2027

Name of Line	Number E-bus in operation	Type of E-bus	E-bus Technology/Charging type
EXPO 1, Aerodrom N.Tesla-EXPO	6	12m	Battery/ slow at depot
EXPO 2, Beograd na vodi-EXPO	13	12m	Ultracapacitor/ fast at terminal
EXPO 3, Borča-EXPO	24	12m	Battery/ slow at depot
EXPO 4, Vukov spomenik-EXPO	15	12m	Ultracapacitor/ fast at terminal
EXPO 5, Ustanička-EXPO	14	12m	Battery/ slow at depot
EXPO 6, Blok 20-EXPO	10	12m	Ultracapacitor/ fast at terminal
EXPO 7, Blok 45-EXPO	6	24m	Ultracapacitor/ fast at terminal
Fider 1, EXPO žel.stanica-EXPO	2	24m	Ultracapacitor/ fast at terminal
Total	90		

good example of practice in the region when it comes to the promotion and application of electric buses. Measures to improve the bus fleet from the aspect of environmental requirements include the planned renewal of the fleet with vehicles that meet the highest environmental standards, primarily vehicles with zero and low emissions of harmful gases, and the withdrawal of diesel-powered vehicles from use.

The greater presence of electric buses is imposed as a realistic option in the medium term for significantly reducing harmful gas emissions on the streets of Belgrade, which will contribute to improving the quality of the environment and reducing the costs that the local community allocates for eliminating the consequences of its damage. The environmental benefits of the operation of electric buses in Belgrade are the best argument and support for the further development of this concept in Belgrade. The long-term strategy involves the exclusive use of electric vehicles in accordance with EU directives and good practices of public urban transport companies from Europe and the world.

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DOI: 10.7251/JTTTP2601066S
UDC: 351.811(497.6RS):[625.7:656.1.08

PROFESSIONAL PAPER

The effects of the preventive campaign "cautious drivers watch for level crossings " on road traffic safety in the Republic of Srpska

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Recived: December 3, 2025
Revised: May 3, 2026
Accepted: May 29, 2026

Abstract: Railway level crossings represent critical points in the road traffic safety system, where serious incidents with severe consequences occur despite the presence of prescribed signaling. From 2021 to 2025, the Republic of Serbian implemented a multi-sector preventive initiative entitled "Cautious Drivers Watch for Level Crossings", aimed at raising awareness among road users and reducing the number of extraordinary events at railway crossings. This paper analyzes the effects of the campaign through statistical data on the number of fatalities and injuries, as well as through the results of monitoring driver and pedestrian behaviour at crossings with different levels of protection. Special emphasis is placed on the role of local communities and cooperation with institutions in identifying high-risk locations, eliminating unsafe railway crossings, and educating the public. The presented results highlight the importance of continuous communication, systemic cooperation, and consistent enforcement as prerequisites for improving safety at railway level crossings.

Keywords: railway level crossings, road traffic safety, local communities, preventive campaigns

INTRODUCTION

Rail crossings are critical points in the traffic safety system, where despite the prescribed signage and technical infrastructure, serious traffic accidents with serious or fatal consequences occur. The European Union is 2022. more than 600 fatalities were recorded at road crossings over the year, with over 95% of these events being caused by human factors, most often by non-compliance with traffic regulations by road vehicle drivers (Cheng et al., 2023). Similar trends have also been observed in the Western Balkans region, where rail crossings represent a weak point of the security system, both due to insufficient technical equipment and due to insufficient awareness of traffic participants.

In Serbia, for example, in the period from 2018. by 2022. more than 200 accidents on railway crossings were recorded, with 33 fatalities — which confirms that in the region such locations have a disproportionately high security risk (ABS, 2023).

In order to improve security at these sites, targeted preventive activities are being carried out across Europe and the world. In the United States, the "Operation Lifesaver" program reduced the number of fatal outcomes by more than 40% during the first decade of application. According to data FRA, U past years recorded is more from 2.000 incidents annual on produžni crossings, what confirms need for continuous merama promotions security (Federal Railroad Administration, 2022). In Canada, Rudin-Brown et al (2014) analyzed traffic accidents at uncontrolled, rural rail crossings in 2003-2012, and identified nine dominant human factors as the cause – from reduced visibility to distraction and driver fatigue.

Within the framework of the European SAFER-LC project (2017-2020), which included 17 partners, 48 mea-

sures were developed to improve security at provided crossings, including technological solutions, video surveillance, anti-trespass panels and psychological interventions aimed at changing behavior. Research from the SAFER-LC project has also shown that a combination of technological solutions(e.g. video surveillance, sensors, DSRC communication) and behavioral interventions (visual alerts, training) are the most effective approach to risk reduction (SAFER-LC, 2020). According to the European railway agency (ERA), 224 people died in the EU at crossings in 2023. 71% of all incidents occurred at uncontrolled or light-controlled crossings without bumpers (MDPI, 2023). Selcat studies from 2008. they found that no-bumper crossings were still the most risky, with human factor accounting for 29% of direct causes. Modeling based on Poisson and negative binomial approaches is increasingly used as a reliable basis for identifying and prioritizing measures. In addition, the application of statistical models such as *Poisson* and *negative binomial* it demonstrated high reliability in predicting the frequency of accidents and in determining priority crossovers for intervention (Saccomanno et al., 2006; Elias and Bell, 2007).

In Studios from Lithuania (Gailienė and SAR., 2013) Al-Baqarah Su data American and European statistics, according to Kojima is the United States period 2006–2010 annual bilo over 2000 nezgoda on produžni crossings the EU more from 400 mortal cases, PRI what is human factor cause in over 90% cases. In Croatia, a study by the Zagreb FPZ (Starčević, Barić and Pilko, 2023), involving 185 experts, showed that combinations of technical and educational measures-especially those aimed at the youngest – are among the most effective in reducing risk.

In the Netherlands and Belgium, the application of anti-Trespas panels resulted in a 30-90% reduction in illegal track crossings in the initial period and up to 78% in three months, with long-term effects maintained at a level of 2% re-behaviour (Rosehill Rail, 2023).

According to a study published in the journal *Safety* The European Union is 2023. a year recorded 224 deaths and 176 serious injuries at rail crossings, with as many as 71% of incidents occurring at uncontrolled or light-controlled crossings without physical barriers (Cheng et al., 2023).

In the Republic of Srpska, as a response to frequent extraordinary events at rail crossings, 2021. a year ago, a campaign was launched called"Beware of rail crossings". The campaign was implemented by the Ministry of transport and communications of the Republic of Srpska, the Ministry of internal affairs of the Republic of Srpska, the Transport Security Agency of the Republic of Srpska, the Republic administration for inspection Affairs-Inspectorate of the Republic of Srpska, Railways of the Republic of Srpska, PE "roads of the Republic of Srpska", Auto-Moto Federation of the Republic of Srpska, and local self-government units, with the aim of reducing the number of traffic accidents and raising the level of awareness of participants in traffic. Activities included field tours of critical crossings, meetings with representatives of local self-government units through whose territory the railway infrastructure passes, distribution of educational material, counting the behavior of drivers and pedestrians at railway crossings with different levels of insurance, and a media campaign in local communities.

Data collected during the implementation of the campaign from 2021. by 2024. the years indicate certain positive developments, but also the need for further institutional strengthening, technical investments and formalization of cooperation between all actors. A special role in this process belongs to local communities, which have data on risk sites, manage a significant part of the infrastructure and directly participate in informing citizens.

