AN ESTIMATE OF THE NUMBER OF ACCIDENTS ON POLISH HIGHWAYS BASED ON THE KIND OF ROAD

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Resume

A surprising number of people die on Polish highways every year. Despite the fact that number is decreasing year after year, it is still rather considerable. Due to the epidemic, the costs of the road accidents were significantly lowered, but they still remain fairly large. Understanding the roads where the majority of accidents happen and the anticipated number of accidents in the next years are necessary to lower this number. The purpose of the article was to forecast the number of accidents that would happen on Polish roads based on the kind of roads. To do this, annual accident statistics from the Police's statistics for the years 2001-2021 were reviewed, and a forecast for the years 2022-2031 was produced. It is clear that either the accident rate is increasing or it is steady. Predictions also suggest that a large increase in accidents on Polish roads may be expected given the current situation.

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1 Introduction

The road accidents are situations that result in both property damage and injury or death to other motorists. According to the WHO Every year, 1.3 million people worldwide die in car accidents. Road accidents cause a 3% GDP loss in the average nations. Children and teenagers between the ages of 5 and 29 die most frequently from traffic accidents [1]. By 2030, the UN General Assembly wants to see a 50% decrease in traffic accident fatalities and injuries.

A traffic collision's size is a factor in evaluating how serious it is. For the responsible authorities to develop the road safety legislation with the intention of preventing accidents, minimizing injuries, fatalities, and property damage, it is critical to quantify the severity of accidents [2-3]. Before implementing countermeasures to prevent and minimize accident severity, it is vital to identify the critical components that influence it [4]. A multi-node Deep Neutral Network (DNN) architecture is provided by Yang et al. for forecasting various degrees of injuries, fatalities, and property loss. It makes it possible to fully and accurately assess how serious traffic incidents are [5].

The accident numbers come from a number of sources. Typically, government representatives use the pertinent government agencies to obtain and evaluate them. Numerous sources, including hospital files, insurance company databases, and police reports, are used to collect data. As a result, the transportation industry is conducting more extensive analyses of data related to traffic accidents [6].

Currently, the most significant information source for the analysis and forecasting of traffic events is intelligent transportation systems. The GPS equipment mounted on moving vehicles may be used to process these data [7]. Roadside microwave vehicle detection systems may continually capture information about moving vehicles, such as speed, traffic volume, and vehicle type [8]. Additionally, a lot of traffic data may be gathered over a predetermined period of time using a license plate recognition system [9]. Social media is another possible source for information on traffic and accidents, albeit the accuracy of the reports may not be sufficient due to the inexperience of the reporters [10].

Work with various data sources need to be properly questioned in order for accident data to be of any use. Analytical outcomes can be more precise by integrating many data sources and combining diverse traffic accidents data [11].

To determine the severity of the situation and establish a connection between the traffic participants and accidents, Vilaca et al. [12] carried out a statistical analysis. The study's findings include raising the bar for traffic safety rules and implementing more traffic safety precautions.

Based on the quantity of traffic accidents, which serves as a barometer for the investigation into accident causes, Bak et al. [13] conducted a statistical analysis of traffic safety in a chosen Polish area. The study examined the safety factors of persons who cause accidents using multivariate statistical analysis.

The type of traffic problem being addressed determines the source of accident data to be used for analysis. The accuracy of accident prediction and accident elimination is increased by combining statistical models with additional data from the real driving or other information collected from intelligent traffic systems [14].

The literature contains a number of techniques for predicting the probability of accidents. The most popular methodologies for forecasting accident frequency [15-16] have the drawback of not allowing for evaluation of forecast accuracy based on previous forecasts and the frequent residual component of autocorrelation [17]. While Sunny et al. [18] employed the Holt-Winters exponential smoothing method, Prochazka et al. [19] used a multi-seasonality model. One of the model's drawbacks is that exogenous variables cannot be included [20].

