

## Research Paper

## Open Access

Mladen Tomašković\*, Ivica Završki

# Analysis of the road safety in the EU countries and the impact of PBM on its improvement

DOI 10.2478/otmcj-2024-0010

Received: February 20, 2024; accepted: May 12, 2024

**Abstract:** The occurrence of a large number of road fatalities necessitates making improvements in road safety conditions. Governments and experts of European countries have been involved in this activity by investing efforts to increase security as well as achieve the goals of the European Commission (EC) to reduce fatalities by 50% by 2030. They aim to achieve road traffic without any fatalities occurring by 2050. Including a series of innovations for safety in the auto industry, deploying ITS technology, enforcing stringent legal regulations, emphasising on higher education of all traffic participants and undertaking other such important actions help achieve the set goals. Furthermore, adequate road maintenance with the use of modern models will definitely contribute to improving road safety. Moreover, it is necessary to regularly monitor road safety indicators and react accordingly on time. This paper presents a current state safety analysis from the perspective of road fatalities and road maintenance investments (RMIs) in the European Union (EU) and in European Free Trade Association (EFTA) countries. The main objectives of this paper are to analyse road safety aspects and emphasise on the relation existing between road fatalities and RMI. Concurrently, the objective of this paper is to verify the possible influence of the performance-based maintenance (PBM) model on improving road safety in the European Union. As part of the research, 27 EU member states and 3 EFTA members were analysed in the period 2010–2021. The results indicate a connection between road fatalities and RMI. Thus, this particular one is almost linear at the average EU level and that PBM models can directly contribute to improving traffic safety and indirectly by savings in maintenance costs.

\*Corresponding author: Mladen Tomašković, University of Zagreb, Faculty of Civil Engineering, Zagreb, Croatia,  
E-mail: mladentomaskovic1@gmail.com

Ivica Završki, University of Zagreb, Faculty of Civil Engineering, Zagreb, Croatia

**Keywords:** traffic roads safety, number of road fatalities, road infrastructure maintenance investment, performance-based maintenance, traffic road security analysis

## 1 Introduction

For many years, increasing the safety on roads has been a matter of great interest to a large number of European and other governments across the world. It has remained as one of the main focus areas of academic and professional communities from that domain. Despite the large number of security solutions implemented in modern vehicles, safer roads, better driver education and some other factors, traffic accidents are still a significant problem for European roads on which unfortunately many participants end fatally. There have been recorded significant positive changes during the COVID-19 pandemic with respect to the fatality's trends. There was a decrease of 17% in road fatalities in the period 2019–2020 due to a sharp drop in traffic activities. However, these trends are returning to pre-pandemic levels and unfortunately again turning to a less desirable direction (EC 2023a). According to the latest data, in 2022, a total of 20,640 people lost their lives in accidents in the European Union (EU), which unfortunately represents an increase compared to 2021 (EC 2023b). Simultaneously, the average mortality rate (the number of people killed in road accidents per million inhabitants) in 2022 at the European level was 46 fatalities, while the safest roads in Sweden had an average rate of 21 fatalities and Denmark had 26 fatalities, much differing from the countries with the least safe roads (Romania with 86 and Bulgaria with 78 fatalities per million inhabitants; EC 2023a).

We find a similar trend at the world level among the 34 members of the International Traffic Safety Data and Analysis Group (IRTAD), where a slight increase of 0.1% fatalities was registered in 2021 compared to the average between 2017 and 2019. By comparison, the risk rate of

dying in a traffic accident in Colombia is 22 times higher than in Norway. Europe is from that aspect the safest area in the world with the least number of deaths per 100,000 inhabitants, far ahead of the worst areas in Africa and Southeast Asia, which implies that the world road safety situation is significantly worse than in the Europe and far from ideal (WHO 2018; ITF 2022). Everything mentioned in this paper is supported by the fact that annually 1.28 million people worldwide still die in accidents according to the available data from 2019. All negative figures of the total fatalities and serious injuries are not only due to road safety, but are also due to general health problems. Meanwhile, accidents are the 12th leading death cause in the world among people of all ages straight after cardiovascular and respiratory diseases, and the 1st death cause among children and youth aged 5–29 years (WHO 2023). Along with the suffering and pain experienced by the families of the dead, society loses members who are the basis of social and economic events. Health systems are also under pressure due to the high financial treatment and rehabilitation costs, as well as the requirement for a number of professionals (PACE 2016). In addition to the fact that human lives are the greatest and priceless loss, accidents are at the same time economically unsustainable, and their costs are estimated by studies at 3% of developed countries gross domestic product (GDP; Elvik 2000; Wijnen and Stipdonk 2016). The European Commission (EC) calculates the cost based on sum of four components: human cost, loss of productive economic capacities cost, medical and administrative costs, and they concluded that accidents create a cost of 3,298,909 euros for every life lost. With the latest data of 20,640 fatalities in 2022, the total EU fatalities cost in 2022 is estimated to over 68 billion euros (EC 2019; EC 2023b). For comparison, the total maintenance financial fund invested in road network of all EU members in 2021 amounts to 27 billion euros, 2.5 times less than the total fatalities cost in 2022 (ITF 2023).

Numerous road safety researches have studied a number of different macro and micro factors that directly and indirectly affect road safety. Thus, we have a number of recent studies on the impact of different technical, economic, social and demographic factors on the road safety increase (Kopits and Cropper 2005; Hakkert and Gitelman 2014; Michalaki et al. 2016; Nikolaou and Dimitriou 2018; Nikolaou et al. 2021; Brands et al. 2022; Quistberg et al. 2022; Georgakopoulos et al. 2023; Kanavos and Vandoros 2023; Ngoc et al. 2023). There is ongoing research on (1) the impact of traffic laws, policies and agencies on road safety (Nazif-Munoz et al. 2023), (2) European traffic laws and regulations and their impact on

reducing fatalities and increasing general road safety in EU members (Castillo-Manzano et al. 2014), (3) impact of GDP on increasing road safety (Yannis et al. 2014; Antoniou et al. 2016) and (4) even the impacts of economic recession, financial trends (Wegman et al. 2017; Fry and Farrell 2022) and the COVID-19 pandemic on road security (Barnes et al. 2020; Gupta et al. 2021; Shaik and Ahmed 2022).

An interesting study investigates the trend of accidents, more closely road construction or maintenance investments' impact on the road safety increase, i.e. the reduction of fatalities by different categories (Yannis et al. 2008; Nguyen-Hoang and Yeung 2014; Albalade and Bel-Pinana 2019; Kehagia and Giannaki 2022; Pulido and Raffo 2022; Navarro-Moreno et al. 2023a, 2023b). In his recent research, Valila (2023) gives a brief overview of how investments impact the research on increasing road safety in the period from the 1980s to today. The author highlights how everyone is having a common assumption that investments contribute to increased security, but also states that their results had not reached a mutual conclusion.

The fact that the results obtained on the impact of investments on safety vary (significantly from positive to neutral to negative) is surprising and confuses political decision-makers, as well as road managers. Similar results were obtained from recently conducted research in Spain that put forth the positive effects of maintenance investments and the slightly negative impacts of construction investments on the fatalities reduction (Calvo-Poyo et al. 2020).

All previous research works presenting different results are related to the road maintenance investment (RMI) impact on the road fatalities reduction, thus fact that there are no studies, that provide a common overview of RMI trends and increasing road safety at the whole EU level, with clear guidelines for its improvement and fulfilment of EU goals by 2030 and 2050, is sufficient motivation to achieve this paper's objectives. The main objectives are to collect and analyse the available data and provide a clear overview of the trends and the mutual relation between RMI and fatalities reductions at the EU level, considering the latest data in the period 2010–2021, i.e. to investigate whether the substantial impact is positive, negative or neutral. Additionally, if the effects of the investments on the fatalities reduction are positive, then the purpose of this paper is to calculate the necessary investment growth for achieving the goals of the EC by 2030 or 2050 and additionally consider how the performance-based maintenance (PBM) models can impact their realisation.

