ANALYSIS OF THE LENGTH OF HIGHWAYS AND THE NUMBER OF MOTOR VEHICLES IMPACT ON THE INTENSITY OF ROAD ACCIDENTS IN SELECTED EUROPEAN COUNTRIES IN 2010-2020

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Resume

The main purpose of this study was to compare the frequency of road fatalities in selected European countries, including Poland. Moreover, based on statistical data, the determination index R2 was determined for both the total number of road accidents and fatalities in road accidents in terms of the number of registered vehicles and the length of motorways in selected European countries. Results show the dependence of factors, such as road infrastructure and the number of registered motor vehicles, influence on the level of road safety in selected European countries.

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1 Introduction

The behavior and driving style are individual for each driver. Although the driving process is largely supported by electronic safety systems (ADAS), the attention and behavior of the driver have a decisive impact on the road safety. While driving the vehicle, the actions of driver also influence other road users. The dynamically changing road situation forces the driver to quickly assess events and make precise decisions. The amount of information and signals reaching the driver may cause them to misjudge the situation and to react incorrectly, which may lead to a dangerous traffic incident. When analyzing all the risks in road traffic, three categories of accident causes can be listed [1-2]:

- man-made hazards, in all the situations and events, which arise as a result of the driver or another participant in an accident (pedestrian, cyclist) behavior;
- threats caused by natural forces, such as fog, blizzards;
- threats resulting from infrastructure defects, e.g. defects in the road surface.

The human factor is one of the most common causes of the road accidents and collisions. The former may occur as a result of the psychophysical features of drivers, non-compliance with the road traffic regulations, or the lack of driving skills [3]. Advanced research on influence of a person's psychophysical predisposition on their behavior in the road traffic was carried out in the 1980s [4-7]. Since then, there have been numerous studies and projects focused on determining the influence of the personality, character and emotional state of the driver as well as their skills and individual habits on their driving behavior.

How a driver's personality influences their driving style is of interest to the transport psychology specialists and road safety scientists. The results of the research presented, among others, in the works [8-10], confirm that the personality of the driver can influence the behavior while driving. Certain personality traits may more define a specific driver behavior on the road. Likewise, individual driving skills and experience contribute to it, as well. The research results presented in the works [11-13] show that the age of the driver and experience in driving have a significant impact on the road safety. The authors showed that older drivers with more driving experience have a higher awareness of the risk of road incidents and are less likely to perform dangerous maneuvers. The surprising research results

presented, among others, in the works [14-16], show that drivers characterized by a high level of perceptual and motor skills show a riskier driving style. This is evidenced by the number of accidents committed by them and received fines.

The emotional state of the driver can also influence the driving behavior. Emotions that accompany the vehicle driver, e.g. fatigue, drowsiness, depression, worry, nervousness or anger affect the manner of driving and performing road maneuvers. The research results included, inter alia, in works [17-20], show that when a driver is tired, sleepy, sick or bored while driving, they incline to a more careful driving style. Conversely, if the driver is depressed, worried, nervous or angry, they drive the vehicle more aggressively.

Due to the individual characteristics and skills of the driver influencing driving behavior, the term "driving style" has been developed. Driving style refers to the way the driver habitually drives the vehicle. It is based on a combination of the driver's cognitive, emotional, sensory and motor factors [21]. Driving style is generally believed to determine the manner in which the road maneuvers are performed. In the work [22], two groups of factors influencing the driving style were distinguished: subjective factors and objective factors. The subjective factors are: psychological characteristics, physiological characteristics (age, gender), social characteristic (occupation, income). The objective factors included: road conditions, road type, driving resistance situation (air resistance coefficient, rolling resistance coefficient, acceleration characteristics).

Although each driver has their own individual driving style, there are behaviors that are common to multiple drivers. Thanks to this, common driving style categories were distinguished, characterized by a specific behavior and attitude while driving. There are many classifications in the literature, but the following driving styles are mainly observed [23-26]:

- reckless and careless driving style, characterized by a tendency to drive at high speed and to ill-considered and risky maneuvers;
- anxious driving style, characterized by uncertainty and indecision when maneuvering;
- aggressive driving style, which reflects hostile and aggressive behavior towards other drivers, as well as violent performance of the road maneuvers and non-compliance with the road rules;
- patient and attentive driving style, which shows a tendency to be polite towards other drivers and to behave rationally on the road;
- dissociative driving style, which describes the tendency to be distracted and inattentive while driving and to make driving mistakes related to a lack of concentration.

Much work and projects have been devoted to development of algorithms which recognize and determine the driver's driving style for the purposes of the ADAS systems. Based on selected parameters, e.g. acceleration, engine speed, position of the accelerator and brake pedals, the algorithm determines the driving style of the driver. The driving style category information is then used to determine how the assistance systems are adjusted to the driver's characteristics. This solution increases the safety and comfort of driving - especially if the driving style is defined as aggressive (dangerous). Examples can be found, among others, in works [27-29].

The phenomenon of road accidents and fatalities in road accidents has been an interesting issue for many researchers around the world for years. Road accidents in the works [30-33] are considered as an individual case of the driver's behavior. In the work [34-35] the intensity of the road accidents is comparable to the European Union countries. In the works [36-37], road accidents are subject to statistical analysis in order to divide the European Union countries in terms of the road safety. In the works [38-39], the number of road accidents and the number of fatalities in road accidents is analyzed in the assumed period of time in order to better understand their intensity. It should be noted that in the works [40-42] the intensity of road accidents in selected European Union countries is analyzed with help of forecasts in order to show the problem of road accidents.

As mentioned before, many factors can affect the road safety. There are still a large number of accidents and collisions on the roads, with a significant number of casualties. The aim of this study was to present the number of road accidents which involve fatalities, in Poland and European Union countries. The study analyzed the number of accident victims in terms of a specific day of the week and time of day.

2 Methodology

Social and economic losses of road accidents in Poland and in EU Member States indicate the need to develop the road safety programs. Due to the long-term activities of the adopted programs heading to the improvement of road safety, it is necessary to develop the low-cost projects to eliminate dangerous places of occurrence of the road accidents occurrence. It is also important to determine in statistical terms the impact of parameters such as the number of vehicles, the age of vehicles, the length of motorways and expressways, the number of electric vehicles, or the age of the driver affects the intensity of road accidents and the intensity of fatal road accidents.

This study uses a methodology for analyzing the historical data on road accidents in Poland and selected European countries in order to analyze the impact of the length of motorways, the number of vehicles registered on the intensity of road accidents and the intensity of fatal road accidents.

The coefficient of determination R^2 was used to analyze the relationships between the previously

mentioned variables. The coefficient of determination takes values between 0 and 1. The coefficient of determination R^2 in the article explains to what extent the change in the length of motorways and the number of registered vehicles affect the change in the number of road accidents and the number of fatalities in road accidents. The coefficient of determination was obtained as, [43]:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_l)^2}{\sum_{i=1}^{n}(\dot{y}_l - \bar{y}_l)^2}. \quad (1)$$

The coefficient of determination R^2 in this publication is treated as the first parameter determining the impact of selected parameters on the number of road accidents and the number of fatalities. Based on the R^2 determination index and the use of multiple regression, European countries can be classified in terms of the road safety.

3 Road infrastructure

The total length of highways in the European Union and the Schengen area is over 82,000 kilometers. Nowadays, the system of interconnected motorways allows free passage from the border of one state to the border of another state without having to leave the motorway routes even for a moment. Unfortunately, for economic reasons, the motorway networks in individual Member States of the European Union differ significantly in terms of size and degree of advancement. The most extensive network of express roads can be found in the western countries of the European continent. Spain has the longest motorway network, over 17,228 km. In 2020, the total length of highways in Germany exceeded 13,190 km. In Poland, the length of motorways in 2020 was over 1,712 km. Figure 1 presents the characteristics of the motorway length of the European countries in 2010 and 2020. Figure 2 presents the characteristics of the percentage changes in the length of the motorway in European countries. Comparing the condition of motorways from 2020 to 2010, Romania recorded the largest increase of 177 %. In Romania, in 2010, the total length of motorways was 332 km and in 2020, the total length of motorways was 920. Poland is the second largest European country in terms of motorway growth in 2010-2020. In the period under consideration, Poland doubled the number of motorways. In 2010, there were 857 km of highways in Poland, while in 2020 there were 1,712 km. Bulgaria is in the third place with an increase of 84 % by motorway. Figure 3 presents the characteristics of the length of motorways for selected European Union countries. To compare the length of motorways in 2010-2020, countries, such as France, Germany, Poland, Spain, Slovakia and Romania, were selected. It should be noted that despite the doubling of the length of motorways in Poland in 2010-2020, the length of motorways in Poland is still much shorter than in France, Spain or Germany. It is similar with Slovakia and Romania.

In Poland, in 2010, the total length of highways was 857.4 km and of expressways - only 674.7 km. Figure 4 shows the length of highways and expressways in Poland in 2010-2020. In 2020, the total length of highways in Poland was 1712.2 km and express roads 2548.5 km. In 2020, the length of motorways increased

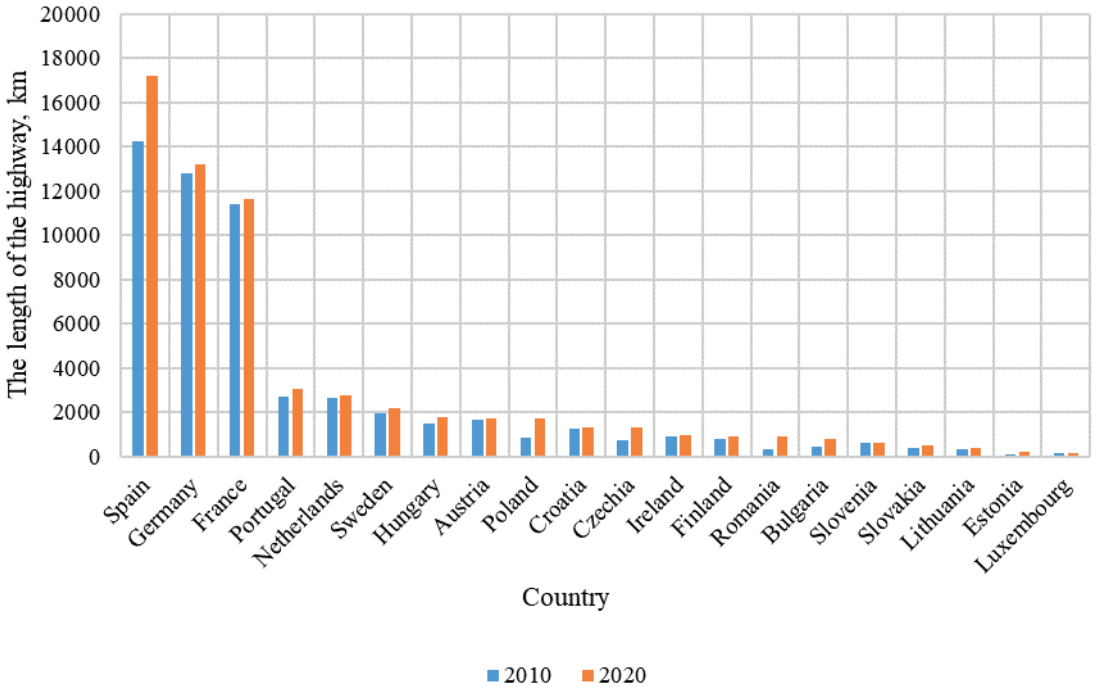

Figure 1 *Characteristics of the motorway length in European countries in 2010 and 2020*