The frequency of traffic accidents has been predicted using the curve-fitting regression models of Al-Madani [21] and Monedero et al. [22] for analyzing the number of fatalities, as well as the vector autoregressive model, which has the disadvantage of requiring many observations of variables to accurately estimate their parameters [23]. Assuming the series are already stationary, these only require an order of autoregression [24] and a few straightforward linear connections [25].

Random Forest regression was used by Biswas et al. [26] to forecast the frequency of traffic accidents. The approach and peak prediction are unstable [27], the data comprise groups with associated features that are as important to the original data, and in this case the smaller groups are preferred over the bigger ones [28]. For the proposed forecasting problem, Chudy-Laskowska and Pisula [29] used an autoregressive quadratic trend model, a univariate periodic trend model, and an exponential smoothing model. The problem at hand might potentially be anticipated using a moving average model, however, this approach has the poor forecast accuracy, data loss within a sequence, and is unable to take into account trends and seasonal fluctuations [30].

The GARMA approach, which restricts the parameter space, was employed by Prochazka and Camej [31] to ensure that the process is stationary. Forecasting frequently uses the ARMA model for stationary systems [19, 32-33] and the ARIMA or SARIMA model for the non-stationary phenomena. The benefit of these models is that they give the models under investigation a considerable deal of flexibility; nevertheless, the drawback is that they demand more advanced research skills from the researcher than, for instance, the regression analysis [34]. The linearity of the ARIMA model is another drawback [20].

In their study [35], Chudy-Laskowska and Pisula employed an ANOVA to forecast the frequency of traffic accidents. This approach's drawback is that it makes additional assumptions, most notably the assumption of sphericity, the failure of which could result in incorrect conclusions [36]. The frequency of auto accidents is also predicted using neural network approaches. Since neural networks are frequently referred to as "black boxes" where input is data and the model outputs the results without being aware of the analysis, the disadvantages of neural networks include the need for prior expertise in the field [35, 37-38], the dependence of the final result on the initial conditions of the network, and the inability to interpret the results conventionally.

Kumar et al. [39] used the Hadoop model as a cutting-edge prediction technique. This strategy's drawback is that it is unable to handle small data sets [40]. The Garch model was employed by Karlaftis and Vlahogianni [33] to provide predictions. This strategy's intricate model and complicated shape are a problem [41]. However, McIlroy and his team's usage of the ADF test [42] has the drawback of not having sufficient power to detect the autocorrelation of the random component [43].

To make predictions, authors of publications have also utilized data-mining algorithms, which frequently struggle with having a lot of broad descriptions [44-46]. Sebego et al.'s collection of models [47], which is another example of a model combination, are one more. Bloomfield's work [48] also suggests parametric models. Additionally, topics linked to forecasting and transportation safety are covered in [49].

The authors projected the number of accidents on Polish roads using the aforementioned data. The number of accidents was predicted using a few exponential models.

2 Materials and methods

On Polish roads, there is an increasing number of modern automobiles. Currently, there are about 750 cars per 1000 persons in Poland. As a result, the number of traffic accidents either increases or stabilizes (Table 1). An occurrence, involving a moving vehicle on the road that causes fatalities or significant injuries, damage to movable things like equipment or products, or other sorts of material harm, is referred to as a road traffic accident. Poland has the following varieties of roadways,

***Table 1** Number of accidents in Poland from 2007 to 2021, broken down by the kind of road [50]*

Date/type of road	Motorway	Expressway	2 one-way carriageway	Single carriageway	1 carriageway 2 directions
2007	3699	1468	55379	21427	324332
2008	3873	1371	56257	23507	326965
2009	3828	1508	57539	23063	329335
2010	4253	1845	68557	26827	353425
2011	3902	1692	63292	24645	313109
2012	4454	1725	58536	23175	288645
2013	5443	2444	60769	24671	298432
2014	6369	3114	62871	25364	285259
2015	7011	3751	64476	27481	292457
2016	8646	4739	71175	28791	326927
2017	9836	5882	71568	32326	349604
2018	9775	6542	72656	33386	345698
2019	10559	8082	73960	35680	357460
2020	8632	7856	59077	29680	300413
2021	10593	9999	65029	35254	324560

