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A COMPARATIVE ANALYSIS OF INJURIES AND DEATHS CAUSED BY ROAD TRAFFIC ACCIDENTS IN POLAND AND SELECTED EU COUNTRIES

Summary. The article examines the relationship between three dependent variables: the quantity of accidents on roads in Poland and the quantities of those hurt and killed as a result. Data were obtained from police websites between 2016 and 2021. Multidimensional comparative analyses were used for the research, which, by grouping data and compiling them dynamically in various scales depending on the needs, allowed us to observe trends such as seasonality on a monthly basis (data in a month - Fig. 2) and a downward trend (data in years Fig. 3). This became a premise for building a multiple regression model, which allowed us to dynamically observe the correlation between the quantity of accidents in Poland and the quantity of people hurt and killed as a result. The above-mentioned regularity was described by the function: Y = –67,9212 + 1,3341*v(2) + 0,7332*v(3) + +28,4305*v(4) and the built model was analyzed and evaluated. Then, information on the quantity of road accidents and quantities of people killed and hurt in the capital city of Warsaw from January 2021 to December 2022 were used for the research and compared with the data observed throughout Poland. To observe the impact of the random factor, which was a strong increase in the scale of fines in 2022, especially for exceeding the limit of speed by approximately more than 31 km/h. Dynamic indices on a constant base were calculated for the research. It was found that in 2022, compared to 2021, there was a visible decline in the quantity of people killed in road accidents in Warsaw from 42 to 30 people. A similar regularity can be observed in the data on fatalities in road accidents throughout Poland in the identical time period [11]. Moreover, there was no correlation between the time series of fatalities in road accidents in Warsaw and the quantity of accidents and injuries in 2022.

1. INTRODUCTION

Globalization has a huge impact on the widespread need for transportation, including road transport, one of the most popular means. One of the secondary effects of road transport is accidents and the resulting fatalities. This article aims to answer the question, "To what extent does the quantity of accidents on the roads in Poland dynamically affect the quantities of those hurt and killed as a result?"

This question was addressed by examining the correlation between the quantity of road accidents in Poland and the quantities of people hurt and killed as a result between 2016 and 2021.

The thesis resulting from the research problem and the aim of the work is as follows: the quantity of road accidents in Poland is dynamically correlated with the quantities of deaths and injuries, and this correlation may be influenced by a large increase in fines.

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2. ANALYSIS OF THE LITERATURE

The term "transport" in the literature is interpreted as activities related to the management of supply chains [2, 5, 14, 18, 20] and chargeable services with respect to, among other things, dislocation, warehousing, and packing [17]. It has an impact on the economic growth of countries and supports the purchase and sale of goods in various global markets. One kind of transport is road transport, which is considered the most frequently used and popular in terms of speed and flexibility of services provided due to the extensive road network [16]. In the literature, one can find information about advanced IT systems for planning transport [10] in a broad sense, including domestic and international road transport. An example of such a system is LOGFAS [19]. This article focuses on road accidents.

The analysis of data compiled on the Eurostat website shows that in 2021, Poland was ranked fourth out of 32 considered European countries in terms of the quantity of deaths caused by road accidents [24], with a total of 2245 [4]. The first ranking was taken by France (2947 people killed in road accidents). Italy was ranked second (2843 deaths), and Germany was ranked third (2569 deaths). The above-mentioned countries occupy the highest places in terms of the quantity of deaths, but this quantity is decreasing [4]. Another way to rank the quantity of deaths in road accidents is to calculate the quantity of deaths per 100,000 inhabitants. Between 2000 and 2017, the leaders in Europe based on this classification were Latvia and Lithuania [8]. This article focuses on the subject of road accidents that happened in the territory of the Republic of Poland between 2016 and 2022.

The information available on the MUBI website (an insurance comparison website) shows that the most general reasons for traffic accidents in 2021 were [6] not respecting the rules on priority (27%), not adjusting speed to traffic conditions (25.5%), difficulty giving way to a pedestrian on a crossing for pedestrians (10.2%) and not keeping a secure distance in between vehicles in road traffic (7.8%). These results most likely caused the increase in fines in Poland. The information available on the police website indicates that a new scale of fines came into force in Poland on January 1, 2022 [22]. The applicable amounts for offenses in 2021 and since 2022 are presented in Table 1.

