DOI: 10.7409/rabdim.025.014

PAWEŁ TUTKA [1)]
ORCID: 0000-0003-0879-0310

PIOTR KUNIKOWSKI [2)]
ORCID: 0009-0005-3526-6217

EMIL ŁOPATA [3)]
ORCID: 0009-0005-9928-3139

An analysis of the influence of legal changes on the number of traffic crashes and fatalities in Poland in 2022

Abstract: The aim of this article is to examine the impact of the tightening of road laws in Poland in 2022 on the number of recorded crashes involving casualties and fatalities. Throughout 2022, a series of legal changes were introduced in Poland that increased penalties, primarily financial, for traffic violations and crimes. At the same time, the number of crashes involving casualties in the analysed year significantly decreased compared to 2021. This study examined the statistical significance of the impact of these legal changes on road safety and estimated the decrease in the number of crashes involving casualties and fatalities due to legislative activity. Interrupted time series analysis was the primary tool used for this purpose. Additionally, the results obtained for Poland were compared with data from selected neighbouring countries. The findings indicate a significant and statistically meaningful impact of the legal changes. Based on the proposed model, the decrease can be estimated at approximately 6-8% for the number of crashes and about 22% for the number of fatalities.

Keywords: crashes preventions, COVID influence, interrupted time series, law enforcement, legal tightening.

[1)] Warsaw University of Technology, Faculty of Civil Engineering, 16 Armii Ludowej Av., 00-637 Warsaw, Poland; pawel.tutka@pw.edu.pl (✉)
[2)] Heller Consult, 8 Chałubińskiego St., 00-613 Warsaw, Poland; p.kunikowski@heller-consult.pl
[3)] Heller Consult, 8 Chałubińskiego St., 00-613 Warsaw, Poland; e.lopata@heller-consult.pl

1. INTRODUCTION

1.1. BACKGROUND

Road crashes and related fatalities remain a major social concern globally. Reducing road deaths is a priority in both developed and developing countries, though approaches differ. While some advocate for stricter traffic laws and enforcement, others highlight alternative factors, questioning whether legal tightening is the primary driver of change. Scientific analysis is crucial in guiding this debate.

This article examines the impact of legal changes introduced in Poland in 2022 on the number of crashes involving casualties (referred to also as 'crashes' throughout the text) and fatalities. Poland has followed a long-term trend of tightening traffic laws, coinciding with a decline in crashes [1], often interpreted as a positive effect of these reforms [2]. However, similar declines have occurred across the EU [3], suggesting other influencing factors such as infrastructure improvements, vehicle modernization, and demographic shifts.

The 2022 Polish amendment to the road traffic law offers a unique case study, as neighbouring countries did not implement comparable changes. The law, passed on December 2 and signed on December 9, 2021, came into force on January 1, 2022, with some provisions enacted later that year. Key changes, outlined in Table 1, focused on substantial increases in traffic fines – up to 100% or 200% for speeding offenses – and granted insurers access to drivers' offense histories, introducing significant financial consequences for violations.

1.2. SCOPE

The main hypothesis of the study is formulated as follows: The changes in the law in 2022 in Poland had an impact on reducing the number of crashes involving casualties and fatalities, significantly altering the observed variable values. It should be noted that the gradual nature of the introduced changes, as well as the potential influence on drivers' behaviour merely by announcing legal changes, makes it challenging to assess the impact of individual provisions. Ultimately, the study examined the possibility of a change in the number of crashes at two points: January 1, 2022, when the law came into force, and September 17, 2022, when most of the provisions introducing financial penalties for traffic violations became effective.

Table 1. Changes in Polish law in 2022 tightening penalties for traffic violations

The date of implementation of legal changes	The content of the legal changes
01.01.2022	1. Outstanding fines will be deducted from tax refunds. 2. Falsifying tachograph readings by road carriers will result in a three-month suspension of their driving licenses.
17.06.2022	1. Insurance companies will have access to the CEPiK database (the Polish database of all registered crashes), providing them with information about drivers' offenses, imposed fines, and awarded penalty points. This access will allow insurance companies to adjust proposed insurance premiums based on the number and severity of offenses committed, as well as the number of penalty points. They will be able to review a driver's offense history for up to two years prior to the law's entry into force.
17.09.2022	1. Exceeding the speed limit by 30 km/h or more will result in a fine of at least 1,500 PLN. Repeating this offense within 2 years of the first fine will result in a fine of at least 3,000 PLN. 2. Creating a hazard for pedestrians, such as overtaking at a pedestrian crossing, will result in a fine of at least 1,500 PLN. Repeating this offense within 2 years of the first fine will result in a fine of at least 3,000 PLN. 3. Driving without the appropriate qualifications to operate a vehicle will result in a fine of at least 1,000 PLN, arrest, or imprisonment. Repeating this offense within 2 years of the first fine will result in a fine of at least 2,000 PLN. 4. Increasing the maximum fine in summary proceedings to 5,000 PLN (or 6,000 PLN in the case of multiple offenses). 5. Increasing the maximum fine in the Code of Petty Offenses to 30,000 PLN (previously, the maximum amount was 5,000 PLN). 6. A police officer will be able to impose a maximum of 15 penalty points on a driver at once (previously, the maximum was 10 penalty points during one stop). 7. Penalty points may be revoked no earlier than 2 years after paying the imposed fine.

Used methods based on the application of interrupted time series analysis and the comparison of the number of crashes involving casualties and fatalities with selected neighbouring countries. Four countries were considered: Germany, the Czech Republic, Slovakia, and Lithuania. All neighbouring countries to Poland for which data were available were analysed (Ukraine, Belarus, and Russia were omitted). Furthermore, most of these countries are culturally like Poland and are at a similar level of economic development.

1.3. INSIGHTS FROM LITERATURE

Road safety is a priority in the policies of numerous countries and international organizations. The World Health Organization (WHO) introduced an action plan for 2011-2020 to save human lives [4], later extended to 2021-2030 [5]. Polish efforts within the 2011-2020 WHO plan are summarized by [6]. Similarly, the European Union set ambitious goals to reduce crashes, including a 50% reduction in fatalities and serious injuries by 2030 and achieving zero fatalities by 2050 (Vision Zero) [3]. In Poland, the number of road fatalities remains notably high compared to Western EU countries [2], despite significant declines since the peak in 1991 [2]. Measures to address this include legislative reforms and initiatives detailed by [2]. Neighbouring countries have also intensified their road safety efforts [7, 8]. These initiatives are driven not only by humanitarian concerns but also by the substantial economic costs of crashes [3].

The reduction of road crashes and fatalities has been extensively analysed in the scientific community [9-17]. Legal reforms are often cited as critical factors in reducing traffic crashes. Study [18] analyse the impact of stricter laws – seatbelt use, motorcyclist protection, drink driving, sanctions, and speed controls – in developing countries, demonstrating crashes reductions, though with varying magnitudes across regions. Similarly, studies [19] and [20] confirm the positive effects of stricter laws.

Alcohol-related crashes also receive considerable attention. Studies [21] and [22] indicate fewer alcohol-related incidents following stricter legal measures. Conversely, [23] reported no significant impact of legal changes on alcohol-related driving cases or crash rates, while [24] found alcohol's influence on road mortality in Rio de Janeiro to be statistically insignificant.