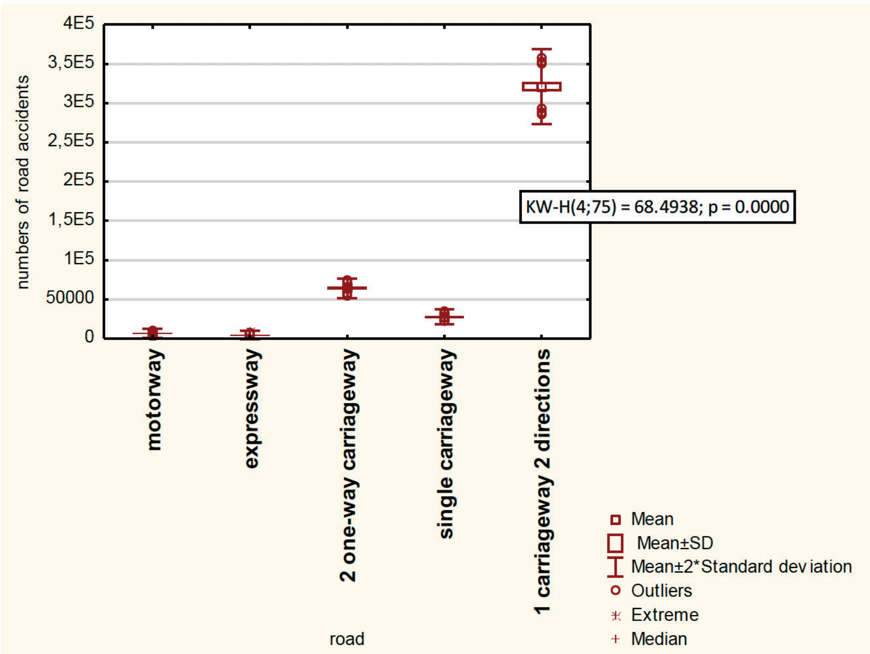

***Figure 1** The average number of accidents on Poland's roads compared by the kind of road for the period 2007 to 2021*

per police statistics [50]:

- Motorway,
- Expressway,
- 2 single carriageways,
- single carriageway,
- 1 carriageway 2 directions.

Selected time series models were used in the investigation in Statistica software.

The Kruskalla-Wallis test was used to examine the relationship between the kind of road and the frequency of accidents. The test probability is p = 0.000 and the test statistic has a value of 68 (Figure 1). The resulting statistics implies that it is best to abandon the presumption of an equal mean level of traffic accidents.

3 Estimating the number of accidents on the road

Using certain exponential equalization models, the frequency of accidents was forecasted for each type of the road. The key distinction between the two methods is that the weights are selected using an exponential function, while the forecast variable's time series is provided by a weighted moving average. These weights were carefully chosen by the Statistica program, which was utilized to carry out the applied analysis.

The number of accidents, for each type of route under consideration, was predicted using a weighted average of recent and historical information. The results of forecasts created using these methods depend on the model chosen and the ideal values for its parameters. Predictions of the number of accidents on Polish roads by kind of road were made using specific time series models.

Measures of analytical forecasting perfection were calculated using the errors of forecasts that had expired, which were calculated using Equations (1)-(5):

- ME - mean error

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

- MAE -mean average error

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|Y_i - Y_p|, \tag{2}$$

- MPE -mean percentage error

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\frac{Y_i - Y_p}{Y_i}, \tag{3}$$

- MAPE - mean absolute percentage error

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

- MSE - mean square error

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - Y_p)^2, \tag{5}$$

where: n - the length of the forecast horizon,
Y - observed number of the road accidents,
Y_p - forecasted number of the road accidents.

The mean absolute percentage error was reduced to compare the number of accidents during a pandemic and when a pandemic is not included in the study.