## 2 Road safety state analysis in EU countries

Road safety levels increased in the last 10 years due to modern safety solutions introduced in new vehicles and better quality and safer roads and other safety solutions deployed in the traffic road system. Despite the indicators that favour increased security levels such as a decrease of accidents by 15%, decrease of fatalities by 33% and a simultaneous decrease of fatalities of all traffic road user categories in the period 2010–2021, the last available data for 2022 speak of 20,640 fatalities in the European Union, which represents a growth of 4% compared to 2021 (EC 2023b, 2023c). Although fatalities in 2022 represent a decrease of 11% compared to the average of period 2017–2019, this number is still very high.

Additionally, the EC plan on increasing the road safety level as defined in 2010, with the aim of reducing fatalities and number of the seriously injured by 50% by 2020 at the EU level unfortunately has not been achieved, except partially in Norway, Greece and Switzerland, which managed to get close to the 50% reduction target (ITF 2022). Simultaneously, despite decreasing fatality trends in the past 3 years, they are not significant enough to achieve the new EC goals and the joint Stockholm Declaration on the additional reduction of fatalities and injuries by 50% in the period 2020–2030 (EC 2020, EC 2023c). The Declaration also defines the ultimately accepted EC goal on achieving ‘Vision Zero’ with zero fatalities or seriously injured in road traffic by 2050, which emphasises the current EU road safety problem challenging the professional and academic community for its realisation.

From the given fatality data in Table 1, it can be concluded that the road safety level in EU members is unsatisfactory and the negative trend in the past 2 years would not support achievement of the EU’s road safety goals, i.e. reducing the fatalities for 50% by 2030 and the realisation of ‘Vision Zero’ by 2050, and it is necessary to turn the trends to a positive direction. One of the possible measures to achieve the above-said goals is increasing the RMI, which contributes to reducing the fatalities and the severely injured, i.e. a general road safety increase. A similar view not only on the current road safety situation, but also on the trend in relation to the set EU goals until 2030 and 2050 was presented in reports from 2023, made by two institutes for road safety research located in Belgium and the Netherlands (EC 2023b, 2023c).
































By calculating the fatalities decrease in the period 2010–2019 at the EU level, we can observe an average drop of 762 fatalities annually. Furthermore, if we take this rate

of 762 fatalities annually, we will reach the figure of 11,976 fatalities in 2030, measured from the level of 18,834 fatalities in 2020, which represents a decrease of 36%, far from the planned 50% in accordance with the Stockholm Declaration. To fulfil the declaration requirements and achieve the planned goals, it is necessary to lessen the number of fatalities for 1046 each year, i.e. to achieve all predispositions that will further reduce the fatalities by 284 people more each year. Additionally, if we consider the current data of 20,640 fatalities in 2022, i.e. their growth by 4% compared to 2021, we conclude that the road fatalities trend is not going in the desired direction and it is necessary to further improve the required annual decrease. Herein arises the question of what measures, methods, technologies and policies have to be implemented in the further period to achieve all the EC’s set goals until 2030 and 2050?

Many studies speak in favour of the importance of road maintenance for achieving the required road safety level, and inadequate and irregular road maintenance is one of the most important factors in the occurrence of traffic accidents (Verma and Singh 2015). There are a few road elements that must be adequately maintained to ensure adequate safety level, and the pavement stands out among them. It has a role in the direct contact between vehicle wheels and the road and on its parameters such as roughness, grip, geometry, absence of holes and ruts, adequate surface drainage and others, which largely depend on the safety of vehicle movement and traffic flow (Chan et al. 2010; Labi 2011; Li et al. 2013; Gao et al. 2014; Lee et al. 2015; Pembuain et al. 2018). Moreover, improved road surface conditions can reduce accidents between 1.5% and 40%, improved road surface geometry and drainage can reduce them by 20%–90% and adequate traffic equipment can reduce additionally by 20%–50% (Verma and Singh 2015). Concurrently, a lot of studies indicate a significant connection between the accidents and pavement skid resistance; thus, the probability of occurrence of accidents is up to 300 times higher on a pavement with a friction coefficient (SFC) <0.30 than on the pavement with a coefficient of 0.60 or higher, which significantly proves the importance of pavement quality and maintenance for road safety (Lee et al. 2015; Pembuain et al. 2018; EC 2023d). To fulfil all the mentioned road safety conditions, it is necessary to build roads in accordance with the latest safety standards, and even more important, it is pivotal to adequately maintain them, so that all the prescribed safety standards shall be continuously met.

Additionally, there are numerous studies that have confirmed the significant relation existing between road construction and maintenance investments, and also

Tab. 1: Overview of the fatalities in the 27 EU and 3 EFTA members for the period 2017–2022.

Country	State mark		Total road fatalities in 2017	Total road fatalities in 2018	Total road fatalities in 2019	Total road fatalities in 2020	Total road fatalities in 2021	Total road fatalities in 2022
Austria		AT	414	409	416	344	362	370
Belgium		BE	609	604	644	499	516	540
Bulgaria		BG	682	611	628	463	561	531
Cyprus		CY	53	49	52	48	45	*
Czechia		CZ	577	656	618	518	532	528
Denmark		DK	175	171	199	163	130	*
Estonia		EE	48	67	52	60	55	47
Finland		FI	238	239	211	223	225	196
France		FR	3448	3248	3244	2541	2944	3267
Greece		EL	731	700	688	584	624	640
Ireland		IR	155	136	140	147	136	155
Italy		IT	3378	3325	3173	2395	2875	3159
Iceland		IS	16	18	6	8	9	9
Latvia		LV	136	151	135	141	146	112
Lithuania		LT	191	173	186	176	147	120
Luxembourg		LU	35	36	22	26	24	*
Malta		MT	19	18	16	12	9	*
Hungary		HU	625	633	602	460	544	537
Netherlands		NL	613	678	661	610	582	745
Germany		DE	3180	3275	3046	2719	2562	2788
Poland		PL	2831	2862	2909	2491	2245	1896
Portugal		PT	602	704	689	536	561	*
Romania		RO	1951	1867	1864	*	*	*
Slovakia		SK	276	260	270	247	247	266
Slovenia		SI	104	91	102	80	114	85
Spain		ES	1830	1806	1755	1370	1533	*
Sweden		SE	252	324	221	201	210	241
Switzerland		CH	230	233	187	227	200	241
Norway		NO	106	108	108	93	80	116
Croatia		HR	331	317	297	237	292	275
<b>EU</b>		<b>EU</b>	<b>23,392</b>	<b>23,331</b>	<b>22,756</b>	<b>18,834</b>	<b>19,900</b>	<b>20,640</b>

Source: ERSO, European Road Safety Observatory (2023); Annual Accident Report 2022, European Commission, OECD Statistics (2023), Transport, Performance indicators, Safety, Road fatalities (30 days).  
EFTA, European Free Trade Association; EU, European Union.

the reduction of accidents and fatalities (Fridstrom and Ingebrigtsen 1991; Albalade et al. 2013; Nguyen-Hoang and Yeung 2014; González et al. 2018). Although some of the latest research show even minimal negative road investments effect on the fatalities increase by 0.0013594 persons for each thousand euros invested, it appeared

that RMI have a positive effect on fatalities reduction by a factor of two greater than road construction investment, whereby for every thousand euros invested in maintenance reduces fatalities by 0.00246654 people (Calvo-Poyo et al. 2020). That is sufficient reason for further research on RMI trends throughout the European Union.