The aim of this paper is to analyze the effects of the campaign "careful attention to rail crossings", show the role of local communities in its implementation, compare the results with similar initiatives in Europe, and offer recommendations for improving security at rail crossings in the Republic of Srpska in the coming period.

METHODOLOGY

The work relies on data and documentation collected within the preventive campaign "careful attention to rail crossings", which were in the period 2021-2024. the relevant actors in the field of traffic safety in the Republic of Srpska have implemented for years. Primary data sources include:

- internal reports of the Transport Security Agency,
- statistics on extraordinary events of Railways of the Republic of Srpska,
- results of field activities (counting the behavior of participants at crossings),
- media and educational reports on the implementation of the campaign.

For the sake of note, the data for emergency events include only those cases of a train running into a road vehicle or other participant in traffic.

This paper will present the results of the analysis of traffic counts and monitoring of the behavior of participants in traffic in 2024. years. The analysis includes 34 cross-border crossings in 10 local communities, divided by type of insurance (higher or lower level of insurance). In total, almost 14,000 observations of the behavior of drivers and pedestrians were made, with a record of whether they complied with the prescribed signage. Additional data on emergency events and incidents at crossings in the period 2020-2024 were analyzed. years.

The data were analyzed using a descriptive and comparative method, with particular reference to:

- frequency of non-compliance with rules by type of transition,

- the effects of time continuity of the campaign,
- and the role of the local community in organizing and adapting activities.

RESEARCH RESULTS

Field count results from 2024. years at 34 railway crossings in the Republic of Srpska show marked differences in driver behavior depending on the level of insurance.

At rail crossings with a higher level of insurance – i.e. those equipped with light-sound signaling and half – guards-extremely low non-compliance was observed: a total of 16 recorded violations on more than 8,594 samples, which represents only 0.18% of violations, and it is visible on Figure 1.

On the other hand, in Figure 2. crossings provided exclusively by traffic signs and the visibility triangle (lower level of insurance) were shown, where a total of 1,488 violations were recorded on 5,270 passes, meaning that every fourth to fifth driver (28.23%), did not pay attention to traffic signage. These data clearly indicate the necessity of additional technical interventions at critical

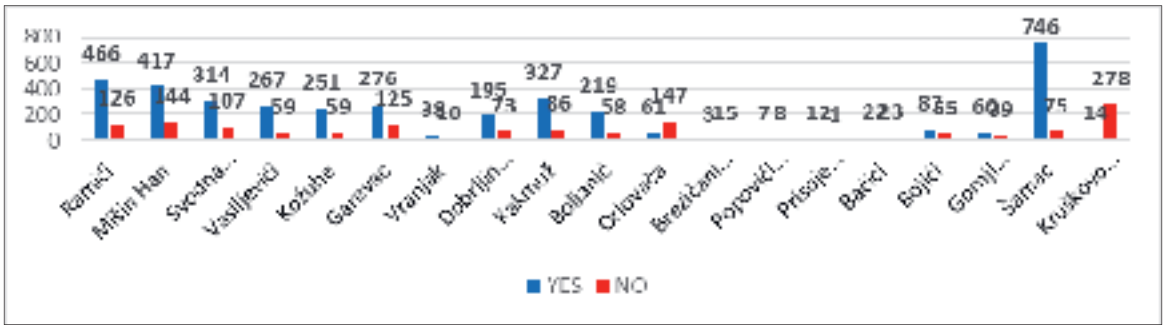

Figure 1. Counting traffic at rail crossings with a higher level of insurance

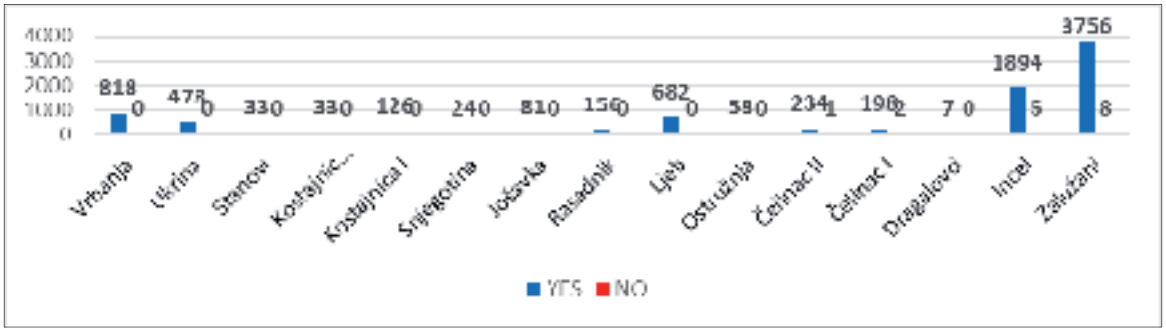

Figure 2. Counting traffic at rail crossings with a lower level of insurance

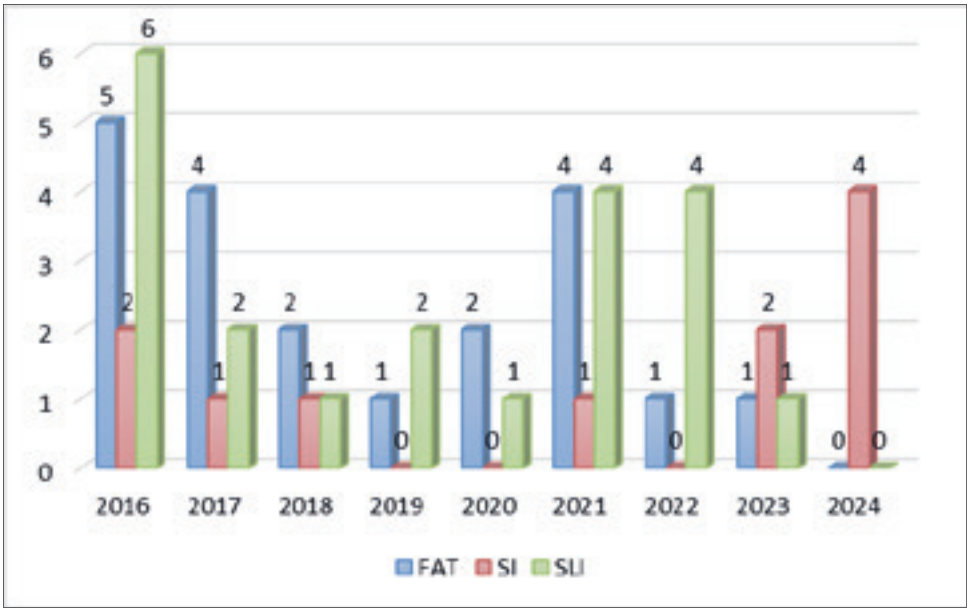

Figure 3. Structure of emergency events

sites and confirm that the human factor, in conditions of poor infrastructure support, significantly increases the risk of accidents.

As for emergency events, in the period from 2020. by 2024. in 2020, the number of traffic accidents on railway crossings was reduced from 11 to 4, with the number of deaths reduced from 4 (2020) to 1 (2024), and the number of seriously injured from 7 to 2. Although these are relatively small absolute numbers, the downward trend indicates a potential positive effect of a preventive campaign.

On Figure 3. the structure of extraordinary events in the observed five-year period is presented, according to the categories of consequences: killed persons (POG), severely injured persons (TTP) and lightly injured persons (LTP). The number of dead and seriously injured is the highest in 2021. years, followed by a significant decline. By 2024. for the first time, no deaths were recorded, and the number of minor injuries was reduced to zero.

The results indicate that the greatest effects were achieved in local communities that demonstrated the highest level of cooperation, supported field activities and integrated the campaign into their educational programs.