For the study's route categories, annual police records from 2007 to 2021 were utilized to project the number of accidents. The projected results for the roads are shown in Figures 2 to 6. The study's numerous forecasting methods are identified by the codes M1, M2,..., Mn. The forecasting techniques used in the study are as follows:

M1 - moving average method 2-points,
M2 - moving average method 3-points,
M3 - moving average method 4-points,
M4 - exponential smoothing no trend seasonal component: none,
M5 - exponential smoothing no trend seasonal component: additive,
M6 - exponential smoothing no trend seasonal component: multiplicative,
M7 - exponential smoothing linear trend seasonal component: none HOLTA,
M8 - exponential smoothing linear trend seasonal component: additive,
M9 - exponential smoothing linear trend seasonal component: multiplicative WINTERSA,
M10 - exponential smoothing exponential seasonal component: none,
M11 - exponential smoothing exponential seasonal component: additive,
M12 - exponential smoothing exponential seasonal component: multiplicative,
M13 - exponential smoothing fading trend seasonal component: none,
M14 - exponential smoothing fading trend seasonal component: additive,
M15 - exponential smoothing fading trend seasonal component: multiplicative)

Based on the research conducted for the highway (Figure 2), regardless of the research method used, one can conclude that one can still expect an increase in the number of traffic accidents in Poland in the coming years. This is mainly due to the increase in the number of kilometers of highways in Poland. In the case analyzed, the smallest MAPE error occurred when using the M13 method - exponential smoothing fading trend seasonal component: none.

The situation is similar for expressways, which are increasing year by year. As can be seen (Figure 3), the largest increase is observed with the M11 method, and the smallest with M3. In the case analyzed, the smallest MAPE error occurred with the M8 method - exponential smoothing linear trend seasonal component: additive.

Another of the analyzed roads is a dual carriageway (Figure 4). Based on the analyzed data, one can further expect stabilization and minimal increase in the number of traffic accidents during the analyzed period. In the analyzed case, the smallest MAPE error occurred using the M9 method - exponential smoothing linear trend seasonal component: multiplicative WINTERSA.

Another of the analyzed roads is a one-way road (Figure 5). In this case, one can still expect an increase in the number of traffic accidents. This is particularly evident with the M15 method. In the case analyzed, the smallest MAPE error occurred with the M12 method - exponential smoothing seasonal multiplicative component.

The last of the analyzed roads is the road 1 roadway 2 directions (Figure 6). In this case, there is a large change in the amplitude of the input data. For this reason, large differences in the data can still be expected. In the case analyzed, the smallest MAPE error occurred with the M14 method - exponential smoothing fading trend seasonal component: additive.

The aforementioned information leads to the conclusion that not all the approaches utilized in the case study were successful. The best forecasting

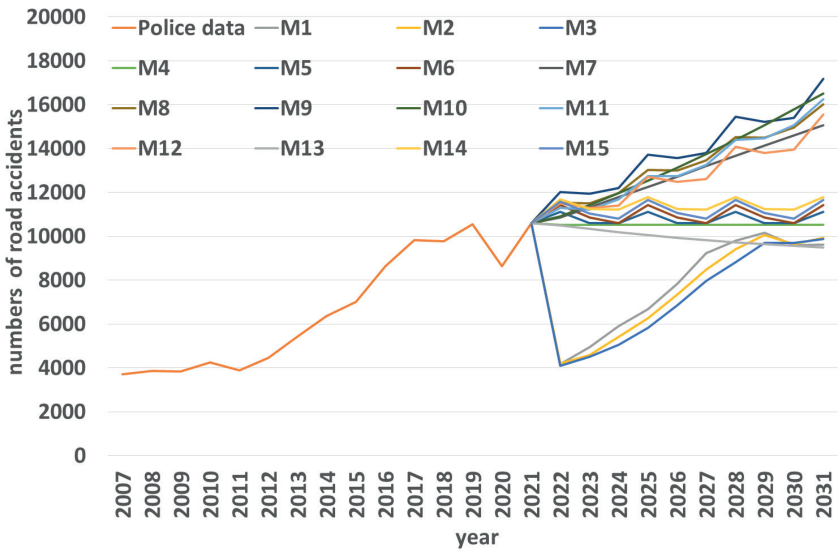

Figure 2 *Forecasting the number of road accidents for the motorway between 2022 and 2031*

