A NOVEL APPROACH TO ANALYSIS OF ROAD ACCIDENTS USING THE TREND ANALYSIS AND IPTA METHOD: A CASE STUDY OF KOSOVO

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Abstract. Road accidents in Kosovo cause more than 100 deaths each year and about EUR 40 million in property damage. The paper presents an accident prediction model that relates accident frequency to various contributory factors and is developed using trend analysis and the Innovative Polygon Trend Analysis method. In addition, the study investigates road traffic accidents using a novel methodology to compare the different modes and other parameters. The presented research also discusses the road safety in Kosovo, which is a Republic with relatively low economic growth based on GDP per capita, a young population, an increase in the number of vehicles per capita, and an increase in the number of road accidents, but a decline in the number of deaths from road accidents in recent years.

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Introduction

According to the World Health Organization (WHO), every year over 1.2 million people worldwide die on the roads, and 20 to 50 million suffer non-fatal injuries. In most regions of the world, this epidemic of road traffic injuries is still on the rise (WHO, 2004). Over 90% of the world's road fatalities occur in low-income countries, which make up only 40% of the world's registered vehicles (WHO, 2004). Percentages of deaths have fallen over the past four or five decades in many high-income countries. Even in these countries, road traffic injuries remain an important cause of death, injury, and disability. In addition, more than 2.4 million people are injured in road accidents each year. This problem is most pronounced in the age group of 5–29 years, the age group for which injuries from road traffic are the main cause of death (WHO, 2004).

For Kosovo, road safety is also an important issue; the occurrence of road accidents in Kosovo in terms of the number of deaths is much

Figure 1. Map of Kosovo – study area (ICMM, 2022)

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closer to the standards of the European Union than to those of Eastern European countries (MI, 2015a). The two main differences from Western European countries are that there has been a significant increase in fatalities in the past decade and that the number of pedestrians represents the majority of road users in Kosovo. The number of persons killed in road accidents is very high: 1223 for the period of 2011–2020 (KAS, 2021a; MI, 2015a). Figure 1 illustrates the position and branching of the road transport network.

According to the road safety indicators in Kosovo, based on data from the Ministry of Infrastructure, there are 7.0 road traffic fatalities per 100 000 inhabitants and 43 deaths per 100 000 vehicles (KAS, 2021b; MI, 2015a).

Dynamics of traffic accidents in Kosovo (in total and by category) for the period from 2011 to 2020 is presented in Table 1.

Table 1. The total number of traffic accidents in Kosovo for the period of 2011–2020 (KP, 2021)

Year	AF	DP	AI	IP	AMD	AHR*	TA
2011	130	157	4490	8321	13 338	930	18 888
2012	116	121	4555	8561	14 044	1039	19 754
2013	104	119	4960	9817	13 878	1012	19 954
2014	111	127	4876	9713	10 333	980	16 300
2015	117	129	5275	10 671	11 145	1 185	17 722
2016	99	110	6130	12 009	12 312	/	18 541
2017	122	137	6390	12 645	11 183	/	17 695
2018	100	129	6217	12 359	9424	/	15 741
2019	100	113	6140	11 865	9959	/	16 199
2020	76	81	5396	10 194	8375	/	13 847

Abbreviations:
AF – Accident with Fatality;
DP – Dead Persons;
AI – Accidents with Injuries;
IP – Injured Persons;
AM – Accidents with Material damages;
AH – Hit and Run Accident;
TA – Total Accidents.

Note: From 2016, Hit and Run Accidents are included in the statistics according to the nature of the accidents (Fatality, Injuries, and Material Damages).

Road traffic injuries have been the leading cause of death for many years. The main parties that directly play a role in road management and road traffic safety are the Ministry of Infrastructure, Kosovo Police, and municipalities. Other parties indirectly involved in road traffic safety are the Ministry of Education, Science, Technology and Innovation, the Ministry of Justice, and the Ministry of Health.

To increase road traffic safety, the Ministry of Infrastructure has drafted and approved the Road Safety Strategy 2016–2020 (NAO, 2019; MI, 2015b). The aim of this strategy is for all parties involved in road traffic safety to take appropriate and concrete steps to improve road traffic conditions to reduce the number of accidents and fatalities. This plan provides for the analysis and assessment of the factual situation, the objective, the institutions responsible for implementation, the timelines, and the approximate budget for the implementation of the activities.