DISCUSSION OF RESULTS

The behavior of road users varies significantly depending on the location of the crossing and the level of technical security. Figures 1 and 2 show the number of drivers who obeyed (yes) or failed to comply with (no) regulations when crossing the railway at different crossings.

When it comes to crossings with a higher level of insurance (equipped with light-sound signaling and half-guards), the highest number of violations were recorded at The Incel rail crossing and in Zalugani, which indicates that the presence of equipment does not exclude risky behavior, especially in zones with high exposure and vehicle flow. In contrast, in most other transitions of this type (e.g. No violations of the rules have been recorded.

At transitions with lower levels of insurance (insured by signs and a visibility triangle), violations were significantly more common. Kruškovsko Polje stands out in particular, where as many as 278 of the 292 drivers ignored regulations, as well as Orlovača and Brezičani station. Data obtained from field observation and Accident Analysis indicate that the activities of the campaign "careful attention to rail crossings" had a measurable impact on reducing the risk at rail crossings in the Republic of Srpska. The reduction in the number of dead and injured, as well as the high percentage of correct behavior in most locations, indicate that the campaign has not only remained at a symbolic level, but has managed to reach citizens.

These results are consistent with the findings of the SAFER-LC project, which highlights the importance of combining technical and behavioral measures to improve safety at crossings. Comparable data from Poland, Croatia and Lithuania also suggest that multisectoral campaigns, when well targeted and consistent, can lead to concrete results. In particular, in Poland, the program "Bezpieczny Przejazd" has become a long-term part of the education and media system, which has significantly reduced the number of incidents at rail crossings (PKP Polskie Linie Kolejowe S. A., 2024).

Differences in behavior at individual crossings in the Republic of Srpska indicate the importance of adapting activities to the specificities of the place. At rail crossings where high levels of proper behavior were recorded, it is assumed that campaigns were better coordinated with local structures, media or schools. In contrast, high levels of rule-breaking indicate the need for a more intensive and targeted approach.

In addition, the results confirm the findings of FPZ research in Croatia (Starčević and associates, 2023) which recommend combining education, technical equipment and sanctions as the most effective model of action. It is shown that not only physical infrastructure is sufficient, but that a key role is also played by continuous communication with participants in traffic, tailored to the place and target group.

Although progress is visible, it is necessary to institutionalize cooperation between the Ministry of Interior, Railways, municipalities and educational institutions, and to develop a single action plan for risk crossings, based on risk assessment models such as those applied within SAFER-LC or in Lithuania. In this way, it is possible to maintain the achieved results and improve them in the long term.

CONCLUSION

Campaign "careful attention to rail crossings", implemented in the Republic of Srpska in the period 2021-2024. the year, is an example of an integrated preventive activity that included fieldwork, education, media promotion and technical interventions. The results of the analysis indicate significant positive effects: the number of traffic accidents decreased, the number of dead persons decreased, and the behavior of road users, especially in local communities that actively participated in the campaign, significantly improved.

These results support the conclusions of previous research conducted within projects such as SAFER-LC, where it was confirmed that multimodal interventions – technical, behavioural and institutional – have the greatest potential for Risk Reduction at cross-border crossings. The comparison with experiences from Croatia, Poland, Lithuania and the United States further confirms that the results are not accidental, but can be interpreted

as a product of a well-planned and directed preventive policy.

It is particularly significant that the positive effects are most pronounced in communities where the campaign has had the support of local institutions, the media, schools and the civil sector. This indicates the importance of adapting activities to a specific local context, which is in line with modern principles of Traffic Safety Management. Differences in behavior at different crossovers show that a uniform approach is not sufficient, but that interventions must be based on risk analysis and actual data on participants ' behavior.

Also, this campaign highlighted the potential of Field counting, behavioral observation and engagement of the local community as useful tools not only for diagnosing problems but also for changing the culture of behavior. The experience of the Republic of Srpska can serve as a model for other countries in the region, but at the same time indicates the need for further institutionalization of cooperation between security subjects – from the railway sector, through the police and municipalities, to educational and media subjects.

Based on the conclusions drawn, it is necessary to continue and expand the existing activities and improve them by establishing systemic mechanisms for monitoring, analysis and risk management at the provided crossings. Only through such an approach is it possible to ensure permanent improvement of safety and improve the culture of behavior of all participants in traffic.

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DOI: 10.7251/JTTTP2601071J
UDC: 656.1.08:656.11.021(497.6)

PROFESSIONAL PAPER

Analysis of Traffic Safety on the Laktasi – Klasnice 1 Road Section

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Recived: March 30, 2026
Revised: April 27, 2026
Accepted: April 30, 2026

Abstract: Road traffic safety represents one of the major challenges of modern society due to the significant negative consequences that traffic accidents have on human life, health and material property. The analysis of safety on specific road sections enables an objective assessment of safety conditions, identification of dominant accident causes, and recognition of hazardous locations, which provides a basis for improving road traffic safety. This paper analyses traffic safety on the main road M-1-101, specifically the Laktasi-Klasnice 1 road section, which is located on the territory of the City of Laktasi. The analysis covers the period from 2020 to 2022 and is based on statistical processing of traffic accident data, including their structure, consequences, and causes. The research analyzes the total number and structure of traffic accidents, the consequences per person (road users), the time distribution of accidents, as well as accident causes. In addition, traffic accidents were mapped and dangerous spots were identified, along with an assessment of public and traffic risk on the observed road section. The results indicate the presence of critical sections with an increased level of risk. The results obtained can serve as a basis for planning and implementing measures to improve traffic safety and reduce the number of traffic accidents and their consequences.

Keywords: traffic safety, traffic accidents, risk analysis, dangerous spots

INTRODUCTION

Road transport plays a dominant role in the overall transportation system, but it is also associated with significant safety challenges, among which traffic accidents represent the most serious issue. Traffic accidents constitute a major social problem due to their severe human and economic consequences. According to reports by the World Health Organization, approximately 1.3 million people die annually in road traffic accidents worldwide, while between 20 and 50 million people sustain non-fatal injuries. Road safety is influenced by multiple factors, including road infrastructure characteristics, road user behavior, vehicle condition, and traffic flow organization. The analysis of road safety on specific road sections is particularly important, as it enables the identification of hazardous locations, the recognition of dominant accident causes, and the assessment of accident structure and consequences. Based on such analyses, targeted and effective measures for improving road safety can be defined. This paper analyzes road safety on the section of the main road M-1-101 (Banja Luka – Gradiska), specifically the Laktasi – Klasnice 1 section, located within the territory of the City of Laktasi. The section has strategic importance due to its role in connecting major urban centers and is characterized by high traffic volumes and increased safety risk. The aim of this study is to assess the state of road safety on the observed section for the period 2020–2022, identify key risk factors, and determine hazardous locations. The analysis is based on statistical processing of traffic accident data, including their structure, consequences, temporal distribution, and causes, as well as the assessment of public and traffic risk. The obtained results provide a basis for proposing measures aimed at improving road safety on the analyzed section.