The financial implications of road safety are discussed in [25], which highlights the role of mandatory insurance. Findings suggest that a higher prevalence of third-party liability insurance correlates with increased road fatalities due to moral hazard, where financial safety nets encourage riskier driver behaviour.

Overall, the literature presents mixed results regarding the effects of stricter penalties. While most studies indicate reductions in negative road incident outcomes, some exceptions reveal statistically insignificant impacts.

2. METHODS

2.1. INTERRUPTED TIMES SERIES

The method employed in the study was based on the analysis of time series data of the number of crashes and fatalities on roads in Poland. Initially, data for the entire country from January 2015 to December 2022 was considered at a monthly resolution. Interrupted time series with seasonal autoregressive integrated moving average (SARIMA) was applied. This method is designed to detect statistically significant changes in the occurrence of the phenomenon under study and is commonly used in the social sciences [26-28]. The method used in the article involves creating a statistical model of the phenomenon with components typical of time series analysis applied in the SARIMA model, along with additional components related to segmented linear regression. This model was utilized in the so-called intervention period (events that can change the number of observed phenomena, such as the number of crashes with casualties), the effectiveness of which we plan to verify. Typical factors for the SARIMA model can be expressed as follows:

$$\mathrm{SARIMA}(p,d,q) \times (P,D,Q)_{\mathrm{m}}, \tag{1}$$

where: p is the order of the autoregressive (AR) part of model, q is the order of the moving average (MA) part of model, d is the degree of non-seasonal differencing, D is the degree of seasonal differencing, P is autoregressive term of the seasonal component, Q is moving average for the seasonal component, m is length of the seasonality cycle [28]. The values of parameters p, d, q, P, D, Q were chosen to minimize the Akaike information criterion (AIC) [29]. The value of m was set to 12.

The intervention part of the model generally takes the form:

$$Y_t = b_0 + b_1 T + b_2 I + b_3 R + \varepsilon_t, \tag{2}$$

where: Y_t is the outcome variable (for example number of crashes or number of fatalities), T is a continuous variable which indicates the time passed from start of the observational period. I is a variable indicating observation collected before ($I = 0$) or after ($I = 1$) the intervention. R is a continuous variable indicating time passed since the intervention has occurred (before intervention has occurred is equal to 0).

The introduction of changes in the Road Traffic Law (January 1, 2022) and the implementation of the highest number of financial penalties (September 2022) were treated as interventions that could affect the number of crashes and fatalities. For these interventions, coefficients of segmented linear regression were considered. Additionally, we cannot overlook the impact of the COVID-19 epidemic, which reduced traffic on the roads and the number of incidents. Ultimately, the analysed model included five interventions, two related to changes in the law, and three to the COVID-19 epidemic. The interventions related to changes in the law began in January 2022 (denoted as $1st_{intervention}$) and September 2022 (denoted as $2nd_{intervention}$) and lasted until the end of the analysed period. The three identified abrupt changes related to COVID-19 are as follows:

- from March 2020 until the end of the analysis – introducing changes related to the onset of the pandemic (denoted as $COVID_{start}$);
- from July 2020 to September 2020 – introducing changes related to the reduced perception of risk associated with COVID-19 during this period (denoted as $COVID_{relief}$);
- from April 2021 until the end of the analysis – introducing changes related to the end of the impact of the COVID-19 epidemic during this period (denoted as $COVID_{end}$).

A symbolic chart depicting all interventions and their expected impact on the number of crashes is shown in Fig. 1.

The SARIMA model with the described interventions was selected using the maximum likelihood method. Additionally, SARIMA model parameters were chosen to achieve the lowest possible value of the *AIC* parameter [30]. Only models for which the residuals are independently distributed (i.e., exhibiting no serial autocorrelation) were considered. This condition is met when the *p*-value for the Ljung-Box test [30] is significantly greater than 0.05. Additionally, autocorrelation and partial autocorrelation function (ACF and PACF) plots were examined.

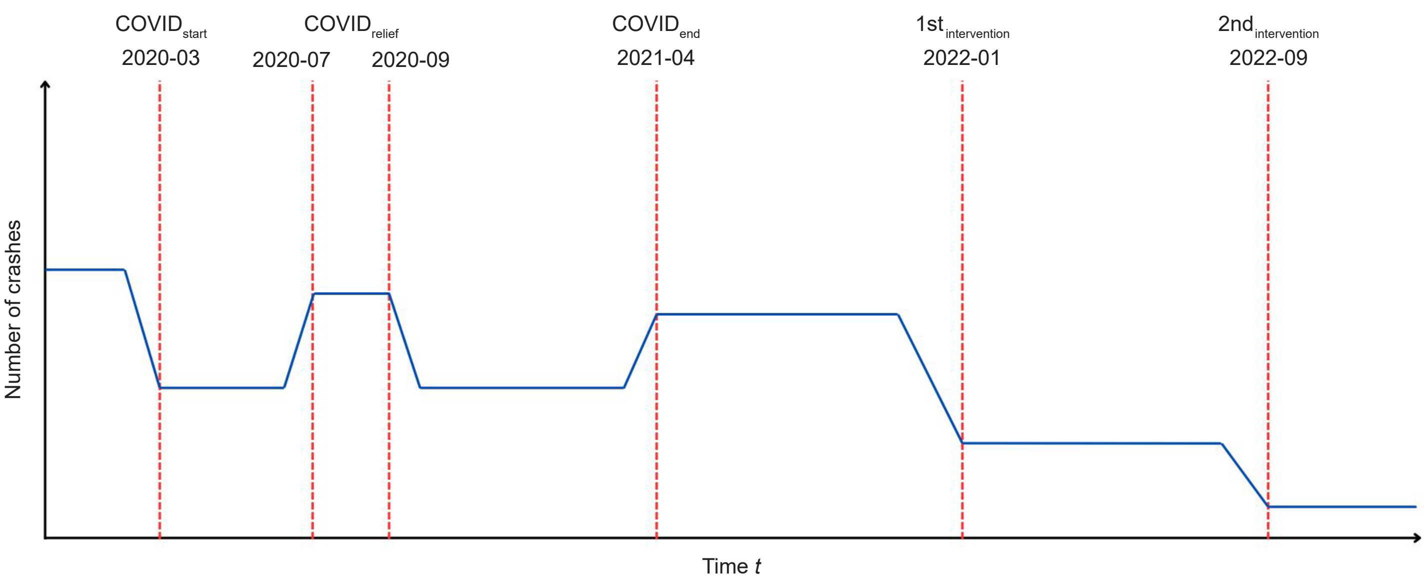

Fig. 1. A simplified diagram illustrating interventions affecting the number of road crashes in Poland

The effectiveness of interventions related to changes in the law is indicated by obtaining statistically significant coefficients associated with the interventions in the applied model [28]. The coefficient values determine the magnitude of the intervention's impact.