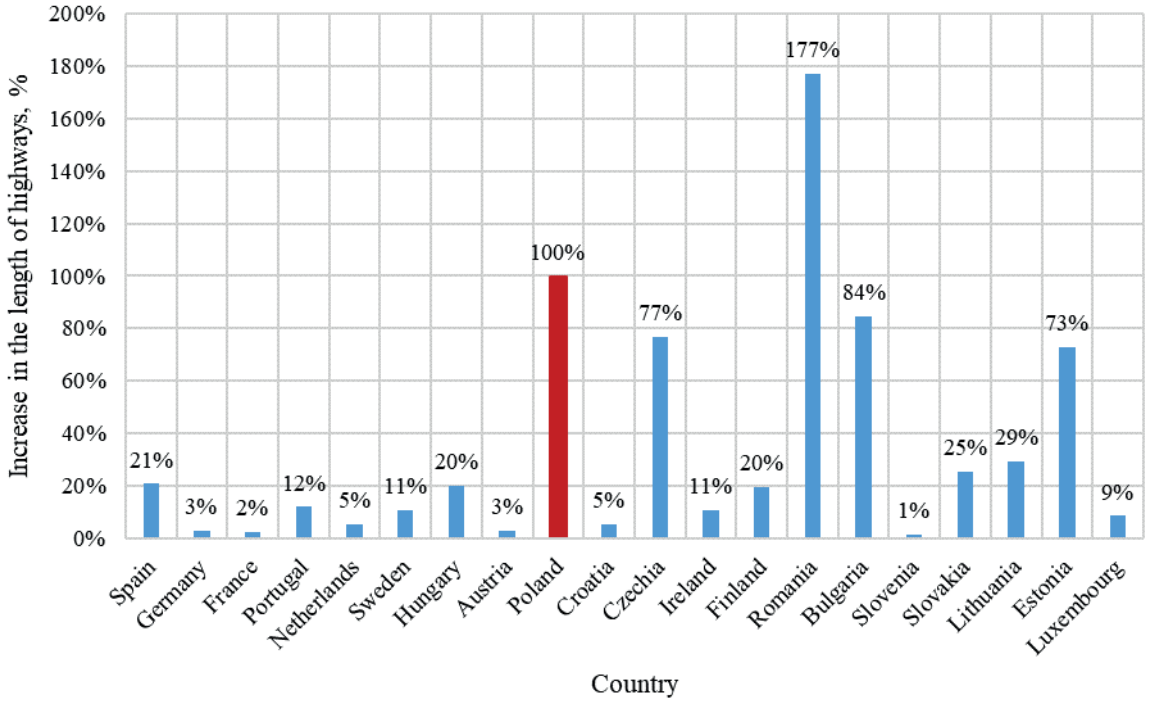

Figure 2 *Characteristics of the increase in the length of highways in European countries in 2020 compared to 2010*

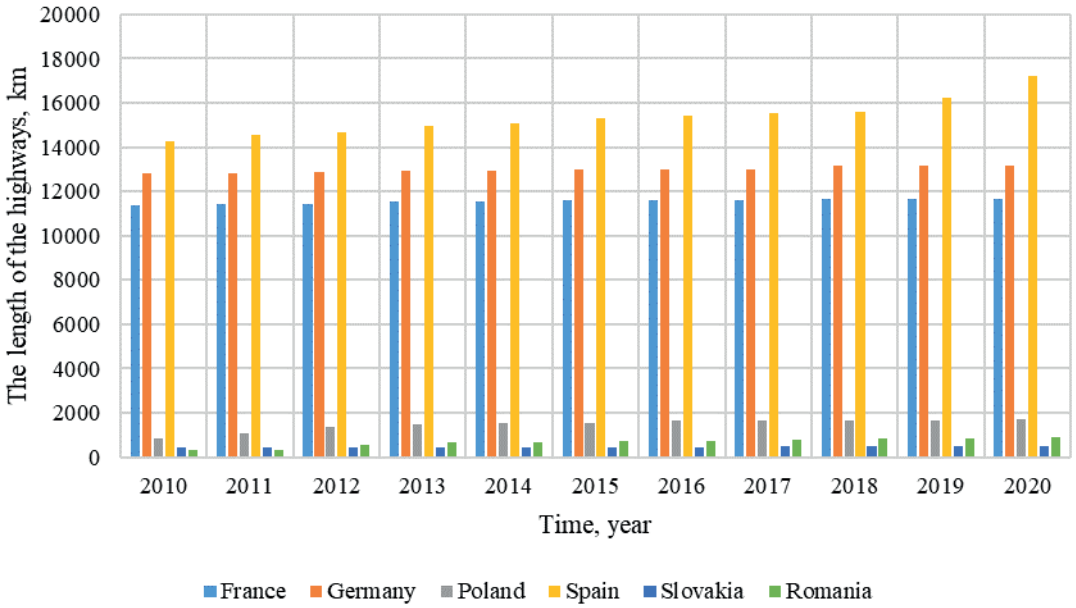

Figure 3 *Comparison of the length of highways in selected EU countries in 2010-2020*

by approximately 100% compared to 2010. The length of expressways in 2020 increased by 297% compared to 2010. Despite the fact that Poland differs significantly in terms of the length of motorways from Spain or Germany, it is pleasing that within 10 years the road infrastructure is subject to continuous development and extension of expressways [44-47].

The number of registered motor vehicles in Poland in 2010-2020 has changed significantly. Figure 5 shows the number of registered motor vehicles in Poland in 2010-2020. This number increased from 23 million (2010) to 33 million (2020) [44-47]. On average, the number of motor vehicles in Poland increases by 3% each year.

The number of vehicles registered in European countries is increasing every year. Most motor vehicles in 2020 were registered in Germany (53,651,934 units) and Italy (44,980,390 units). Figure 6 presents the characteristics of the change in the number of registered vehicles in European countries in 2010 and 2020. Figure 7 shows the percentage change of registered vehicles in

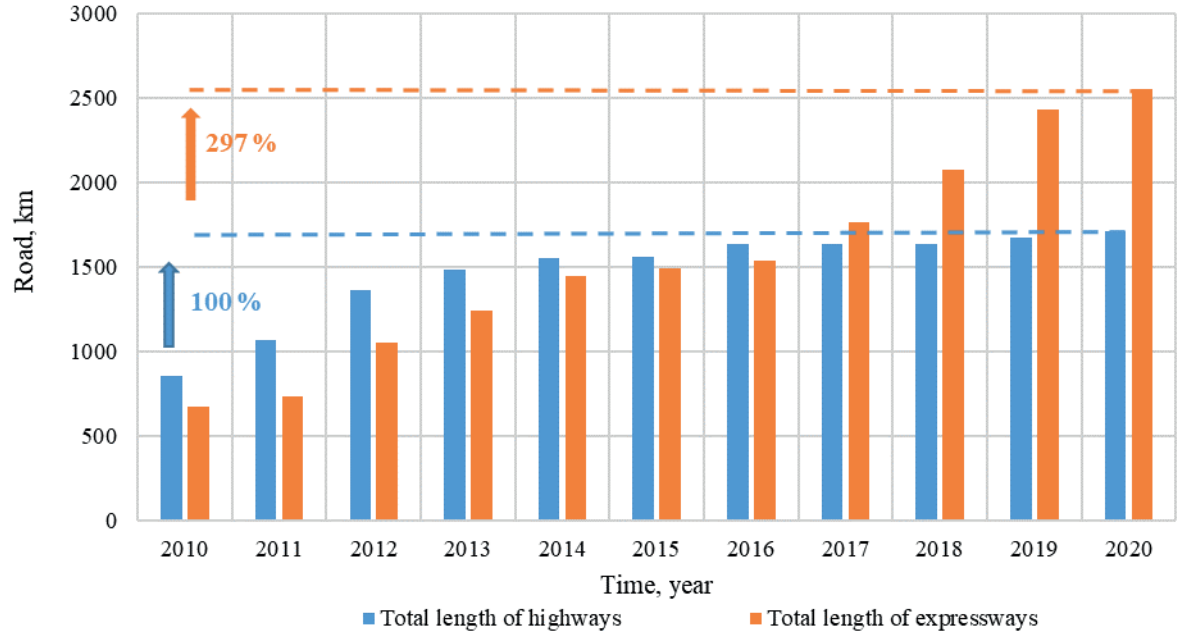

Figure 4 *The length of highways and expressways in Poland in 2010-2020*

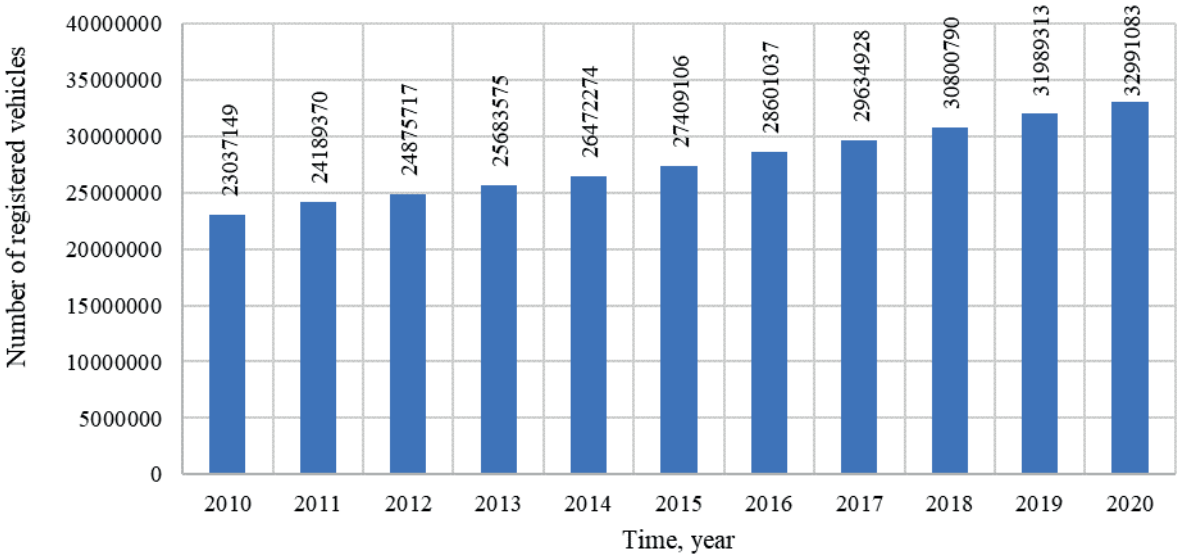

Figure 5 *Number of motor vehicles in Poland in 2010-2020*

European countries in 2020 compared to 2010. It should be noted that in the period under consideration, from 2010 to 2020, the highest increase in motor vehicles was recorded in Romania and amounted to 68%. During that period, the number of motor vehicles in Romania increased from 5,058,500 to 8,518,166. In Germany, during the period under consideration, the number of motor vehicles increased by 16% and in Italy by 8%. In Poland, the number of motor vehicles in the years 2010-2020 increased by 44%. In Poland, in 2010, the number of registered motor vehicles was 20,458,100, while in 2020 it was 29,466,460.

Compared to 2010, in 2020 the number of registered passenger cars in Poland increased by 29%, motorcycles by 36% and trucks by 19% [44-47]. Figure 8 shows the growth characteristics of registered passenger cars in Poland in 2010-2020, while Figure 9 shows the growth characteristics of registered motorcycles and trucks in Poland in 2010-2020.

4 Road accidents in Poland

The road traffic poses a risk of collisions and road accidents. Unfortunately, those events still constitute a serious social problem. Despite many measures taken in Poland and in the EU, it was not possible to reduce the number of fatalities by 50% compared to 2010. The number of road accidents in Poland in 2010-2020 decreased from 38,832 to 23,540 (-39.4 %), while the

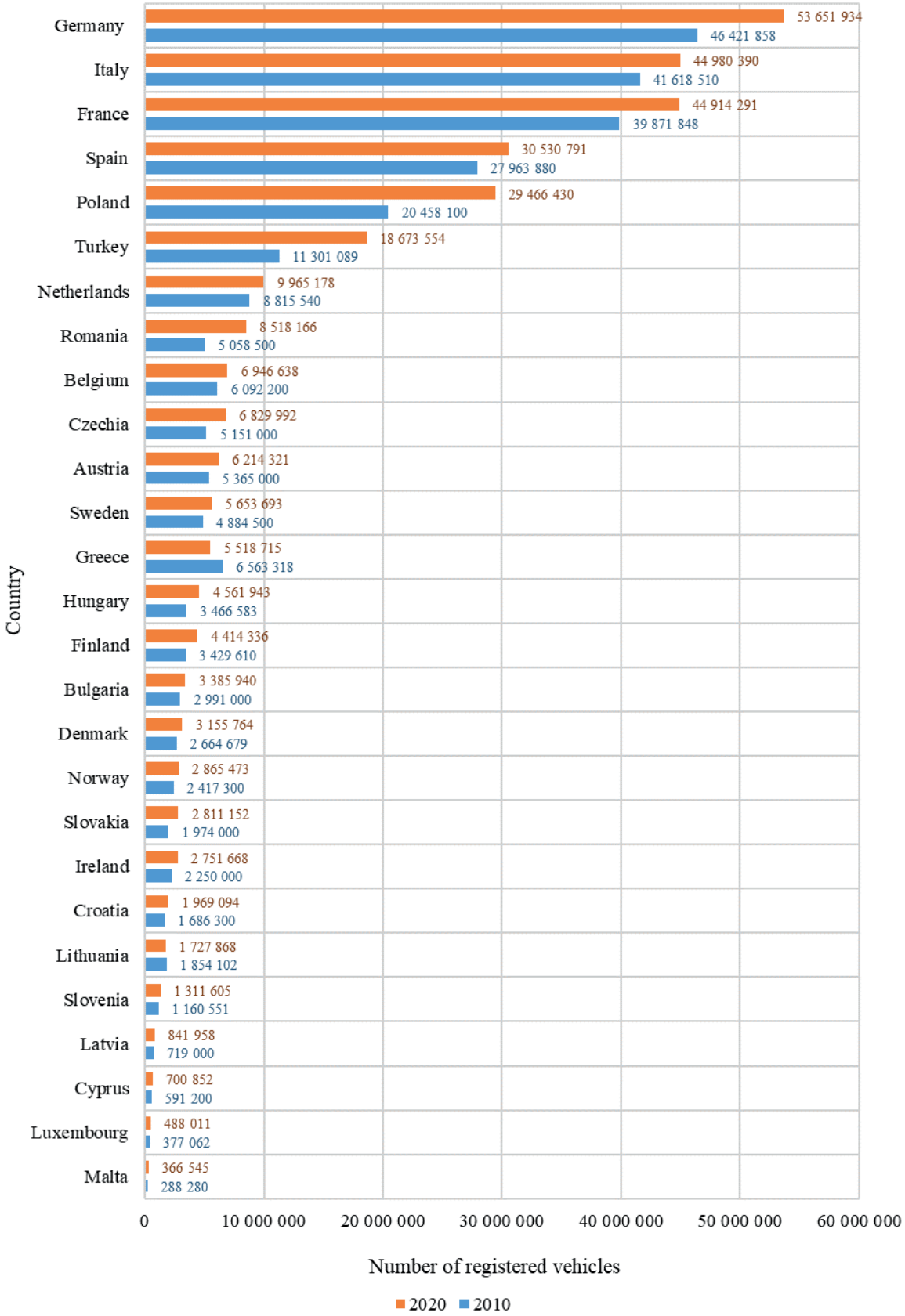

Figure 6 *Characteristics of the change in the number of registered vehicles in European countries in 2010 and 2020*