LITERATURE REVIEW

Traffic safety analysis and the identification of hazardous locations represent an important area of research aimed at improving road safety and reducing the number of traffic accidents. In this context, hazardous locations, commonly referred to as "black spots", are defined as road sections with a significantly higher concentration of traffic accidents compared to other parts of the road network. Modern approaches to traffic safety analysis emphasize that accident occurrence is not the result of a single factor, but rather a combination of infrastructural characteristics, traffic flow conditions, and road user behavior. Therefore, the identification of hazardous locations requires a comprehensive analysis that includes both spatial distribution of accidents and the characteristics of the road environment ,[18]. Particular attention in the literature is given to the impact of road infrastructure on accident occurrence. Road sections with a high density of direct access points, intensive linear development, and mixed traffic conditions are often identified as high-risk areas due to the increased number of conflict points. Frequent vehicle entry and exit maneuvers, combined with insufficient traffic organization, significantly increase the probability of accidents . In addition to infrastructure, the presence of vulnerable road users, such as pedestrians, further increases the complexity of traffic conditions. Locations with pedestrian crossings, public transport stops, and direct access to residential and commercial facilities are especially sensitive, as they involve frequent interactions between vehicles and pedestrians. Research conducted in the Western Balkan region highlights that road design and infrastructure management play a key role in traffic safety. Inadequate infrastructure and insufficient control of access points are recognized as significant contributors to accident occurrence . Furthermore, studies focusing on traffic safety in the Republic of Srpska indicate that there has been no significant decrease in the number of traffic accidents, injured, and fatalities in recent years, emphasizing the need for detailed analysis of specific locations and the identification of key risk factors. Based on these findings, this study focuses on the spatial analysis of traffic accidents and the identification of hazardous locations, with particular emphasis on the influence of infrastructural characteristics and traffic conditions on accident occurrence.

Previous research indicates that hazardous locations should not be identified solely based on accident frequency, but rather in relation to the expected safety level of similar road sections . Advanced spatial analysis methods, such as kernel density estimation, are increasingly used for identifying accident clusters, as they provide more accurate spatial representation of risk . In addition, recent studies have emphasized the importance of incorporating traffic exposure indicators, such as traffic volume (AADT), in order to achieve a more accurate assessment of accident risk and to avoid bias related to raw accident frequency. Modern approaches to traffic safety analysis also emphasize the importance of combining infrastructural, behavioral, and traffic flow factors in order to achieve a comprehensive assessment of road safety conditions.

REGULATORY AND INSTITUTIONAL FRAMEWORK

Road safety in Republic of Srpska and Bosnia and Herzegovina is regulated by national legislation and international documents that define risk management, the identification of hazardous locations, and the implementation of preventive measures. At the level of Republic of Srpska, the field of road safety is governed by the Law on Road Traffic Safety of Republic of Srpska , which prescribes traffic rules, institutional responsibilities, and safety management. Procedures for the identification and remediation of hazardous locations on the road network are further elaborated through by-laws, primarily the Rulebook on the Identification of Hazardous Locations, Methods and Criteria for Determining Priorities for Their Elimination, and Methods of Hazardous Location Treatment , adopted pursuant to the aforementioned law. At the state level, the Law on the Basics of Road Traffic Safety in Bosnia and Herzegovina defines the fundamental rules of conduct for road users, the requirements that drivers and vehicles must meet, as well as a unified system for recording traffic accident data, thereby ensuring comparability and systematization of data across the entire territory of the country.

The international framework is defined by Directive 2008/96/EC on road infrastructure safety management, which emphasizes the importance of a systematic and preventive approach to road safety management through the identification of accident concentration locations (black spot analysis), risk assessment, and continuous improvement of infrastructure throughout the entire road lifecycle. In accordance with this Directive, European Union Member States are required to introduce procedures that include road safety impact assessments in the early planning stages, safety audits during the design phase, management of hazardous locations on the existing network, as well as regular road safety inspections. Particular emphasis is placed on problem definition and analysis of the existing situation, consideration of the "do-nothing" scenario, the establishment of measurable road safety objectives, and the comparative analysis of proposed alternatives, including the assessment of their effectiveness and justification. The Directive also provides for the systematic consideration of key elements affecting safety, such as severe consequences (fatalities and serious injuries), the presence of vulnerable road users (pedestrians, cyclists, motorcyclists), traffic volume and structure, impacts on the existing road network (intersections, access points), seasonal and climatic conditions, as well as road geome-

try and roadside equipment characteristics. Furthermore, criteria are defined for application during the conceptual and detailed design phases, as well as prior to commissioning and during the initial period of operation, with the possibility of subsequent review based on actual user behavior. The fundamental principles of this Directive are also recognized in national legislation, particularly in the segments related to hazardous location management and road safety audits. The presented regulatory framework provides the methodological basis for the analysis conducted in this paper, particularly in the segment related to the identification of hazardous locations and the assessment of public and traffic risk on the observed section of the main road M-1-101.

METHODOLOGY

The road safety analysis was conducted on the section of the main road M-1-101 Laktasi – Klasnice 1 for the period from 01 January 2020 to 31 December 2022. During the observed period, the official database of traffic accidents of the Ministry of Interior of the Republic of Srpska was used, and the collected data were analyzed using descriptive statistical methods. Data on the population of the City of Laktasi were obtained from the results of the 2013 Population , while data on the number of registered vehicles were taken from official statistical publications . The methodological framework and part of the analyzed data are based on the author's previously completed undergraduate thesis . The analysis included the structure of accidents according to consequences, causes, age and gender structure of participants, temporal distribution (by year, day of the week, and hour), as well as the spatial concentration of accidents. The identification of hazardous locations was carried out in accordance with the applicable regulatory framework . Based on the obtained results, an assessment of public and traffic risk was performed. The spatial analysis of traffic accidents was conducted using GIS-based tools, specifically Google Earth, which enabled precise geolocation and visualization of accident locations along the observed road section. In addition to accident mapping, an assessment of access density was conducted. The number of intersections with local roads and direct access points from residential and commercial properties was determined through visual inspection and counting using GIS tools along the observed road section. Based on these data, access density was calculated as the number of access points per kilometer. Each accident was positioned according to available coordinate data, allowing for the identification of spatial clusters and the analysis of accident distribution patterns.

ROAD SAFETY ANALYSIS ON THE LAKTASI – KLASNICE 1 ROAD SECTION

The analysis of traffic accidents represents a key part of this paper, as it enables an assessment of the actual state of road safety on the observed road section. This chapter presents the results of the analysis of traffic accidents that occurred on the Laktasi – Klasnice 1 road section in the period from 2020 to 2022. The analysis was conducted according to multiple criteria in order to obtain a comprehensive overview of the scope, structure, and causes of traffic accidents.

Statistical Overview of Traffic Accidents (2020–2022)

During the observed period, a total of 169 traffic accidents were recorded on the road section. By year, 42 accidents were recorded in 2020, 54 in 2021, and 73 in 2022. The total increase in the number of accidents in 2022 compared to 2020 amounts to 73.8%, indicating a continuous growth of safety risk on the observed section. This is presented in **Figure 1**.

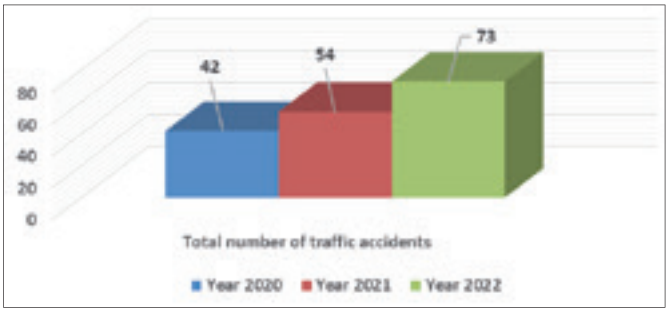

Figure 1. Graphical presentation of the total number of traffic accidents in the period 2020–2022

Consequences of Traffic Accidents for Persons

During the observed period, out of a total of 169 traffic accidents, 141 accidents (83.4%) resulted in material damage, while 28 accidents (16.6%) involved injured persons. No fatal traffic accidents were recorded. Within the structure of accidents involving injured persons, 7 accidents with seriously injured persons and 21 accidents with slightly injured persons were recorded. The increase in the number of accidents involving injured persons was particularly pronounced in 2022, indicating a rise in the severity of consequences during the observed period, as shown in **Figure 2**.