2.2. COMPARISON WITH NEIGHBOURING COUNTRIES

Crashes data for Germany, the Czech Republic, Slovakia, and Lithuania were analysed. These countries are relatively culturally close to Poland, and their trend of change should be similar. For these mentioned countries, analogous statistical models were checked for the effect of interventions in January 2022 and September 2022. If such an effect were to occur, it would be attributed to common causes shared by the neighbouring countries and Poland. This would limit or completely exclude the effect of changes in the law (which took place only in Poland on these specific dates).

The data on the number of crashes and fatalities in Poland from 2015 to 2022 were sourced from reports by the National Road Safety Council [31], an interministerial advisory and auxiliary body to the Council of Ministers on road safety matters. Data regarding the number of road incidents in the Czech Republic and Lithuania were obtained from the respective national police websites [32, 33], from the Ministry of Interior of the Slovak Republic's website in Slovakia [34], and from The Federal Statistical Office's website in Germany [35].

3. RESULTS

3.1. DATA ANALYSIS

The number of road crashes in Poland from January 2015 to December 2022 is presented in Fig. 2. Significant seasonality of the phenomenon is evident. Additionally, a decreasing trend is observed before and after the pandemic. However, during the pandemic, there was a significant decrease in the number of crashes, which did not return to pre-pandemic levels despite the return of traffic to pre-epidemic levels [36].

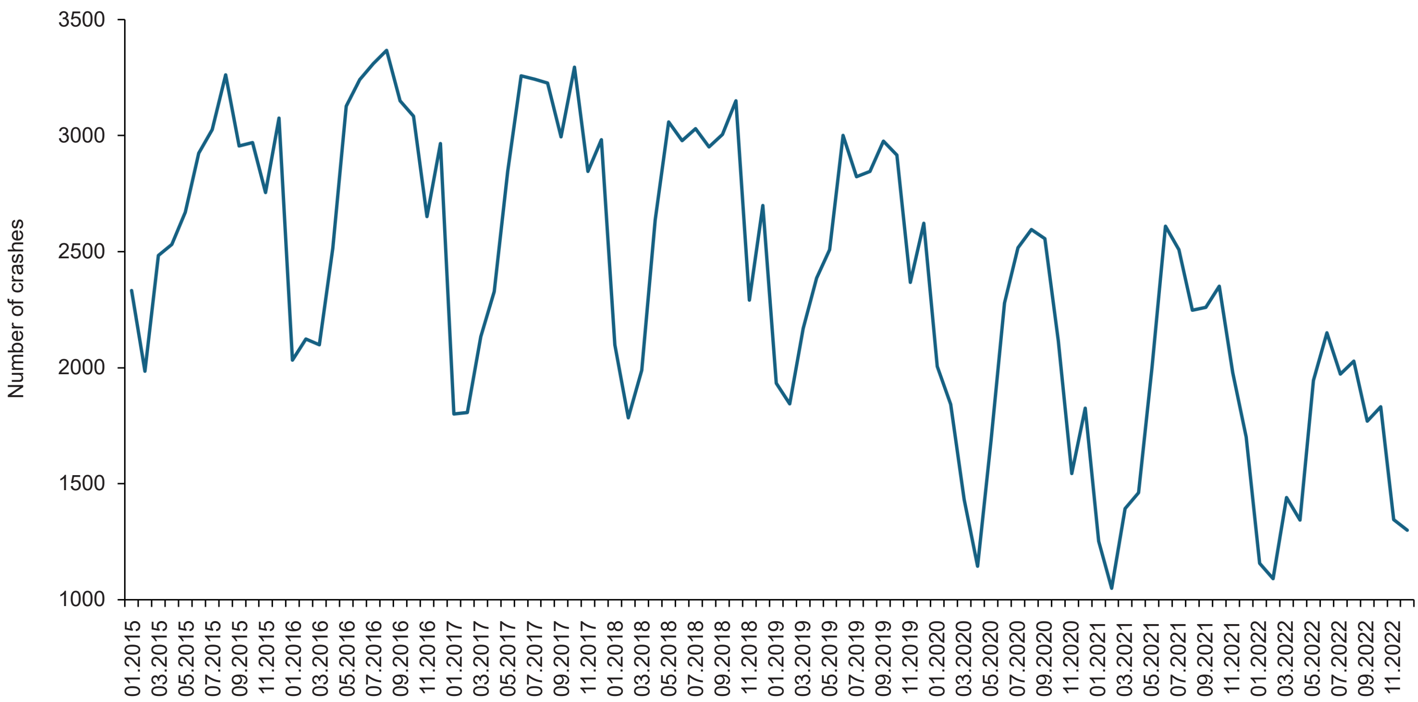

Fig. 2. The number of crashes in Poland from 2015 to 2022 by individual months

In the calculations, for easier comparison between countries, it was decided to divide the number of crashes in individual months by the average number of crashes per month in 2019 (referred to as the crash ratio), and further calculations were carried out based on these processed data. Fig. 3 presents seasonally adjusted results for the key period from January 2020 to December 2022. Seasonal adjustment was performed as follows: the proportion of the number of crashes in individual months from 2015-2019 (months unaffected by COVID-19 seasonality) to the average monthly total number of crashes from the period 2015-2019 was calculated. These obtained coefficients were used to divide the crash ratio from the corresponding months in the period 2020-2022, and the results are presented in Fig. 3. In the absence of a pandemic, values close to 1 would be expected in individual months, with a slight downward trend. Variability indicates the influence of COVID-19 and other interventions. The resulting graph supports the adoption of the proposed interventions and the intervals of their validity. It reflects a sudden decrease in the number of incidents at the onset of the pandemic, a temporary increase in their number in the period from June to September 2020, and then from June 2021 onwards, a further partial reduction in the impact of the pandemic on reducing the number of crashes. Additionally, a decrease in the number of crashes related to interventions caused by changes in the law is visible.

3.2. STATISTICAL MODEL FOR CRASHES INVOLVING CASUALTIES

For the proposed variables, regression coefficients and time series coefficients were calculated. Each time an intervention occurred, a change in the linear trend (non-zero R variable indicating time passed since the intervention has occurred) and a sudden change at the time of the intervention were considered. Possible parameter values $(p, d, q) \times (P, D, Q)_m$ were also verified, assuming only seasonality with a value of $m = 12$. Models where each change was statistically significant, and the spread of residuals was assumed to be white noise (checked by the Ljung-Box test, where white noise was assumed when p-value > 0.5) were considered. The effectiveness of the model was measured by the AIC value (the model with the lowest AIC value was chosen). For modeling the number of crashes in Poland, the optimal SARIMA model obtained was $(0, 0, 0) \times (2, 0, 0)_{12}$, with statistically significant variables mainly showing sudden changes during interventions (the "b_3R" factor was not statistically significant). The first of the obtained models considers only the intervention related to the legal change in January 2022, and the parameters for the model are presented in Table 2.