Table 1

Scale of fines in 2021 and 2022 in Poland in PLN

Speed km/h	Amounts (2021)	Penalty points (2021)	Amount (2022)	Amount (recidivism) (2022)	Penalty points (2022)
1-10	0-50	0	50		1
11-15	50-100	2	100		2
16-20	50-100	2	200		3
21-25	100-200	4	300		5
26-30	100-200	4	400		7
31-40	**200-300**	**6**	**800**	**1600**	**9**
41-50	**300-400**	**8**	**1000**	**2000**	**11**
51-60	**400-500**	**10**	**1500**	**3000**	**13**
61-70	**400-500**	**10**	**2000**	**4000**	**14**
71 - more	**400-500**	**10**	**2500**	**5000**	**15**

Source: own study based on: [22, 3].

The main changes in the scale of fines in 2022, compared to 2021, relate primarily to offenses that caused road accidents, usually with tragic consequences. The amounts of fines were increased to the greatest extent for exceeding the speed limit in groups of variables above 31 km/h. The highest fine is issued for exceeding the speed limit above 71 km/h, and in the case of recidivism, the fine is over PLN 5000; until 2021the maximum fine was PLN 500. If the ticket is not accepted, the amount of PLN 5000 may be increased by a court decision to even PLN 30,000. In the new scale of fines of 2022, one can find a new fine of PLN 500 for using a mobile phone while driving. It is possible to obtain a fine of PLN 1500 for failing to give way to a pedestrian on a pedestrian crossing and the same amount for

overtaking another vehicle on a pedestrian crossing. In the event of recidivism, these amounts may increase to PLN 3000. The change in 2022 also applies to the running of penalty points and an increased quantity of their assigning, mainly for exceeding the speed limit by over 31 km/h. Penalty points have been extended to two years from 2022. After this time, they will be deleted [22]. The aim of the increases is to reduce the quantity of fatalities caused by road accidents in Poland.

A multidimensional comparative analysis was used for the current research. In the literature, it is defined as a group of statistical methods by which at least two variables describing a given research object are analyzed. Another interpretation is that it is the ordering of the set of compared objects. Data were obtained mainly from the websites of the police in Poland and Eurostat. The data were grouped and compiled on line/bar charts using different scales. In addition, indices were calculated as dynamics indices on a constant base, arithmetic means, standard deviations [25], and coefficients of determination [7]. Time series of the aforementioned dependent variables were analyzed in terms of seasonality observation [13] and trends.

The tendencies observed during the research – seasonality, trends, and the correlations among three groups of dependent variables (the quantities of road accidents, deaths, and injuries) are extremely interesting in terms of maintaining and improving road safety. R. Zięba defines the term "security" as the lack of threats [23, 9], and in dictionary definitions, it is associated with certainty and a state opposite to threat. One type of security is road security, which is a set of regulations and obligations for road users, including first aid rules, information on roads, speed limits, and other important factors for those participating in this process [12].

3. MULTIDIMENSIONAL COMPARATIVE ANALYSIS OF ROAD ACCIDENTS IN POLAND

The outline of the information on the quantity of people killed in road accidents between 2011 and 2021 in five European countries (France, Italy, Germany, Poland, and the Czech Republic) is presented in Fig. 1. Due to large differences in the values of the analyzed dependent variables, the data from the Czech Republic were assigned to the value of the scale on the right *y*-axis and from the other four countries to the scale value on the left *y*-axis.

The data summarized in Fig. 1 shows that between 2011 and 2020, in the five European countries under consideration, there was a decreasing tendency in the quantity of people killed in accidents on roads. In total, in the analyzed countries, 16,794 deaths from road accidents were recorded in 2011, 10,663 deaths were recorded in 2020, and 11,135 deaths were recorded in 2021. In 2022, compared to 2021, decreases in the quantity of people killed in road accidents were observed in two of the five European countries under consideration: Poland (a decrease of 246) and Germany (a decrease of 150).

Fig. 2 presents data on the quantities of road accidents, deaths, and injuries in Poland from January 2016 to December 2021.

In Fig. 2, seasonality was observed on a monthly basis in the three analyzed secondary data time series. In the group of the dependent variable, the quantity of road accidents in the Republic of Poland shows a decrease each year from 33,664 accidents in 2016 to 22,816 in 2021. However, in the time series of people hurt in road accidents in Poland, there was a decrease from 40,766 in 2016 to 26,415 in 2021. The decrease is also visible in the time series of fatalities from road accidents, from 3026 in 2016 to 2245 in 2021. It was only in Poland that the huge growth in deaths caused by accidents on roads was observed in 2019, from 2909 to 2862 in 2018.

4. MULTIPLE REGRESSION MODEL

The analysis was used as a premise for building a zero-one model of multiple regression in order to dynamically examine the relationship between the considered variables. The outcomes of this model are presented in Table 2.