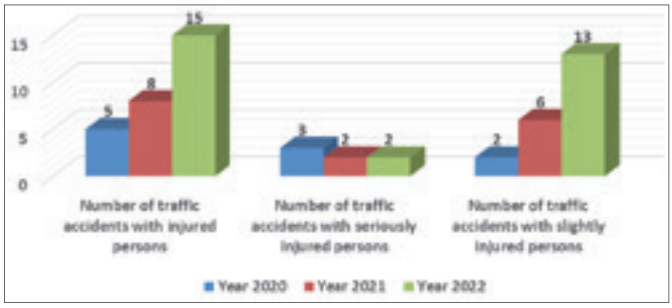

Figure 2. Graphical presentation of the number of t/a with consequences for persons in the period 2020–2022

Table 1. Categories of seriously injured persons in the period 2020-2022

Category of seriously injured persons	2020.	GENDER	2021.	GENDER	2022.	GENDER
Number of seriously injured persons	3	M: 3	3	M: 2 F: 1	2	M: 1 F: 1
Driver of a passenger vehicle	2	M: 2	1	M: 1	0	-
Front-seat passenger in a passenger vehicle	0	-	1	M: 1	0	-
Pedestrian	0	-	1	F: 1	2	M: 1 F: 1
Pedestrian – child	1	M: 1	0	-	0	-

Table 2. Categories of slightly injured persons in the period 2020-2022

Category of slightly injured persons	2020.	GENDER	2021.	GENDER	2022.	GENDER
Number of slightly injured persons	3	M: 1 F:2	9	M: 1 F: 8	19	M: 6 F: 13
Driver of a passenger vehicle	2	M: 1 F: 1	2	M: 1 F: 1	9	M: 3 F: 6
Front-seat passenger in a passenger vehicle	1	F: 1	1	M: 1	5	M: 1 F: 4
Passenger	0	-	3	F: 3	2	F: 2
Driver of a goods vehicle	0	-	1	F: 1	0	-
Motorcycle rider	0	-	0	-	2	M: 2
Pedestrian	0	-	1	F: 1	0	-
Pedestrian – child	0	-	1	F: 1	1	F: 1

In the continuation of the text, **Tables 1 and 2** present the structure of injured persons by category and gender. Table 1 shows the distribution of seriously injured persons, indicating that drivers and pedestrians are the most affected categories. **Table 2** presents slightly injured persons, where a significantly higher number of cases is observed, with a noticeable increase in 2022, especially among drivers and passengers of passenger vehicles.

DISTRIBUTION OF TRAFFIC ACCIDENTS IN TIME AND SPACE

In order to assess the dynamics and spatial characteristics of traffic accidents on the observed road section, an analysis of their distribution in time and space was conducted for the period 2020–2022.

Description of the Observed Road Section

The observed section covers a part of the main road M-1-101 (Banja Luka – Gradiska), specifically the Laktasi – Klasnice 1 section, with a total length of approximately 4 km (around 4000 m). The section is located within the territory of the City of Laktasi and passes through the settlements of Jakupovci and Laktasi. In Jakupovci, the section runs along Omladinska Street, while in Laktasi it continues along Karadjordjeva Street. On the observed section, mixed traffic takes place, with pronounced linear development and a large number of direct access points from residential and commercial buildings to the main road. The observed road section is characterized by a very high access density. A total of 35 intersections with local roads and 95 direct access points from residential and commercial properties were identified along a section of approximately 4 km, resulting in an overall access density of about 32.5 access points per kilometer. Such a high density of access points significantly increases the number of conflict points and represents a major contributing factor to the occurrence of traffic accidents on the analyzed section. In Jakupovci, Svetosavska Street (Glamocani settlement) connects to the section, while in Laktasi the section is linked with other segments of the main road M-1-101, including the direction towards Aleksandrovac and the connection to the motorway. The characteristics of the section, such as high traffic volume, numerous intersections with local roads, and direct access to properties, significantly affect the level of road safety and represent the reason for selecting this section as the subject of analysis. The analysis of temporal distribution shows that the highest concentration of traffic accidents was recorded in the period from 10:00 to 18:00, with a pronounced peak interval from 14:00 to 16:00. This pattern is consistent across all three observed years, with the highest number of accidents in 2022 recorded precisely within this period. The increased frequency of accidents in this time interval can be associated with the afternoon traffic peak, intensive daily activities of the population, and transit flows on the main road, as shown in **Figures 3 and 4.**

