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Martin Jurkovic*, Piotr Gorzelanczyk, Tomas Kalina, Jaroslav Jaros and Malaya Mohanty

Impact of the COVID-19 pandemic on road traffic accident forecasting in Poland and Slovakia

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Abstract: The COVID-19 pandemic significantly affected the performance of the transport sector and its overall intensity. Reducing mobility has a major impact on road traffic accidents. The aim of this study is to forecast the number of road traffic accidents in Poland and Slovakia and to assess how the COVID-19 pandemic affected its trend. For this purpose, data for Poland and Slovakia in the selected relevant period were analyzed. Based on actual data from the past, a forecast was made for the future considering two scenarios – one where there is no effect of pandemic, and another with effect of pandemic. Forecasting the number of accidents in Poland was carried out using selected time series models related to linear trend (Holt and Winters method) and the exponential model. In the case of Slovakia, the model without trend and the exponential model were used to forecast the number of traffic accidents. The results of the research show that the pandemic caused a decrease in the number of traffic accidents in Poland by 31% and in Slovakia by 33%. This is a significant decline, but it is linearly dependent on restrictive measures that affect the mobility of the population. A similar trend can therefore be expected on a European scale.

*** Corresponding author: Martin Jurkovic,** Faculty of Operation and Economics of Transport and Communication, University of Zilina, Univerzitna 1, 010 26 Zilina, Slovakia, e-mail: martin.jurkovic@fpedas.uniza.sk
Piotr Gorzelanczyk: Stanislaw Staszic University of Applied Sciences in Pila, Podchorazych 10 Street, 64-920 Pila, Poland, e-mail: piotr.gorzelanczyk@puss.pila.pl
Tomas Kalina: Faculty of Operation and Economics of Transport and Communication, University of Zilina, Univerzitna 1, 010 26 Zilina, Slovakia, e-mail: tomas.kalina@fpedas.uniza.sk
Jaroslav Jaros: University Science Park, Center for Technology Transfer, University of Zilina, Univerzitna 1, 010 26 Zilina, Slovakia, e-mail: Jaroslav.jaros@uvp.uniza.sk
Malaya Mohanty: KIIT – Kalinga Institute of Industrial Technology, Patia, Bhubaneswar, Odisha 751024, India, e-mail: malaya.mohantyfce@kiit.ac.in
ORCID: Martin Jurkovic 0000-0001-7673-1350; Piotr Gorzelanczyk 0000-0001-9662-400X; Tomas Kalina 0000-0003-0564-086X

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1 Introduction

Road traffic accidents are events that cause not only injuries or death to road users, but also damage to property. According to the WHO, approximately 1.3 million people die each year as a result of traffic accidents. Traffic accidents account for around 3% of their GDP for most of the countries in the world. Road traffic accidents are the leading cause of death for minors and young people aged 5–29 [1]. The UN General Assembly has set an ambitious goal of halving the number of road deaths and injuries by 2030.

The extent of a traffic accident is an attribute for determining its severity. Predicting the severity of accidents is important for competent authorities when designing transport safety policies to eliminate accidents, reduce injuries, deaths, and property losses [2–4]. The identification of critical factors that affect the severity of accidents is a precondition for taking countermeasures to eliminate and mitigate the severity of accidents [5]. Yang et al. propose a DNN (Deep Neutral Network) multi-carbon framework to predict different levels of severity of injury, death, and property loss. It allows a comprehensive and accurate analysis of the severity of traffic accidents [6].

There are several sources of accident data. They are mostly collected and analyzed by government authorities through the relevant government agencies. Data collection is carried out through police reports, insurance databases, or hospital records. Partial traffic accident information is subsequently processed for the transport sector on a larger scale [7].

Intelligent transportation systems are currently the most important source of data related to the analysis and prediction of traffic accidents [8]. The data can be processed due to the use of global positioning system

(GPS) devices in vehicles [9]. Microwave vehicle detection systems on roadsides can continuously record vehicle data (speed, traffic volume, and vehicle type) [10]. The Vehicle License Plate Recognition system also makes it possible to collect large amounts of traffic data over a monitored period [11]. Another source of data for obtaining traffic and accidents information can be social media, but their relevance may be insufficient due to the incompetence of reporters [12].

For the relevance of accident data, it is necessary to work with several data sources that need to be confronted correctly. The combination of different data sources by consolidating heterogeneous traffic accident data helps to increase the accuracy of the analysis results [13].

A statistical survey aimed at assessing the severity, and finding out the connection between traffic accidents and road users was performed by Vilaça et al. [14]. The result of the study is a proposal to improve road safety standards and the adoption of other policies related to transport safety.

Bak et al. conducted a statistical survey of traffic safety in a selected region of Poland based on the number of traffic accidents, the pace of finding out the causes of their occurrence [15]. The survey applied a multidimensional statistical analysis to examine safety aspect of persons responsible for accidents.

The choice of the source of traffic accidents data for the analysis depends on the type of traffic problem being addressed. The combination of statistical models with other natural driving data or other data obtained through intelligent transport systems contributes to increasing the accuracy of accident forecasts and contributes to their elimination [16]. Szumska et al. investigated the main accidents in Poland in the selected period. The study summarizes statistics on the number of accident offenders by gender and age, as well as dynamic aspects of changes related to new passenger and truck vehicles in Poland over the years 2009–2019 [17].