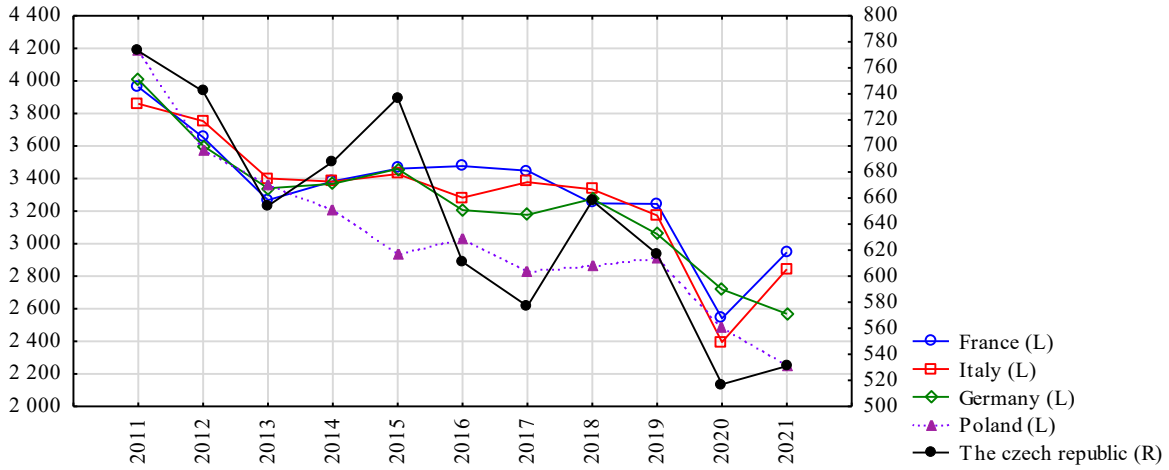

Fig. 1. Categorized line chart of data on the quantity of people killed in road accidents between 2011 and 2021 in five European countries (Czech Republic – right *y*-axis scale, other countries – left *y*-axis scale). Source: [4]

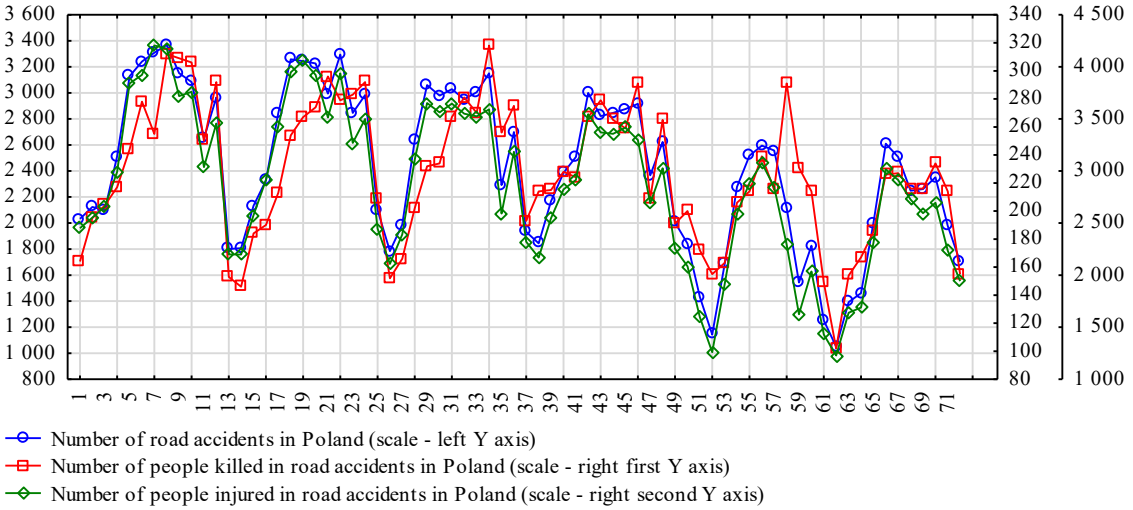

Fig. 2. Categorized line chart of data on the quantity of road accidents and people killed and hurt in these accidents in Poland from January 2016 to December 2021 (quantity of accidents – left *y*-axis scale; quantity of fatalities – right first *y*-axis; quantity of hurt in accidents cases – right second *y*-axis). Source: [15]

The built multiple regression model matched very well with the data in Figs. 1 and 2. The multiple R^2 was 0.99, as was the adjusted R^2. The standard error of the estimation was 50,442. The research made it possible to dynamically observe the correlation between the variables: the quantity of road accidents and the quantities of people killed and hurt in accidents. This demonstrates the significance of predictors as explanatory variables: the quantities of people killed and hurt in road accidents and log(t). The constructed function is Y = –67,9212+1,3341*v(2)+0,7332*v(3)+ +28,4305*v(4).

The data in Fig. 3 indicate a good match between the observed and predicted values.