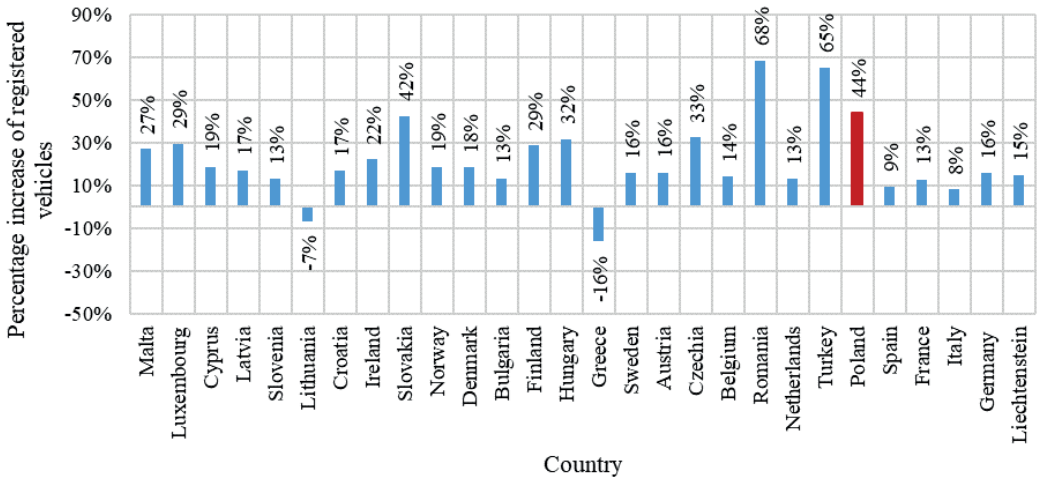

Figure 7 *Percentage change of registered vehicles in European countries in 2020 compared to 2010*

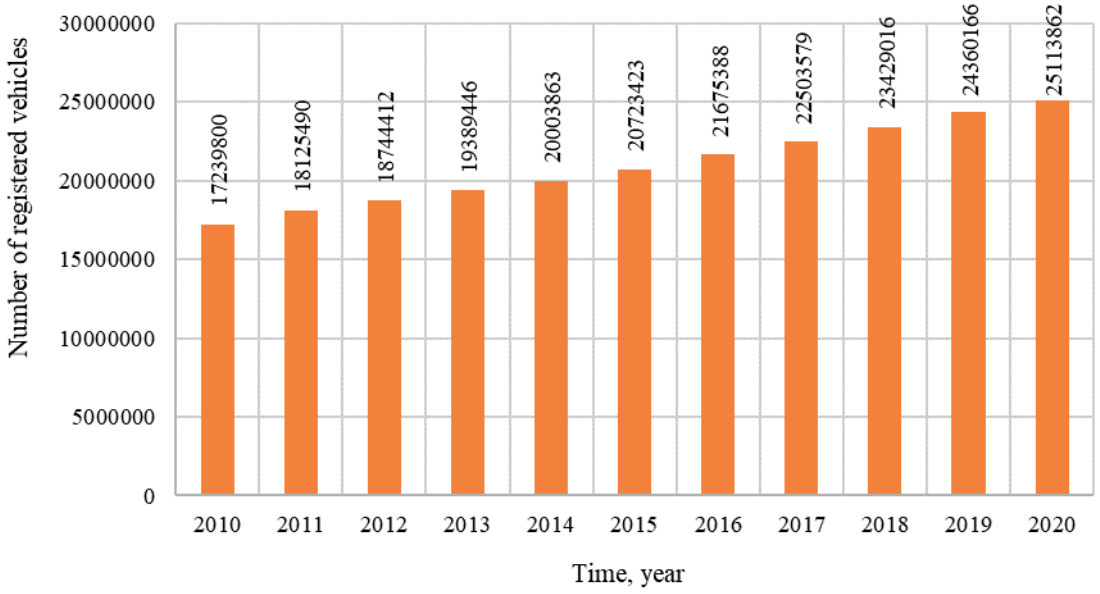

Figure 8 *Variation of the registered passenger cars growth in Poland in 2010-2020*

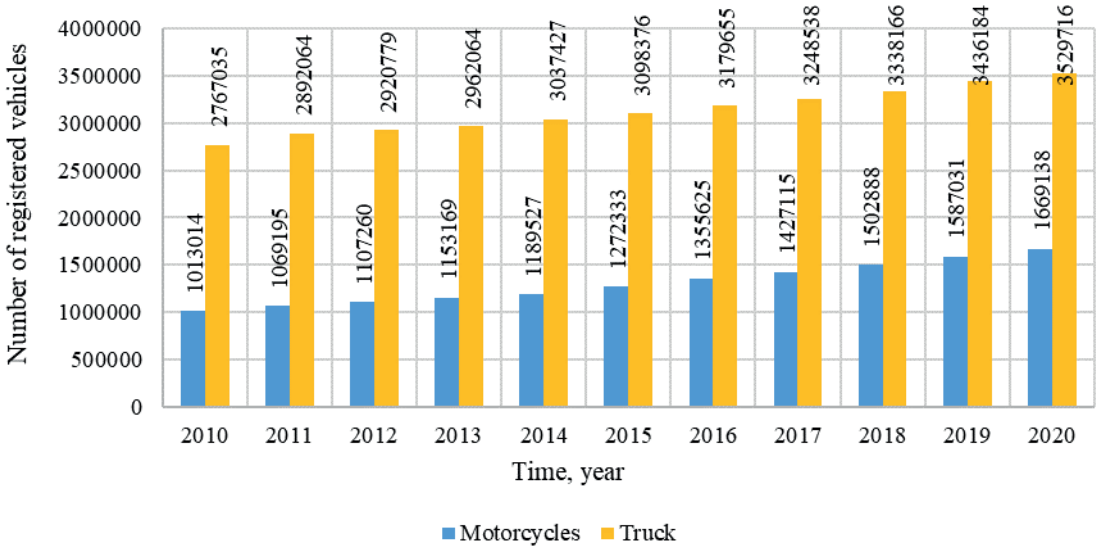

Figure 9 *Characteristics of the registered motorcycles and trucks growth in Poland in 2010-2020*

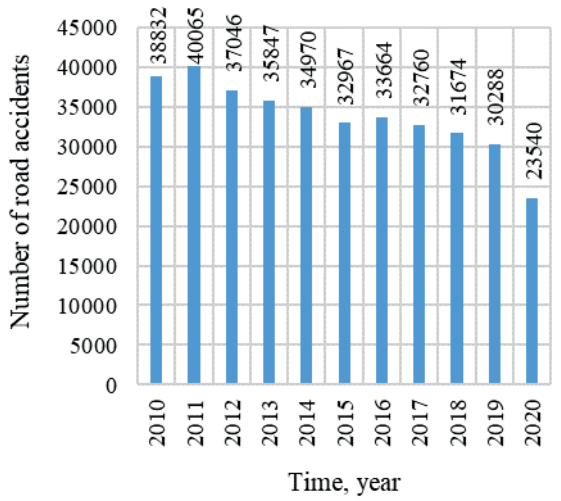

Figure 10 *Number of road accidents in 2010-2020*

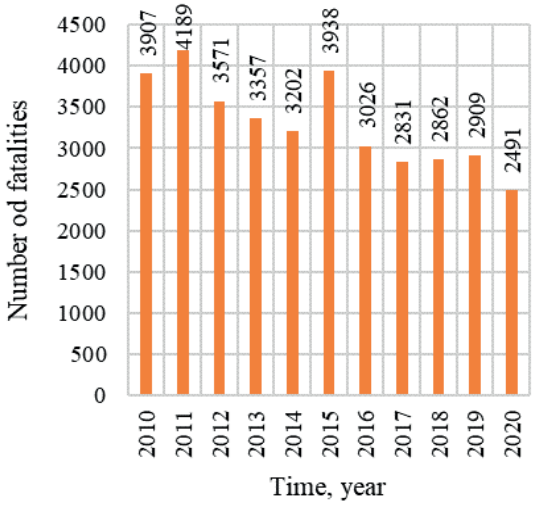

Figure 11 *Number of fatalities in road accidents in 2010-2020*

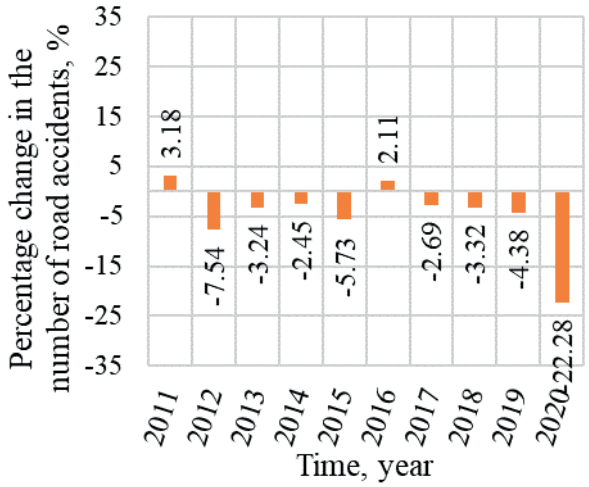

Figure 12 *Annual change in the number of road accidents in Poland in 2010-2020*

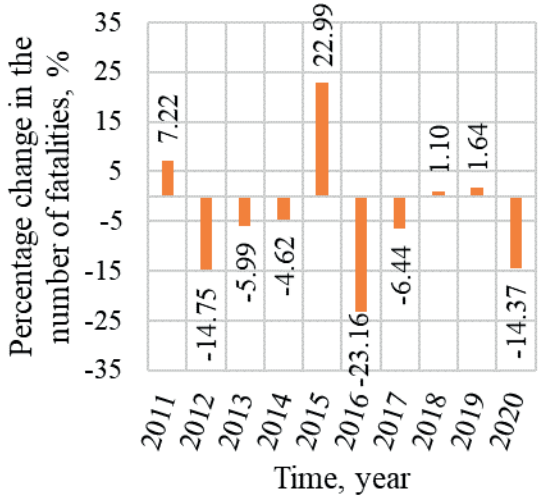

Figure 13 *Annual change in the number of road fatalities in Poland in 2010-2020*

number of fatalities decreased from 3,907 to 2,491 (-36.3 %). Poland, like the EU member states, assumed a 50% reduction in the number of fatalities in the analyzed period. The assumed number of fatalities in road accidents in Poland in 2020 should be 1954. Unfortunately, the real number was higher by as many as 538 fatalities [44-47]. Figure 10 presents the characteristics of the number of road accidents and Figure 11 shows the number of fatalities in road accidents in 2010-2020.

In the analyzed period, the largest decrease in the number of road accidents took place in 2020 compared to 2019 and amounted to -22.3%. Over the last 10 years, only in 2011 and 2016 there was an increase in the number of accidents compared to the previous year. The number of fatalities in 2015 increased in fatalities by as much as 22.9% compared to 2014. In addition, there was an increase in death toll in 2011, 2018 and 2019 [44-47]. Figure 12 shows the annual change in the number of road accidents in Poland in 2010-2020. Figure 13 shows the annual change in the number of road fatalities in Poland in 2010-2020.