According to the statistics, the numbers of fatal road traffic accidents in the Republic of Kosovo are represented by the following percentage (NAO, 2019):

– 34% of fatal road traffic accidents occurred on national roads (highways);
– 27% of fatal road traffic accidents were vehicle–pedestrian;

Table 2. The total number of traffic accidents in Kosovo for the period of 2011–2020 (KAS, 2021)

Year	POK	NVR	TA
2011	1 739 825	205 366	18 888
2012	1 815 606	212 851	19 754
2013	1 820 631	272 107	19 954
2014	1 804 944	288 828	16 300
2015	1 771 604	342 142	17 722
2016	1 783 531	319 615	18 541
2017	1 798 506	334 440	17 695
2018	1 795 666	343 631	15 741
2019	1 782 115	355 829	16 199
2020	1 798 188	356 962	13 847

Abbreviations:
POK – Population of Kosovo;
NVR – Number of Vehicles Registered;
TA – Total Accidents.

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–   28% of fatal road traffic accidents occurred in the interval from 18:00–22:00;
–   64% of fatal road traffic accidents were caused by drivers with a national driving license, 26% were without a driver's license, while 6% were with a foreign driving license.

According to the Road Safety Analysis conducted by the Kosovo Police, the main causes of accidents for the first six months of 2018 were (NAO, 2019):

–   19.6% unsafe handling of the vehicle (negligence);
–   17.7% non-adaptation of speed to road conditions;
–   16.6% failure to maintain a safe distance;
–   6.4% unsafe road connection;
–   6.3% U-turns, driving in reverse.

The types of tickets given for traffic violations in this period were as follows (NAO, 2019):

–   41.9% non-compliance with the limited speed;
–   11.4% no safety belt;
–   11.2% irregular parking;
–   6.5% ignoring traffic signs.

The Kosovo Police is an important part of the management of road traffic safety and aims to reduce accidents, but although it has taken certain actions to increase road safety, the trend of fatal accidents leaves much to be desired.

In the analysed period (2011–2020), the total number of traffic accidents has increased, and it reached its peak in 2013 (19 954). Since 2013, there has been a decrease in the number of traffic accidents, and this number has stabilized over the past 5 years, i.e., there are no significant discrepancies (Table 2).

The aim of the present research is to determine whether there are discrepancies and irregularities within the analysed data, first, in order of the number of Total Accidents (TA) during the year. Such a determination will provide reliable analysis and forecasting of the accidents in the future. In addition, traffic safety policies and strategies can be applied much more effectively if a description of the actual situation is provided. Focus of the paper will be on the time series analysis.

1.   Literature review

There are many models and procedures for traffic accident analysis. The most used ones are Machine Learning Methods (Dominique & Fred, 2010), Genetic Algorithms (Assi et al., 2020), Bayesian Networks (BNs)

(Deublein et al., 2013), Support Vector Machines (SVMs) (Li et al., 2012), Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) (Naseer et al., 2020), Artificial Neural Networks (ANNs) (Moghaddam et al., 2020) as well as a combination of particular methods, i.e., data mining techniques (Sohn & Shin, 2001).

Machine Learning Methods (Dominique & Fred, 2010) are complex for the application, due to the complicated mathematical theoretical base. Also, these model often cannot be generalized to other data sets. Genetic Algorithms are widely used as well as more accurate compared with all mentioned methods (Assi et al., 2020). Application of the Bayesian Networks (Deublein et al., 2013) shows that predicted risk models can be adapted and updated to new available data. Also, good compliance was found between model predictions and real observations. Support Vector Machines provides results, which are comparable with all other methods (Li et al., 2012). Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (Naseer et al., 2020) take into account, as much as is possible, complex traffic environment, human behaviour, and lack of real-time traffic-related data. In other words, a high accurate deep learning model for traffic accident risk has been constructed. Moghaddam et al. (2010) created a series of Artificial Neural Networks in order to model and estimate crash severity and to identify significant crash-related factors in urban highways. Also, one remarkable feature of the Artificial Neural Networks models is to predict and present desired results in spite of limited data sets. Data mining techniques (Sohn & Shin, 2001) are very efficiently used to select a set of influential factors and to build up classification models for accident severity.

The limitation of the presented methods is that they require prior mathematical and statistical knowledge, depending upon the sophistication of the particular method. This was the motivation for proposing a novel methodology for solving the described problem in order to avoid complex analytical procedures. In addition, the commonly used trend analysis can result in misleading conclusions owing to superficially adopted views with respect to the relatively high coefficient of the regression equation.

Although trend analysis is often used, it is necessary to combine such a method with another in order to determine the homogeneity and isotropy of the observed data in the analysis of the obtained trends. The Innovative Polygon Trend Analysis (IPTA) Method is very appropriate for such an analysis as a stand-alone application and also in combination with other methods. This method first analyses the appearances of the up-to-date movements or the resolution of the appearances that significantly affect the analysed problem and then quantifies the dependencies that exist between those representations. IPTA is based

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on a corresponding extension of the current trend and explains the movements during the past period and the reasons for these movements. Advances in the application of quantitative methods have resulted from the rapid development of computers and software that have enabled using large amounts of data, comparing different variants, and choosing the optimal solution (Ceribasi & Ceyhunlu, 2021).