The residuals of the built model show an oscillatory character and are visible in the box plot, which may indicate a dependence on the respective delays of the residuals of the outlined multiple regression model. Then, the analysis and evaluation of the residuals of the built model were conducted.

Table 2

Zero-one model of multiple regression

N = 72	R = 0.99656682 R^2 = 0.99314542 Correctness R^2 = 0.99284301 Standard error of the estimation: 50,442					
	b*	Standard error	b	Standard error	t(68)	p
Absolute term			-67.9212	41.02544	-1.65559	0.102414
Killed	0.109121	0.018169	1.3341	0.22213	6.00590	0.000000
Hurt	0.920779	0.019460	0.7332	0.01550	47.31604	0.000000
lnt	0.043457	0.011445	28.4305	7.48730	3.79716	0.000314

Source: [21, 15].

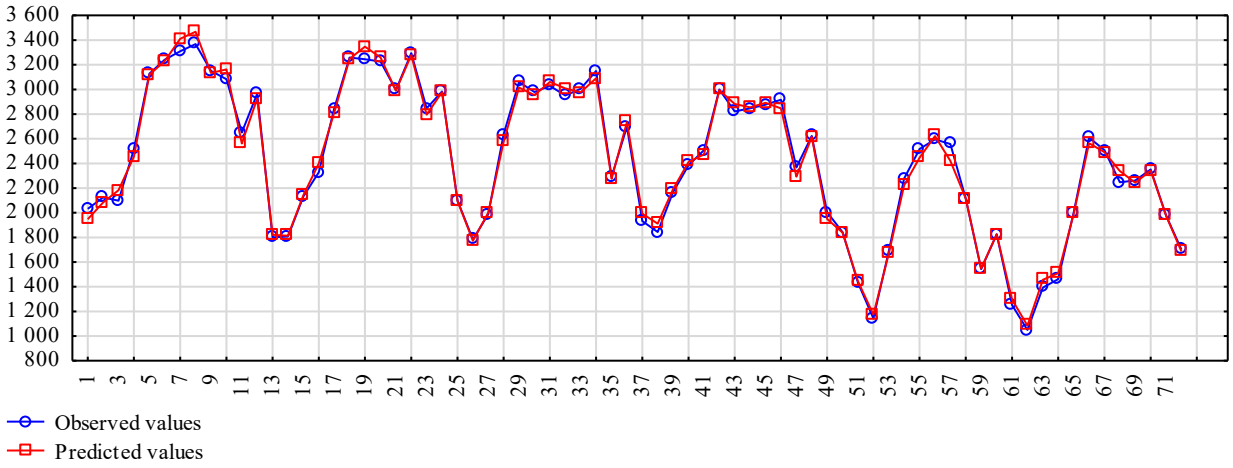

Fig. 3. Line graph of predicted and observed values.
Source: [21, 15]

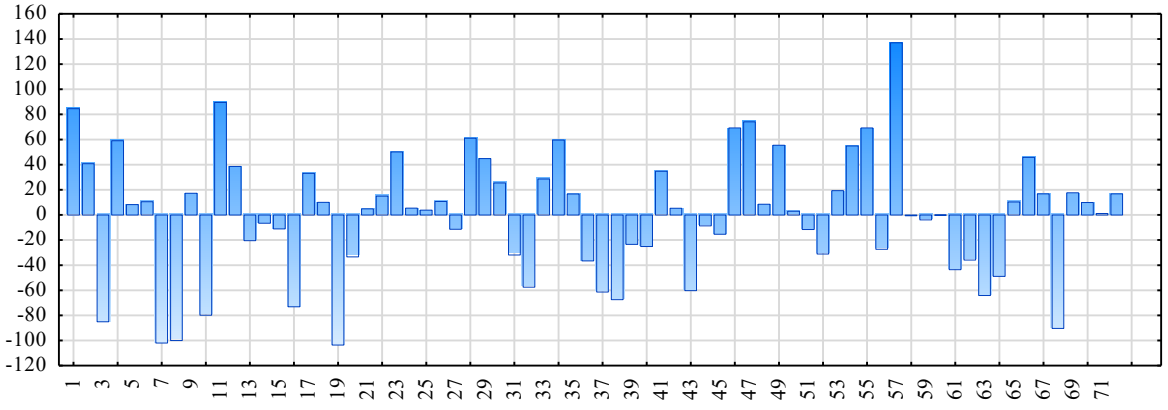

Fig. 4. Bar chart of residuals of the built model.
Source: [21, 15]