5 Road accidents and their consequences

The approach to improvement of the road safety is primarily aimed at ensuring a safe transport system for all the road users. The cornerstone of the road safety improvement system is elimination of the fatal accidents and reduction of serious injuries, as a result of the safe roads and roadsides and the determination of a safe speed for traveling on certain types of roads. At the same time, safety systems in vehicles are under constant development [3, 47]. Every year, road accidents generate huge costs for society. The total number of road fatalities per 1 million inhabitants in the EU decreased by 37% in 2020 compared to 2010. Unfortunately, the number

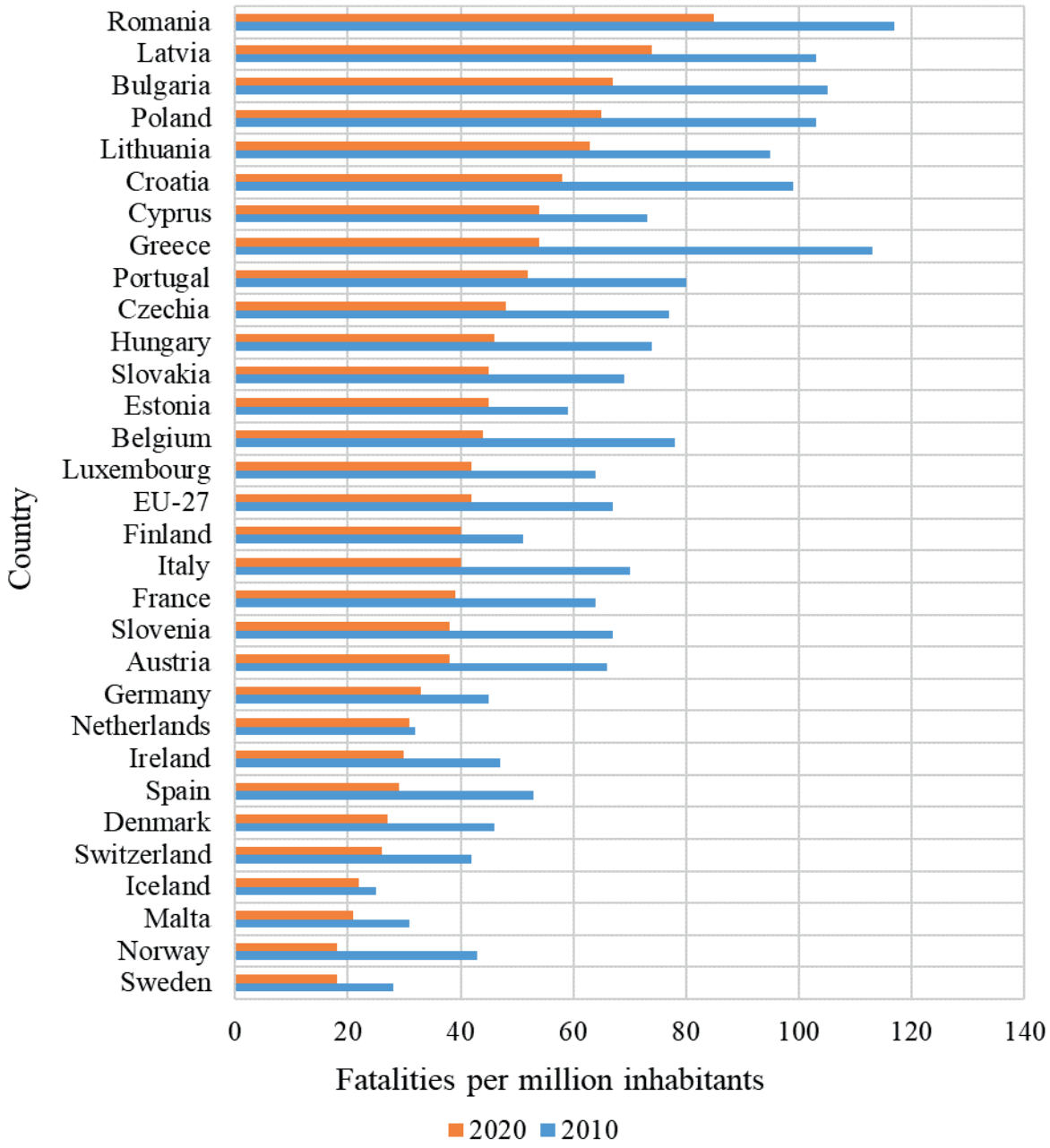

Figure 14 *Number of road fatalities per million inhabitants in individual EU member states*

of deaths per 1 million inhabitants has not decreased in the last decade in all the EU Member States. Among the European Union countries, the lowest number of fatalities in road accidents is noted in Sweden (18 deaths per million inhabitants), while the highest occurred in Romania (85 deaths per million inhabitants). The European Union fatality rate in 2020 was 42 deaths per 1 million inhabitants; this result is almost 5 times lower than the world average, which in 2020 was 180 deaths in road accidents per million inhabitants [44-47]. Figure 14 presents the characteristics of the number of road fatalities per million inhabitants in individual EU member states.

It should be noted that within a decade, Greece and Norway achieved a 50% reduction in the number of road fatalities. Countries such as Belgium, Bulgaria, Spain, Croatia, Italy, Lithuania, Portugal and Slovakia recorded a decline of more than 40%. In Poland, in 2010, the number of fatalities in road accidents per million inhabitants was 103 people, while in 2020 it was 65 people, so there was a decrease by 37% [-44-47]. The percentage change in the number of road fatalities per million inhabitants in individual EU member states in the period 2010-2020 is presented in Figure 15.

The annual change in the number of fatalities in accidents on EU roads shows a downward trend in

the period 2010-2019 (Figure 16). The largest annual decrease took place in 2013 and amounted to 8.6% compared to 2012. Only in 2015, the number of fatalities on EU roads increased by 0.9% compared to 2014. The annual downward trend in the number of fatalities in the Member States varies significantly. In Germany, in 2011, 2014, 2015 and 2018, there was an increase in the number of fatalities compared to the previous year (Figure 17). In France, the increase in the number of fatalities occurred in 2014, 2015 and 2016 (Figure 19). In contrast, in Spain, the annual rise in the number of fatalities was recorded from 2014 to 2017 (Figure 18). In Slovakia, the increase in the number of fatalities occurred in 2012, 2014, 2015, 2017, 2019 (Figure 20); on the other hand, in Romania in 2012, 2015, 2016, 2017 (Figure 21) [-44-47].

The number of road fatalities in the EU in 2019 is presented in Figure 22. The highest number of road fatalities in the EU as a whole occurs during the holiday period between June and August. In these months in 2019, the total number of fatalities on EU roads amounted to 6,653 people. The lowest number of road fatalities in the EU in 2019 was recorded in February and amounted to 1,560 people. It can be noted that in Germany, France, Italy, Portugal, Spain, Poland, the highest number of fatalities in road accidents during the year is recorded in the period from July to September. In Romania, on the other hand, the record number of fatalities occurs from October to December (Figure 23) [44-47].

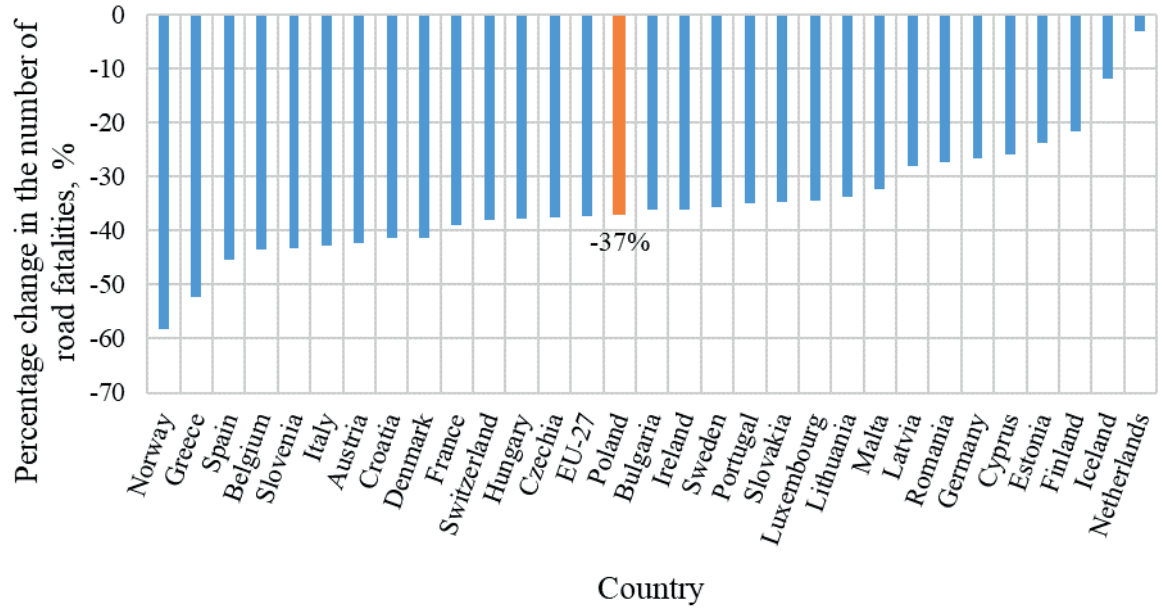

Figure 15 *Percentage change in the number of road fatalities per million inhabitants in individual EU Member States in 2010-2020*

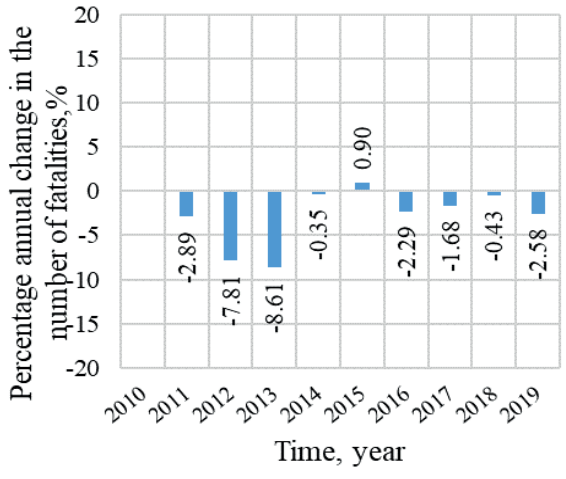

Figure 16 *Annual change in the number of fatalities in accidents on EU roads in 2010-2019*

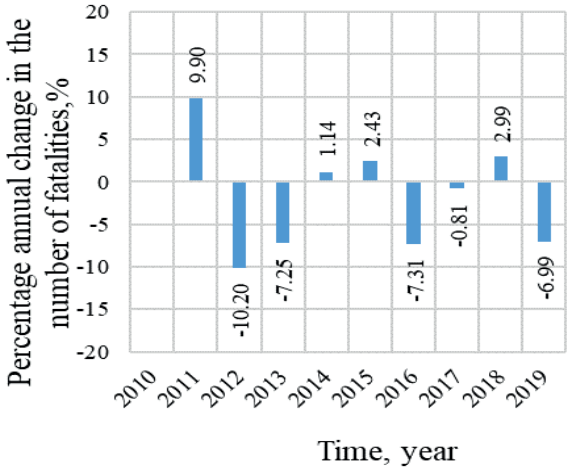

Figure 17 *Annual change in the number of fatalities in road accidents in Germany in 2010-2019*

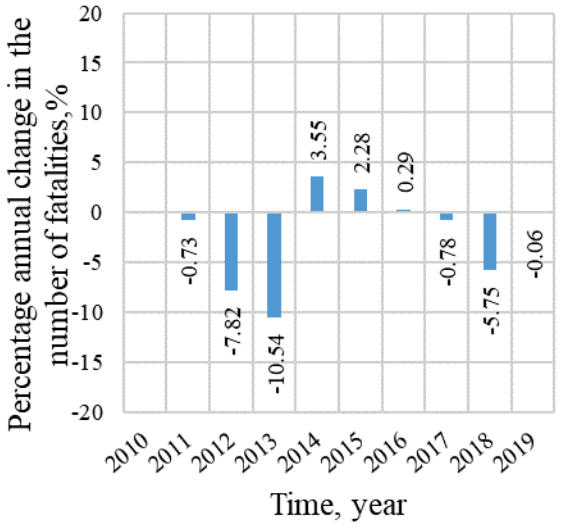

Figure 18 *Annual change in the number of road fatalities in accidents on Spain's roads 2010-2019*

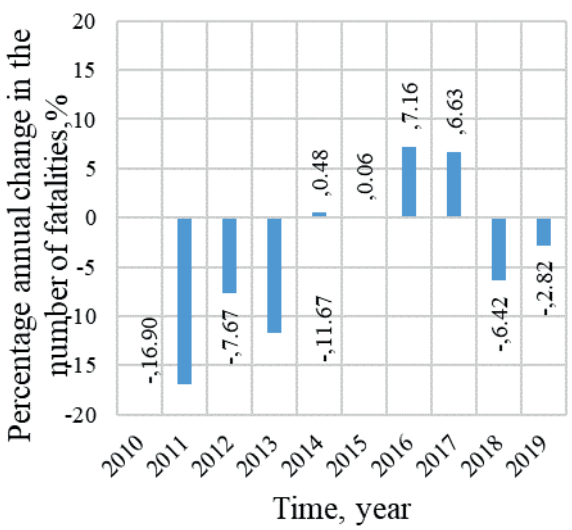

Figure 19 *Annual change in the number of fatalities in road accidents in France in 2010-2019*