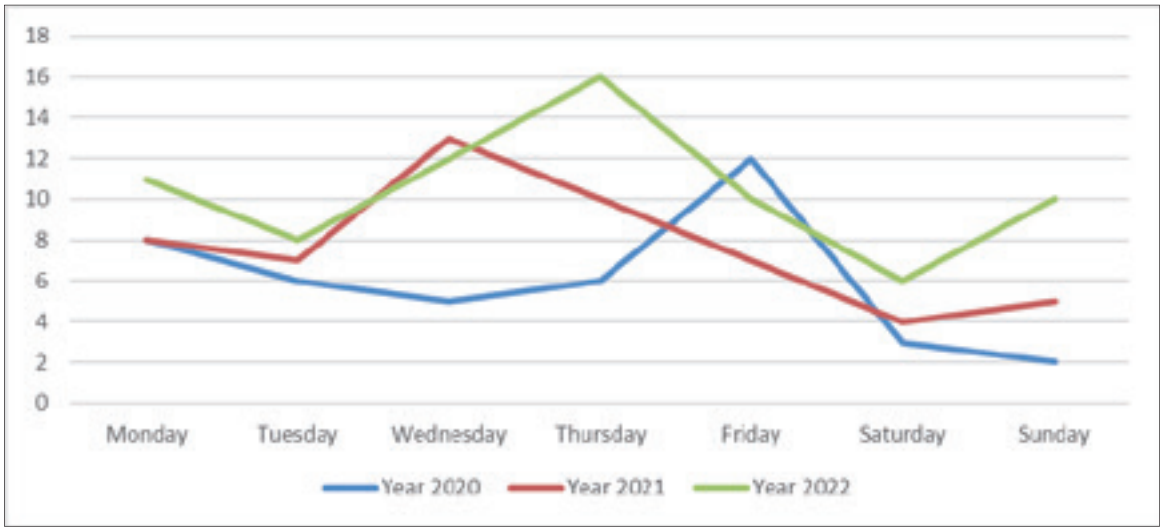

Figure 3. Graphical presentation of traffic accidents by days

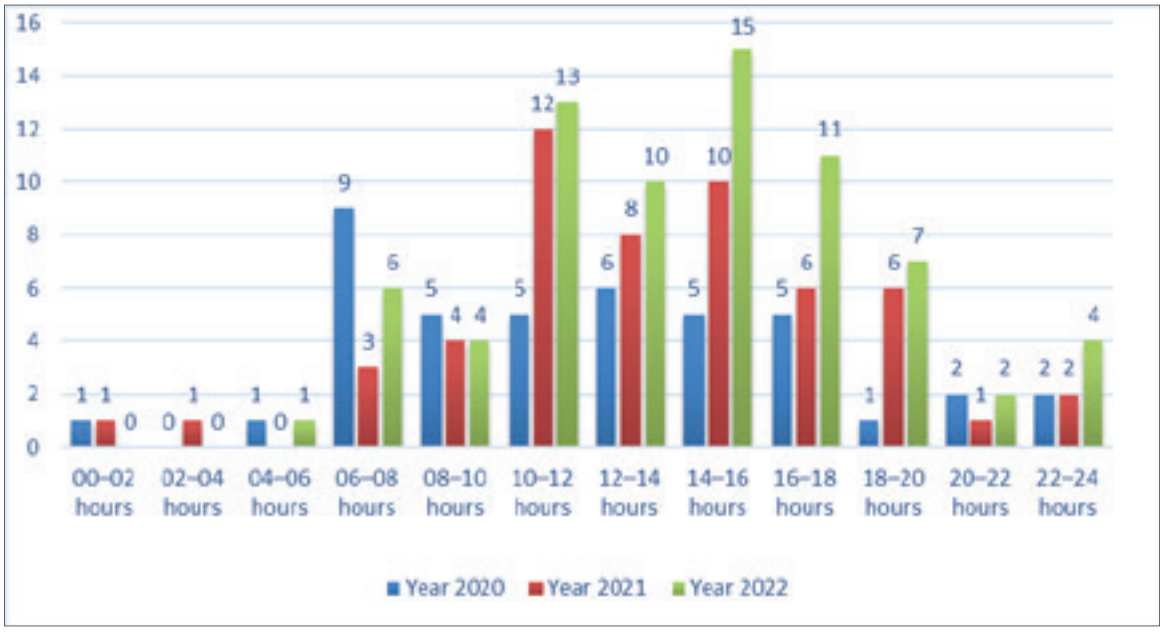

Figure 4. Graphical presentation of the hourly distribution of traffic accidents during the day

Spatial Analysis

The spatial analysis was conducted using the method of mapping traffic accident locations and identifying sections with an increased concentration of accidents (black spot analysis). A hazardous location was identified as a zone with a statistically significant frequency of accidents compared to the rest of the section. The spatial distribution of accidents was further examined using GIS-based visualization.

Identification of Hazardous Locations

The spatial analysis of traffic accidents was carried out by mapping the locations of accidents that occurred in the period 2020–2022. Based on the geographical distribution, sections of the road with an increased concentration of traffic accidents were identified.

The spatial analysis of a total of 169 traffic accidents recorded in the period 2020–2022 determined that the distribution of accidents along the observed section is not uniform. The highest concentration of accidents was observed in sections with intensive linear development along the main road, where there is a large number of direct access points from residential and commercial buildings. The absence of collector roads and an organized access system results in frequent vehicle entry and exit maneuvers, which increases the number of conflict points and the risk of traffic accidents. A lower concentration of accidents was observed in sections with fewer access points, indicating that the structure of access to the main road is a significant factor in the spatial distribution of accidents. The spatial distribution of accidents is shown in **Figure 5**. The identified hazardous location is situated in the settlement of Laktasi, on Karadjordje-

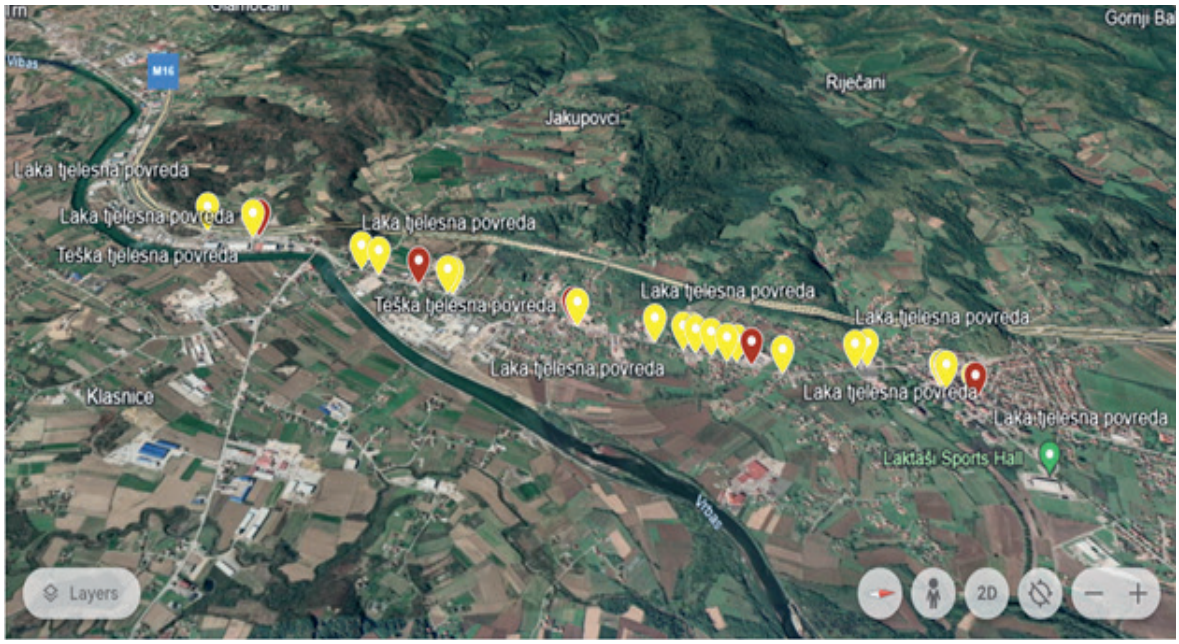

Figure 5. Mapping of traffic accidents with consequences for persons

va Street, within the zone of a public road in a built-up area. During the observed period (2020–2022), a total of six traffic accidents with consequences for persons were recorded at this location, including two with seriously injured persons and four with slightly injured persons. At the identified hazardous location, with a length of approximately 138 m, significant infrastructural and traffic-related factors influencing the increased risk of traffic accidents are present. Observed in the direction Banja Luka – Gradiska, this section is characterized by multiple direct access points to the main road, including access from individual residential buildings, access for collective housing users, as well as a bus stop area used for vehicle entry into the traffic flow. It is particularly important to note that within this zone there is a road widening of approximately 50 m in length, which, in addition to serving public transport purposes, is also used for vehicle stopping (e.g., by users of nearby commercial facilities). This leads to additional conflict situations during vehicle entry and merging into the traffic stream. Furthermore, two pedestrian crossings are located within this section, which significantly increases the number of interactions between vehicles and pedestrians. Traffic at the observed location is characterized by high intensity, as it represents a main road with significant transit function and the presence of heavy vehicles. Traffic is conducted in both directions, with one traffic lane per direction and without physical separation of flows, while the speed limit is 50 km/h. Although sidewalks are present on both sides of the road, the presence of pedestrian crossings and direct access points contributes to increased complexity of traffic conditions. The combination of a high number of direct access points, intensive traffic flow, the presence of pedestrians, and additional maneuvering activities in the bus stop zone leads to an increased number of conflict points and a higher level of infrastructural risk. Such conditions result in a higher probability of traffic accident occurrence, which is confirmed by their spatial concentration at the identified location. The analysis of the structure of traffic accidents at the identified location further confirms the increased level of risk. Out of a total of 6 traffic accidents with consequences for persons, pedestrians were involved in 3 cases, including 2 accidents with slightly injured persons and 1 accident with a seriously injured person. This structure of accidents indicates a pronounced risk for vulnerable road users, which is directly related to the presence of pedestrian crossings, the bus stop, and intensive interactions between vehicles and pedestrians at the observed location. According to the Rulebook on the Identification of Hazardous Locations, Methods and Criteria for Determining Priorities for Their Elimination, and Methods of Hazardous Location Treatment , a hazardous location in a built-up area is defined as a road section up to 100 meters in length where at least six traffic accidents with consequences for persons have occurred over a period of three consecutive years. Since the required number of accidents within the three-year period has been recorded at the observed location, the normative condition for identifying a hazardous location has been fulfilled. The spatial concentration of accidents covers a section approximately 138 meters in length. The measurement of this section was performed by determining the distance between the outermost accident locations, i.e., between the first and the last recorded accident. In order to define a single hazardous zone, an analysis of the distances between consecutive accident locations was conducted. The results showed that all recorded accidents are located in close spatial proximity, without significant gaps in their distribution along the observed road section. The criterion for grouping acci-