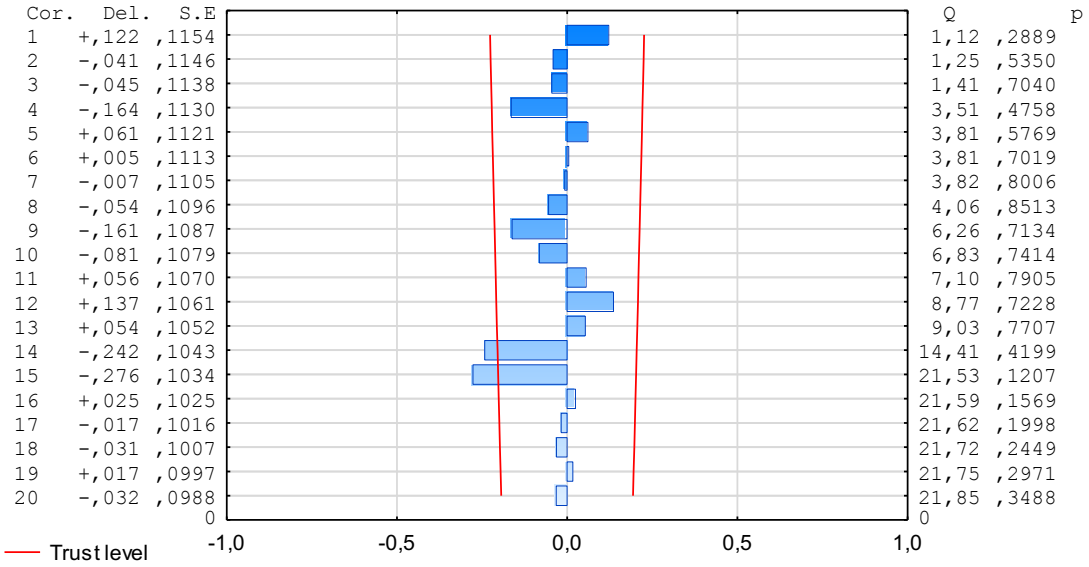

Fig. 5. Autocorrelation of the model residuals.
Source: [21, 15]

Autocorrelation coefficients 14 and 15 are significant. On the other hand, the Q statistic falls slowly, and the p_{value} in each of the autocorrelation coefficients is above the significance level.

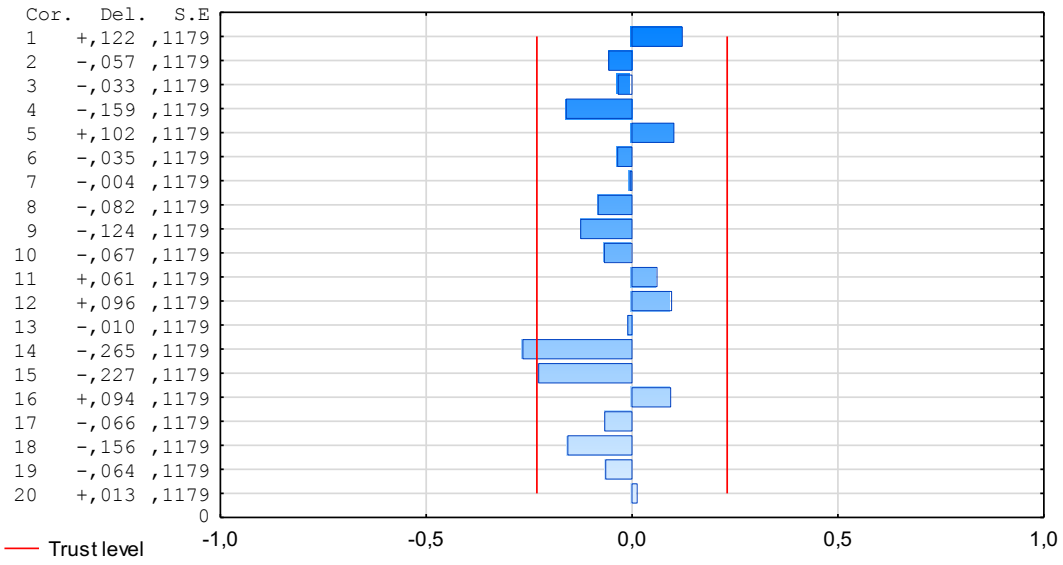

Fig. 6. Partial autocorrelation of the model residuals.
Source [21, 15]

The data in Fig. 6 show that coefficients 14 and 15 are significant and that the standard deviation of the residual term is constant at 0.1179.