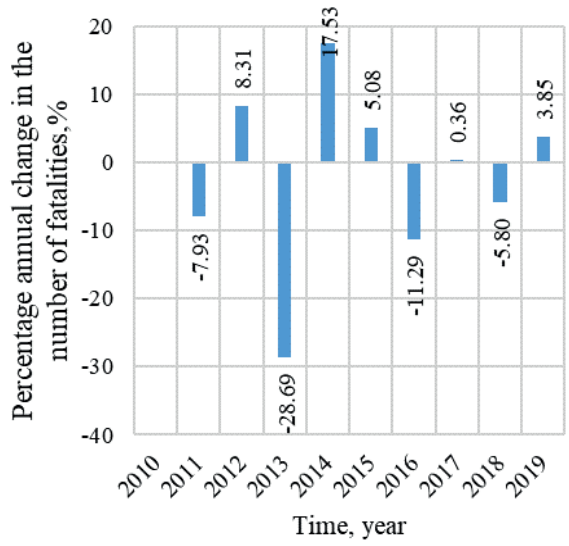

Figure 20 *Annual change in the number of road fatalities in accidents on Slovakia roads 2010-2019*

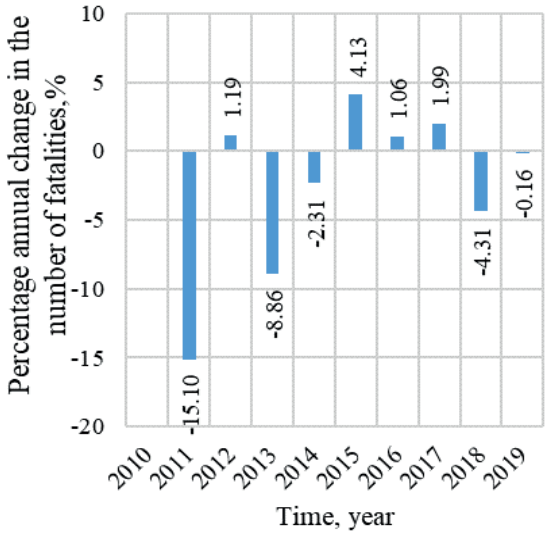

Figure 21 *Annual change in the number of fatalities in road accidents in Romania in 2010-2019*

The number of road fatalities in the EU and selected Member States on specific days of the week is presented in Figure 24. When analyzing accidents in 2019 in the EU, the lowest number of fatalities was recorded on Tuesdays (2,906 victims), while the highest number was recorded on Saturdays (3,782 victims). Similarly, in Poland, in 2019 the most fatalities were noted on Saturdays, 485 victims. In Germany, the highest number of deaths in road accidents in 2019 was recorded on Sundays (464 victims) and the lowest on Thursdays (394 victims). In the case of France and Italy, the highest number of road fatalities was observed on Saturdays [44-47].

The number of fatalities in road accidents by time, in the EU and selected Member States, is shown in Figure 25. It should be noted that the most fatalities in road accidents in the EU in 2019 occurred between 3 PM and 5 PM, while the lowest was at night. A similar situation occurs in Poland, France and Germany. In Italy, the highest number of road fatalities occurred between 6 PM and 8 PM [44-47].

6 Statistical analysis

The number of road fatalities in the European Union and in the Member States is getting smaller every year. Some countries experience an increase in the number of road fatalities in one year, but the overall downward trend is maintained. The "Zero Accident

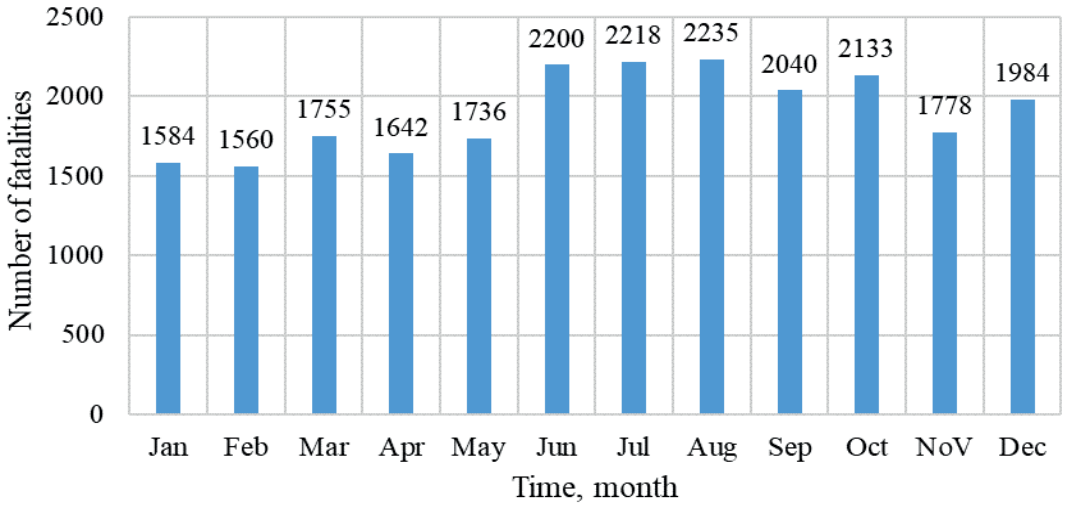

Figure 22 *Number of road fatalities in the EU in 2019*

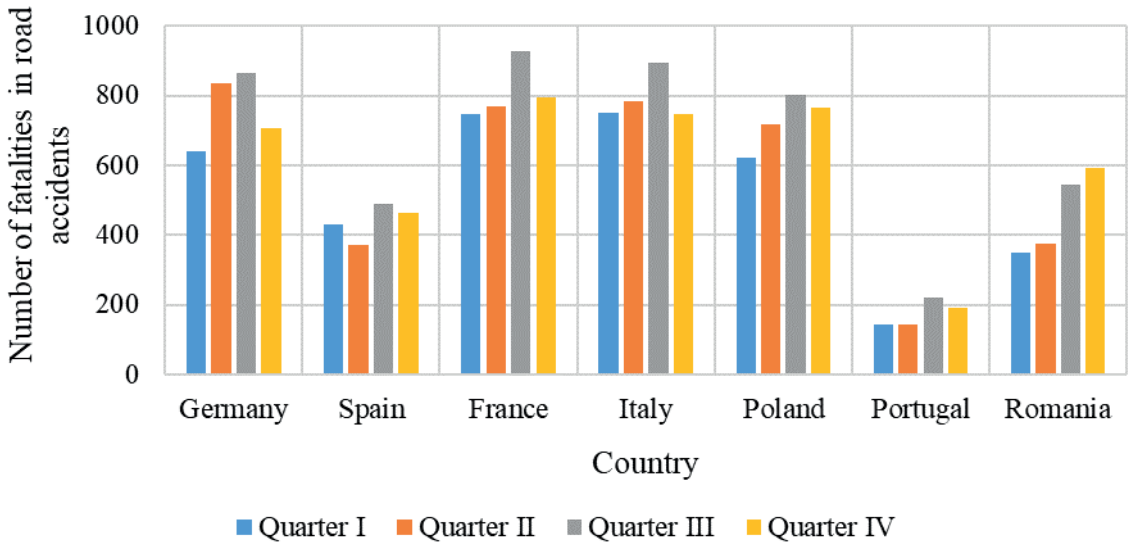

Figure 23 *Number of fatalities in road accidents in individual quarters of 2019 in selected EU Member States*

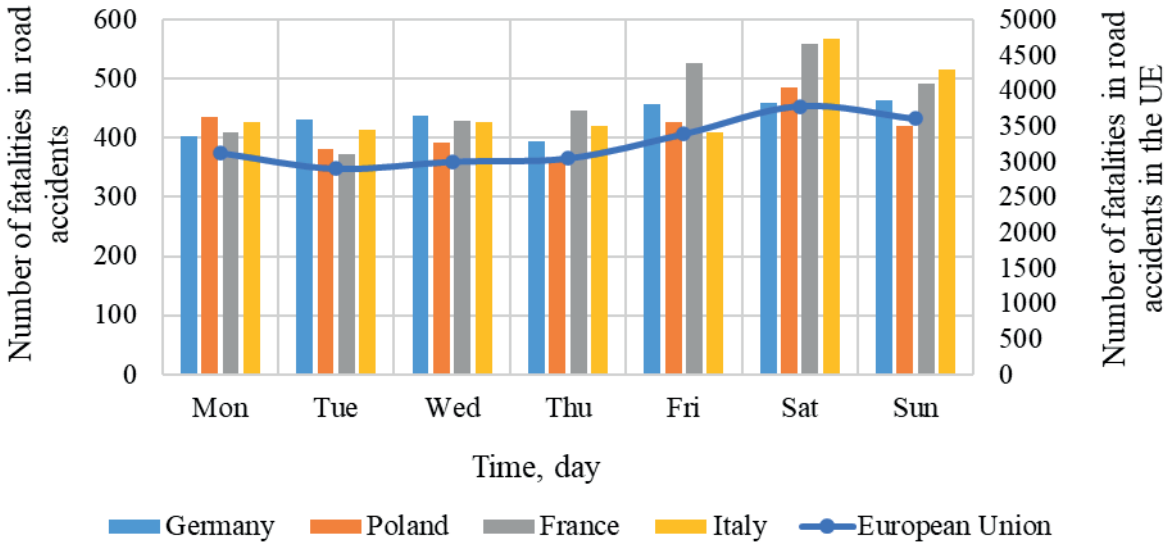

Figure 24 *Number of fatalities in road accidents in the EU and selected Member States on specific days of the week in 2019*

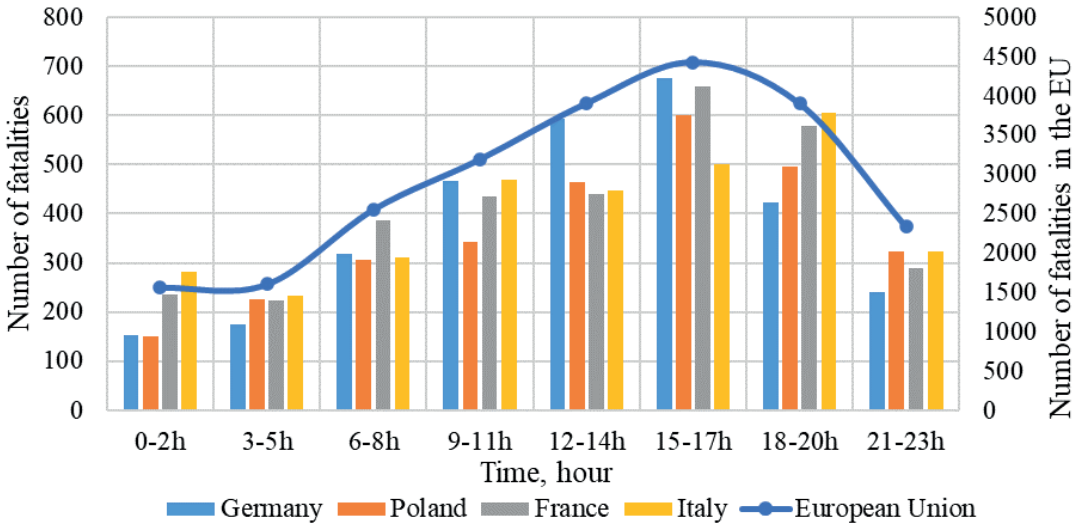

Figure 25 *Number of fatalities in road accidents in the EU and selected Member States at different times of the day in 2019*

Table 1 *The coefficient of determination R^2 for data on the number of fatalities in selected EU countries*

Country	R^2 coefficient	Country	R2 coefficient
Poland	0.6705	Ireland	0.2279
Austria	0.1866	Italy	0.9614
Belgium	0.9131	Latvia	0.0941
Bulgaria	0.4676	Lithuania	0.6234
Croatia	0.9285	Luxembourg	0.0194
Czech Republic	0.0236	Malta	0.0013
Denmark	0.4769	Netherlands	0.0478
Estonia	0.0475	Portugal	0.0522
Finland	0.6945	Romania	0.0802
France	0.9690	Slovak Republic	0.3967
Germany	0.2421	Slovenia	0.8537
Greece	0.9663	Spain	0.0976
Hungary	0.505	Sweden	0.3441