### 3 Methodology

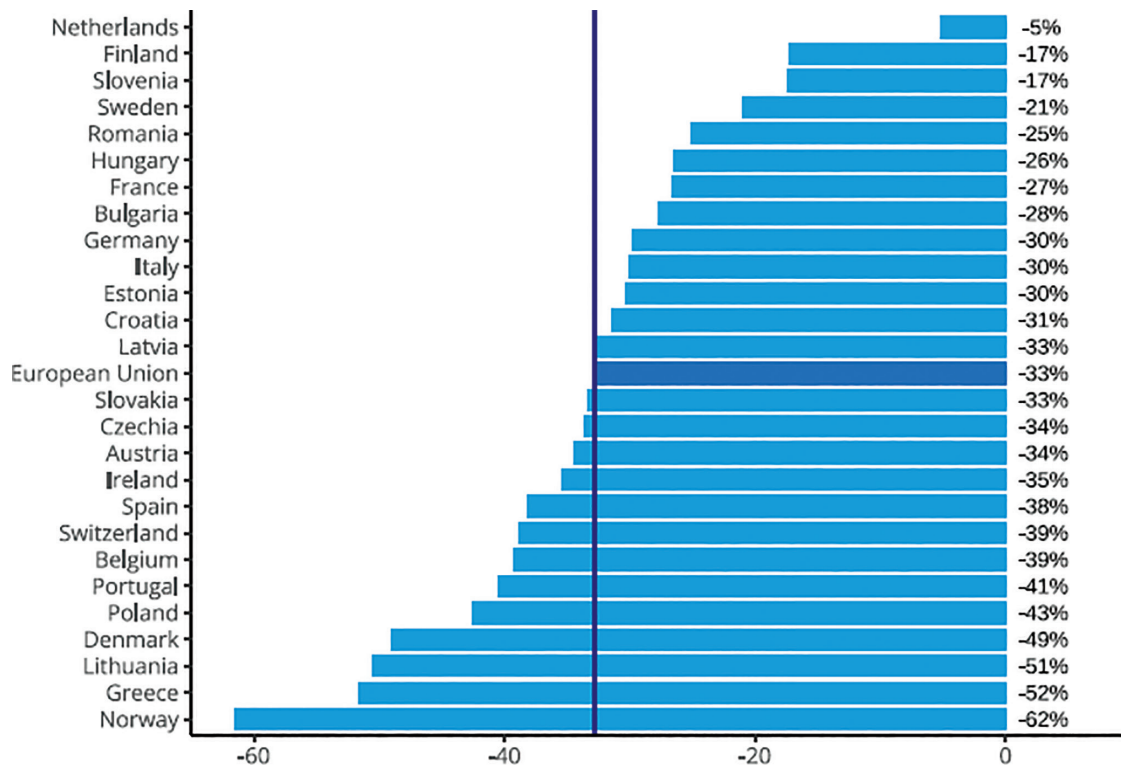
The purpose of this research is to contribute to reducing the number of traffic fatalities in the European Union. Some guidelines are given on how to do this. The main goal is to research whether and what kind of relationship exists between RMI and the total number of traffic fatalities at the level of the entire EU, as well as each of the observed countries individually, so that based on the above relationship, we could give guidelines for reducing traffic accidents. Additionally, the goal of this research paper is to calculate how much the RMI needs to be increased in order to achieve the EC safety goals by 2030 or 2050. Then, to verify the PBM model influence possibility on the road-safety improvement (reducing fatalities). Upon completion of the collection and synthesis of all data from the countries involved, mathematical analysis was conducted and is graphically presented in Graphs 1 and 2.

The PBM model, created by research carried out as part of the doctoral dissertation and presented in this paper as one of the possible solutions for reducing the number of traffic fatalities and enabling the growth of RMI, is a performance-based road maintenance model, intended for regular maintenance of state roads and highways in

Europe, and for which respondents had to choose up to 18 maintenance parameters distributed in five groups of maintenance parameters (traffic safety, quality of transport infrastructure, mobility, environmental protection and efficiency of the road management agency).

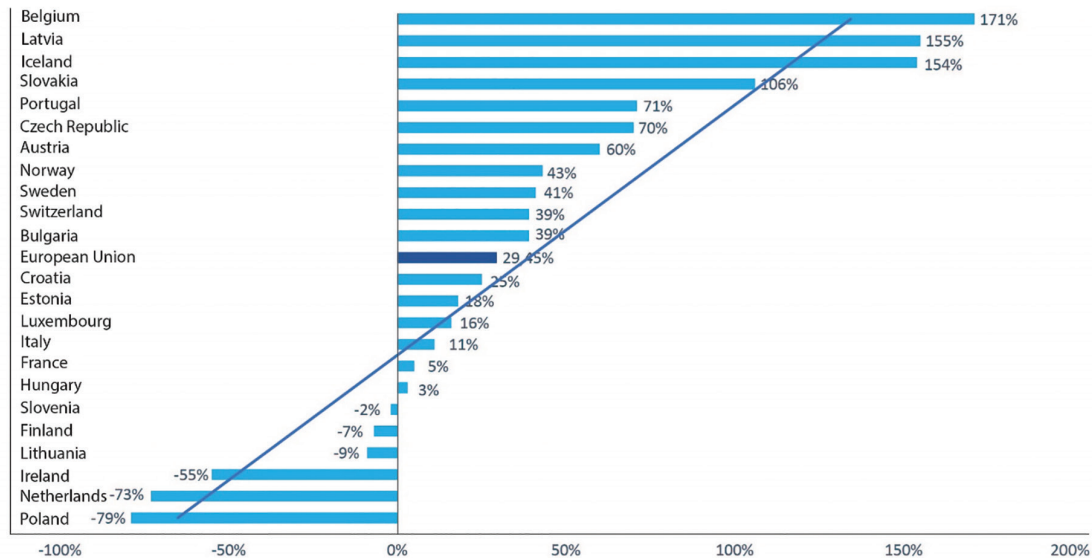
To complete the research, we implemented the steps shown in Figure 1 and simultaneously used data search and synthesis and mathematical analysis methods at the end. In the first step of the research, we selected two relevant sources, by searching Google Scholar for data on total fatalities and total RMI at the level of a particular country, Eurostat and OECDstat, which contain official statistical data for each year. For research purposes, we selected 31 European countries: 27 EU members and 4 European Free Trade Association (EFTA) members.

In the second step, we have chosen countries with available data from at least one of the two mentioned sources (OECDstat or Eurostat). To obtain data on the total fatalities, we examined the period 2010–2022, and for RMI data, the period 2010–2021 (latest available data). Based on the two categories, in the third step, we included 24 countries (21 EU members and 3 EFTA members), along with available data regarding the RMI for the period 2010–2021, and 30 countries (27 EU and



**Graph 1:** Long-term road fatalities change in the 27 EU and 3 EFTA countries (2010–2021). EFTA, European Free Trade Association; EU, European Union.





**Graph 2:** Long-term investment change in road infrastructure maintenance in the 20 EU and 3 EFTA countries (2010–2021)

Source: OECD Statistics (2023), Transport infrastructure investment and maintenance, Road infrastructure maintenance. EFTA, European Free Trade Association; EU, European Union.

3 EFTA members) with data of the total fatalities, available for the period 2010–2022. In the fourth step of the research, we have overlapped the available data of the countries that have the data simultaneously from both categories in the observed period (fatalities and the RMI). Thus, the spectrum of observed countries is reduced to a total of 24 countries (21 EU and 3 EFTA members). Exceptionally in the case of Denmark, we observed the data in the period 2013–2021. For the remaining six EU members (Greece, Romania, Spain, Germany, Malta) and one EFTA member (Cyprus), data were not available for both categories in the observed period and are excluded. For further research, a shorter observed period was selected (2010–2021), because the periods of available data for both categories do not match fully.

Based on the data of the 24 selected countries, the average RMI growth value was calculated as well as the average fatalities declining value in the observed period at the EU level and for the selected countries with values above and below the EU average. Based on the obtained values, the average RMI growth and fatalities decline value, the calculation of the necessary total RMI growth to achieve the set EC goals until 2030 and 2050 is given. Additionally, the research results are presented after conducting surveys using questionnaires as part of the doctoral dissertation, where 71 respondents participated. The task was to create the PBM model by selecting the offered maintenance parameters and then responding to a series of questions, including the questions about the particular

model impact on increasing road safety and reducing maintenance costs.