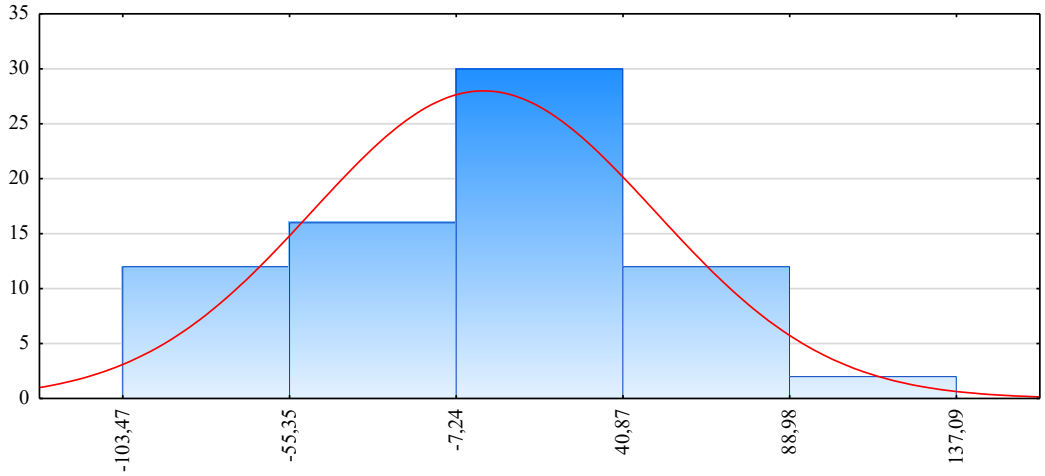

Fig. 7. Histogram.
Source: [21, 15]

The layout of the residuals of the model is similar to the normal one (Fig. 7).

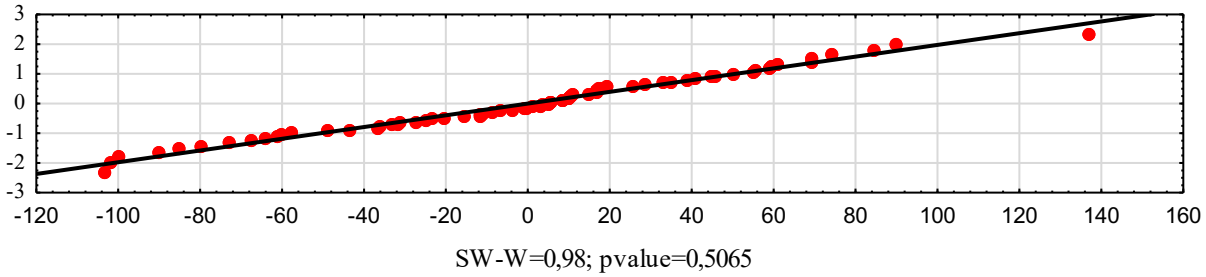

Fig. 8. Quantile-quantile chart with the Shapiro-Wilk test.
Source: [21, 15]

Fig. 8 shows that the layout of residuals of the constructed multiple regression paradigm is quite normal. This is confirmed both by the overlapping of the quantiles with the straight line drawn and by the result of the Shapiro–Wilk test, which yielded a p_{value} of 0.5065.

The above analysis of the residuals of the built multiple regression model confirms the correct construction of the model and visible regularities including seasonality monthly and a downward trend.

The next step was to analyze the quantity of accidents on roads, as well as the quantities of those hurt and killed as a result in the capital city of Warsaw between 2021 and 2022 on a monthly basis. The information was considered a research sample illustrating the tendency of accidents, injuries, and deaths in the Republic of Poland (at the time of the study, there was no data covering the entire territory of Poland).

Fig. 9 shows the correlation between two dependent variables: the quantity of accidents and the quantities of people hurt in accidents in Warsaw. The relationship between the quantity of deaths and other variables is not particularly visible in 2022.

Fig. 10 presents the sums of the respective three dependent variables within the period under consideration.