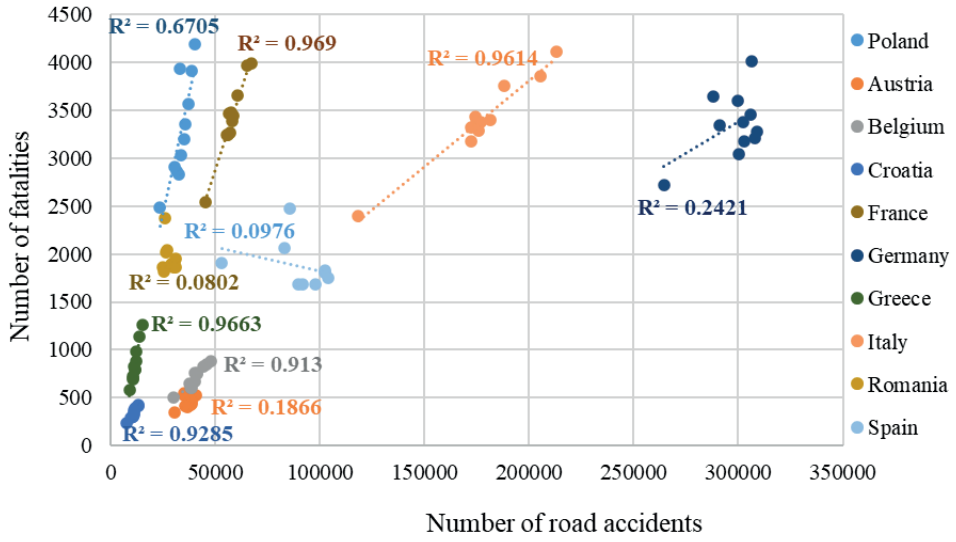

Figure 26 *Number of road accidents versus number of fatalities for selected EU Member States*

Vision" policy, pursued in the Member States of the European Union, contributes to increasing the safety of the newly manufactured motor vehicles, improving the road infrastructure and tightening the provisions of the Highway Code. Apart from the driver's fault, the above factors are the most often mentioned as the cause of a road accident. By determining the R^2 coefficient, which is a measure of the quality of the model fit. The authors wanted to check which of the above factors (the number of registered motor vehicles, the total number of road accidents, the length of highways) has the greatest impact on the drop in the number of fatalities in selected European countries

Analyzing the available statistical data on the number of fatalities, attention should be paid to the relationship between the number of road accidents and the number of fatalities. The coefficient of determination R^2 for data on the number of fatalities, taking into account the total number of road accidents, in selected European countries, is presented in Table 1.

The R^2 coefficient of determination for data on the number of fatalities in selected European countries is presented in Table 1. The value of the R^2 coefficient of determination for France (R^2 = 0.9690), Greece (R^2 = 0.9663), Italy (R^2 = 0.9614), Croatia (R^2 = 0.9285), Belgium (R^2 = 0.9285) and Slovenia (R^2 = 0.8537), proves that the number of fatalities is closely related to the number of road accidents. This is an obvious statement, but it should be borne in mind that in countries where the value of the R^2 coefficient is close to 1, it indicates

Table 2 *The coefficient of determination R2 for data on the number of road accidents in terms of the number of registered motor vehicles in selected European countries*

Country	R^2	Country	R^2
Belgium	0.878	Spain	0.484
Austria	0.844	Ireland	0.449
Latvia	0.808	Netherlands	0.279
Slovakia	0.781	Greece	0.250
Poland	0.743	Sweden	0.205
France	0.730	Denmark	0.160
Italy	0.704	Luxembourg	0.120
Germany	0.702	Slovenia	0.106
Czechia	0.687	Lithuania	0.077
Hungary	0.676	Estonia	0.025
Finland	0.637	Portugal	0.025
Romania	0.545	Malta	0.020
Croatia	0.492	Bulgaria	0.004

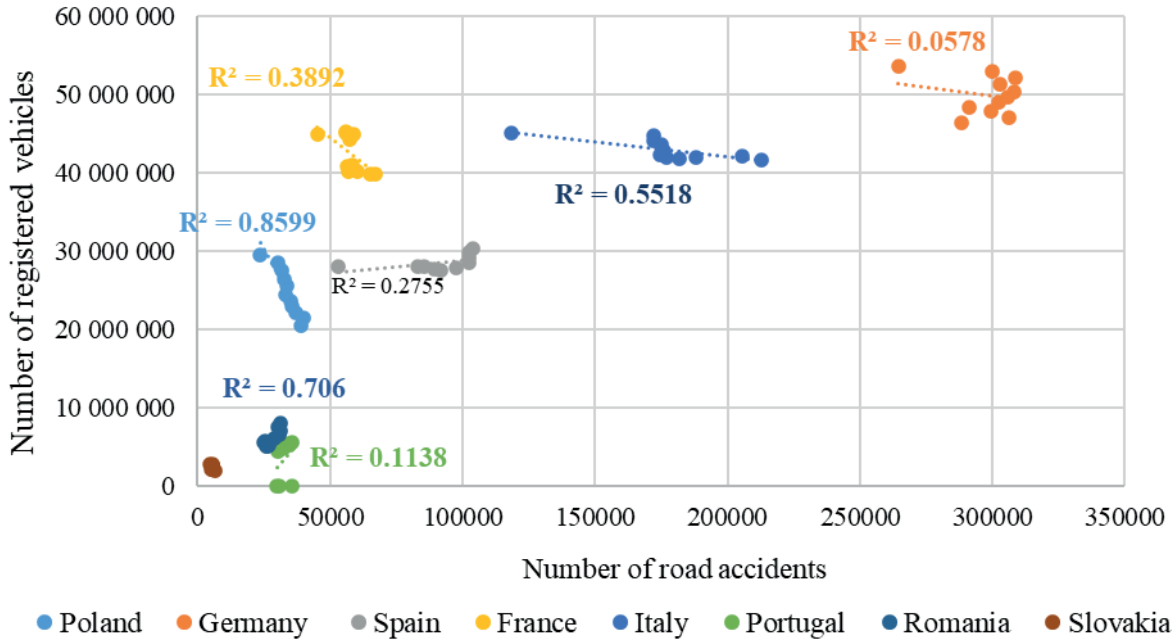

Figure 27 *The number of road accidents versus the number of registered motor vehicles for selected EU Member States*

a large number of accidents with fatalities in the total number of accidents. Therefore, in order to reduce the number of fatalities in these countries, the overall number of road accidents should be reduced. The lowest values of the determination indicator R^2 occurred in the Czech Republic (R^2 = 0.0236), Luxembourg (R2 = 0.0194) and Malta (0.0013) (Figure 26). In these countries, the number of fatalities is not closely related to the total number of road accidents. The coefficient of determination R^2 for Poland is 0.6705 in the period in question. This proves a moderate dependence of the number of fatalities on the total number of road accidents.

When analyzing the available statistical data on the number of road accidents, attention should be paid to the relationship between the number of road accidents and the number of registered motor vehicles. The determined coefficient of determination R2 for data on the number of road accidents, in terms of the number of registered motor vehicles in selected European countries, is presented in Table 2.

The results of the coefficient of determination R^2, for Belgium (R^2 = 0.878), Austria (R^2 = 0.844), Latvia (R^2 = 0.808), Slovakia (R^2 = 0.781), Poland (R^2 = 0.743) and France (R^2 = 0.730), show that the number of road accidents is related to the number of registered motor vehicles. Therefore, in order to reduce the number of road accidents in these countries, the total number of registered motor vehicles should be reduced. In addition, it should be noted that in Germany and Italy,

Table 3 *The coefficient of determination R^2 for data on the number of fatalities in terms of the number of registered motor vehicles in selected European countries*

Country	R^2	Country	R^2
Finland	0.9608	Croatia	0.495
Malta	0.9149	Spain	0.450
Poland	0.8599	Slovenia	0.400
Belgium	0.7807	Italy	0.343
Slovakia	0.7765	Netherlands	0.324
Germany	0.7013	Romania	0.265
Greece	0.6942	France	0.231
Hungary	0.6915	Bulgaria	0.222
Portugal	0.6770	Austria	0.176
Latvia	0.6621	Estonia	0.029
Denmark	0.5291	Lithuania	0.019
Luxembourg	0.5231	Ireland	0.011
Sweden	0.5102	Czechia	0.001

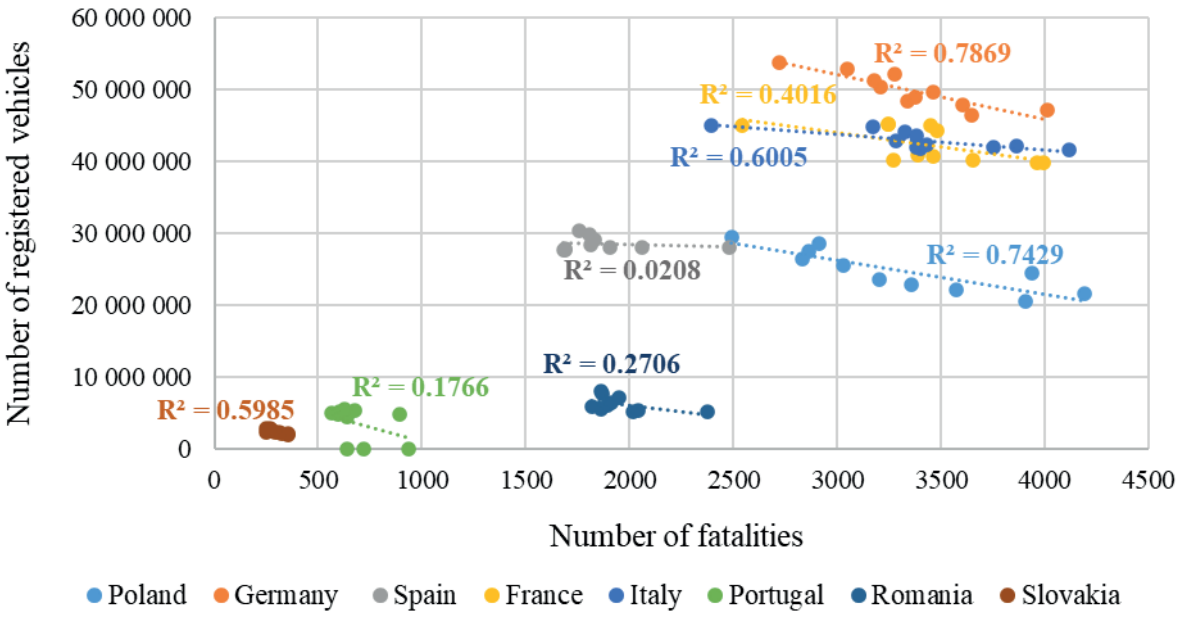

Figure 28 *Number of road fatalities versus the number of registered motor vehicles for selected EU Member States*

Table 4 *The coefficient of determination R^2 for data on the number of road accidents in terms of the length of motorways in selected European countries*

Country	R^2	Country	R^2
Spain	0.8700	Slovenia	0.3592
Finland	0.8337	Netherlands	0.2447
Slovakia	0.6960	France	0.2286
Germany	0.6834	Portugal	0.2189
Sweden	0.6455	Austria	0.1940
Poland	0.6079	Ireland	0.1013
Croatia	0.6071	Denmark	0.0281
Luxembourg	0.5829	Estonia	0.0218
Italy	0.4828	Bulgaria	0.0037
Romania	0.4461	Czechia	0.0021
Hungary	0.4310	Lithuania	0.0001

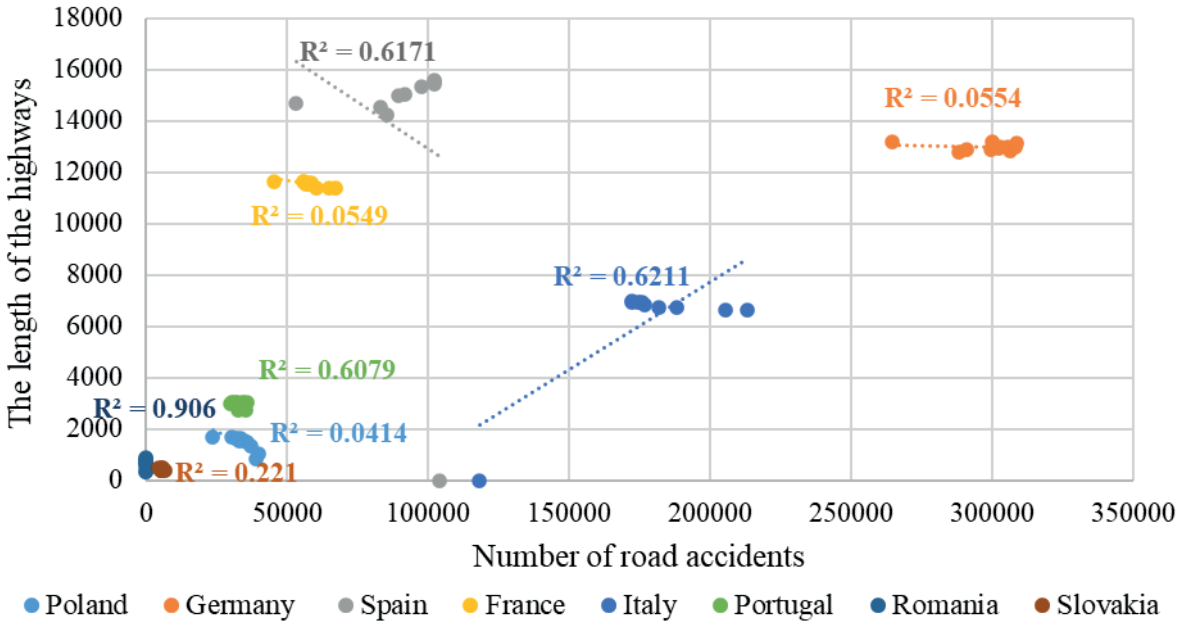

Figure 29 *The number of road accidents versus the length of motorways for selected EU Member States*

where the most registered motor vehicles are present, the coefficient of determination R^2 is 0.7, this result is much lower than for Belgium or Austria, where the number of registered motor vehicles is almost 10 times lower. The lowest values of the determination indicator R^2 were recorded in Lithuania, Estonia, Portugal, Malta and Bulgaria. For those countries, the value of the determination index R^2 did not exceed 0.1 (Figure 27); in those countries, the number of road accidents is not related to the total number of registered motor vehicles.