Various methods of forecasting the number of accidents can be found in the literature. Most often, time series methods are used for forecasting the number of road traffic accidents [18,19], the disadvantages of which are the impossibility of assessing the quality of forecast based on expired forecasts and the often-occurring autocorrelation of the residual component [20]. Procházka et al. used the multiple seasonality model for forecasting [21], and Sunny et al. used the Holt-Winters exponential smoothing method [22]. Its limitations include the inability to introduce exogenous variables into the model [23,24].

For forecasting the number of road accidents, the vector autoregression model has also been used, whose drawback is the need to have many observations of the variables in order to correctly estimate their parameters [25], as well as the autoregression models of Monederoa et al. for analyzing the number of fatalities [26] and Al-Madani, curve-fitting regression models [27]. These, in turn, require only simple linear relationships [28], and the order of the autoregression (assuming that the series are already stationary) [29].

Biswas et al. used Random Forest regression [30] to predict the number of road accidents. In this case, the data contain groups of correlated features with similar significance to the original data, smaller groups are favored over larger ones [31], and there is instability in the method and spike prediction [32]. Chudy-Laskowska and Pisula [33] used the autoregressive model with quadratic trend, the univariate periodic trend model, and the exponential equalization model for the forecasting issue discussed. A moving mean model can also be used for forecasting the discussed issue, the disadvantages of which are low forecast accuracy, loss of data in the sequence, and lack of consideration of trends and seasonal effects [34]. Prochazka and Camaj used the GARMA method, in which some restrictions are imposed in the parameter space to guarantee the stationarity of the process [35]. Very often the ARMA model for a stationary process or ARIMA or SARIMA for a nonstationary process is used for forecasting [21,22,36,37]. These models result in very high flexibility of the discussed models, but it is also their disadvantage. Good model identification requires more experience from the researcher than, for example, regression analysis [38]. Another disadvantage is the linear nature of the ARIMA model [39].

Chudy-Laskowska and Pisula in their work [40] used the ANOVA method to forecast the number of road crashes. The disadvantage of this method is the adoption of additional assumptions, especially the assumption of sphericity, the violation of which may lead to erroneous conclusions [41]. Neural network models are also used to forecast the number of road accidents. The disadvantage of ANN is the need for experience in this field [40,42] and the dependence of the final solution on the initial conditions of the network, as well as the lack of interpretability in the traditional way since ANN is usually referred to as blackbox where you give input, and the model gives output without any knowledge about the analysis [43].

A new prediction method is the use of the Hadoop model by Kumar et al. [44]. The drawback of this method is its inability to work with small data files [45]. Karlaftis and Vlahogianni used the Garch model for prediction [37].

The disadvantage of this method is its complex form and complicated model [46,47]. On the other hand, McIlroy and his team used the augmented Dickey-Fuller test [48], which has the disadvantage of poor power in the case of autocorrelation of the random component [49].

Authors of publications [50,51] have also used data-mining techniques for forecasting, which usually have the disadvantage of huge sets of general descriptions [52]. The combination of models proposed by Sebego et al. as a combination of different models is also encountered [53]. Parametric models are also proposed in the work of Bloomfield [54].

2 Materials and methods

The number of road accidents on Polish roads is continuously decreasing. This follows from the analysis of monthly data in the monitored regions. However, while comparing these data with the data of the European Union, the value is still very high. In Slovakia, the number of road accidents has also decreased, especially during the pandemic period, but the decrease is not as visible as in Poland (Figure 1).

Selected exponential equalization models were used to forecast the number of traffic accidents. The essence of this method is that the time series of the forecast variable is pronounced with a weighted moving mean and the weights are determined according to the exponential function. In this study, the optimal weights were selected by the Statistica software.

The forecast in this case is based on the weighted mean of current and historical series values. The result of the forecast using this method depends on the choice of the model and its parameters.

Forecasting the number of accidents in Poland was carried out using selected time series models related to linear trend.

One of the methods discussed is the Brownian method, which is categorized as an exponential smoothing method. It is most often used in the case of a time series in which there is no trend, i.e., the series used does not show a developmental trend, while its fluctuations are due to the action of random factors that occurs when forecasting the number of traffic accidents. The weights used in this method are determined according to the right exponential. The model of the change in lwd(t) over the analyzed time takes the form:

- for the first moment in time:

$$\mathrm{Plwd}_1^* = \mathrm{lwd}_0. \tag{1}$$

- to subsequent time periods:

$$\mathrm{Plwd}_1^* = \alpha \cdot \mathrm{Plwd}_{t-1} + (1-\alpha)\cdot\ \mathrm{Plwd}_{t-1}^*, \tag{2}$$

where Plwd_{t-1}^* is the forecast value of the number of traffic accidents for the optimal value of the smoothing parameter α, and α is the constant value of the process smoothing parameter taking a value in the range $\alpha \in 0, 1$.