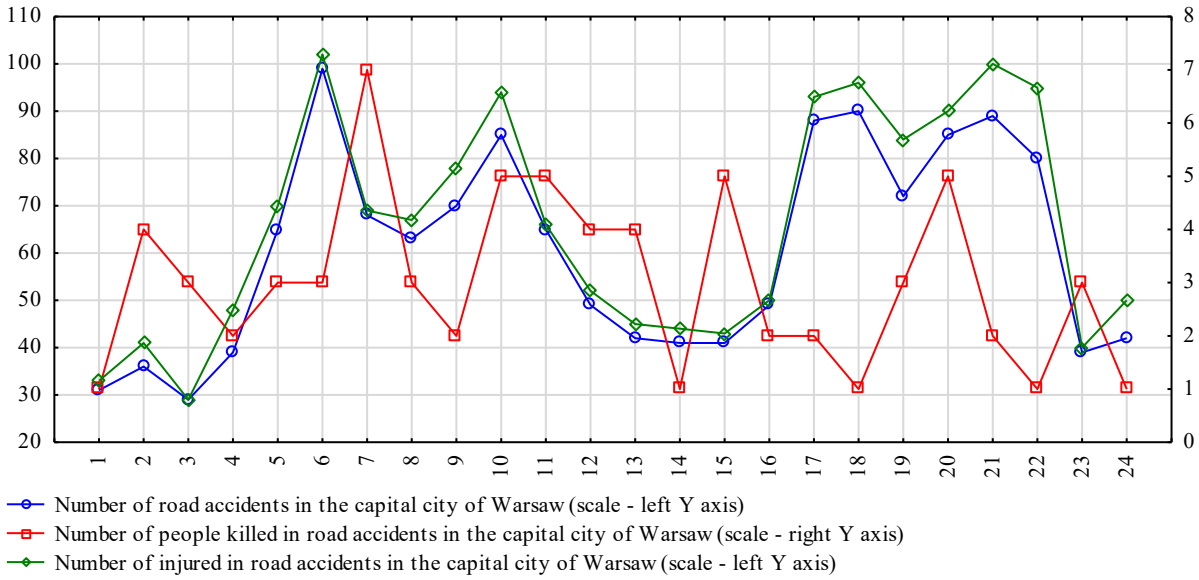

Fig. 9. Categorized line chart of data on the quantity of road accidents and the quantities of people killed and hurt in the capital city of Warsaw from January 2021 to December 2022 (the quantity of accidents and quantities of people hurt in accidents – left scale of the *y*-axis; quantity of killed in accidents – *right y*-axis).
Source: [21]

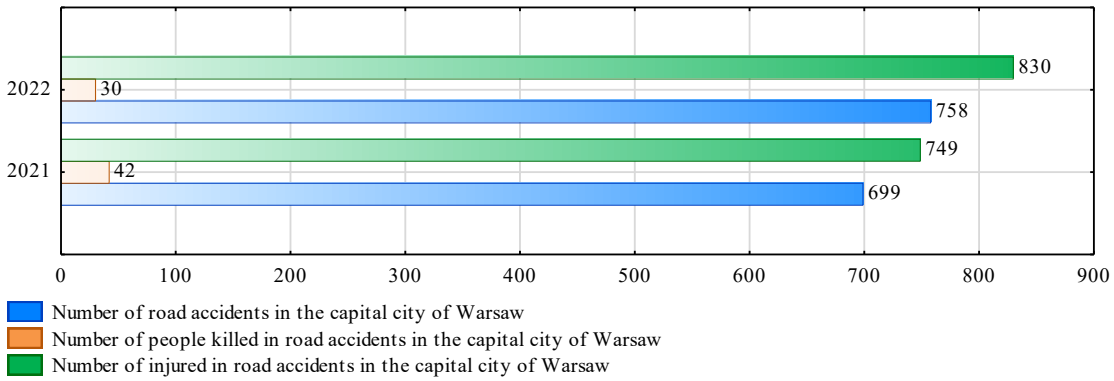

Fig. 10. Categorized bar graph of information on the sum of the quantity of road accidents and the quantities of fatalities and injuries in the Warsaw capital in 2021 and 2022.
Source: [21]

The data in Fig. 10 indicate an upward trend in the dependent variables of the quantity of road accidents and the quantity of hurt people in Warsaw between 2021 and 2022. However, the dependent variable of the quantity of deaths in the same time period shows a downward trend. In 2021, 42 deaths from road accidents were recorded in Warsaw; in 2022, the quantity fell to 30.

The last stage of the research is the use of certain dynamics indices set on a constant basis to evaluate the impact of the increase in ticket prices in Poland in 2022 on the quantity of deaths in accidents on roads.