2.   Methodology

In the paper, IPTA was used with trend analysis.

In the paper, linear, parabolic (2nd and 3rd order), exponential, logarithmic, and power trends were calculated with the input data. A forecast for the years 2020 to 2025 was also calculated with regards to the mentioned trends.

Equation (1) shows the general matrix format of the IPTA method (Ceribasi & Ceyhunlu, 2021):

$$
\begin{bmatrix}
x_{1,1}, x_{1,2}, \ldots, x_{1,12} \\
x_{2,1}, x_{2,2}, \ldots, x_{2,12} \\
\vdots \quad \vdots \quad \vdots \quad \vdots \\
x_{i,1}, x_{i,2}, \ldots, x_{i,12} \\
\vdots \quad \vdots \quad \vdots \quad \vdots \\
x_{n,1}, x_{n,2}, \ldots, x_{n,12}
\end{bmatrix}
\begin{array}{l}
\left. \vphantom{\begin{matrix}a\\a\\a\end{matrix}} \right\} \text{Upper Series (First Half)} \; n = 1,2,3,\ldots,\dfrac{n}{2}, \\[2em]
\left. \vphantom{\begin{matrix}a\\a\\a\end{matrix}} \right\} \text{Lower Series (Second Half)} \; n = \dfrac{n}{2}+1, \; \dfrac{n}{2}+2,\ldots,n.
\end{array}
\tag{1}
$$

Data series, in this case, total number of the traffic accidents TA, were divided into two equal parts. They are presented graphically in a Cartesian coordinate system in Figure 2. Values of the upper series are placed on the X-axis and values of the lower series are placed on the Y-axis.

There are rules and guidelines for interpretation of the IPTA diagram (Sen et al., 2019):

- The straight line between 2 consecutive years indicates the change in the monthly values. The closed polygon implies the natural balance behaviour of the traffic accident numbers for 1 year;
- The consecutive yearly changes are represented by the length of each straight line length;
- If the slopes of each straight line in the IPTA template are close enough to each other in both vertical and horizontal directions, it implies that the relative yearly values contribute insignificantly to the mean of the traffic accident number variation for each

consecutive month. Likewise, all the straight lines in the IPTA template first provide an explanation of the 12-month variation for qualitative (linguistic) inference at each record location;

– Each polygon side implies the assumption that there is a linear change between consecutive years. The linearity assumption smaller than 1 year implies more realistic results in the trend analysis;

– If the slopes of all the straight lines in an IPTA template are not different from each other, all the sides appear around a single global direction; then the connection of the polygon vertices provides a broken line that is very close to the global regression line fit. In this case, the polygon is very narrow, which means that the internal change within the traffic accident number is quite homogenous, isotropic, and has uniform variation behaviour, whereas comparatively wider polygons indicate heterogeneous temporal variation;

– In general, any polygon with a rising form implies that the prevailing conditions are almost in balance. On the contrary, there may arise two or more polygons (loops) rather than a single one.
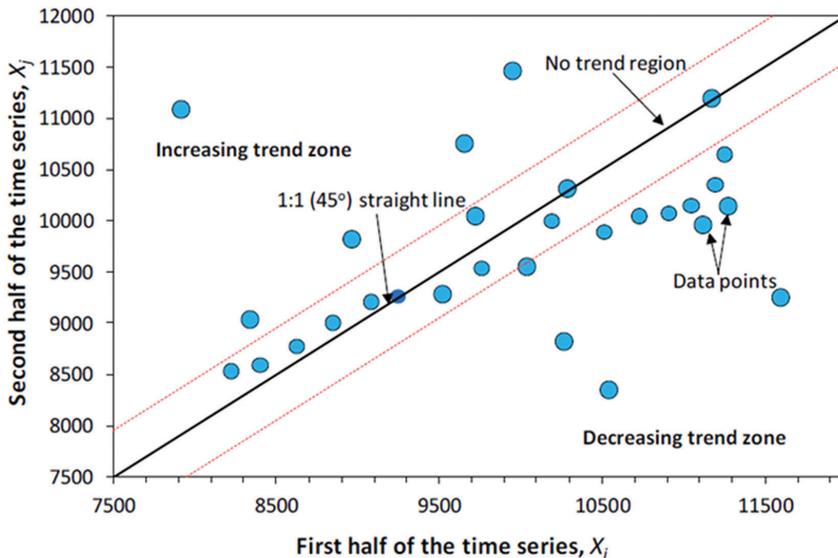

Figure 2. Graphical presentation of the IPTA method (Ali et al., 2019)

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3.   Case study

For the prediction of road accidents in Kosovo by applying the time series analysis (TSA), the MS Excel program was used. All data are given for the period from 2011 to 2020. Figure 3 shows road accidents in Kosovo from 2011 to 2020. From 2011 to 2020, there was a periodic decrease in the number of car accidents in Kosovo, from 18 888 in 2011 to 16 300 in 2015 and, finally, 13 847 in 2020.