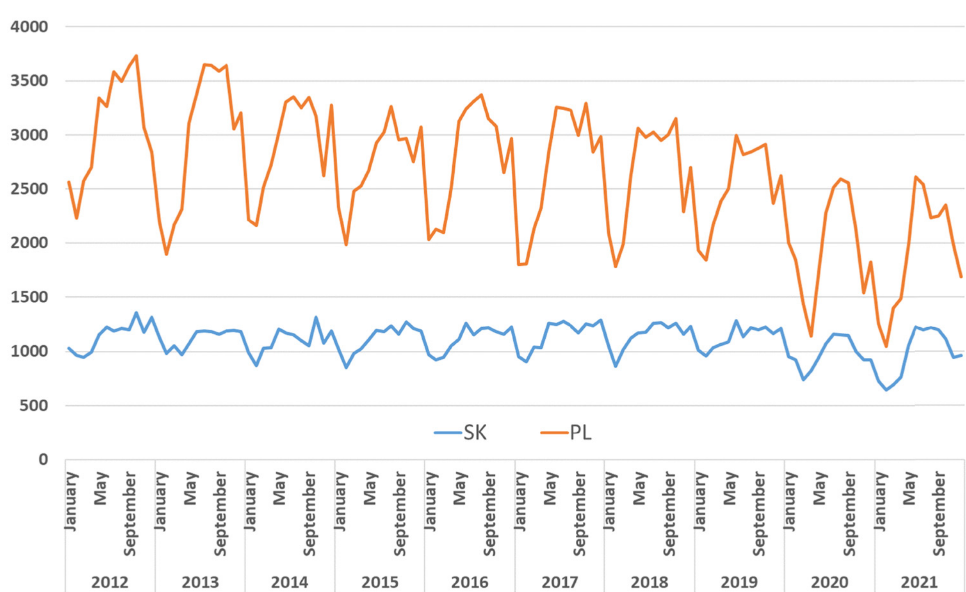

Figure 1: Comparison of the number of traffic accidents in Poland and Slovakia in 2012–2021 [55,56].

The study was divided into two groups: monthly data and annual data. The following errors of expired forecasts determined from equations (3–7) were used to calculate measures of analytical forecast perfection:

- ME – mean error

$$ME = \frac{1}{n}\sum_{i=1}^{n}(Y_i - Y_p). \tag{3}$$

- MAE – mean average error

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|Y_i - Y_p|. \tag{4}$$

- MPE – mean percentage error

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\frac{Y_i - Y_p}{Y_i}. \tag{5}$$

- MAPE – mean absolute percentage error

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|Y_i - Y_p|}{Y_i}. \tag{6}$$

- SSE – mean square error

$$SSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i - Y_p)^2}, \tag{7}$$

where n is the length of the forecast horizon depending on the research (month or year), Y_i is the observed value of road traffic accidents, and Y_p is the forecasted value of road traffic accidents.

In order to compare the number of road traffic accidents during a pandemic and if it did not exist, the mean percentage error was minimized.

3 Results

A statistical test was performed to compare fluctuations in the number of traffic accidents in Poland and Slovakia during the year. The value of the statistic for the non-parametric Kruskal–Wallis test for Poland is 70.07 and for Slovakia is 72.66 with a test probability of $p < 0.05$. In both cases, the hypothesis of equality of the average level of road accidents in both countries during the analyzed period should be rejected. This means that in the present case there is a systematic decrease in the average accident rate in individual years (Figures 2 and 3). It is clear from the data analysis that the largest number of traffic accidents occurs during the summer holidays (June–September). This increase is due to the higher flow of vehicles and mobility of people, as well as suitable weather conditions. These conditions can often decrease drivers' attention while driving. The lowest number of traffic accidents is recorded in the winter months (January, February), when days become shorter,

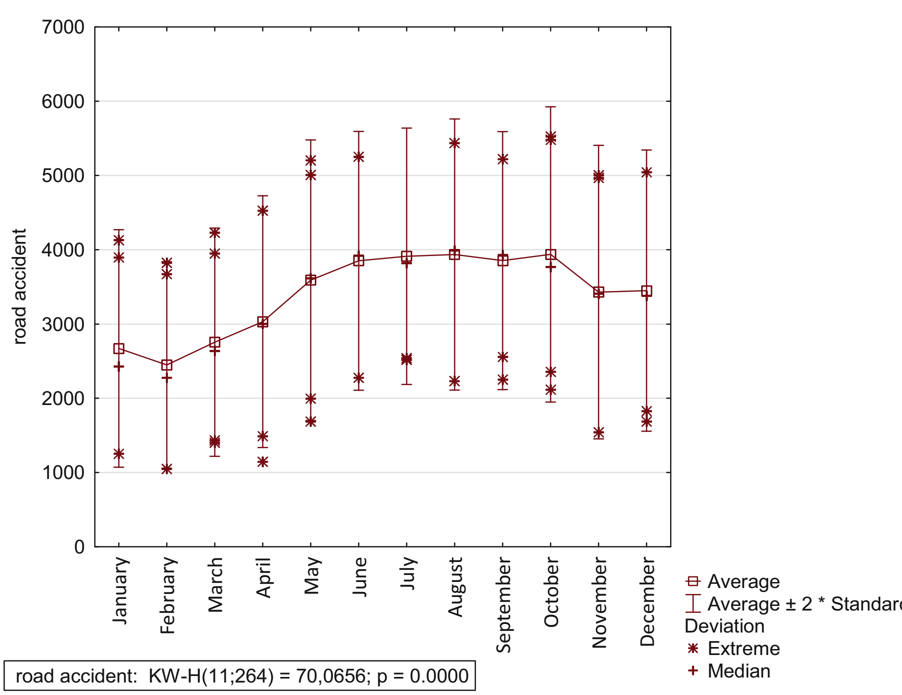

Figure 2: Comparison of the mean number of road accidents in Poland by month over the years 2000–2021.