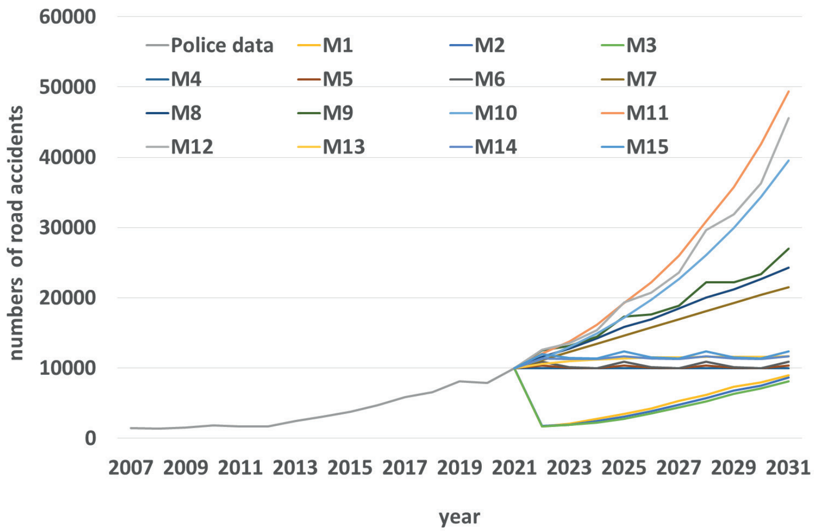

Figure 3 *Forecasting of the number of road accidents for the express road between 2022 and 2031*

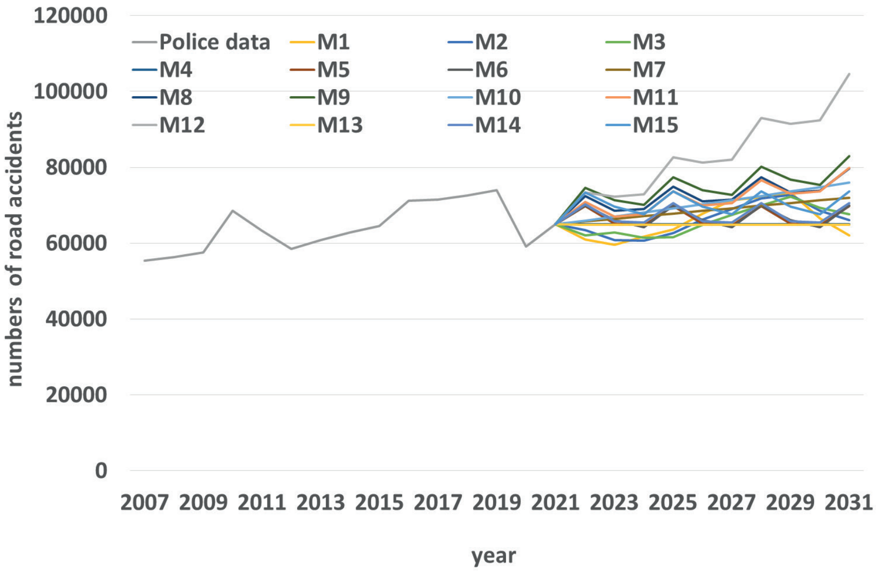

Figure 4 *Forecasting the number of road accidents for a 2 carriageway road from 2022 to 2031*