Figs. 4–8 show linear, parabolic (2nd and 3rd order), exponential, logarithmic, and power trends with the corresponding equations. For all trends, x = 1 for 2011, and also x = 10 for 2020, where unit x is 1 year, and unit y is the number of accidents.
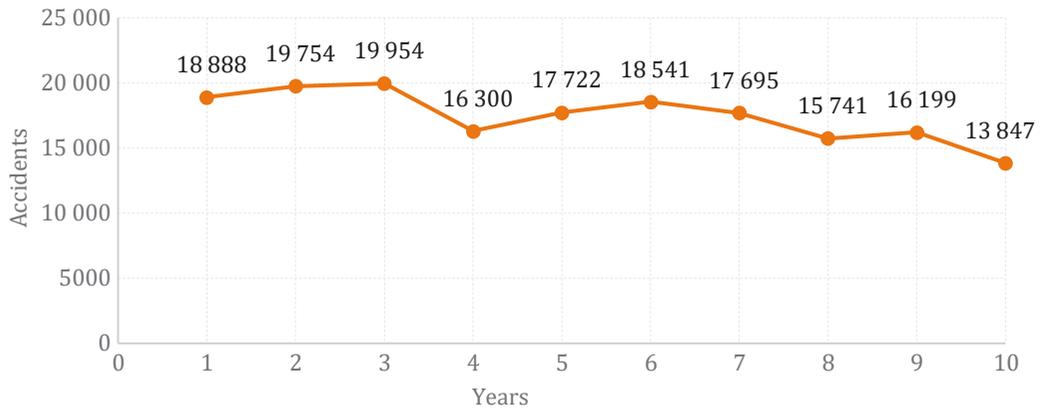
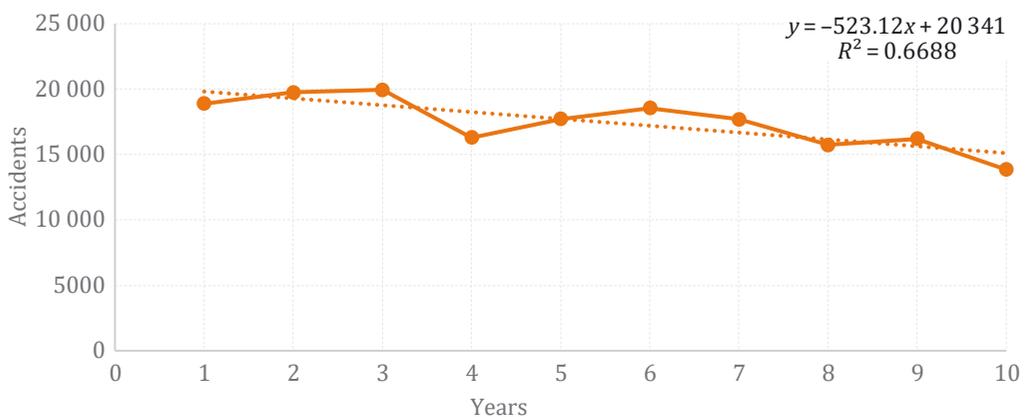**Figure 3.** Road accidents in Kosovo from 2011 to 2020

$$y = -523.12x + 20\,341$$
$$R^2 = 0.6688$$

Figure 4. Number of accidents for the period of 2011–2020 associated with a linear trend

$$y = -54.606x^2 + 77.545x + 19\ 140$$
$$R^2 = 0.7154$$
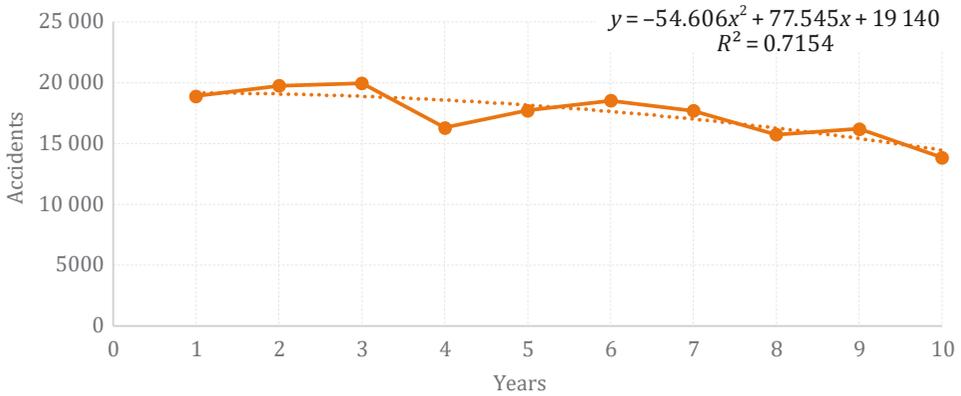
Figure 5. Number of accidents for the period of 2011–2020 associated with a polynomial trend of the 2nd order