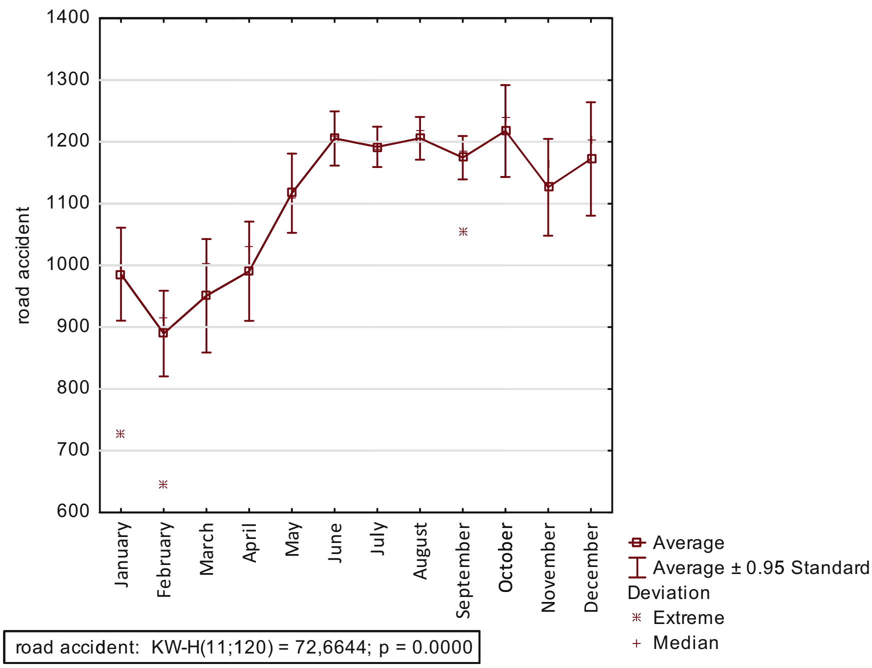

Figure 3: Comparison of the mean number of road accidents in Slovakia by month over the years 2000–2021.

and night comes early due to which people drive more carefully [55].

Based on the analysis of the number of road accidents in Poland, it can be concluded that they have a seasonal character with a decreasing trend. In both countries, the data have a seasonal character. Therefore, for further analysis, selected time series models were used to forecast the estimated number of road traffic accidents.

3.1 Forecasting the road traffic accidents in Poland

To forecast the annual number of accidents in Poland, Polish Police data from 1990–2021 were used, while to forecast the monthly number of road accidents, data from 2001 have been utilized. Previously, the Polish Police did not collect monthly data in this regard [55].

In order to answer the question of how the pandemic affected the number of road traffic accidents, the study was also divided into two timelines. The results of the study in the case of a pandemic are shown in Figure 4, and in the case of no pandemic in Figure 5.

Based on the conducted research, and considering the ongoing pandemic, it can be concluded that the forecasted number of road accidents in Poland, in the last studied period of 2031, varies from 10 to 18 thousand, depending on the method used. Based on the presented research results, it can be concluded that the number of road accidents in Poland will decrease year by year.

To compare the number of accidents in Poland during the pandemic and as if there was no pandemic, case no. M1 – the Holt linear model, for which the mean percentage error is the smallest, was adopted.

In the next step, the forecast of the number of road accidents in case there was no pandemic was made. The research was conducted in order to find an answer to how the pandemic influenced the number of road accidents in Poland. For this purpose, the number of road accidents between 1990 and 2019 was used.

Based on the obtained results, it can be concluded that the estimated number of road accidents in Poland changes for the year 2029, and depending on the method, it ranges from 21,678 to 23,583. Based on the presented research results, it can be concluded that the number of road accidents in Poland will decrease from year to year. To compare the number of accidents in Poland during the pandemic and in the situation, if there was no pandemic, case no. M3 of the additive linear model, for which the mean percentage error (3) is the smallest, was adopted.

3.2 Forecasting the road accidents in Slovakia

To forecast the annual number of accidents in Slovakia, Slovak Police data for the period 2009–2021 were used,