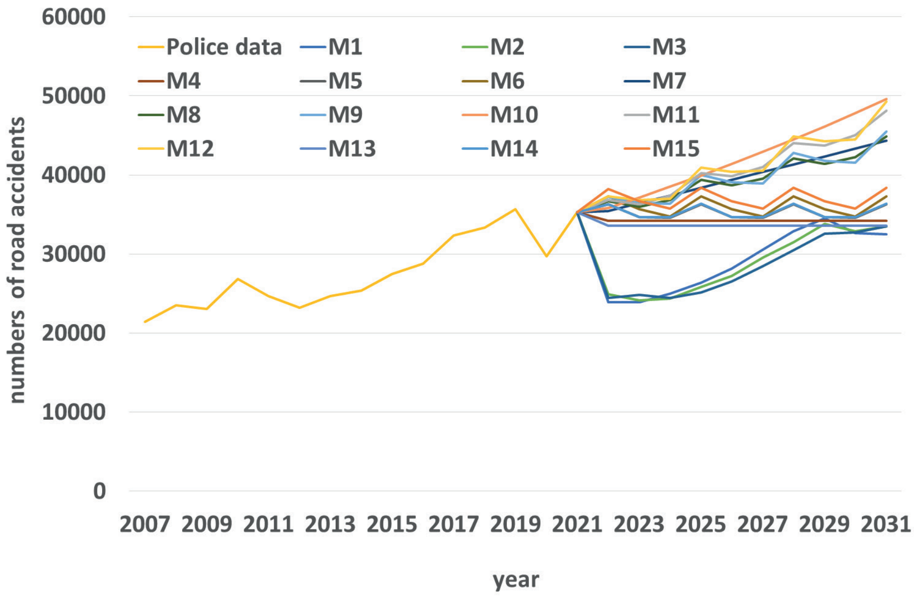

Figure 5 *Forecasting the number of road accidents for a one-way road from 2022 to 2031*

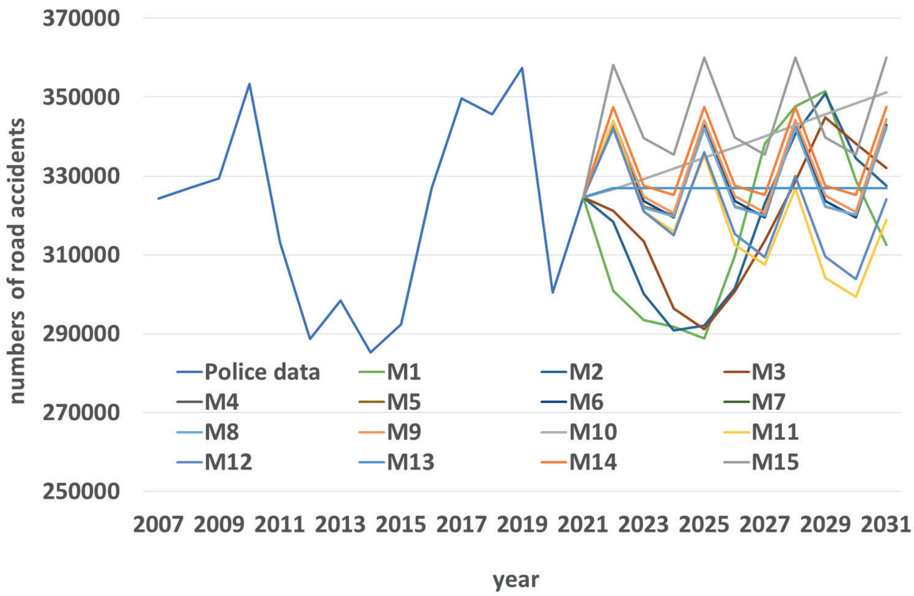

Figure 6 *Projected number of road accidents for road 1 carriageway 2 directions in 2022-2031*

techniques for each road were determined to be the following:

- Motorway - M13
- Expressway - M8
- 2 single carriageway road - M9
- Single carriageway - M12
- 1 carriageway 2 directions - M14

The information gathered makes it possible to conclude that the technique picked is dependent on the kind of route being researched. The MAPE error was consistently the minimum when using the linear trend and fading trend strategies. Figure 7 illustrates a forecast of the number of accidents on the roads that were examined based on this information.