$$y = -13.125x^3 + 161.96x^2 - 921.3x + 20\ 266$$
$$R^2 = 0.7312$$
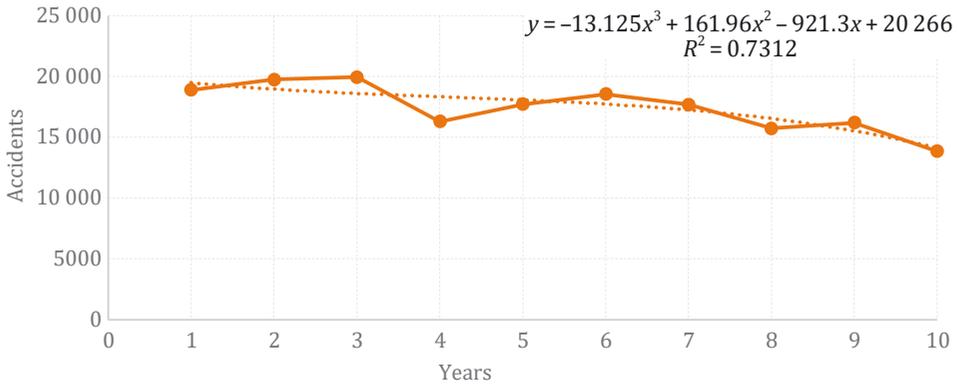
Figure 6. Number of accidents for the period of 2011–2020 associated with a polynomial trend of the 3rd order

$$y = 20566e^{-0.031x}$$
$$R^2 = 0.6543$$
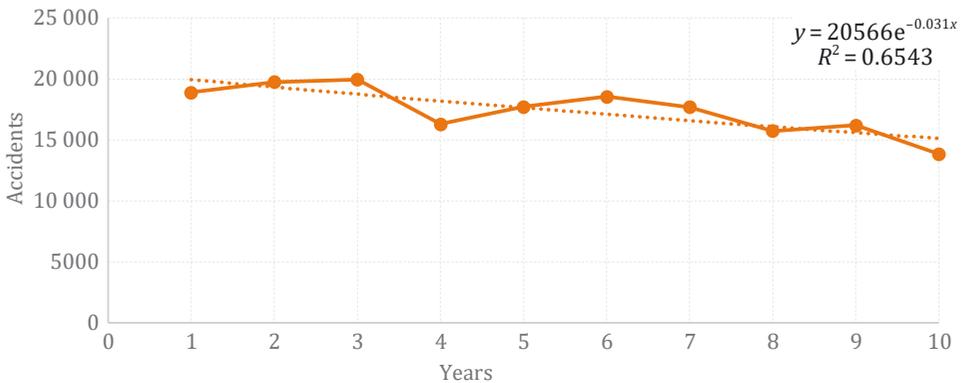
Figure 7. Number of accidents for the period of 2011–2020 associated with an exponential trend

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$$y = -1900 \ln x + 20\,334$$
$$R^2 = 0.5172$$
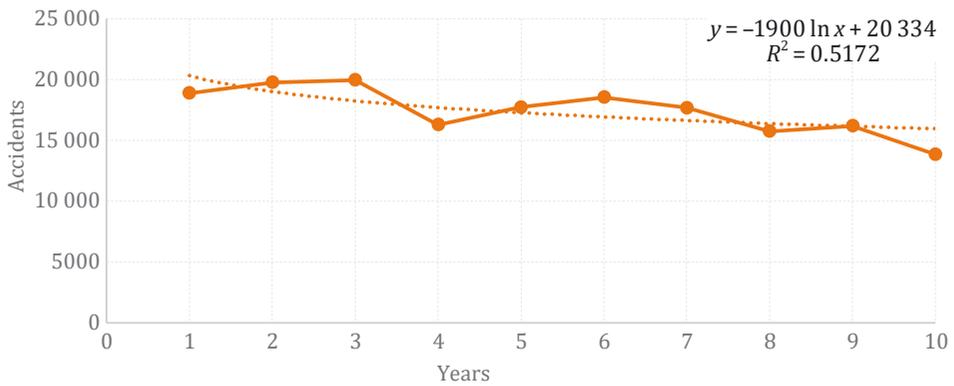
Figure 8. Number of accidents for the period of 2011–2020 associated
with a logarithmic trend