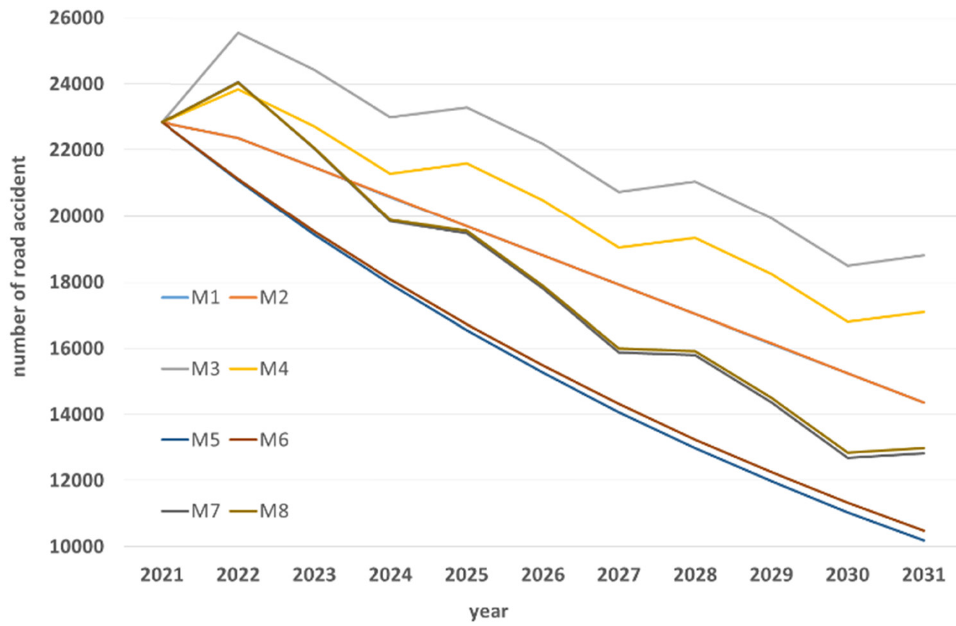

Figure 4: Forecasting the number of road accidents in Poland in 2022–2031 (M1 – linear Holt model – MPE; M2 – linear Holt model – SSE; M3 – linear additive model – MPE; M4 – linear additive model – SSE; M5 – exponential model – MPE; M6 – exponential model – SSE; M7 – additive exponential model – MPE; and M8 – additive exponential model – SSE).

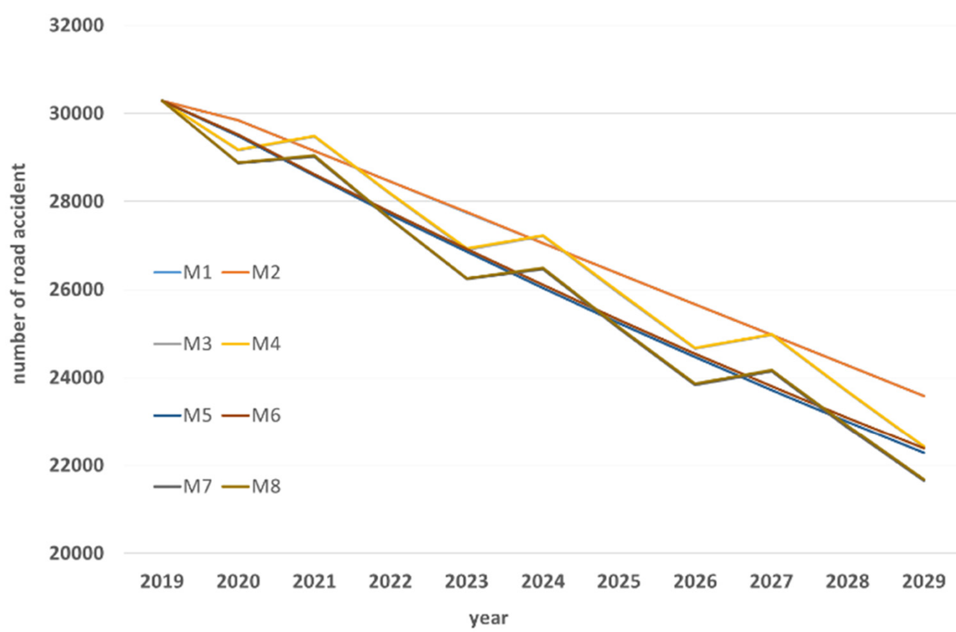

Figure 5: Forecasting the number of road accidents in Poland in 2020–2029 if there was no pandemic.

while to forecast the monthly number of traffic accidents, data from 2012 onward were used. Previously, the Slovak Police did not collect monthly data in this regard. The legal norm changed in 2009, so there is a drop in the number of accidents. Since 2009, it is not mandatory to call the police for every accident.

The results of the study in the case of a pandemic are presented in Figure 6, and in the case of no pandemic are shown in Figure 7.

Based on the outcomes of models, and considering the ongoing pandemic, it can be concluded that the estimated number of road accidents in Slovakia, in the last