## 4 Results and Discussion

Upon completion of the collection and synthesis of all data in the observed countries, mathematical analysis was conducted and graphically presented in Graphs 1 and 2.

By analysing and processing the collected data, we arrive at the calculation of the average RMI growth at the EU level in the period 2010–2021 by 29.45%. This data was obtained by calculation of the average value of the percentage growth of investments in the maintenance of road infrastructure. At the same time, the fatalities decreased amounted to 33% (EC 2023c). Thus, it follows that for 1% of the RMI growth, a 1.12% decrease in fatalities at the EU level is achieved.

Additionally, by comparing the RMI growth of individual countries with the EU average, we ranked the countries above and below the EU average (Graph 2) and compared the data with the data from Graph 1. We determined 9 of 11 EU and EFTA members that have higher investment growth than the EU average and have fatalities decrease higher than the EU average (Graph 3). Reciprocally, 9 of the 13 EU members have investment growth lower than the average EU and have fatalities decline smaller than the average of the EU (Graph 4) or, in the worst case, they have fatalities increasing. The only observed exceptions

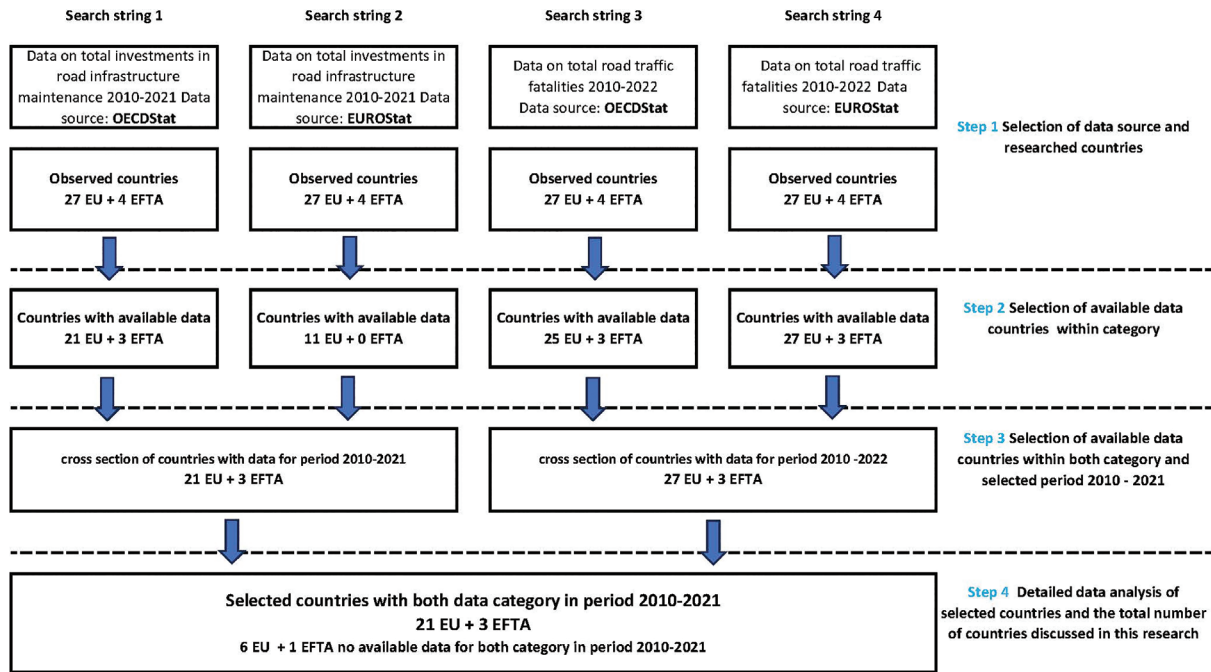


Figure 1: Research methodology. EFTA, European Free Trade Association; EU, European Union.

are Bulgaria and Sweden, which despite the RMI growth being higher than the average EU, registered fatalities decrease lower than the EU average, as well as Iceland, the only one observed EFTA member that registers fatalities increase by one person more in observed period, despite RMI growth.

If we consider that RMI growth at the EU level of 1% produces a 1.12% fatalities decrease and meets the EC goals until 2030 or 2050, we arrive at the subsequent calculation and the consequent conclusion.

Furthermore, to achieve the original EC goal until 2030 by 50%, we must increase investment by almost 45%, which is evident from the calculation below.

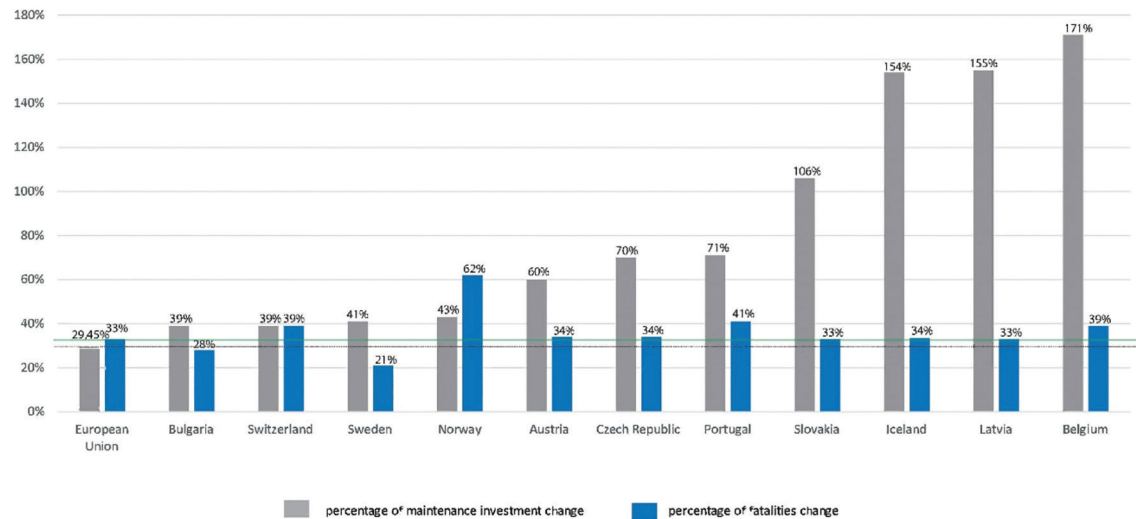
**Total fatalities in 2020 in EU: 18,835 people**  
**Total RMI in 2021 in EU: 17,976 billion €**  
*P* (Planned fatalities decrease at EU level by 2030): **decrease by 50%**  
**Maximum planned fatalities at EU level in 2030: 9418 people**  
*N*... Total required RMI growth  
*P*... Required decrease of fatalities  
*V*... Required RMI in 2030  
 $N = P/1,12$   
 $N = 50\%/1.12 = 44.64\%$   
 $V = 17,976,000,000.00 \times 1.4464$   
**V = €26,00 billion**

According to the previous calculations, to achieve the EC's goal of reducing the fatalities and the seriously