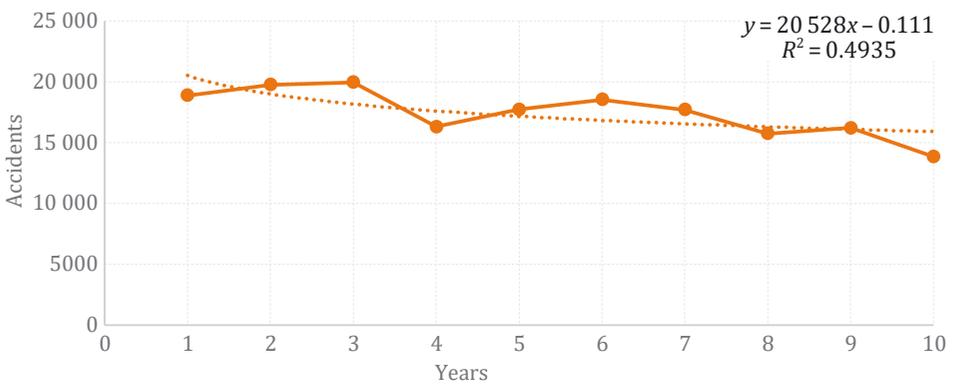$$y = 20\,528x - 0.111$$
$$R^2 = 0.4935$$

Figure 9. Number of accidents for the period of 2011–2020 associated
with a power trend

It was noticed that the polynomial trend of the 3rd order had the biggest R^2 value, so that trend fit best among the analysed data. Table 3 shows the calculated (predicted) values of the traffic accidents for all trends.

Although the polynomial trend of the 3rd order showed the biggest R^2 value, it was excluded from further analysis because of negative calculated values in the future. The linear trend predicted the smallest number of accidents, but it also had the smallest R^2 value. The power trend predicted the greatest number of traffic accidents. However, differences between all trends were small regarding the R^2 values. Thus, it could be concluded that trend analysis did not provide a clarified conclusion about accident prediction in the future. Nevertheless, further analysis was required, so the IPTA method was applied by using Equation (1) to determine the differences between all observed and calculated values for each year (Figs. 10–15).

Table 3. The total number of predicted traffic accidents in Kosovo for the period from 2021 to 2025

Year	Linear	Exponential	Polynomial 2nd order	Logarithmic	Polynomial 3rd order	Power
2021	14 587	14 624	13 386	15 778	12 259	15 731
2022	14 064	14 177	12 207	15 613	9 853	15 580
2023	13 540	13 745	10 920	15 461	6 825	15 442
2024	13 017	13 325	9 523	15 320	3 097	15 315
2025	12 494	12 918	8 017	15 189	–1 409	15 198
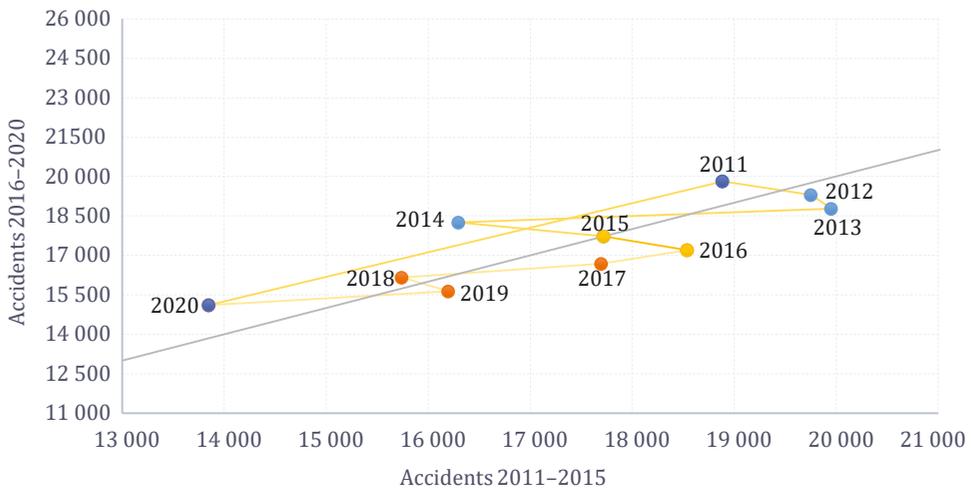
Figure 10. IPTA diagram of the linear trend