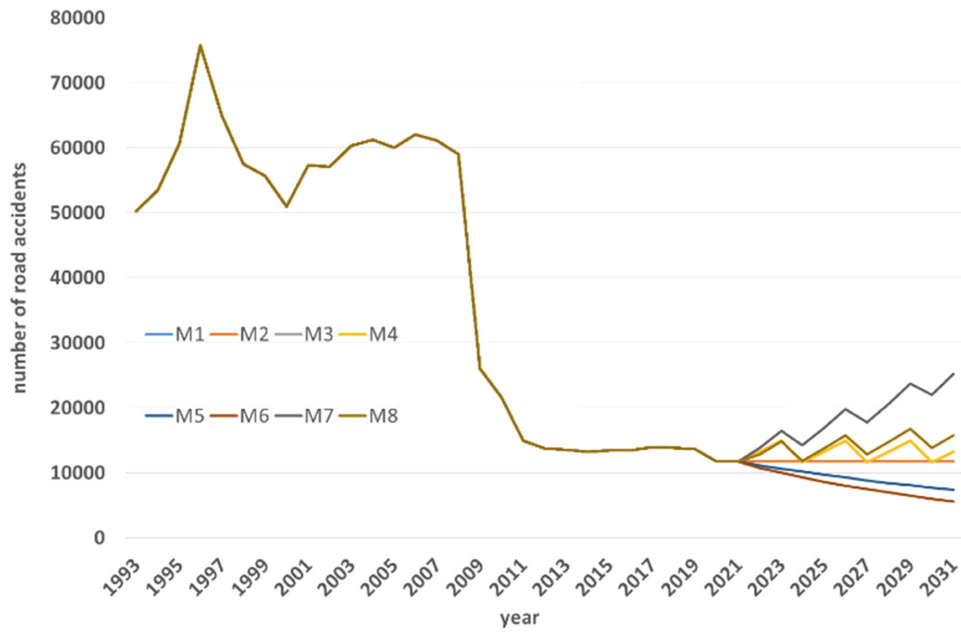

Figure 6: Forecasting the number of road accidents in Slovakia from 2022 to 2031 (M1 – no trend – ME; M2 – no trend SSE; M3 – no trend additive ME; M4 – no trend additive SSE; M5 – exponential model ME; M6 – exponential SSE; M7 – exponential additive ME and M8 – exponential additive SSE).

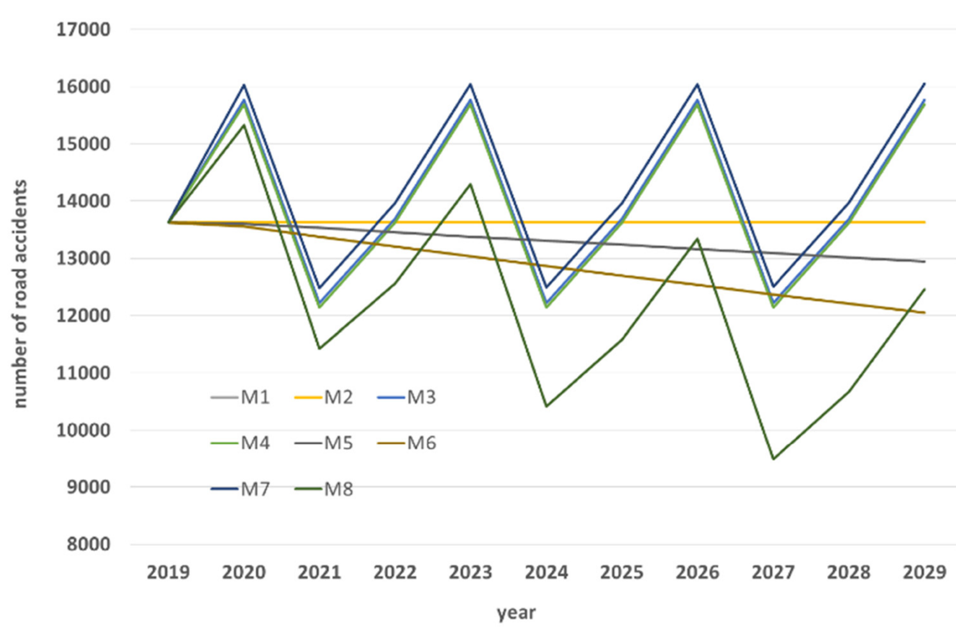

Figure 7: Forecasting the number of road accidents in Slovakia in 2020–2029 if there were no pandemic.

studied period of 2031, varies from 5.5 to 25 thousand, depending on the method used. Based on the presented research results, it can be concluded that the number of road accidents in Slovakia will decrease from year to year.

To compare the number of accidents in Slovakia during the pandemic and as if there was no pandemic, case no. 5 was adopted, M5 – the exponential model, for which the mean percentage error is the smallest.

In the next step, the prediction of the number of road accidents in case there was no pandemic was made. The research was conducted to answer the question of how the pandemic affected the number of road accidents in

Slovakia. For this purpose, the number of road accidents between 2009 and 2019 was used.

Based on the research, it can be concluded that the estimated number of road accidents in Slovakia changes for the year 2029 depending on the method from 12,047 to 15,765. Based on the presented research results, it can be concluded that the number of road accidents in Slovakia will decrease from year to year. To compare the number of accidents in Slovakia during the pandemic and as if there was no pandemic, case M5 was adopted – an exponential model for which the mean percentage error is the smallest.

4 Discussion

The estimated number of road accidents for 2020 was compared with the number of road accidents actually reported by the police [55,56]. These data are presented in Figure 8. Based on this analysis, it can be concluded that the pandemic has reduced the number of accidents by a mean of 31% over the analyzed period in Poland. This is most evident in 2027, when the value reaches over 39%. It is least evident in the year 2020, when the pandemic only started in March of that year.

In addition, a monthly analysis of the number of accidents in the period March 2020–February 2021, i.e., a year from the beginning of the pandemic, was carried out. During the forecast, the lowest average percentage error occurs for the additive linear trend model (M3), the results of which were compared with the number of road accidents occurring in this period. In the analyzed period, the pandemic reduced the number of accidents by nearly 50% (Figure 9). This is most noticeable at the start of the pandemic (April and May) when people mostly sat at home doing remote work.

The estimated number of road accidents for Slovakia in the year 2020 was compared with the number of road accidents actually registered by the Police. These data are presented in Figure 10. Based on the analysis, it can be concluded that the pandemic caused a reduction in the number of accidents by 32% of the mean during the analyzed period. This is most evident in 2029 when the value reaches over 60%.