Table 2 presents the outcomes of the forecasting blunders. According to the findings, there will probably be more accidents in the future. This is particularly crucial for highways. It is important to note that the epidemic has affected the outcomes. With the exception of highways, where the error value is 3.5%, the choice of an effective forecasting approach is demonstrated by a maximum error value of 1%. The smallest MAPE error on the analyzed roads, at 0.03%, occurred for single carriageway road 1 with 2 directions of travel. The next largest error was for single carriageway road 2 (0.31 %), expressway (0.69%) and single carriageway road (0.76 %). During the survey, the largest error occurred when predicting the number of accidents on highways (3.56%)

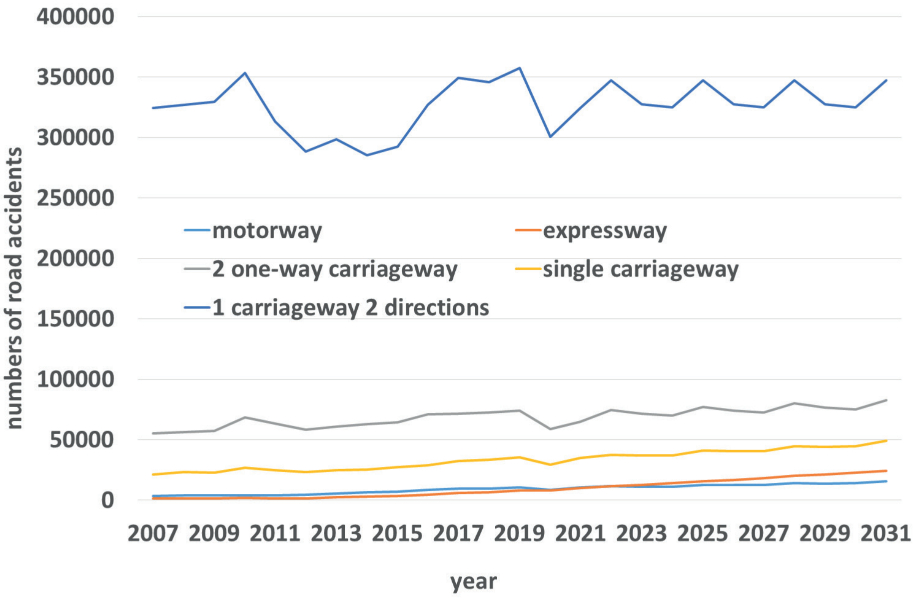

Figure 7 *Projected number of road accidents by analyzed road types in 2022-2031*

Table 2 *Forecasting errors for the best forecasting methods*

Road type/forecast error	ME	MPE	MSE	MAPE [%]	MAE [%]
Motorway	296.02	678.91	781259.3	3.56	9.39
Expressway	99.86	410.92	406005.5	0.69	10.22
2 single carriageway road	471.47	3832.82	23170378	0.31	5.98
Single carriageway	8.33	1922.17	5491637	0.76	6.86
1 carriageway 2 directions	0.41	16.51	410.1266	0.03	5.19

4 Conclusions

The number of accidents in Poland was predicted using an exponential equalization method using the Statistica application. The method found the weights that would be the most useful in lowering the mean absolute error and the mean absolute percentage error.

According to the study's conclusions, the number of traffic accidents would probably be similar to what it was before the epidemic. The exception is that as the number of highways increases, so does the number of accidents that take place on them. It is important to note that the epidemic has affected the outcomes. An error value of no more than 3.5% can serve as evidence that one has chosen a reliable forecasting method. The smallest MAPE error on the analyzed roads, at 0.03%, occurred for single carriageway road 1 with 2 directions of travel. The next largest error was for single carriageway road 2 (0.31 %), expressway (0.69%) and single carriageway road (0.76 %). During the survey, the largest error occurred when predicting the number of accidents on highways (3.56%)

The estimated number of road accidents found in this article can be used to create future strategies to lower the number of accidents on roads, especially on motorways. For example, the measures took effect on January 1, 2022, with the application of tougher penalties for moving violations on Polish roadways.

The authors plan to explore additional factors influencing accident rates in Poland in the subsequent study. The volume of traffic, the day of the week, or the age of the accident's perpetrator are a few examples of these. In the subsequent investigations, the authors also intend to examine how the quantity of cars, traffic volume, and vehicle type affect the frequency of road accidents.

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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.

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