Figure 6. Identification of Hazardous Locations

dent locations into a single hazardous zone was based on spatial continuity. Accident locations were considered part of the same zone if they formed a continuous spatial sequence without pronounced gaps that would indicate the existence of separate and independent locations. Based on this approach, a continuous spatial cluster of accidents was identified, representing a functionally connected zone in which accidents occur under similar infrastructural and traffic conditions. Although the Rulebook prescribes a maximum length of 100 m, previous research indicates that hazardous locations should not be defined strictly by fixed geometric limits, but rather by spatial clustering and functional homogeneity of accidents . Therefore, the analyzed section was defined as a single hazardous location, as it represents a continuous and unified risk zone. The location is shown in **Figure 6**.

Public risk

In order to more precisely assess the severity and intensity of traffic accidents on the observed section, relative indicators of public and traffic risk were calculated for the period 2020–2022.

The analysis of relative indicators of public and traffic risk indicates an upward trend in safety indicators during the observed period. The increase in public risk of participation and public risk of casualties per 10,000 inhabitants, as well as the growth of traffic risk in relation to the number of registered vehicles, indicate a deterioration of the safety situation on the observed section. For the purpose of assessing the severity and intensity of traffic accidents on the observed section, relative indicators of public and traffic risk were defined for this research.

Public risk (PR) is defined as the ratio of the number of traffic accidents (by structure) and the number of casualties (by structure) per 10,000 inhabitants of the City of Laktasi, i.e., it represents the risk for each resident to be involved in a traffic accident or to suffer consequences from a traffic accident per 10,000 inhabitants (period 2020–2022).

Public risk of participation in traffic accidents:

PR_n = number of accidents × 10,000 / population = 56 × 10,000 / 34,210 = 16 accidents (per 10,000 inhabitants)

Total public risk of casualties or probability of injury for residents of Laktasi per 10,000 inhabitants:

PR_s = number of casualties × 10,000 / population = 28 × 10,000 / 34,210 = 8 casualties (per 10,000 inhabitants)

Public risk by consequence structure:

PRs_i = (22 × 10,000) / 34,210 = 6 persons (per 10,000 inhabitants)

PR_{si} = (6 × 10,000) / 34,210 = 2 persons (per 10,000 inhabitants)

During the observed period, no fatal outcomes were recorded; therefore, the public risk of fatality is equal to zero.

PR_n (2020) = (42 × 10,000) / 34,210 = 12 persons

PR_s (2020) = (5 × 10,000) / 34,210 = 1 person

PR_n (2021) = (54 × 10,000) / 34,210 = 16 persons

PR_s (2021) = (8 × 10,000) / 34,210 = 2 persons

PR_n (2022) = (73 × 10,000) / 34,210 = 21 persons

PR_s (2022) = (15 × 10,000) / 34,210 = 4 persons

The obtained results indicate that, in the observed three-year period, the public risk of participation in traffic accidents amounted to 16 accidents per 10,000 inhabitants, while the public risk of casualties amounted to 8 persons per 10,000 inhabitants.

Observed by year, a continuous increase in the public risk of participation is evident, from 12 in 2020 to 21

in 2022. A similar trend is observed for the public risk of casualties, which increased from 1 in 2020 to 4 in 2022.

The structure of consequences shows that slight injuries dominate (6 per 10,000 inhabitants), while serious injuries are significantly less represented (2 per 10,000 inhabitants). No fatal outcomes were recorded during the observed period, which positively affects the overall safety assessment of the section.

Traffic risk (TR) is defined as the ratio between the number of traffic accidents and the number of registered vehicles per 1,000 registered vehicles, i.e., it represents the risk of vehicle involvement in traffic accidents in relation to the level of motorization.

The formula is:

TR = (Number of accidents × 1,000) / Number of registered vehicles

Total traffic risk (2020–2022)

Total number of registered vehicles (sum):

17,442 + 18,410 + 19,194 = 55,046

TR_n = (169 × 1,000) / 55,046 = 3 accidents (per 1,000 registered vehicles)

TR_s = (28 × 1,000) / 55,046 = 1 casualty (per 1,000 registered vehicles)

TR_n (2020) = (42 × 1,000) / 17,442 = 2 accidents (per 1,000 registered vehicles)

TR_s (2020) = (5 × 1,000) / 17,442 = 0 casualties (per 1,000 registered vehicles)

TR_n (2021) = (54 × 1,000) / 18,410 = 3 accidents (per 1,000 registered vehicles)

TR_s (2021) = (8 × 1,000) / 18,410 = 0 casualties (per 1,000 registered vehicles)

TR_n (2022) = (73 × 1,000) / 19,194 = 4 accidents (per 1,000 registered vehicles)

TR_s (2022) = (15 × 1,000) / 19,194 = 1 casualty (per 1,000 registered vehicles)

The obtained results indicate a gradual increase in the traffic risk of vehicle involvement in traffic accidents during the observed period 2020–2022. The traffic risk of participation increased from 2 accidents per 1,000 registered vehicles in 2020 to 4 accidents in 2022, indicating a deterioration of safety indicators in relation to the level of motorization. Although the number of registered vehicles increased year by year, the growth in the number of traffic accidents was more pronounced, which led to an increase in relative risk.

The traffic risk of casualties, observed in relation to the number of registered vehicles, remains relatively low in all three years of analysis. In 2020 and 2021, the values were below one casualty per 1,000 registered vehicles, while a slight increase was recorded in 2022. However, the absence of fatal outcomes during the observed period indicates that, although the frequency of accidents increased, the severity of consequences did not reach a critical level.

Overall, the traffic risk on the Laktasi – Klasnice 1 road section can be assessed as moderate, but with a clearly noticeable upward trend, indicating the need for timely implementation of preventive and infrastructural measures in order to stabilize and reduce the risk in the coming period.

DISCUSSION OF RESULTS

The results of the analysis indicate a continuous increase in the number of traffic accidents on the observed road section during the period 2020–2022, with the most significant increase recorded in 2022. Although no fatal traffic accidents were recorded, the increase in the number of accidents involving injured persons indicates a deterioration in safety indicators. It should be noted that the year 2020 included a period of restricted movement due to the COVID-19 pandemic, which may have influenced reduced traffic volume and a lower number of recorded accidents. However, the increase observed in 2022 cannot be explained solely by the normalization of traffic flows. When relative indicators are considered, the public risk of participation increased from 12 to 21 accidents per 10,000 inhabitants, while the public risk of casualties increased from 1 to 4 persons per 10,000 inhabitants. These indicators suggest an increased exposure of the local population to traffic risk. Traffic risk, observed in relation to the number of registered vehicles, also shows an upward trend, indicating that the increase in the number of accidents is not exclusively a consequence of motorization growth, but also of the structural characteristics of the road section. Spatial analysis confirms that accidents are not evenly distributed, but rather concentrated in the urban segment of the section, where infrastructural complexity and traffic interactions are most pronounced. Similar findings have been reported in previous studies, which indicate that human factors represent the dominant cause of traffic accidents, accounting for the majority of crash occurrences ,. However, numerous studies also emphasize the significant role of infrastructural characteristics, particularly in urban environments with a high density of access points and mixed traffic conditions . The analyzed section exhibits these characteristics, including multiple direct access points, the presence of pedestrian crossings, a bus stop zone, and high traffic intensity, which together increase the number of conflict points and the likelihood of accidents. This is further supported by the calculated access density of approximately 32.5 access points per kilometer, which can be considered very high for a road with a dominant transit function, as also indicated in previous research on access management. The identified hazardous location accounts for a significant share of the total number of accidents involving injured persons, indicating the need for targeted infrastructural and organizational interventions. The observed upward trend in public and traffic