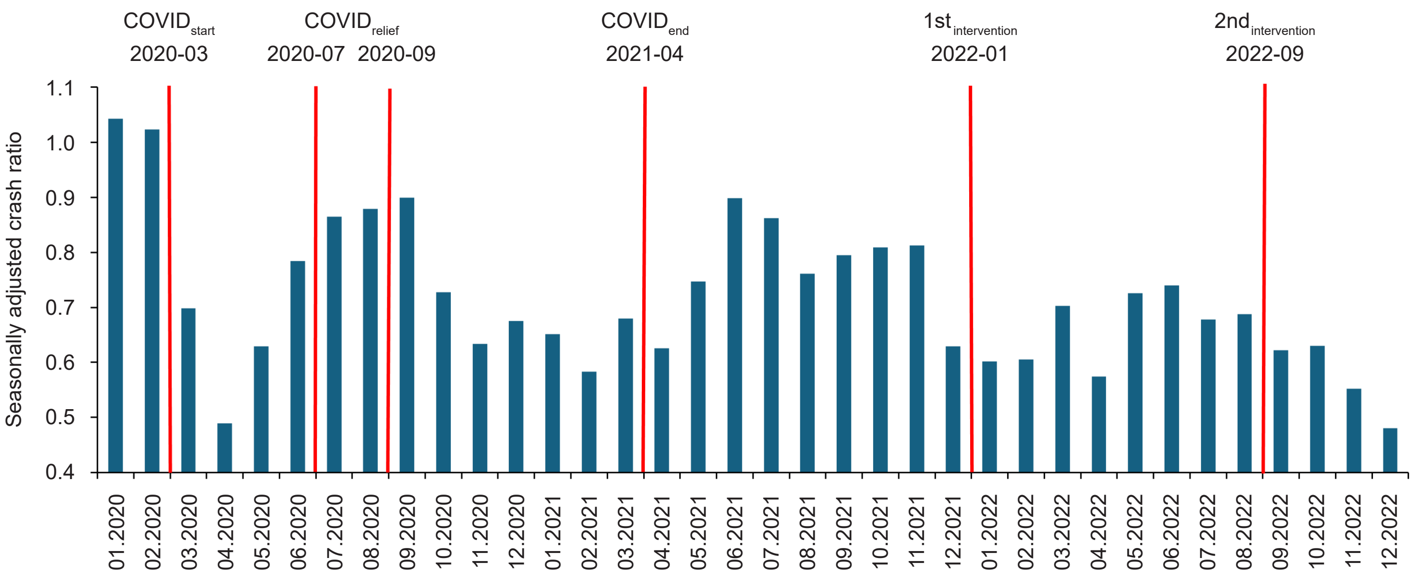

Fig. 3. Unseasonal ratio of crashes involving casualties in 2020-2022 Poland

Table 2. The parameters of the model estimating the number of crashes involving casualties, based on a single intervention related to a legal change

Coefficient name	Coefficient value	*Std* dev	*Z* score	*p*-value	CI 2.5%	CI 97.5%
Const.	1.1247	0.051	22.059	0	1.025	1.225
T	–0.0018	0.001	–2.614	0.009	–0.003	0
$\text{COVID}_{\text{start}}$	–0.3067	0.031	–9.842	0	–0.368	–0.246
$\text{COVID}_{\text{relief}}$	0.1983	0.083	2.392	0.017	0.036	0.361
$\text{COVID}_{\text{end}}$	0.1389	0.032	4.326	0	0.076	0.202
$1\text{st}_{\text{intervention}}$	–0.1477	0.041	–3.601	0	–0.228	–0.067
ε_{t-12}	0.5501	0.122	4.494	0	0.31	0.79
ε_{t-24}	0.3492	0.14	2.498	0.012	0.075	0.623

The coefficients presented in the table constitute the model determining the number of events using the following formulas:

$$Y_t = 1.125 - 0.0018T - 0.307\text{COVID}_{\text{start}} + \\ + 0.198\text{COVID}_{\text{relief}} + 0.139\text{COVID}_{\text{end}} + \\ - 0.1477\ 1\text{st}_{\text{intervention}} = \varepsilon_t\,, \tag{3}$$

$$\varepsilon_t = 0.550\varepsilon_{t-12} + 0.349\varepsilon_{t-24} + \eta_t\,, \tag{4}$$

where:

- η_t – residuals with a normal distribution,
- Y_t – the number of crashes predicted by the SARIMA model for period *t*, and serves as its dependent variable,
- ε_t – estimated difference between the registered number of crashes and the model-derived number in period *t*,
- T – the number of months since January 2015,
- $\text{COVID}_{\text{start}}$ – the variable equals 0 before March 2020 and equals 1 after that month,
- $\text{COVID}_{\text{end}}$ – the variable equals 0 before April 2021 and equals 1 after that month,
- $\text{COVID}_{\text{relief}}$ – the variable has a value of 1 in July, August, and September 2020; in other periods, its value is 0,
- $1\text{st}_{\text{intervention}}$ – the variable has a value of 1 for months in 2022; for the remaining months, the value is 0.

The terms ε_{t-12} and ε_{t-24} represent the model residuals from 12 and 24 months prior to time *t*, respectively. These components capture seasonal temporal dependencies and are part of the seasonal autoregressive structure in the SARIMA model.

It should be noted that, in addition to the considered interventions, the time series model includes a factor representing a steady linear decrease in the number of crashes over time. In equation (3), this is expressed as $-0.0018 \times T$, where T denotes the number of months. This downward trend is clearly visible and should not be attributed to the legal changes introduced in 2022.

The root mean square error (RMSE) for the obtained model is 0.064, with a variance of the residual values equal to 0.0054. The coefficient of determination (R-squared) between the actual values and those obtained from the model is 0.946. The model predictions and recorded results are shown in Fig. 4, demonstrating that the model accurately describes the actual ratio of crashes. Additionally, the obtained autocorrelations of the residuals are close to 0. The residuals indicate that the difference between the number of crashes in individual months and the model predictions is white noise (*Ljung-Box* value = 11.93). This suggests that the data are independently distributed, any observed correlations in the data result from the randomness of the sampling process. The obtained model, which describes the phenomenon well, clearly indicates statistically significant events from January 2022 (described as the $1\text{st}_{\text{intervention}}$), which reduced the number of crashes. The number of crashes resulting from this intervention decreased by 14.8% compared to the number of crashes in 2021. Additionally, the model captures the scale of the decrease in the number of crashes during different phases of the COVID-19 epidemic. Initially, the outbreak of the epidemic reduced the number of crashes by about 30%. During the period from July to September, there was a transient increase in the number of crashes by 20% (traffic during this time in Poland was practically at pre-epidemic levels), and at the end of the COVID-19 epidemic, there was an increase of about 14%. The epidemic caused a significant reduction in the number of crashes on the roads in Poland, which may be partly due to changes in road traffic laws in 2021.

The attempt to create a model considering two interventions did not yield statistically significant results. When including the variable $2nd_{intervention}$, neither of the 2022 interventions remained statistically significant. The lack of statistical significance is likely due to the small sample size after the intervention in September 2022 (only three months of data). This prevents treating the intervention marked as $2nd_{intervention}$ separately from the intervention in January 2022. Therefore, in the subsequent part of the article, only model for the intervention occurring in January 2022 will be presented.