In addition, a monthly analysis of the number of accidents in the period March 2020–February 2021, i.e. a year from the beginning of the pandemic, was carried out. During the forecast, the lowest average percentage error occurs for the additive linear trend model (M3), the results of which were compared with the number of road accidents occurring in this period. In the analyzed period, the pandemic, as in Poland, reduced the number of accidents by nearly 20% (Figure 11). This is most evident during the onset of the pandemic and in the winter months, when people were mostly home and working remotely, and the next wave of the pandemic hit during the winter.

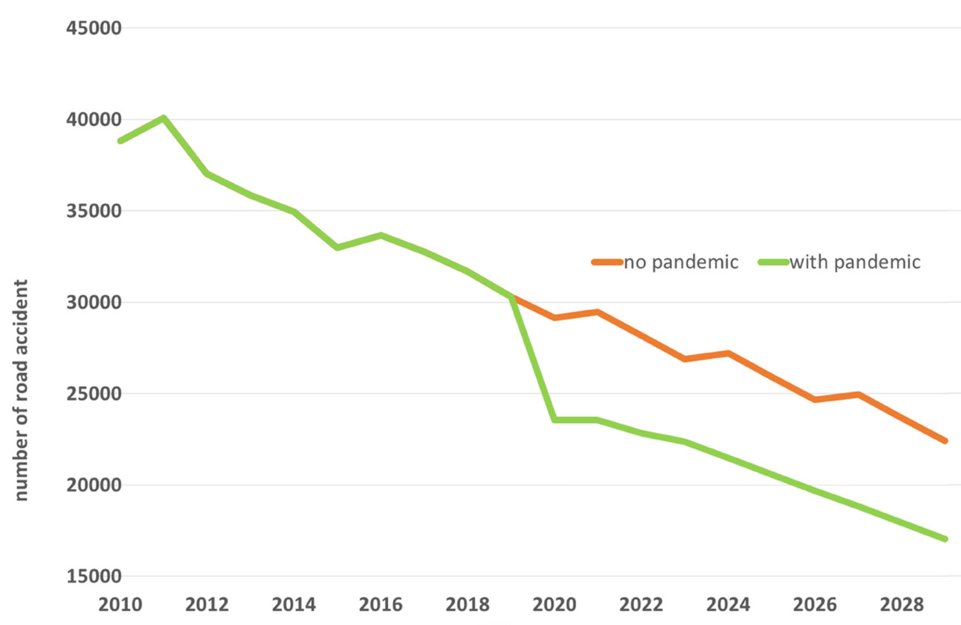

Figure 8: Comparison of the number of road accidents in Poland with and without the pandemic.

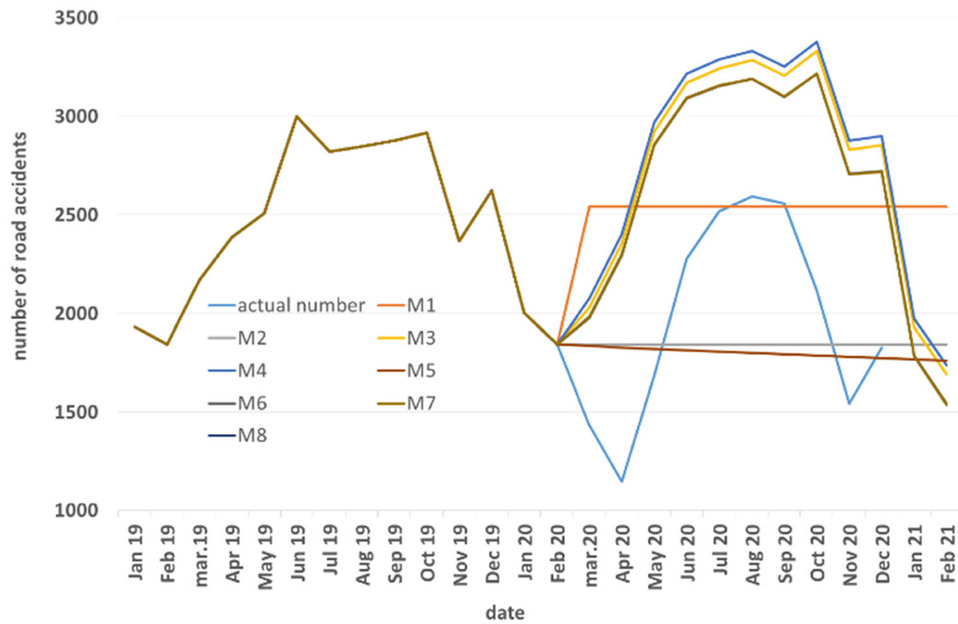

Figure 9: Comparison of road accidents in Poland.