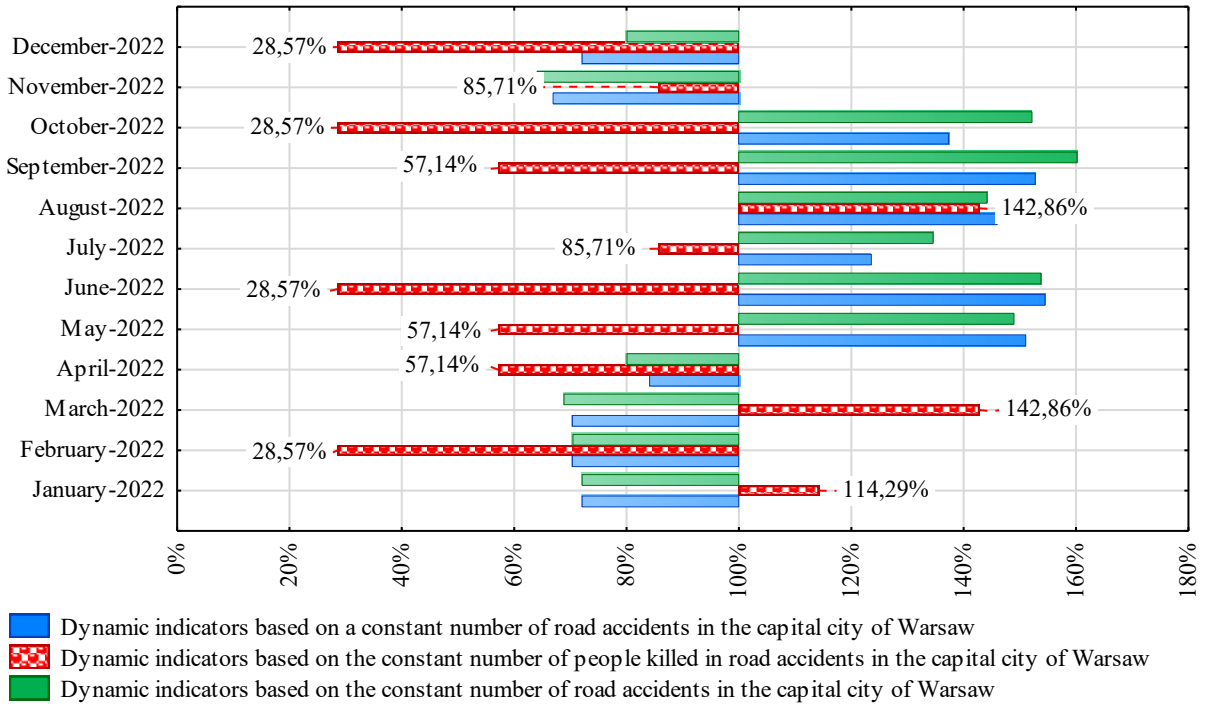

Fig. 11. Categorized bar graph of dynamics indices set on a constant base for information on the quantity of road accidents and the quantities of fatalities and injuries in the capital city of Warsaw from January to December 2022 (the constant base is the arithmetic mean of respective dependent variables: the quantity of road accidents and the quantities of fatalities and people hurt in the capital city of Warsaw from January to December 2021).
Source: [21]

The information in Fig. 11 clearly shows that the dynamic indices set on a constant basis of fatalities in accidents on the roads in Warsaw in 2022 were lower than the monthly arithmetic means of these indices for 2021. Additionally, no relationship between the quantity of deaths and the other two dependent variables – the quantity of accidents and the quantity of injuries from accidents.

5. CONCLUSIONS

This research shows that in the five European countries under consideration between 2011 and 2021, there is a decreasing tendency in the quantities of deaths in accidents on roads. In 2022, this downward trend was observed to continue in Poland and Germany. The other three observed European countries showed an increase.

In the three groups of dependent variables (the quantity of road accidents in Poland and the quantities of people hurt and killed), was visible seasonality on a monthly basis and a downward trend.

This research makes it possible to dynamically observe the correlation between the time series of the quantity of road accidents in Poland and the quantities of people hurt and killed in accidents, which is described by the function: $Y = –67{,}9212 + 1{,}3341*v(2) + 0{,}7332*v(3) + 28{,}4305*v(4)$. Thus, the purpose of the research has been accomplished. The described function was created by building a zero-one multiple regression model. Then, the model was analyzed and evaluated. Its correctness was confirmed by the good match of the predicted and observed values, the normality of the model residuals, and the high values of indexes such as multiple R and corrected R^2 amounting to 0.99.

The study analyzed the monthly quantity of road accidents and the quantities of people killed and hurt in these accidents in Warsaw between 2021 and 2022. It was observed that in 2022, compared to 2021, there was a visible decline in the quantity of people killed in road accidents from 42 to 30 people. A similar trend can be seen in the data on fatalities in road accidents throughout Poland in the identical

time period in the data available at motofakty.pl [11]. In 2022, 1883 deaths in road accidents were recorded in Poland; in 2021, 2245 accidents were recorded. Such a low quantity of people killed in road accidents in Poland in 2022 has not been recorded for several years [1]. On the other hand, in the other two groups of dependent variables in 2022, compared to 2021, increases were visible in Warsaw. The research shows no relationship between the time series of fatalities in road accidents in Warsaw and the quantities of accidents and injuries in 2022. This phenomenon was highlighted by the use of a bar graph of dynamics indices set on a constant base of data on the quantity of road accidents and the quantities of fatalities and injuries in Warsaw from January to December 2022. The data could have been influenced, among others, by the increase in the scale of fines in Poland in 2022, especially for those driving faster than 51 km/h in built-up areas. The speed limit may have resulted in fewer deaths in 2022.

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