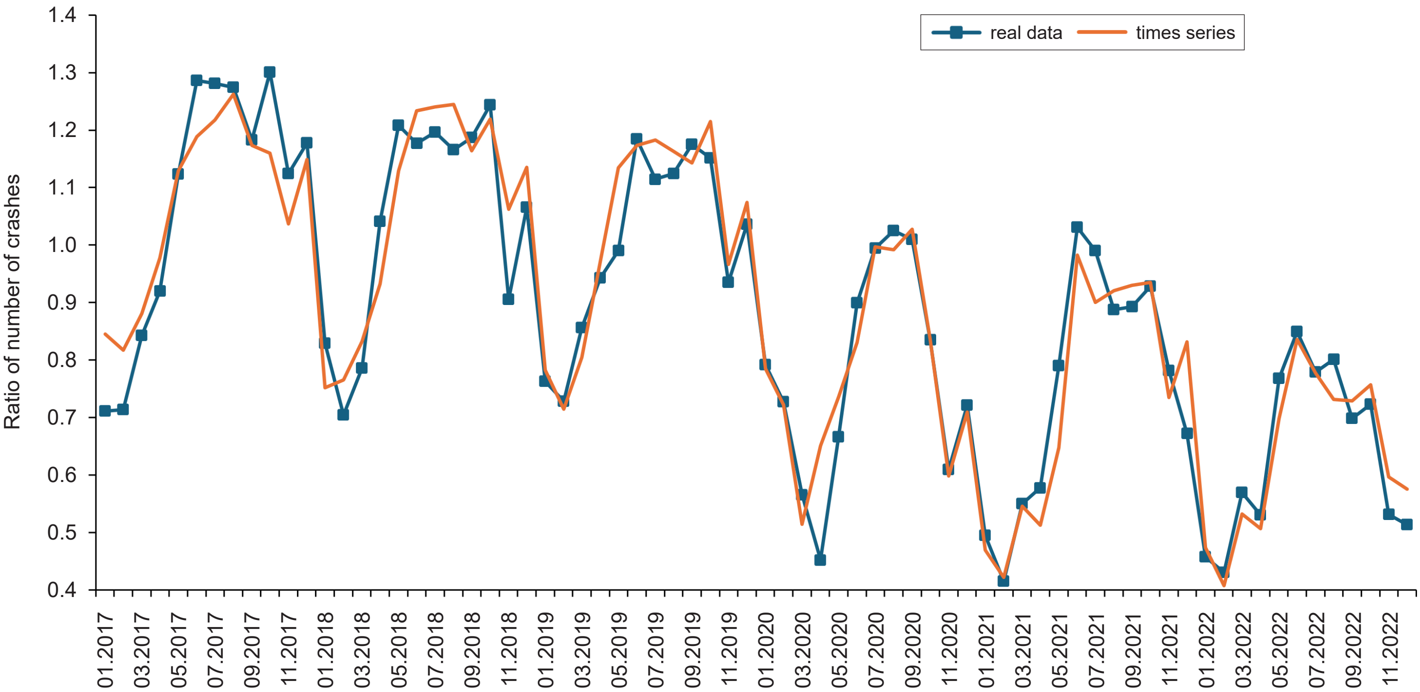

Fig. 4. The actual and time series-based ratio of crashes in Poland

3.3. STATISTICAL MODEL FOR FATALITIES

A time series describing the number of fatalities in Poland from 2015 to 2022 was also prepared. The model was created based on data obtained by dividing the number of fatalities in each month by the average number of fatalities per month in 2019 (denoted as the ratio of fatalities). The method used was analogous to the analysis of crashes. In this case, again, the most favourable SARIMA series turned out to be $(0,0,0) \times (2,0,0)_{12}$. Among the variables related to interventions, only $COVID_{start}$ and $1st_{intervention}$ were statistically significant.

The chart comparing the model results to the actual values is shown in Fig. 5. The mean squared error (MSE) for the obtained model is 0.100, with a variance of the residual values equal to 0.0113. The coefficient of determination (*R*-squared) between the actual and model-predicted values is 0.859. The obtained autocorrelations of the residuals are close to 0. The residuals indicate that the difference between the number of fatalities in individual months and the model predictions is white noise (*Ljung-Box* value = 8.39). According to the proposed model, the number of fatalities in Poland decreased by an estimated 22.4% due to the intervention in 2022.

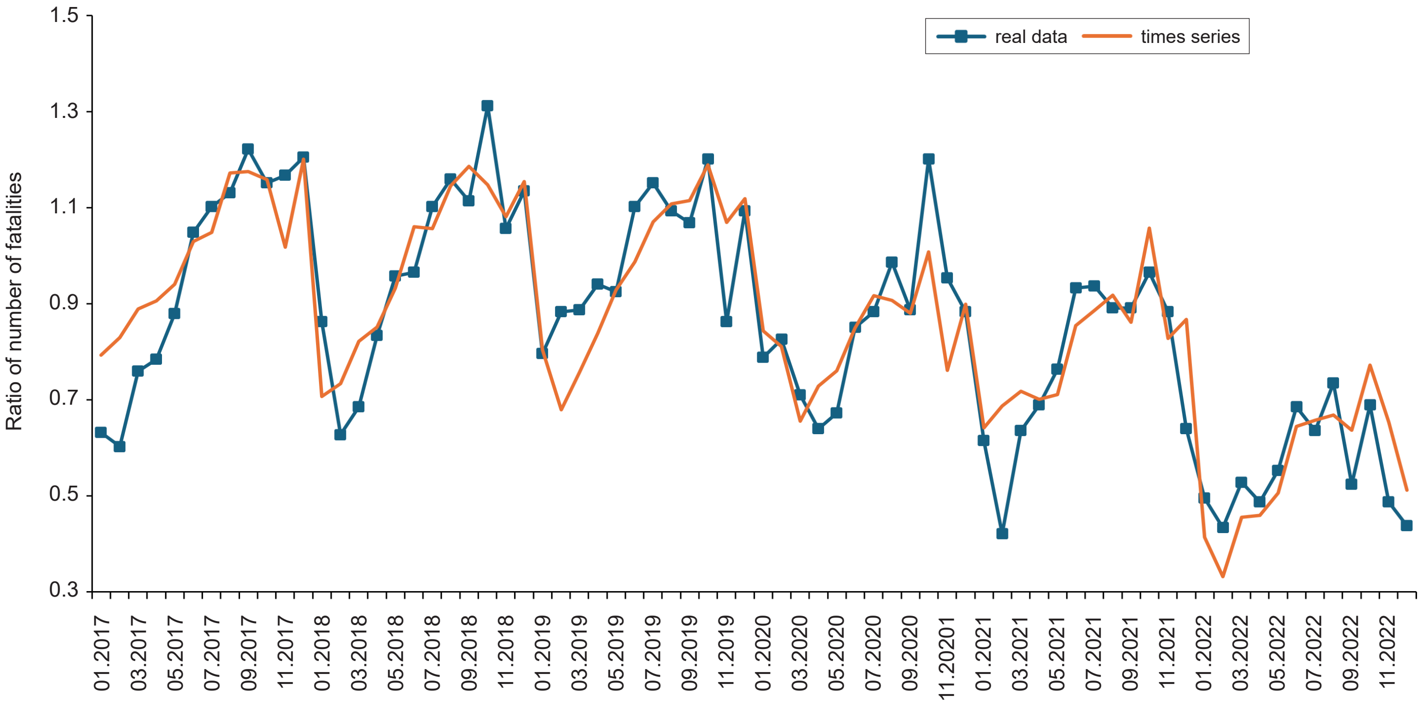

Fig. 5. The actual and model-derived ratio of fatalities based on time series in Poland from 2017 to 2022

3.4. RESULT OF COMPARISON WITH NEIGHBOURING COUNTRIES

The data on crashes and fatalities in Poland were compared with occurrences in neighbouring countries to exclude the possibility of another factor, shared with neighbouring countries, which reduced the number of crashes and fatalities in Poland in 2022. The crash ratio (number of crashes divided by number of crashes in 2019) values for each country are shown in Fig. 6a. The decline in Poland is significantly greater than in other countries, although higher declines in Poland were already observed before the epidemic. The decrease in the number of crashes between 2022 and 2019 in Poland was about 36%, compared to about 13% for Slovakia and 9.5% for the Czech Republic.