risk indicates that the safety problem on the observed section has a continuous character rather than representing isolated incidents. The combination of increased population exposure to risk, the rise in the number of accidents relative to the level of motorization, and the spatial concentration in the urban sector points to structural deficiencies in traffic organization and the access system to the main road. The obtained results are consistent with previous research, which emphasizes the significant influence of infrastructural characteristics on traffic accident occurrence, **.** Research conducted in the Western Balkan region indicates that road sections with intensive linear development, a high density of direct access points, and mixed traffic conditions represent locations with an increased safety risk due to the higher number of conflict points . The analyzed location in this study exhibits these characteristics, including multiple direct access points, the presence of a bus stop, pedestrian crossings, and high traffic intensity. Such conditions lead to frequent interactions between vehicles and vulnerable road users, which increases the probability of traffic accidents. A limitation of the study is the absence of traffic volume data (AADT), which restricts the possibility of calculating exposure-based risk indicators and performing a more precise risk assessment. This limitation is consistent with previous studies which emphasize the importance of traffic exposure data . In addition, the accuracy of spatial analysis depends on the precision of the geolocation data of traffic accidents. Although more advanced spatial analysis methods, such as kernel density estimation, can provide more precise identification of accident clusters, the applied GIS-based approach is considered sufficient for the scope and objectives of this research. Overall, the results indicate that the increase in traffic risk is not caused by a single factor, but rather by the combined influence of infrastructural characteristics, traffic flow conditions, and road user behavior, which confirms the need for a comprehensive approach to road safety improvement.

PROPOSED MEASURES FOR IMPROVING ROAD SAFETY

Based on the results of the analysis, the spatial concentration of accidents, and the identified hazardous location, the following road safety improvement measures can be defined:

Short-term measures – measures that can be implemented without significant financial investments, including: installation of shock absorbers (protective barriers) or relocation of public lighting poles further from the edge of the carriageway; rehabilitation and proper design of the beginnings and ends of guardrails; renewal of horizontal road markings (pedestrian crossings, edge lines); replacement of worn-out vertical signage and alignment with the current road classification; installation of traffic signage on access roads.

Medium-term measures – regulation or removal of unsignalized access roads; development of collector roads to reduce direct access to the main road; improvement of traffic organization in the zone of the identified hazardous location.

Long-term measures – permanent removal of roadside obstacles; construction of sidewalks along the urban section of the road; construction of bicycle lanes to protect vulnerable road users.

CONCLUSION

The conducted road safety analysis on the Laktasi – Klasnice 1 section of the main road indicates a clear trend of deterioration in safety parameters during the observed period. Although no fatal outcomes were recorded, the increase in the number of accidents and the growth of relative risk indicators point to increased exposure of road users and greater severity of consequences on this section. Relative indicators of public and traffic risk confirm that the increase in the number of accidents is not solely a result of increased motorization, but is also related to the structural characteristics of the section. In particular, the urban segment of the road, characterized by the presence of access points, pedestrian crossings and mixed traffic conditions, creates increased interaction between traffic streams and consequently a higher number of conflict situations. The spatial analysis enabled the identification of a hazardous location that meets the regulatory criteria and represents a priority for intervention. The results indicate that the identified safety problems are not isolated, but reflect typical patterns observed on urbanized road sections with combined transit and local access functions, which is consistent with findings reported in previous studies , . Furthermore, the application of spatial analysis methods proved to be an effective tool for identifying accident concentration zones, as confirmed in recent research , . The obtained results indicate that the safety problem has a systemic nature and requires a coordinated approach that includes infrastructural, organizational, and preventive measures. This paper provides a professional basis for planning further activities aimed at stabilizing and reducing risk on the observed road section, as well as a contribution to understanding similar safety issues in comparable traffic environments.

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Each paper must have an abstract. The abstract must be no longer than 250 words, it must be self-contained, and it must not require reference to the paper to be understood. In some cases, only the abstract of a paper is read; in other cases an abstract prompts further reading of the entire paper. The abstract should present the primary objectives and scope of the study or the reasons for writing the paper; the techniques or approaches should be described only to the extent necessary for comprehension; and findings and conclusions should be presented concisely and informatively. The abstract should not contain unfamiliar terms that are not defined, undefined acronyms, reference citations, or displayed equations or lists.

Following the abstract, about 3 to 5 **key words** that will provide indexing references to should be listed.

Organization of Manuscript

For peer review of Papers, submit the manuscript in a single electronic file organized in the following sequence:

- Title page, including submission date, word count, and author names, affiliations, addresses, phone numbers, fax numbers, and e-mails (please indicate corresponding author);
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(initial capitals, italic, on separate line) **Fourth-Level Subhead** (initial capitals, boldface, on same line as text, with extra letter space between the subhead and text) *Fifth-Level Subhead* (initial capitals, italic, on same line as text, with extra letter space between the subhead and text)

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Table Titles and *Figure* Captions

TABLE 5 Effects of All Factors
(Insert title above the table; "Table" is all capitals; title is initial capitals; all type is boldface; extra space but no punctuation after number; no punctuation at end of title.)

FIGURE 3 Example of results.
(Insert caption below the figure; "Figure" is all capitals; caption is sentence case; all type is boldface; extra space but no punctuation after number; period at end of caption.)

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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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The following examples illustrate the basic TTTP style for references.

EXAMPLES OF ACM PUBLICATION REFERENCES

Journal article [1]

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

Book [2]

[2] Shinar, D. *Psychology on the Road: The Human Factor in Traffic Safety*. John Wiley & Sons, Inc., New York, 1978.

Article in a Periodical [3]

[3] Jolliffe, J.K. and Hutchinson, T.P. A Behavioural Explanation of the Association Between Bus and Passenger Arrivals at a Bus Stop. *Transportation Science*, 9, 3 (August 1, 1975), 248-282.

Government Report [4]

[4] Dempsey, J. Barry. *Climatic Effects of Airport Pavement Systems: State of the Art*. Report DOT2DRD-75-196. FHWA, U.S. Department of Transportation, 1976.

Web Page [5]

[5] Stevens, R.C. Testimony Before United States Senate Special Committee on the Year 2000 Technology Problem. Sept. 10, 1998. http://www.senate.gov/~y2k/statements/091098stevens.html. Accessed Oct. 5, 1998.

CD-ROM [6]

[6] Martinelli, D.R. A Systematic Review of Busways. *Journal of Transportation Engineering* (CD-ROM), Vol. 122, No. 3, May–June 1996.

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Pay particular attention to determining whether weight is to be expressed in mass (kilograms) or in force (newtons), and express poundforce per square meter (N/m^2) of pressure or stress in pascals Pa).

Use prefixes instead of powers for SI units. -In figures and tables, provide only the units in which the original research was conducted.

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Abbreviations, acronyms, and symbols must be fully defined the first time they are used in the paper; the definition should be given first, followed by the abbreviated term in parentheses.

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ISSN 2490-3477