However, attention should be paid to the relationship between the number of road fatalities and the number of registered motor vehicles. The determined coefficient of determination R^2 for data on the number of fatalities in road accidents and the number of registered motor vehicles in selected European countries is presented in Table 3.

The results of the coefficient of determination R^2 for Finland (R^2 = 0.9608), Malta (R^2 = 0.9149), Poland (R^2 = 0.8599), Belgium (R^2 = 0.7807) and Slovakia (R^2 = 0.7765), show that the number of road fatalities is related to the number of registered motor vehicles. Therefore, in order to reduce the number of road fatalities in these countries, the total number of registered motor vehicles should be reduced. The lowest values of the determination indicator R^2 are for Estonia, Lithuania, Ireland and the Czech Republic. For these countries, the value of the determination index R^2 did not exceed 0.1 (Figure 28). In those countries, the number of road fatalities is not linked to the total number of registered motor vehicles.

When analyzing the available statistical data on the number of road accidents, attention should be paid to the relationship between the number of road accidents and the length of motorways. The determined coefficient of determination R2 for data on the number of road

Table 5 *The coefficient of determination R^2 for data on the number of road fatalities in terms of the length of motorways in selected European countries*

Country	R^2	Country	R^2
Spain	0.8561	Italy	0.5263
Czechia	0.7175	Hungary	0.5263
Croatia	0.7090	Netherlands	0.4797
Germany	0.6921	France	0.4779
Slovakia	0.6714	Ireland	0.4068
Portugal	0.6457	Sweden	0.2824
Romania	0.6409	Denmark	0.2304
Poland	0.6334	Luxembourg	0.1802
Austria	0.6234	Bulgaria	0.1763
Finland	0.5628	Slovenia	0.0741
Estonia	0.5410	Lithuania	0.0032

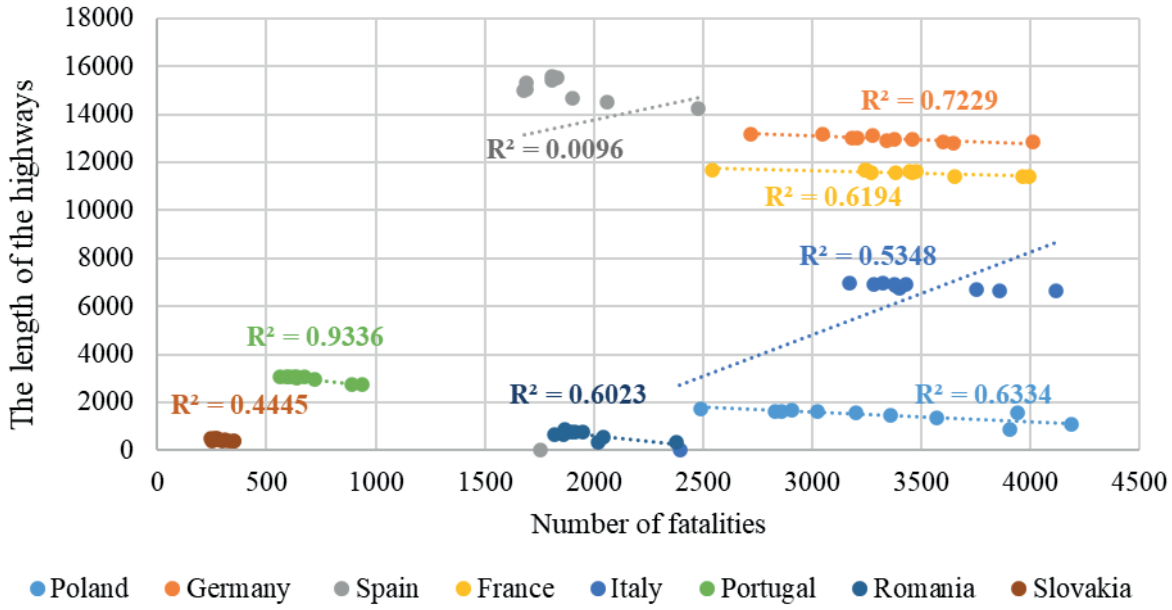

Figure 30 *Number of fatalities in road accidents versus the length of motorways for selected EU Member States*

accidents in terms of the length of motorways in selected European countries is presented in Table 4.

The results of the coefficient of determination R^2 for Spain (R^2 = 0.870), Finland (R^2 = 0.8337) and Slovakia (R^2 = 0.6960) show that the number of road accidents is related to the length of motorways. Therefore, in order to reduce the number of road accidents in these countries, the length of motorways should be increased. Moreover, it should be noted that in Germany (R^2 = 0.6834), Sweden (R^2 = 0.6455), Poland (R^2 = 0.6079) the coefficient of determination R2 indicates a significant relationship between the number of road accidents and the length of motorways. The lowest values of the determination indicator R^2 were recorded in Bulgaria, the Czech Republic and Lithuania. For these countries, the value of the determination index R^2 did not exceed 0.001 (Figure 29). In these countries, the number of road accidents is not related to the length of motorways.

However, attention should be paid to the relationship between the number of road fatalities and the length of motorways. The determined coefficient of determination R^2 for data on the number of fatalities in road accidents and the length of motorways in selected European countries is presented in Table 5.

Results of the coefficient of determination R^2 for Spain (R^2 = 0.8561), Czechia (R^2 = 0.7175), Croatia (R^2 = 0.7090), Germany (R^2 = 0.6921) and Slovakia (R^2 = 0.6714), show that the number of road fatalities is related to the length of motorways. Therefore, in order to reduce the number of road fatalities in these countries, the length of motorways should be increased. The lowest values of the determination index R^2 are for Slovenia and Lithuania. For these countries, the value of the determination index R^2 did not exceed 0.1 (Figure 30).

In these countries, the number of road fatalities is not linked to the length of the motorways.

7 Conclusions

The policy of the European Union is aimed at improving the road safety. A number of changes introduced by the member states of the European Union are aimed at reducing the number of fatalities in road accidents. The introduced changes are directed at improving the safety of motor vehicles, therefore new vehicles are equipped with a series of passive systems contributing to increasing safety, additionally the road infrastructure is developed, thanks to which the collision-free roads (highways, expressways) are created, in which all the participants travel in one direction.

The number of road accidents in the last decade has slightly decreased. Compared to 2010, the number of people who died as a result of a road accident decreased, as well. The overall number of fatalities in the EU in 2020 was lower by about 40% than in 2010. In Greece and Norway, the number of fatalities in road accidents in 2020 was 50% lower than in 2010. In Poland, in 2010, the number of fatalities in road accidents in 2020 was 37% lower than in 2010.

Analyzing the impact of the number of road accidents on the number of fatalities, it was confirmed that in some EU countries, the only way to reduce the number of fatalities is to reduce the total number of road accidents. Such countries include, for example, France, Greece and Italy. At the same time, these member states have very good road infrastructure.

When considering the number of fatalities, certain trends, specific to the EU and individual member states, were noticed. It was noted that the number of fatal accidents was highest in the summer months. It may be related to vacation and holiday trips. When analyzing the days of the week, most accidents with fatalities occur on Saturdays and the least on Tuesdays. Due to the time of day, most accidents take place in the afternoon. These are the so-called transport summit, which occur in most European countries between 3 PM and 5 PM The lowest number of accidents with fatalities is recorded at night.

In the analyzes presented in the paper, the R^2 index was used to assess the relationship between the number of accidents and the number of fatal accidents in individual EU countries. The high value of the index, oscillating around 1, indicates a large number of accidents with fatalities in the total number of accidents. When analyzing individual EU countries, Italy, France and Greece have the highest R^2 ratio. For these countries, the index is 0.97. Countries with the lowest rates are Malta, Luxembourg and the Czech Republic. The R^2 index for these countries is below 0.03.

Analyzing the impact of the number of road accidents on the number of registered motor vehicles, it was confirmed that in some EU countries, the only way to reduce the number of the road accidents is to reduce the total number of registered motor vehicles. Such countries include, for example, Belgium and Austria. At the same time, analyzing the impact of the number of road fatalities on the number of registered motor vehicles, it was confirmed that in some EU countries, the only way to reduce the number of road fatalities is to reduce the total number of registered motor vehicles. Such countries include Finland, Malta and Poland. Analyzing the impact of the number of road accidents on the length of motorways, it was confirmed that in some EU countries, the only way to reduce road accidents is to increase the length of motorways. Such countries include, for example, Spain, Finland and Slovakia. At the same time, when analyzing the impact of the number of road fatalities along the length of motorways, it was confirmed that in some EU countries, the only way to reduce the number of road fatalities is to increase the length of motorways. Such countries include the Spaniards and the Czech Republic. It should be noted that the number of road accidents is influenced by the infrastructure and to a large extent by the motorway network and the number of vehicles moving on the roads.

The R^2 coefficient of determination is used to analyze the impact of road accidents or victims in the road accidents in terms of Infrastructure or the number of registered motor vehicles. It may prove to be a useful indicator comparing the road safety for selected countries. In addition, the indicator can be used as one of the criteria for assessing the danger on the roads of European countries.

Perhaps the only effective measure to reduce the number of road fatalities is to educate road users. Social campaigns on television and social media can help to make drivers and other the road users aware of the consequences of accidents. One of the ways to influence drivers are high financial penalties for breaking the traffic regulations. An important issue for lawmakers and road managers is to ensure the safety of the road infrastructure, e.g. through appropriate marking, lighting, or the introduction of less collision-related intersections and road connections. Continuous development of passive and active safety systems for vehicles is also important, which can contribute to increasing safety for both vehicle users and other road users.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] MONETA, A. The most common causes and effects of road communication hazards / Najczestsze przyczyny i skutki zagrozen komunikacyjnych (in Polish). *Zeszyty Naukowe Ruchu Studenckiego*. 2016, **1**, p. 55-64. ISSN 2084-2279.

[2] WOJTAS, A., SZKODA, M. Analysis of selected factors influencing safety in road transport / Analiza wybranych czynnikow wplywajacych na bezpieczenstwo w ruchu drogowym (in Polish). *Autobusy: Technika, Eksploatacja, Systemy Transportowe*. 2018, **19**(6), p. 1149-1154. ISSN 1509-5878, eISSN 2450-7725.

[3] SZUMSKA, E., FREJ, D., GRABSKI, P. Analysis of the causes of vehicle accidents in Poland in 2009-2019. *LOGI - Scientific Journal on Transport and Logistics* [online]. 2020, **11**(2), p. 76-87. eISSN 2336-3037. Available from: https://doi.org/10.2478/logi-2020-0017

[4] NABI, H., CONSOLI, S. M., CHASTANG, J. F., CHIRON, M., LAFONT, S., LAGARDE, E. Type A behavior pattern, risky driving behaviors and serious road traffic accidents: a prospective study of the GAZEL cohort. *American Journal of Epidemiology* [online]. 2005, **161**(9), p. 864-870. ISSN 0002-9262, eISSN 1476-6256. Available from: https://doi.org/10.1093/aje/kwi110

[5] ANG, B. H., CHEN, W. S., LEE, S. W. H. Global burden of road traffic accidents in older adults: a systematic review and meta-regression analysis. *Archives of Gerontology and Geriatrics* [online]. 2017, **72**, p. 32-38. ISSN 0167-4943. Available from: https://doi.org/10.1016/j.archger.2017.05.004

[6] RASMUSSEN, J. Skills, rules and knowledge; signals, signs and symbols and other distinctions in human performance models. *IEEE Transactions on Systems, Man and Cybernetics* [online]. 1983, **13**(3), p. 257-266. ISSN 0018-9472, eISSN 2168-2909. Available from: https://doi.org/10.1109/TSMC.1983.6313160

[7] VAA, T. Cognition and emotion in driver behavior models: some critical viewpoints. In: 14th ICTCT Workshop: proceedings. 2001. p. 48-59.