For neighbouring countries, statistical models describing the ratio of crashes were prepared, and the results obtained are summarized in Table 3. The comparison was made with the Czech Republic and Slovakia, as these countries were able to build statistically significant models. In the case of Germany and Lithuania, data for 2022 were not available. It should be noted that for the Czech Republic, the data concern the number of road incidents rather than crashes with injuries. To estimate the net effect of the legal intervention introduced in Poland, an interrupted time series model was applied. The model showed a 14.8% decrease in the number of crashes involving casualties. To control for regional trends and unrelated external factors, analogous models were constructed for two neighbouring countries – the Czech Republic and Slovakia – which did not implement similarly strict changes during the same period. These models showed decreases of 6.6% and 8.9% in casualty crashes, and no statistically significant change in fatalities. As a result, the estimated effect for Poland was adjusted by subtracting the average reduction observed in the neighbouring countries. This adjustment accounts for potential confounders unrelated to the intervention, such as broader socioeconomic changes, seasonal effects, or shared road safety campaigns across the region. The difference between Poland and Slovakia is 8.2 percentage points. The range of 6-8% is a realistic estimate of the impact of legal changes on the decrease in the number of crashes. This translates to a decrease of around 1,800 to 2,400 crashes annually in Poland.

On Fig. 6b, the change in the ratio of fatalities (the proportion of the number of fatalities each year to the number of fatalities in 2019) is depicted. The decreases in Poland during the period of 2020-2022 are significantly greater than in the other countries. The decrease for Poland amounts to 44.2% (compared to just 3.9% in the years 2016-2019). For Slovakia and the Czech Republic, the decrease in the number of fatalities in the years 2022/2019 is 17.0% and 12.0%, respectively.

Table 3 presents models for the fatalities ratio for Poland, Czech Republic, and Germany. The number of fatalities for Lithuania and Slovakia was too small to build a statistically significant model. Poland is the only country where a decrease in the number of fatalities occurred because of the analysed intervention on January 1, 2022. The decrease due to the intervention in 2022 amounts to 22.4% (percentage calculated relative to 2019), according to the adopted method, and it can be attributed to changes in the law. This translates to a decrease of about 650 fatalities in the year 2022 compared to the situation without legal intervention.

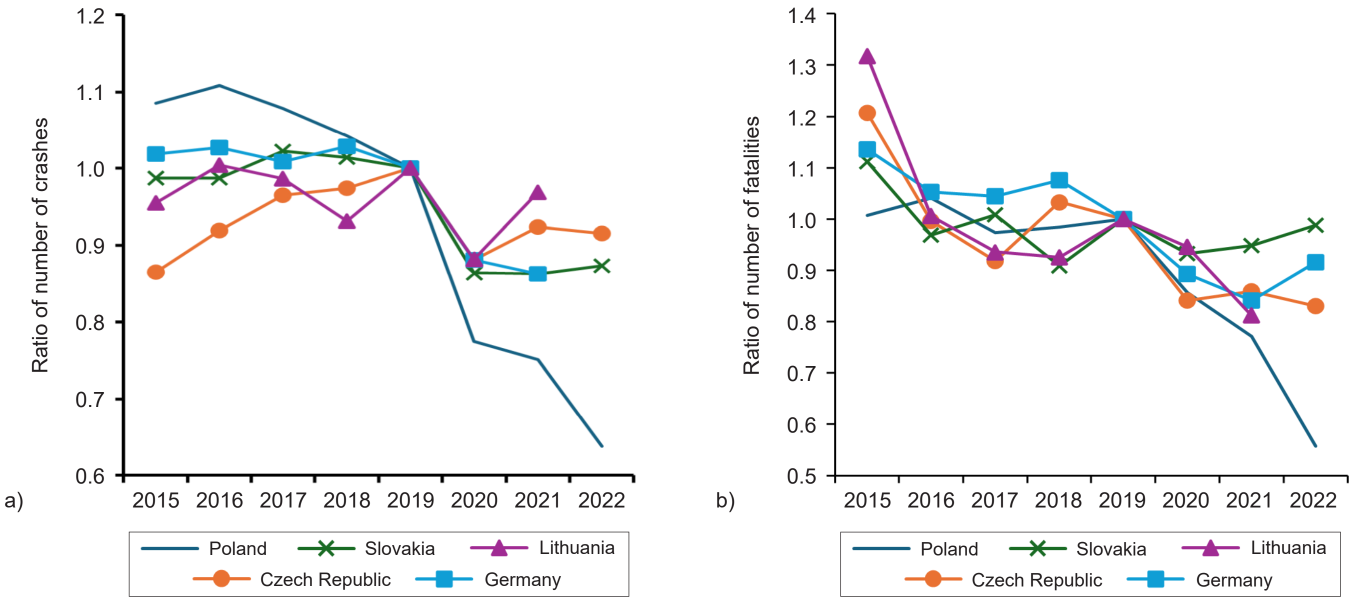

Fig. 6. Comparison of the ratio of crashes in Poland with neighbouring countries (a), comparison of the ratio of fatalities in Poland with neighbouring countries (b)

Table 3. Parameters of the model determining the number of crashes and number of fatalities in Poland, with one intervention related to legal changes

Country	Const.	T	$\text{COVID}_{\text{start}}$	$\text{COVID}_{\text{relief}}$	$\text{COVID}_{\text{end}}$	$\text{1st}_{\text{intervention}}$	ε_{t-12}	ε_{t-24}
	Parameter for crashes model							
Poland	1.1247	–0.0018	–0.3067	0.1983	0.1389	–0.1477	0.5501	0.3492
Czech Republic	0.8559	0.0025	–0.2059	0.1563	0.1277	–0.0891	0.6175	0.2682
Slovakia	0.9882	0.0001	–0.2192	0.1649	0.1622	–0.0660	0.4935	0.3320
Parameter for fatalities model								
Poland	1.0242	–0.0007	–0.1758	–	–	–0.2241	0.4882	0.3201
Czech Republic	1.1353	–0.0021	–0.1430	–	–	0.0232	0.4579	0.2393
Germany	1.0666	–	–0.1853	–	–	0.0591	0.3492	0.5664

The final decreases due to the 2022 intervention for the analysed countries are presented in Table 4. In Poland, the decreases in the number of fatalities and crashes are significantly greater than in the other countries. These differences appear to be a result of legal changes adopted in Poland in 2022.