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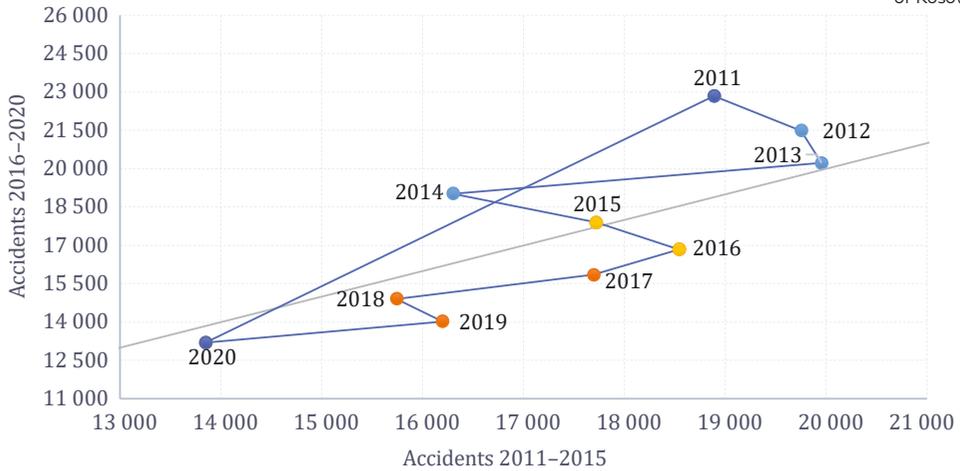*Ebrahim Alamatian*

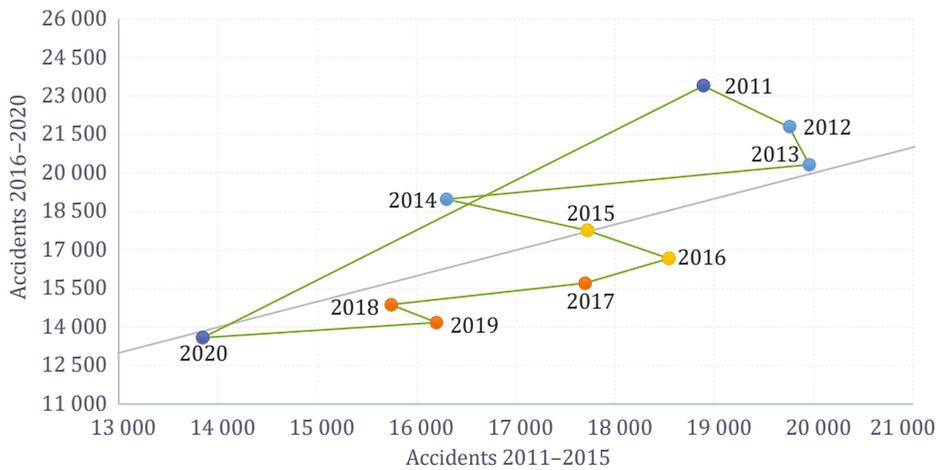**Figure 11.** IPTA diagram of the exponential trend

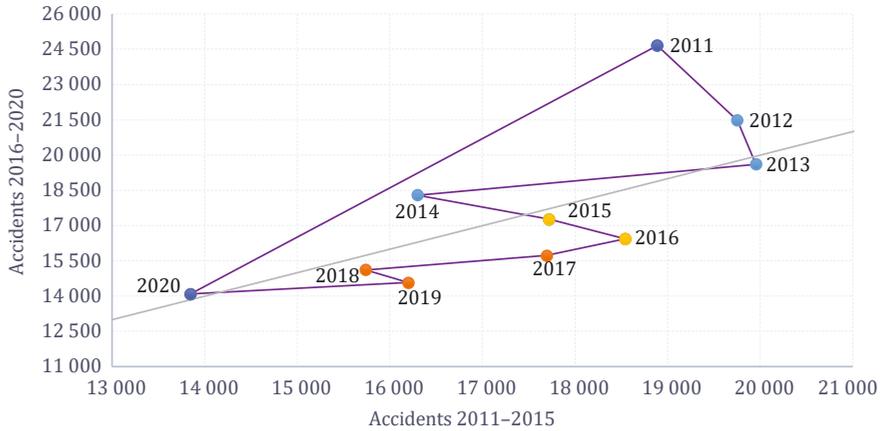**Figure 12.** IPTA diagram of the polynomial trend, 2nd order
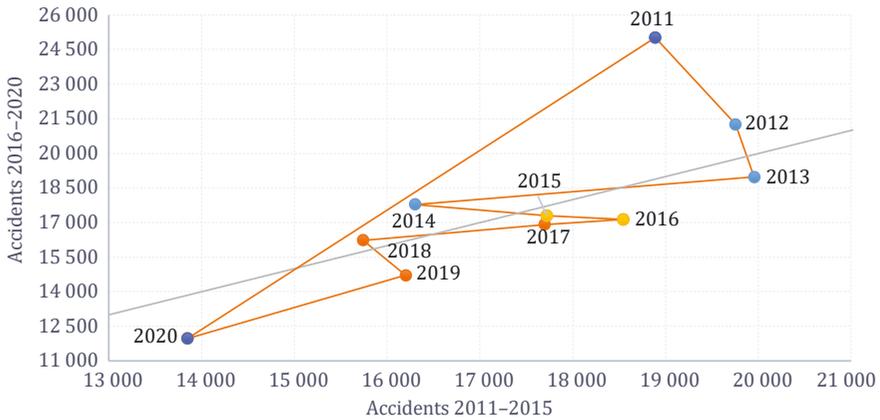
Figure 13. IPTA diagram of the logarithmic trend
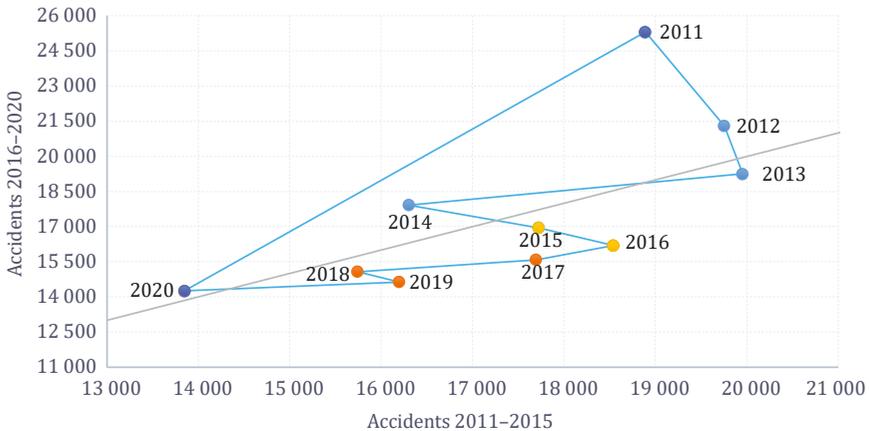