[8] LONG, S., RUOSONG, C. Reliability and validity of the multidimensional driving style inventory in Chinese drivers. *Traffic Injury Prevention* [online]. 2019, **20**(2), p. 152-157. ISSN 1538-9588, eISSN 1538-957X. Available from: https://doi.org/10.1080/15389588.2018.1542140

[9] TOSI, J. D., LEDESMA, R. D. DIAZ LAZARO, C. M., POO, F. M. Implicit attitudes towards risky driving behaviors: evidence of validity for the implicit association test. *Journal of Safety Research* [online]. 2020, **75**, p. 284-291. ISSN 0022-4375. Available from: https://doi.org/10.1016/j.jsr.2020.08.008

[10] ULLEBERG, P., RUNDMO, T. Personality, attitudes and risk perception as predictors of risky driving behavior among young drivers. *Safety Science* [online]. 2003, **41**(5), p. 427-443. ISSN 0925-7535. Available from: https://doi.org/10.1016/S0925-7535(01)00077-7

[11] MARTINUSSEN, L. M., MOLLER, M., PRATO, C. G. Assessing the relationship between the driver behavior questionnaire and the driver skill inventory: revealing sub-groups of drivers. *Transportation Research Part F: Traffic Psychology and Behaviour* [online]. 2014, **26**, p. 82-91. ISSN 1369-8478. Available from: https://doi.org/10.1016/j.trf.2014.06.008

[12] MATTSSON, M. Investigating the factorial invariance of the 28-item DBQ across genders and age groups: an exploratory structural equation modeling study. *Accident Analysis and Prevention* [online]. 2012, **48**, p. 379-396. ISSN 0001-4575. Available from: https://doi.org/10.1016/j.aap.2012.02.009

[13] CHEN, S.-W., FANG, C.-Y., CHIH-TING, T. Driving behaviour modelling system based on graph construction. *Transportation Research Part C: Emerging Technologies* [online]. 2013, **26**, p. 314-330. ISSN 0968-090X. Available from: https://doi.org/10.1016/j.trc.2012.10.004

[14] LAJUNEN, T., GAYGISIZ, E. Born to be a risky driver? The relationship between cloninger's temperament and character traits and risky driving. *Frontiers in Psychology* [online]. 2022, **13**, 867396. eISSN 1664-1078. Available from: https://doi.org/10.3389/fpsyg.2022.867396

[15] CHRAIF, M., ANITEI, M., BURTAVERDE, V., MIHAILA, T. The link between personality, aggressive driving and risky driving outcomes - testing a theoretical model. *Journal of Risk Research* [online]. 2016, **19**(6), p. 780-797. ISSN 1366-9877, eISSN 1466-4461. Available from: https://doi.org/10.1080/13669877.2015.1042500

[16] DE WINTER, J. C. F., DODOU, D. The driver behaviour questionnaire as a predictor of accidents: a meta-analysis. *Journal of Safety Research* [online]. 2010, **41**(6), p. 463-470. ISSN 0022-4375. Available from: https://doi.org/10.1016/j.jsr.2010.10.007

[17] EBOLI, L., MAZZULLA, G., PUNGILLO, G. How drivers' characteristics can affect driving style. *Transportation Research Procedia* [online]. 2017, **27**, p. 945-952. ISSN 2352-1465. Available from: https://doi.org/10.1016/j.trpro.2017.12.024

[18] EBOLI, L., MAZZULLA, G., PUNGILLO, G. The influence of physical and emotional factors on driving style of car drivers: a survey design. *Travel Behaviour and Society* [online]. 2017, **7**, p. 43-51. ISSN 2214-367X. Available from: https://doi.org/10.1016/j.tbs.2017.02.001

[19] LUCIDI, F., GIANNINI, A.M., SGALLA, R., MALLIA, L., DEVOTO, A., REICHMANN, S. Young novice driver subtypes: relationship to driving violations, errors and lapses. *Accident Analysis and Prevention* [online]. 2010, **42**(6), p. 1689-1696. ISSN 0001-4575. Available from: https://doi.org/10.1016/j.aap.2010.04.008

[20] JIN, L., GUO, B., JIANG, Y., HUA, Q. Analysis on the influencing factors of driving behaviours based on theory of planned behaviour. *Advances in Civil Engineering* [online]. 2021, **2021**, 6687674. ISSN 1687-8086, eISSN 1687-8094. Available from: https://doi.org/10.1155/2021/6687674

[21] FUWU, Y., MUTIAN, L., CHANGHAO, D., YI, W., LIRONG, Y. Driving style recognition based on electroencephalography data from a simulated driving experiment. *Frontiers in Psychology* [online]. 2019, **10**, 1254. eISSN 1664-1078. Available from: https://doi.org/10.3389/fpsyg.2019.01254

[22] LEI, Y., LIU, K., FU, Y., LI, X., LIU, Z., SUN, S. Research on driving style recognition method based on driver's dynamic demand. *Advances in Mechanical Engineering* [online]. 2016, **8**(9), p. 1-14. ISSN 1687-8132, eISSN 1687-8140. Available from: https://doi.org/10.1177/1687814016670577

[23] TROGOLO, M., FRANCO M., MEDRANO, L. The role of difficulties in emotion regulation on driving behavior. *Journal of Behavior, Health and Social Issues* [online]. 2014, **6**(1), p. 107-117. ISSN 2007-0780, eISSN 2007-0772. Available from: https://doi.org/10.5460/jbhsi.v6.1.47607

[24] PUGNETTI, C., ELMER, S. Self-assessment of driving style and the willingness to share personal information. *Journal of Risk and Financial Management* [online]. 2020, **13**(3), 53. eISSN 1911-8074. Available from: https://doi.org/10.3390/jrfm13030053

[25] USECHE, S.A., CENDALES, B., ALONSO, F., PASTOR, J.C., MONTORO, L. Validation of the multidimensional driving style inventory (MDSI) in professional drivers: how does it work in transportation workers? *Transportation Research Part F: Traffic Psychology and Behaviour* [online]. 2019, **67**, p. 155-163. ISSN 1369-8478. Available from: https://doi.org/10.1016/j.trf.2019.10.012

[26] TAUBMAN - BEN-ARI, O., SKVIRSKY, V. The multidimensional driving style inventory a decade later: review of the literature and re-evaluation of the scale. *Accident Analysis & Prevention* [online]. 2016, **93**, p. 179-188. ISSN 0001-4575. Available from: https://doi.org/10.1016/j.aap.2016.04.038

[27] CORDERO, J., AGUILAR, J., AGUILAR, K., CHAVEZ, D. PUERTO E. Recognition of the driving style in vehicle drivers. *Sensors* [online]. 2020, **20**(9), 2597. eISSN 1424-8220. Available from: https://doi.org/10.3390/s20092597

[28] LI, G., ZHU, F., QU, X., CHENG, B., LI S., GREEN, P. Driving style classification based on driving operational pictures. *IEEE Access* [online]. 2019, **7**, p. 90180-90189. eISSN 2169-3536. Available from: https://doi.org/10.1109/ACCESS.2019.2926494

[29] MARTINEZ, C. M., HEUCKE, M., WANG, F. -Y., GAO, B. CAO, D. Driving style recognition for intelligent vehicle control and advanced driver assistance: a survey. *IEEE Transactions on Intelligent Transportation Systems* [online]. 2018, **19**(3), p. 666-676. ISSN 1524-9050, eISSN 1558-0016. Available from: https://doi.org/10.1109/TITS.2017.2706978

[30] KOZIOL, S., ZBROWSKI, A. Road accidents involving special fire engines / Wypadki drogowe z udzialem pojazdow specjalnych strazy pozarnej (in Polish). *TTS Technika Transportu Szynowego*. 2013, **10**, p. 941-949. eISSN 2543-5728.

[31] PODGORSKA, A., RAJCHEL, J. Road accidents in Poland and their consequences / Wypadki drogowe w Polsce i ich skutki (in Polish). *Drogownictwo*. 2019, **12**, p. 347-354. ISSN 0012-6357.

[32] SCIESZKO, J, PAPIERNIK, Z. The influence of weather conditions on traffic incidents in the example of Lodz voivodeship / Wplyw warunkow atmosferycznych na zdarzenia drogowe na przykladzie wojewodztwa lodzkiego (in Polish). *Acta Universitatis Lodziensis Folia Geographica Physica* [online]. 2013, **12**, p. 97-115. ISSN 1427-9711, eISSN 2353-6063. Available from: https://doi.org/10.18778/1427-9711.18.06

[33] KADZIOLKA, T., KOWALSKI, S. Analysis of road traffic safety exemplified by selected road crossings / Analiza bezpieczenstwa w ruchu drogowym na przykladzie wybranych skrzyzowan (in Polish). *Autobusy: Technika, Eksploatacja, Systemy Transportowe*. 2016, **17**(12), p. 235-241. ISSN 1509-5878, eISSN 2450-7725.

[34] FREJ, D.; JASKIEWICZ, M., Vehicle accident frequencies on the example of Poland and Slovakia in 2010-2020. *SHS Web Conf* [online]. 2021, **129,** 11003. eISSN 2261-2424. Available from: https://doi.org/10.1051/shsconf/202112911003

[35] PISULA, T., CHUDY-LASKOWSKA, K. Traffic safety in Poland based upon the selected countries of the European Union / Analiza bezpieczenstwa w ruchu drogowym w Polsce na tle wybranych krajow Unii Europejskiej (in Polish). *Logistyka*. 2014, **3**, p. 1061-1072.

[36] JURECKI, R.S. Analysis of road safety in Poland after accession to the European Union. *Communications - Scientific letters of the University of Zilina* [online]. 2020, **22**(2), p. 60-67. ISSN 1335-4205, eISSN 2585-7878. Available from: https://doi.org/10.26552/com.C.2020.2.60-67

[37] LOZIA, Z. Can anything optimistic be found in the statistics of road accidents in Poland in 1975-2018? In: 2020 XII International Science-Technical Conference Automotive Safety: proceedings. IEEE: 2020. ISBN 978-1-7281-5813-6, eISBN 978-1-7281-5812-9, p. 1-4. Available from: https://doi.org/10.1109/AUTOMOTIVESAFETY47494.2020.9293513

[38] WOJCIK, A. Statistical analysis of road traffic safety by voivodeship / Statystyczna analiza bezpieczenstwa w ruchu drogowym w ukladzie wojewodztw (in Polish). *Studia Ekonomiczne*. 2015, **220**, p. 117-137. ISSN 1428-2763.

[39] GABERLE, A. Alcohol and road accidents in Poland in the years 1975-1984 / Alkohol a wypadki drogowe w Polsce w latach 1975-1984 (in Polish). *Archiwum Kryminologii*. 1987, **14**, p. 151-200. ISSN 0066-6890.

[40] GONIEWICZ, M., GONIEWICZ, K. Road accidents in Poland - causes and prevention / Wypadki drogowe w Polsce - czynniki sprawcze i zapobieganie (in Polish). *Bezpieczenstwo Pracy: Nauka i Praktyka*. 2010, **9**, p. 14-7. ISSN 0137-7043.

[41] KORALEWSKI, G., WRONA, R. Failure-to-yield accidents and their dangers / Zagrozenia i wypadki drogowe spowodowane nie ustepowaniem pierwszenstwa (in Polish). *Autobusy: Technika, Eksploatacja, Systemy Transportowe* [online]. 2019, **20**(1-2), p. 84-7. ISSN 1509-5878, eISSN 2450-7725. Available from: https://doi.org/10.24136/atest.2019.012

[42] WNUK, A. Road accidents in the municipality of Szadek between 2010 and 2017 / Wypadki drogowe w gminie Szadek w latach 2010-2017 (in Polish). *Biuletyn Szadkowski* [online]. 2018, **18**, p. 91-105. ISSN 1643-0700, eISSN 2449-8351. Available from: https://doi.org/10.18778/1643-0700.18.07

[43] Coefficient of determination (R^2) | Calculation & Interpretation [online] [accessed 2022-11-08]. Available from: https://www.scribbr.com/statistics/coefficient-of-determination

[44] Road accidents [online] [accessed 28.01.2022] Available from: https://data.oecd.org/transport/road-accidents.htm

[45] Fatal road accidents in EU regions [online] [accessed 28.01.2022] Available from: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20211121-1

[46] Road accident fatalities - statistics by type of vehicle [online] [accessed 28.01.2022] Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Road_accident_fatalities_-_statistics_by_type_of_vehicle&oldid=533779.

[47] Road accidents - annual reports [online] [accessed 28.01.2022]. Available from: https://statystyka.policja.pl/st/ruch-drogowy/76562,Wypadki-drogowe-raporty-roczne.html