Table 4. The relative changes in the number of crashes and fatalities in 2022 caused by intervention according to model for each country

Country	Change of ratio of crashes [%]	Change of ratio of fatalities [%]
Poland	–14.8	–22.4
Czech Republic	–8.9	2.3
Slovakia	–6.6	–
Germany	–	5.9

4. SUMMARY AND CONCLUSIONS

In this study, we estimated the relative change in the number of road crashes involving casualties and fatalities in Poland following legislative interventions introduced in 2022. The recorded decreases were substantial: a 14.8% reduction in crashes and a 22.4% reduction in fatalities. These changes are attributed to the legislative reforms, particularly the amendment passed in late 2021 and enforced from January 2022.

To support this interpretation, we compared Poland's trends with those in neighbouring countries, including Germany, the Czech Republic, and Slovakia. These countries did not implement interventions comparable in scope to those introduced in Poland in 2022 and did not experience declines of a similar magnitude. The Czech Republic introduced some changes to traffic regulations in early 2022, including stricter penalties for serious offenses such as driving under the influence and speeding. However, the scope and likely impact of these changes appear to have been more limited than the comprehensive reforms implemented in Poland. In Slovakia, no significant legal changes were recorded during this period. In Germany, an amendment to the Road Traffic Regulations (StVO Reform) came into effect on November 9, 2021, increasing fines for various traffic violations. Nevertheless, no substantial decrease in the number of fatalities was observed. Minor reductions in the number of crashes observed in the Czech Republic and Slovakia in early 2022 were used to adjust the results from Poland. After accounting for these external trends, we estimate the net effect of the legal changes in Poland on the number of crashes to be between 6% and 8%.

While two distinct interventions in 2022 were considered, the final model includes only the first, due to limited post-intervention data for the second. Nonetheless, the presented results likely capture the combined effect of both changes. Notably, the decline in crashes began as early as December 2021 – prior to the law's implementation – suggesting that drivers may have preemptively adapted to the anticipated legal changes, such as insurers gaining access to driver offense histories.

Since 2022, insurance companies in Poland have had access to data on traffic violations, which they use to determine the pricing of motor insurance policies, including third-party liability (OC) and comprehensive coverage (AC). This access allows insurers to assess risk more precisely by incorporating not only vehicle and insurance history but also the individual driving behaviour of policyholders. Drivers with a higher number of penalty points or more serious infractions are classified as higher-risk and are typically subject to higher premiums. Conversely, drivers with a clean record may benefit from more favourable insurance terms. This system significantly impacts not only the cost of insurance but also driver behaviour. Awareness that traffic violations can result in substantial and long-lasting financial consequences serves as a strong deterrent and encourages greater compliance with road safety regulations. In this way, the pricing mechanism itself acts as an incentive for safer driving practices.

We also considered the influence of the COVID-19 pandemic, which contributed to a sustained decline in crashes and fatalities across Poland, the Czech Republic, and Slovakia. In Poland, the epidemic is estimated to have reduced crashes by approximately 16%. However, since traffic volumes on Polish roads returned to near pre-pandemic levels by 2021-2022 [36], the sharp reductions observed in 2022 cannot be attributed to reduced transportation activity. In contrast, neighbouring countries experienced lower transport volumes without corresponding declines in road incidents, further supporting the legislative explanation for Poland.

Additionally, the durability of the intervention's effects was assessed. The number of crashes involving casualties was 21,322 in 2022, 20,939 in 2023, and 21,519 in 2024. The difference between the 2024 and 2022 figures is only

197 crashes, indicating a minimal increase over the two-year period. Regarding fatalities, the numbers from 2022 to 2024 were 1,896, 1,893, and 1,896, respectively. The stability of fatality figures after 2022 suggests a sustained impact of the legal changes.

Finally, the reductions in road incidents had a measurable economic benefit [37]. We estimate that 1,800 to 2,400 crashes were avoided, translating into approximately 2,124 fewer injuries. This corresponds to a financial saving of around 150 million PLN, including both injury-related and material costs [37]. Additionally, an estimated 600 fatalities were avoided, representing an economic benefit of approximately 1.56 billion PLN.

In the recapitulation the key conclusions from the analysis are as follows:

1. Estimated reduction in Poland in 2022:
   - 1,800-2,400 fewer crashes because of legal intervention,
   - Approx. 2,124 fewer injuries, assuming 1.18 injured persons per crash with casualties.
2. Economic impact of avoided crashes with casualties:
   - ~115.97 million PLN saved due to fewer injured victims,
   - ~34.20 million PLN saved in material losses,
   - Total savings: ~150.17 million PLN.
3. Estimated reduction of fatalities:
   - 600 fewer deaths because of legal intervention.
4. Economic impact of avoided fatalities:
   - ~1.56 billion PLN saved (assuming 2.6 million PLN per fatality).
5. Combined economic benefit:
   - Total savings: over 1.7 billion PLN due to reduced crashes with casualties and fatalities in 2022.

ACKNOWLEDGEMENT

This paper was co-financed under the research grant of the Warsaw University of Technology supporting the scientific activity in the discipline of Civil Engineering, Geodesy and Transport.

REFERENCES

[1] *Jamroz K.*, *Romanowska A.*, *Michalski L.*, *Żukowska J.*: Vision zero in Poland. In: The vision zero handbook. Springer International Publishing, Cham, 2023, 359-397, DOI: 10.1007/978-3-030-76505-7_14

[2] *Jamroz K.*, *Budzyński M.*, *Romanowska A.*, *Żukowska J.*, *Oskarbski J.*, *Kustra W.*: Experiences and challenges in fatality reduction on polish roads. Sustainability, **11**, 4, 2019, Article ID: 959, DOI: 10.3390/su11040959

[3] *Björnberg K.E.*, *Hansson S.O.*, *Belin M.Å.*, *Tingvall C.*: The vision zero handbook: Theory, technology and management for a zero casualty policy. Springer Nature, Berlin/Heidelberg, Germany, 2022, DOI: 10.1007/978-3-030-76505-7

[4] Global Launch: Decade of action for road safety 2011-2020. World Health Organization, 2011

[5] Regional approach to the decade of action for road safety 2021-2030. World Health Organization, 2021

[6] *Michalski L.*, *Jamroz K.*, *Żukowska J.*: UN Decade of action for road safety in the national road safety strategy until 2020 – Polish approach. Proceedings of 16th Road Safety on Four Continents Conference, Beijing, China, 2013, Kent Gustafson Linkoping: VTI, The Swedish National Road and Transport Research Institute, 2013, 1-10

[7] *Hell W.*, *Bodewig K.*, *Hammer U.*, *Kellner C.*, *Klinke C.*, *Mück M.*, *Schreiner M.*, *Walz F.*, *Zielke G.*: Vision zero in Germany. In: The vision zero handbook: Theory, technology and management for a zero casualty policy. Springer International Publishing, Cham, 2022, 337-357, DOI: 10.1007/978-3-030-76505-7_13

[8] *Žuraulis V.*, *Pumputis V.*: Vision zero in Lithuania. In: The vision zero handbook. Springer International, 2023, 398-438, DOI: 10.1007/978-3-030-23176-7_15-1