Figure 14. IPTA diagram of the polynomial trend, 3rd order

Figure 15. IPTA diagram of the power trend

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4.   Analysis of the obtained results

From all IPTA diagrams it can be seen that the logarithmic, polynomial of the 3rd order, and the power trend polygons were closed. This implied that the calculated/predicted numbers of traffic accidents for those trends were homogeneous and isotropic. In other words, there were instabilities during the other trends. Table 4 shows that in the first part (first subperiod from 2011 to 2015) there were more traffic accidents compared with the second subperiod. Table 2 confirms this averment, because in 2015 the number of traffic accidents began to decrease and the population number increased. The key appearance of the rise in the registration of vehicle numbers showed that the appearance of vehicles that passed the technical inspection raised the level of the safety on the roads.

The IPTA diagrams show that the logarithmic, polynomial of the 3rd order, and the power trend should be analysed for a realistic forecast of the number of future accidents. As concluded earlier, the polynomial of the 3rd-order trend was not applicable owing to the negative number of accidents. The logarithmic trend was the most appropriate for the prediction of the number of accidents.

Making a forecast under conditions where Kosovo was in an unstable, unpredictable economic situation was subject to errors because of uncertainty. Otherwise, we recommend not making long-term predictions or forecasts and maximizing for the next half of the estimated period.

However, for a better and more reliable prediction, other factors that influence the estimated phenomena need to be considered.

Table 4. General evaluation for all trends

Trend	Years									
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Linear	↗	↘	↘	↗	→	↘	↘	↗	↘	↗
Exponential	↗	↗	↗	↗	↗	↘	↘	↘	↘	↘
Polynomial trend, 2nd order	↗	↘	↗	↗	→	↘	↘	↘	↘	↘
Logarithmic trend	↗	↘	↘	↗	↘	↘	↘	↘	↘	↗
Polynomial trend, 3rd order	↗	↗	↘	↗	↘	↘	↘	↗	↘	↘
Power trend	↗	↗	↘	↗	↘	↘	↘	↘	↘	↗

Conclusion

The subject of the research has been limited to the road accidents affecting domestic road safety in Kosovo, due to the aim and size of the present research. Using the quantitative methods of time series analysis and regression analysis, the number of road accidents has been predicted to decrease.

It has also been found that in the analysed period from 2011 until today, these variables tend to decline, which is particularly pronounced from 2015 to the present, and the forecast results indicate their further decline, i.e., stagnation, assuming that this trend will last until Kosovo recovers from the great economic crisis and until the market stabilization period that directly affects the movement of the variables evaluated in this paper.

Despite the achieved results, the paper leaves room for further research through the possibility of introducing more variables and eventually combining our model with any qualitative and quantitative methods that will enable new and efficient knowledge. For example, future task is the analysis of all the other parameters from Table 1 (not only the number of the traffic accidents, because such would be out of the aim and a size of the paper).

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