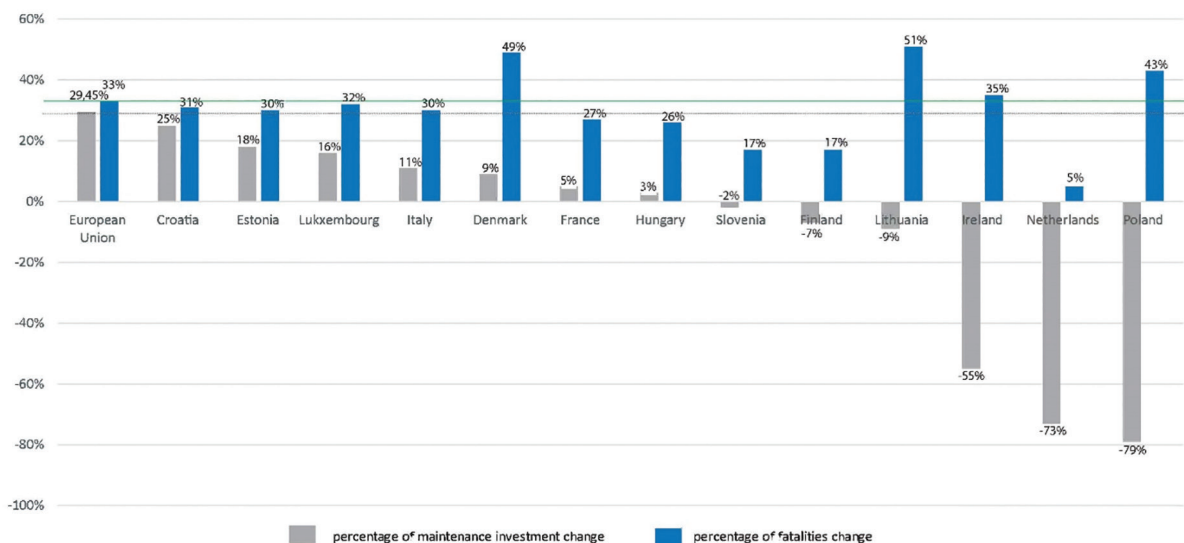
injured until 2030 by 50%, it is necessary to raise the RMI to the level of €26 billion annually, almost 45%, compared to 2021 and €17,976 billion invested at the EU level, which implies that with average linear growth suggested investments must be increased by €1.15 billion euros every year. Simultaneously, to revive 'Vision Zero' by 2050, it is necessary to raise investments to the minimum level of €34.027 billion, according to the calculation.

**Planned fatalities at EU level in 2050: 0 fatalities**  
**Fatalities in 2021 at EU level: 19,917 people**  
*P* (Required fatalities decrease at EU level until 2050): **decrease by 100%**  
**Total RMI in EU 2021: €17,976 billion**  
*N*... Total required investment growth  
*P*... Required fatalities decrease  
*V*... Required RMI in 2050  
**Necessary RMI growth until 2050:**  
 $N = P/1,12$   
 $N = 100\%/1.12 = 89.29\%$   
 $V = 17,976 \text{ billion} \times 1.8929$   
**V = €34.027 billion**

According to the previous calculations, it is necessary to raise the RMI by 2050 to the level of €34.027 billion annually, compared to the last available data from 2021, which shall along with average linear growth imply that it is necessary to continuously increase investments for EUR 944.2 million every year at the EU level. All calculations are based on the latest available fatalities data and



**Graph 3:** Overview of the fatalities decline in countries with investment growth regarding traffic road infrastructure maintenance higher than the EU average (2010–2021). EU, European Union.



**Graph 4:** Overview of the fatalities decline in countries with investment growth regarding traffic road infrastructure maintenance lower than the EU average (2010–2021). EU, European Union.

RMI from 2021, and as the relevant year for the calculation 2023 is marked.

*V2...Required RMI in 2050 = €34.027 billion*

*V...RMI in 2021 = €17,976 billion*

*P...Period of continuous RMI increase until 2050 = 17 years*

*S... Required annual RMI increase until 2050*

$S = (V2-V1)/P$

***S = 944.2 million €***

It is clear that the EU, along with other improvements, must significantly increase its RMI to achieve the planned goals by 2030 or 2050. Considering the data on real

maintenance investments growth in the observed period 2010–2021, as well as the fact that these investments in reality significantly vary over the years depending on factors affecting the government's financial ability, it is realistic to expect that the planned investment's growth would not be realised. Therefore, it is necessary to take other possible measures to achieve the planned EC goals. Along with the previously mentioned solutions that will contribute to reducing accidents and fatalities, it is necessary to consider other possibilities that will contribute to raising road safety. The significant one is the application of the PBM models.



The application of PBM models implies several advantages, and the most interesting fact is that it brings total maintenance costs savings. Numerous conducted researches reached the conclusion that the application of the PBM compared to traditional models can achieve savings of 10% and even up to 50%, depending on a number of parameters, along with simultaneous raising of the provided level of services (Liautaud 2004; Zietlow 2004; McCullough et al. 2009; Anastasopoulos et al. 2010). Simultaneously, potential cost savings can reach up to 60% in cases where the road agency is moving from house to the external maintenance services with the simultaneous application of PBM models (ADB 2018). Some EU members use the PBM models for maintenance of their roads (Finland, Estonia, the Netherlands and a few others) and they achieved substantial savings. Finland achieved 18%, Estonia 20%–40% and Netherlands 30%–40% savings compared to when they used the previously used traditional maintenance models (Pakkala et al. 2007). By applying the relevant models in all EU member countries, we can achieve significant long-term savings in the total maintenance costs, which may replace the need for the increase in the maintenance investments necessary to achieve the planned EC goals. Concurrently, to achieve all the aforementioned aspects, it is necessary to provide a lot of conditions in advance, such as a stable long-term funding, political support in terms of legislation, a sufficient number of potential contractors that are able to fulfil all contractual obligations, healthy and positive market competition and many other conditions; otherwise,

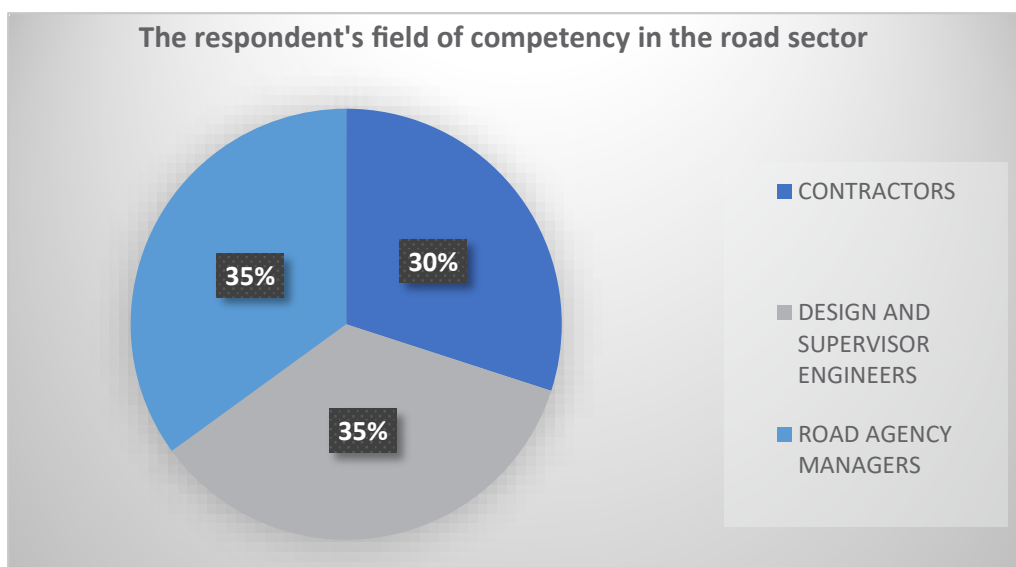
the potential savings in maintenance costs may not be achieved (EBRD 2016; ADB 2018).

In addition to the aforesaid, there is another advantage of the PBM models: an increase of traffic safety level, which directly contributes to reducing the number of accidents and fatalities (Gericke et al. 2014; Susanti et al. 2019).