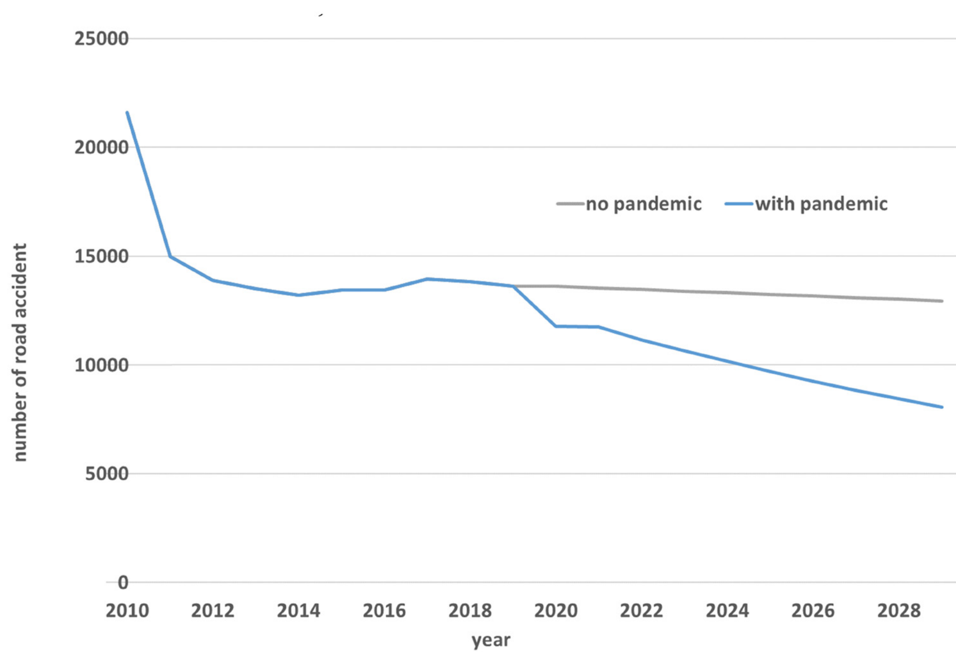

Figure 10: Comparison of the number of road accidents in Slovakia with and without the pandemic.

5 Conclusion

The number of accidents in Poland and Slovakia was forecasted by the exponential equalization method using the Statistica software. The weights used were estimated by the program in such a way as to minimize the mean absolute error and the mean absolute percentage error.

Based on the obtained data, it can be concluded that the pandemic reduced the number of road accidents in Poland by 31% and in Slovakia by 33%. In the current situation, further reduction of road accidents in Poland and Slovakia can be expected.

Moreover, based on the analysis of the obtained results, it may be stated that the forecasts of the number

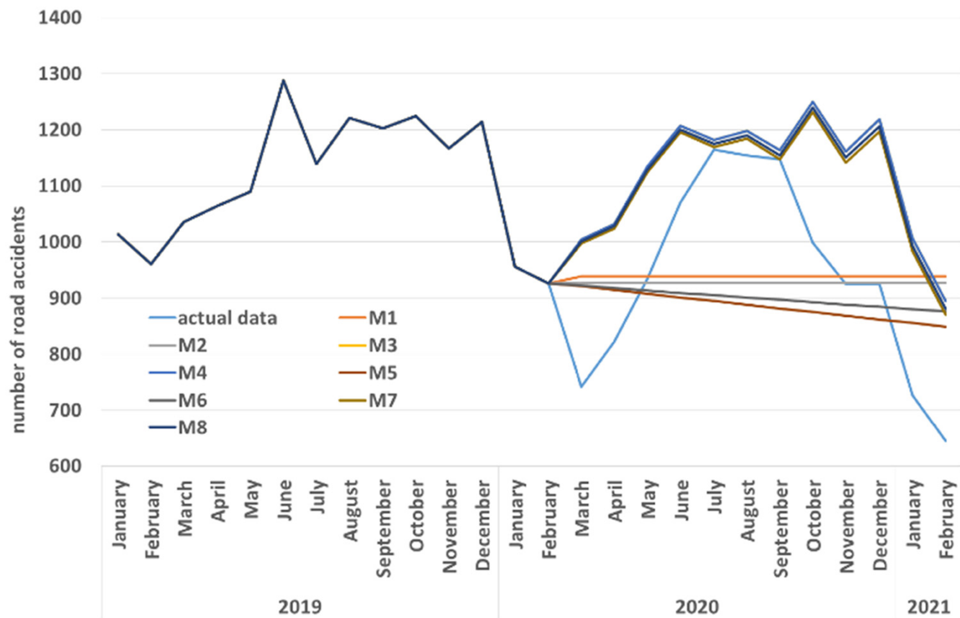

Figure 11: Comparison of the number of road accidents in Slovakia.

of road accidents in Poland and Slovakia for the following years show the decreasing tendency of the analyzed number, especially in the case of further COVID-19 pandemic. The calculated forecast errors prove the accuracy of the used models.

The obtained results for forecasts of the number of road accidents can be used in the future to formulate further actions aimed at minimizing the number of accidents in the analyzed countries. These actions may consist, for example, of the introduction of higher fines for traffic violations on Polish roads from January 1, 2022. It should be noted that in Slovakia it is planned to change the legislation aimed at the obligation to call the police for traffic accidents. So far, this has been made mandatory if the material damage caused by the accident exceeds € 3,990. This limit is due to be abolished in the near future, which will have a major impact on the number of accidents recorded by the police. This will create a major hurdle in the statistical comparison of accidents.

In their further research, the authors plan to consider more factors affecting the level of accidents in Poland. These may include traffic volume, weather conditions, or the age of the accident perpetrator.

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