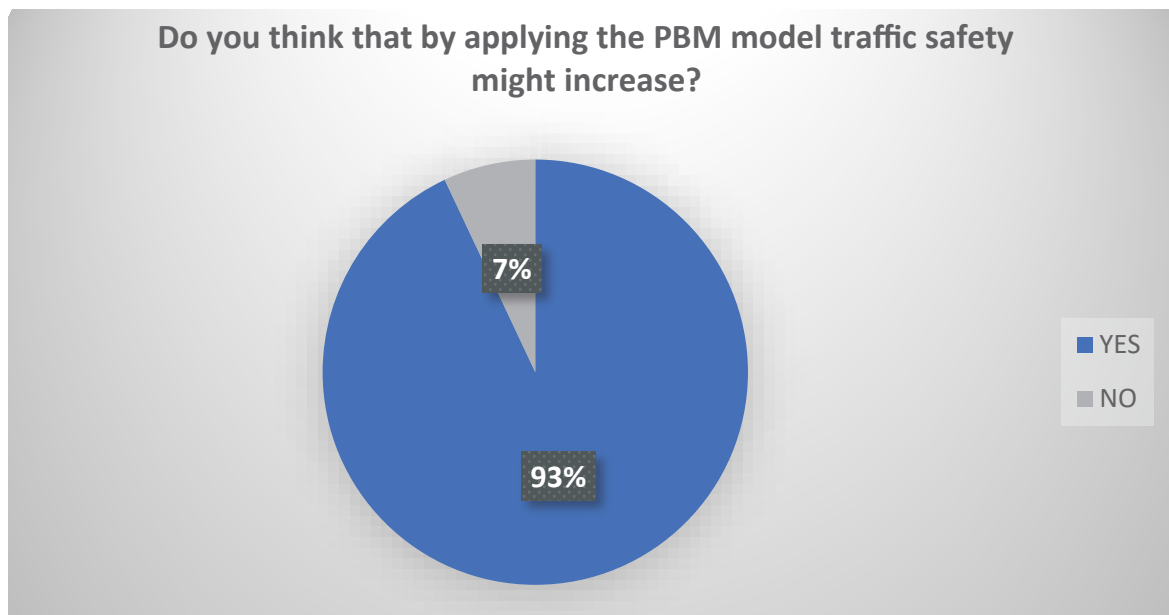
The application of the PBM models by all EU members can greatly contribute to solving the problem of insufficient financial resources intended for road infrastructure maintenance and easily provide better road safety, thus achieving the EC set goals. If we consider the previous calculations, it is necessary to increase the urgent RMI by almost 45% to achieve EC goals by 2030.

Concurrently, numerous studies of the PBM models state the realisation of possible savings by applying them up to 50%, which might under ideal conditions, within one road maintenance cycle, accumulate necessary financial resources sufficient for additional RMI, ultimately ensure the realisation of the EU plan by 2030. Using the same calculations under ideal conditions with the application of PBM models, sufficient financial savings might be achieved sooner and ‘Vision Zero’ may be realised earlier than in the planned 2050.

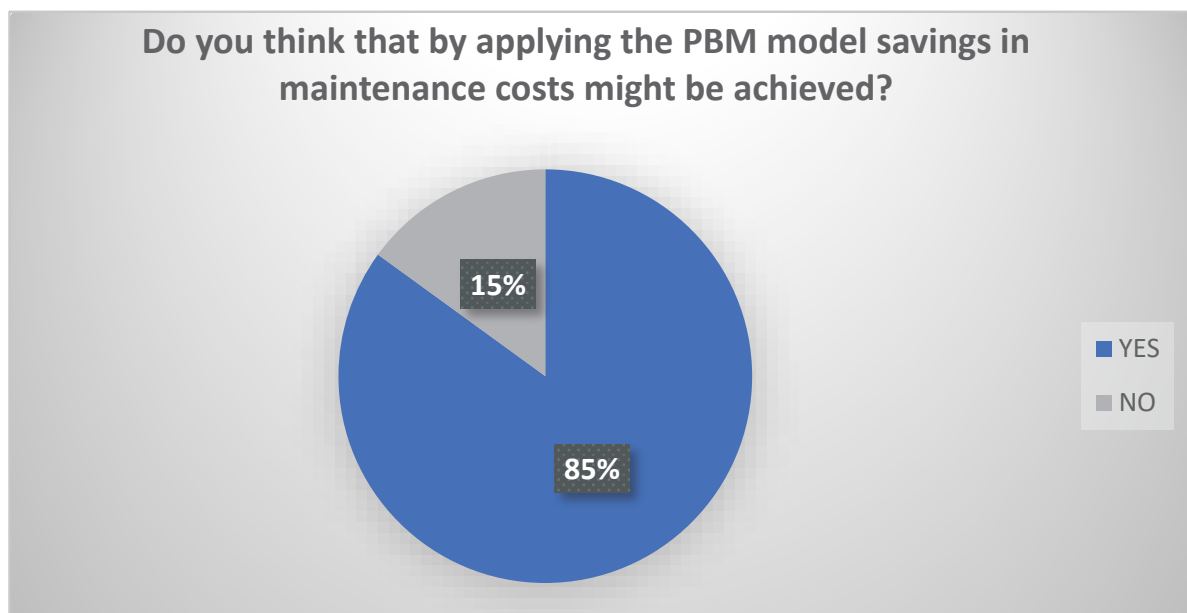
All that is supported by the results of the research conducted as a part of the doctoral dissertation, where 71 respondents took part in the questionnaire, profession according to Graph 5. In all, 66 of them responded positively that by applying the observed PBM model, traffic safety shall improve, and simultaneously 60 of them responded that road maintenance cost savings might be achieved.



Graph 5: Percentage share of the survey respondents according to roles in traffic road transport systems.



**Graph 6:** Percentage share of respondents who believe that safety might be increased by applying the PBM model. PBM, performance-based maintenance.



**Graph 7:** Percentage share of respondents who believe that savings might be achieved by applying the PBM model. PBM, performance-based maintenance.

## 5 Conclusion

This paper presents the road safety condition analysis of the EU and EFTA members in terms of annual fatalities. In the research study, all 27 EU members and 3 EFTA members have been included, but considering the

availability of data in the observed period 2010–2021, 24 countries were analysed.

The main goal of the research paper was to determine if there is a connection between RMI and the number of traffic fatalities not only at the EU level, but also in individual member states.

Concurrently, the objective of this research was to verify whether the PBM model influences increasing road safety and reducing maintenance costs. The conducted road safety and fatalities analysis affirms that despite the decrease in fatalities by 33% at the EU level in the period 2010–2021, the latest data on the increase in fatalities by 4% compared to 2021 and the total number of fatalities being 20,640 in 2022 do not predict positive expectations in the coming period.

Considering the results achieved thus far in reducing fatalities as well as their trend in the last 2 years, we conclude that the current state of road safety is not satisfactory, and it is necessary to urgently take measures that will improve the current fatalities trend with the final objective to achieve the EC set goals until 2030 or 2050. By studying the available literature, it has been determined that one of the possible measures is RMI growth, but it is not necessary for the aforesaid to have a positive impact on the decrease of fatalities.

Therefore, we conducted a mathematical data analysis and determined that at the EU level, there is a positive impact of RMI on the decrease in fatalities. Analysis during the period 2010–2021 can help determine the correlation between the RMI growth at 29.45% and decrease of fatalities by 33%, i.e. 1% of the RMI increase implies a 1.12% decrease of fatalities at the entire EU level.

Concurrently, it was determined that 9 of the 11 observed countries have investment growth higher than the EU average and have a decrease in fatalities larger than the EU average, and reciprocally 9 of the 13 countries have lower investment growth than the EU average and have lower number of fatalities than the EU average or, in the worst case, they have an increase in fatalities. From all the above-mentioned data and their mutual correlation, we can conclude with certainty that there is a strong connection between the positive impact of the RMI growth on the decrease of fatalities in road traffic, which is almost linear at the EU level.

Also, the goals of this research were achieved and the relationship between RMI and number of fatalities has been determined; it is an almost linear connection. Also, it was calculated that it is necessary to increase the existing RMI to the level of €26.00 billion per year, to achieve the EC goal by 2030, or to the level of €34.027 billion per year to achieve the EC goal until 2050.

Moreover, based on browsing through the available literature on the PBM models and their advantages, as well as analysing the obtained results of the conducted research via survey questionnaires, which is part of the doctoral dissertation, we can confirm that with the application of the created PBM model, the road safety level might be increased and maintenance costs reduced.

The available literature suggests the cost savings of road infrastructure maintenance of up to 50% by applying the relevant models, or even up to 60%. Furthermore, from the calculations for achieving the EC goals in this paper, we can conclude that the introduction of PBM in all EU members might significantly increase the prospects for achieving the planned EC goals until 2030 or 2050. Simultaneously for achieving the goals with the support of the PBM model, it is necessary to ensure that the several prerequisites stated in the paper are met.

The limitations of the research lie in the fact that the latest necessary data on investments and the road fatalities for all observed countries in the given period were not available. Hence, the obtained averages at the EU level are based on the data obtained only from 24 countries. Correspondingly, the other limitation of the research is the anomaly in the data obtained during the COVID-19 pandemic. The pandemic caused significantly lower fatalities than in the usual scenario, considering a significant decline in all economic and social activities and the resulting reduction of the people and vehicle movement, and thus, the decreased number of accidents (Gong et al. 2023).

Furthermore, another limitation of the study is that the road-maintenance investment effect in the vast majority of cases is achieved only in the following year from for the reason that most maintenance-intended funds are spent in the second half or at the end of the year. Thus, the results will be visible only in the following year, which have also been confirmed by Calvo-Poyo et al. (2020) using the results of their research in Spain.

Future research should investigate the relationship existing between the RMI and the road fatalities for each EU member separately, and include the latest data from 2024. Furthermore, the results should be obtained individually and later combined to finally possess an even more accurate cross-section of the RMI trend and its relation to the total fatalities at the EU level. The data may provide us with a more accurate and precise assessment of the required maintenance investment with the objective of achieving the EC goals. Moreover, future research shall investigate the reasons why in certain cases stated in the paper, countries achieved a smaller decrease of fatalities than the EU average or, in the worst case, an increase of fatalities despite the RMI growth larger than the EU average.

Also, future research should investigate the impact of RMI on reducing the total number of accidents, or the number of accidents by vehicle category for each state and at the level of the whole of EU. Also, it would be desirable to investigate the impact of the total investments in traffic infrastructure on the reduction of the number of fatalities and to see the proportion of the impact of RMI on the reduction of the number of fatalities.

Likewise, it is necessary to investigate the influence of the remaining possible measures for reducing the road fatalities, such as by the introduction of stricter legislation and regulations, education of participants in road traffic from an early age, wide implementation of ITS technology, and introducing modern vehicles with innovation.

## References

- ADB. (2018). Asian Development Bank, *Guide to performance-based road maintenance contracts*. CAREC, Central Asia Regional Economic Cooperation Program.
- Albalade, D., & Bel-Piñana, P. (2019). The effects of Public Private Partnerships on road safety outcomes. *Accident; Analysis and Prevention*, 128, pp. 53-64.
- Albalade, D., Fernández, L., & Yarygina, A. (2013). The road against fatalities: Infrastructure spending vs. regulation? *Accident Analysis & Prevention*, 59, pp. 227-239.
- Anastasopoulos, P. C., Florax, R. J. G. M., Labi, S., & Karlaftis, M. G. (2010). Contracting in highway maintenance and rehabilitation: Are spatial effects important? *Transportation Research Part A: Policy and Practice*, 44, pp. 136-146.
- Antonioni, C., Yannis, G., Papadimitriou, E., & Lassarre, S. (2016, July). Relating traffic fatalities to GDP in Europe on the long term. *Accident Analysis & Prevention*, 92, pp. 89-96.
- Barnes, S. R., Beland, L. P., Huh, J., & Kim, D. (2020). The effect of COVID-19 lockdown on mobility and traffic accidents: Evidence from Louisiana, global labor organization (GLO), Essen, GLO Discussion Paper No. 616.
- Brands, D., Klingen, J., & Ostermeijer, F. (2022). Hands on the wheel, eyes on the phone: The effect of smartphone usage fees on road safety. *European Economic Review*, 146, p. 104130.
- Calvo-Poyo, F., Navarro-Moreno, J., & De Oña, J. (2020). Road investment and traffic safety: An international study. *Sustainability*, 12(16), p. 6332.
- Castillo-Manzano, J. I., Castro-Nuno, M., & Fageda, X. (2014). Could being in the European Union save lives? An econometric analysis of the Common Road Safety Policy for The EU-27. *Journal of European Public Policy*, 21(2), pp. 211-229.
- Chan, C. Y., Huang, B., Yan, X., & Richards, S. (2010). Investigating effects of asphalt pavement conditions on traffic accidents in tennessee based on the pavement management system (PMS). *Journal of Advanced Transportation*, 44(3), pp. 150-161.
- EBRD. (2016). European Bank for Reconstruction and Development, Policy paper of infrastructure, policy challenges in the implementation of performance-based contracting for road maintenance. London, United Kingdom.
- EC. (2020). European Commission, Directorate general for mobility and transport. European Commission welcomes Stockholm Declaration on Road Safety. Available at <https://transport.ec.europa.eu/news-events/news/european-commission-welcomes-stockholm-declaration-road-safety-2020-02-19>
- EC. (2023a, February). European Commission, Road safety in the EU: Fatalities below pre-pandemic levels but progress remains too slow. Directorate-General for Mobility and Transport. Available at [https://transport.ec.europa.eu/news-events/news/road-safety-eu-fatalities-below-pre-pandemic-levels-progress-remains-too-slow-2023-02-21\\_en](https://transport.ec.europa.eu/news-events/news/road-safety-eu-fatalities-below-pre-pandemic-levels-progress-remains-too-slow-2023-02-21_en) [accessed 13 November, 2023].
- EC. (2023b, October). European Commission, Road safety: 20,640 people died in a road crash last year – progress remains too slow. Directorate-General for Mobility and Transport. Available at [https://transport.ec.europa.eu/news-events/news/road-safety-20640-people-died-road-crash-last-year-progress-remains-too-slow-2023-10-19\\_en](https://transport.ec.europa.eu/news-events/news/road-safety-20640-people-died-road-crash-last-year-progress-remains-too-slow-2023-10-19_en) [accessed 13 November, 2023].
- EC. (2023c). European Commission, *Annual statistical report on road safety in the EU, 2022. European Road Safety Observatory*. European Commission, Directorate General for Transport, Brussels.
- EC. (2023d). European Commission, Directorate-general for mobility & transport - road safety, European Road Safety Observatory, Road and pavement maintenance. Available at [https://road-safety.transport.ec.europa.eu/european-road-safety-observatory/statistics-and-analysis-archive/roads/road-and-pavement-maintenance\\_en](https://road-safety.transport.ec.europa.eu/european-road-safety-observatory/statistics-and-analysis-archive/roads/road-and-pavement-maintenance_en) [accessed 13 November, 2023].
- Elvik, R. (2000, November). How much do road accidents cost the national economy? *Accident Analysis & Prevention*, 32(6), pp. 849-851.
- European Commission. (2019). Directorate general for mobility and transport. In: *Handbook on the external costs of transport*. Publications Office of the European Union, Belgium, Brussels.
- Fridstrom, L., & Ingebrigtsen, S. (1991). An aggregate accident model based on pooled, regional time-series data. *Accident; Analysis and Prevention*, 23, pp. 363-378.
- Fry, J. M., & Farrell, L. (2022). Road accidents: Unexpected costs of stock market movements. *Oxford Economic Papers*, 75(1), pp. 233-255.
- Gao, J., Zhang, J., & Luo, M. (2014). Study on the relationship between asset condition and safety (Part 1). *Journal of Highway and Transportation Research and Development*, 8(2), pp. 99-104.
- Georgakopoulos, D., Nikolaou, D., Roussou, J., & Yannis, G. (2023). The impact of mobility characteristics on public transport and road safety performance in selected European cities. *Transportation Research Procedia*, 72, pp. 1547-1551.
- Gericke, B., Henning, T., & Greenwood, I. (2014). *Review of performance based contracting in the road sector – phase 1*, Transport papers. World Bank Group, Washington, DC.
- Gong, Y., Lu, P., & Yang, X. T. (2023). Impact of COVID-19 on traffic safety from the “Lockdown” to the “New Normal”: A case study of Utah. *Accident Analysis and Prevention*, 184, p. 106995.
- González, M. P. S., Sotos, F. E., & Ponce, Á. T. (2018). Impact of provincial characteristics on the number of traffic accident victims on interurban roads in Spain. *Accident Analysis & Prevention*, 118, pp. 178-189.
- Gupta, M., Mukund Pawar, N., & Velaga, N. R. (2021). Impact of lockdown and change in mobility patterns on road fatalities during COVID-19 pandemic. *Transportation Letters*, 13(5-6), pp. 447-460.
- Hakkert, A. S., & Gitelman, V. (2014). Thinking about the history of road safety research: Past achievements and future challenges. *Transportation Research Part F: Traffic Psychology and Behaviour*, 25(Part B), pp. 137-149.
- ITF. (2022). International Transport Forum, Road safety annual report 2022. OECD Publishing, Paris.

- ITF. (2023). International Transport Forum, Transport infrastructure investment and maintenance spending, Maintenance spending data. Available at [https://stats.oecd.org/Index.aspx?DataSetCode=ITF\\_INV-MTN\\_DATA](https://stats.oecd.org/Index.aspx?DataSetCode=ITF_INV-MTN_DATA) [accessed 13 November, 2023].
- Kanavos, P., & Vantoros, S. (2023). Road traffic mortality and economic uncertainty: Evidence from the United States. *Social Science & Medicine*, 326, p. 115891.
- Kehagia, F., & Giannaki, M. (2022). Road investment and safety in middle- and high-income countries in the framework of sustainability, School of Civil Engineering, Highway Laboratory, Aristotle University of Thessaloniki, OP Conference Series: Earth and Environmental Science, ICED (2022) 012058.
- Kopits, E., & Cropper, M. (2005, January). Traffic fatalities and economic growth. *Accident Analysis & Prevention*, 37(1), pp. 169-178.
- Labi, S. (2011). Efficacies of roadway safety improvements across functional subclasses of rural two-lane highways. *Journal of Safety Research*, 42(4), pp. 231-239.
- Lee, J., Nam, B., & Abdel-aty, M. (2015). Effects of pavement surface conditions on traffic crash severity. *Journal of Transportation Engineering*, 141(10).
- Li, Y., Liu, C., & Ding, L. (2013). Impact of pavement conditions on crash severity. *Accident Analysis & Prevention*, 59, pp. 399-406.
- Liautaud, G. (2004). *Maintaining roads: Experience with output-based contracts in Argentina*. The World Bank, Washington, D.C.
- McCullough, B. G., Sinha, K. C., & Anastopoulos, P. C. (2009). *Performance-based contracting for roadway maintenance operations in Indiana*, Publication FHWA/IN/JTRP-2008/12, Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana.
- Michalaki, P., Quddus, M., Pitfield, D., & Huetson, A. (2016). A time-series analysis of motorway collisions in England considering road infrastructure, socio-demographics, traffic and weather characteristics. *Journal of Transport & Health*, 3(1), pp 9-20.
- Navarro-Moreno, J., Calvo-Poyo, F., & De Oña, J. (2023b). Influence of road investment and maintenance expenses on injured traffic crashes in European roads. *International Journal of Sustainable Transportation*, 17(6), pp. 649-659.
- Navarro-Moreno, J., De Oña, J., & Calvo-Poyo, F. (2023a). How do road infrastructure investments affect Powered Two-Wheelers crash risk? *Transport Policy*, 138, pp. 60-73.
- Nazif-Munoz, J. I., Quesnel-Vallée, A., & Van den Berg, A. (2023, September). Assessing the impact of road safety agencies and health systems in traffic outcomes across 146 countries, 1994-2012. *Accident Analysis & Prevention*, 189, p. 107122.
- Ngoc, A. M., Minh, C. C., Thi Nhu, N., Nishiuchi, H., & Huynh, N. (2023). Influence of the human development index, motorcycle growth and policy intervention on road traffic fatalities – A case study of Vietnam. *International Journal of Transportation Science and Technology*, 12(4), pp. 925-936.
- Nguyen-Hoang, P., & Yeung, R. (2014). Dollars for lives: The effect of highway capital investments on traffic fatalities. *Journal of Safety Research*, 51, pp. 109-115.
- Nikolaou, P., & Dimitriou, L. (2018, October). Evaluation of road safety policies performance across Europe: Results from benchmark analysis for a decade. *Transportation Research Part A: Policy and Practice*, 116, pp. 232-246.
- Nikolaou, P., Folla, K., Dimitriou, L., & Yannis, G. (2021). European countries' road safety evaluation by taking into account multiple classes of fatalities. *Transportation Research Procedia*, 52, pp. 284-291.
- PACE. (2016, June). Parliamentary Assembly Council of Europe, Committee on Social Affairs, Health and Sustainable Development.
- Pakkala, P., Martin de Jong, W., & Aijo, J. (2007). *International overview of innovative contracting practices for roads*. Finnish Road Administration, Helsinki.
- Pembuain, A., Priyanto, S., & Suparna, L. B. (2018). The effect of road infrastructure on traffic accidents. In: 11th Asia Pacific Transportation and the Environment Conference (APTE 2018). *Advances in Engineering Research*, 186.
- Pulido, D., & Raffo, V. I. (2022). *Saving lives through private investment in road safety*. World Bank Group, Mobility and Transport Connectivity Series Washington, D.C.
- Quistberg, A., Hessel, P., Rodriguez, D. A., Sarmiento, O. L., Bilal, U., Caiaffa, W. T., Miranda, J. J., Fatima de Pina, M., Hernández-Vásquez, A., & Diez Roux, A. (2022). Urban landscape and street-design factors associated with road-traffic mortality in Latin America between 2010 and 2016 (SALURBAL), an ecological study. *The Lancet Planetary Health*, 6(2), pp. 122-131.
- Shaik, E., & Ahmed, S. (2022, September). An overview of the impact of COVID-19 on road traffic safety and travel behavior. *Transportation Engineering*, 9, p. 100119.
- Susanti, B., Wirahadikusumah, R. D., Soemardi, B. W., & Sutrisno, M. (2019). Life cycle cost comparison between performance based and traditional contracts in Indonesia. *IJUM Engineering Journal*, 20(2), pp. 57-69.
- Valila, T. (2023). Road safety and road infrastructure expenditure: A bivariate analysis. *Transport Policy*, 140, pp. 148-162.
- Verma, D., & Singh, V. (2015). Road maintenance effect in reducing road accident. *International Journal for Scientific Research & Development*, 3(01), pp. 2321-0613.
- Wegman, F., Allsop, R., Antoniou, C., Bergel-Hayat, R., Elvik, R., Lassarre, S., Lloyd, D., & Wijnen, W. (2017). How did the economic recession (2008–2010) influence traffic fatalities in OECD-countries? *Accident Analysis & Prevention*, 102, pp. 51-59.
- WHO. (2018). World Health Organization, Global status report on road safety, Geneva 2018, Licence: CC BYNC-SA 3.0 IGO.
- WHO. (2023). World Health Organization, Global Health Estimates. Available at <https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/ghe-leading-causes-of-death> [accessed 13 November, 2023].
- Wijnen, W., & Stipdonk, H. (2016, September). Social costs of road crashes: An international analysis. *Accident Analysis & Prevention*, 94, pp. 97-106.
- Yannis, G., Evgenikos, P., & Papadimitriou, E. (2008). Best practice for cost-effective road safety infrastructure investments, Full report, CEDR, Conference of European Directors of Roads.
- Yannis, G., Papadimitriou, E., & Folla, K. (2014, March). Effect of GDP changes on road traffic fatalities. *Safety Science*, 63, pp. 42-49.
- Zietlow, G. (2004). Implementing performance based road management and maintenance contract in developing countries: An instrument of German technical cooperation. GTZ, Germany.