[9] *Benlagha N.*, *Charfeddine L.*: Risk factors of road accident severity and the development of a new system for prevention: New insights from China. Accident Analysis & Prevention, **136**, 2020, Article ID: 105411, DOI:10.1016/j.aap.2019.105411

[10] *Chui K.T.*, *Kochhar T.S.*, *Chhabra A.*, *Singh S.K.*, *Singh D.*, *Peraković D.*, *Almomani A.*, *Arya V.*: Traffic accident prevention in low visibility conditions using VANeTs Cloud environment. International Journal of Cloud Applications and Computing, **12**, 1, 2022, 1-21, DOI: 10.4018/IJCAC.313572

[11] *Kaygisiz Ö.*, *Düzgün Ş.*, *Yildiz A.*, *Senbil M.*: Spatio-temporal accident analysis for accident prevention in relation to behavioral factors in driving: The case of South Anatolian Motorway. Transportation Research Part F: Traffic Psychology and Behaviour, **33**, 2015, 128-140, DOI: 10.1016/j.trf.2015.07.002

[12] *McFarland R.A.*, *Moore R.C.*: Accidents and accident prevention. Annual Review of Medicine, **13**, 1, 1962, 371-388, DOI: 10.1146/annurev.me.13.020162.002103

[13] *Molan G.*, *Molan M.*: Theoretical model for accident prevention based on root cause analysis with graph theory. Safety and Health at Work, **12**, 1, 2021, 42-50, DOI: 10.1016/j.shaw.2020.09.004

[14] *Noh B.*, *Yeo H.*: A novel method of predictive collision risk area estimation for proactive pedestrian accident prevention system in urban surveillance infrastructure. Transportation research part C: Emerging Technologies, **137**, 2022, Article ID: 103570, DOI: 10.1016/j.trc.2022.103570

[15] *von Beesten S.*, *Bresges A.*, *Lubert D.*: Effectiveness of educational interventions in minimizing reactance in traffic accident prevention. Frontiers in Education, **8**, 2024, Article ID: 1276380, DOI: 10.3389/feduc.2023.1276380

[16] *Yang Y.*, *Zhang Y.*, *Zheng T.*, *Tian Q.*: Research on traffic accident prediction of expressway tunnel based on B-NB model. Traffic Injury Prevention, **25**, 3, 2024, 527-536, DOI: 10.1080/15389588.2024.2310584

[17] *Zou X.*, *Vu H.L.*, *Huang H.*: Fifty years of accident analysis & prevention: A bibliometric and scientometric overview. Accident Analysis & Prevention, **144**, 2020, Article ID: 105568, DOI: 10.1016/j.aap.2020.105568

[18] *Miller T.R.*, *Levy D.T.*, *Swedler D.I.*: Lives saved by laws and regulations that resulted from the Bloomberg road safety program. Accident Analysis & Prevention, **113**, 2018, 131-136, DOI: 10.1016/j.aap.2018.01.014

[19] *Dong C.*, *Nambisan S.S.*, *Clarke D.B.*, *Sun J.*: Exploring the effects of state highway safety laws and sociocultural characteristics on fatal crashes. Traffic Injury Prevention, **18**, 3, 2017, 299-305, DOI: 10.1080/15389588.2016.1199864

[20] *Karimpour A.*, *Kluger R.*, *Liu C.*, *Wu Y.J.*: Effects of speed feedback signs and law enforcement on driver speed. Transportation Research Part F: Traffic Psychology and Behaviour, **77**, 2021, 55-72, DOI: 10.1016/j.trf.2020.11.011

[21] *Voas R.B.*, *Tippetts A.S.*, *Fell J.C.*: Assessing the effectiveness of minimum legal drinking age and zero tolerance laws in the United States. Accident Analysis & Prevention, **35**, 4, 2003, 579-587, DOI: 10.1016/S0001-4575(02)00038-6

[22] *Wagenaar A.C.*, *Maldonado-Molina M.M.*, *Erickson D.J.*, *Ma L.*, *Tobler A.L.*, *Komro K.A.*: General deterrence effects of US statutory DUI fine and jail penalties: Long-term follow-up in 32 states. Accident Analysis & Prevention **39**, 5, 2007, 982-994, DOI: 10.1016/j.aap.2007.01.003

[23] *Francesconi M.*, *James J.*: None for the Road? Stricter drink driving laws and road accidents. Journal of Health Economics, **79**, 2021, Article ID: 102487, DOI: 10.1016/j.jhealeco.2021.102487

[24] *Jomar R.T.*, *Ramos D. de O.*, *Fonseca V.A. de O.*, *Junger W.L.*: Effect of the zero-tolerance drinking and driving law on mortality due to road traffic accidents according to the type of victim, sex, and age in Rio de Janeiro, Brazil: An interrupted time series study. Traffic Injury Prevention, **20**, 3, 2019, 227-232, DOI: 10.1080/15389588.2019.1576035

[25] *Goodwin A.H.*, *O'Brien N.P.*, *Foss R.D.*: Effect of North Carolina's restriction on teenage driver cell phone use two years after implementation. Accident Analysis & Prevention, **48**, 2012, 363-367, DOI: 10.1016/j.aap.2012.02.006

[26] *Doucette M.L.*, *Tucker A.*, *Auguste M.E.*, *Watkins A.*, *Green C.*, *Pereira F.E.*, *Borrup K.T.*, *Shapiro D.*, *Lapidus G.*: Initial impact of COVID-19's stay-at-home order on motor vehicle traffic and crash patterns in Connecticut: An interrupted time series analysis. Injury Prevention, **27**, 1, 2021, 3-9, DOI: 10.1136/injuryprev-2020-043945

[27] *Qureshi A.I.*, *Huang W.*, *Khan S.*, *Lobanova I.*, *Siddiq F.*, *Gomez C.R.*, *Suri M.F.K.*: Mandated societal lockdown and road traffic accidents. Accident Analysis & Prevention, **146**, 2020, Article ID: 105747, DOI: 10.1016/j.aap.2020.105747

[28] *Schaffer A.L.*, *Dobbins T.A.*, *Pearson S.A.*: Interrupted time series analysis using autoregressive integrated moving average (ARIMA) models: a guide for evaluating large-scale health interventions. BMC Medical Research Methodology, **21**, 58, 2021, DOI: 10.1186/s12874-021-01235-8

[29] *Aho K.*, *Derryberry D.*, *Peterson T.*: Model selection for ecologists: The worldviews of AIC and BIC. Ecology, **95**, 3, 2014, 631-636, DOI: 10.1890/13-1452.1

[30] *Box G.E.P.*, *Pierce D.A.*: Distribution of residual autocorrelations in autoregressive-integrated moving average time series models. Journal of the American Statistical Association, **65**, 332, 1970, 1509-1526, DOI: 10.1080/01621459.1970.10481180

[31] Raporty o stanie BRD. Krajowa Rada Bezpieczeństwa Ruchu Drogowego, https://www.krbrd.gov.pl/baza-wiedzy/raporty-o-stanie-brd/, available: 15.03.2024

[32] Statistika nehodovosti. Policie České Republiky, https://www.policie.cz/clanek/statistika-nehodovosti-900835.aspx?q=Y2hudW09NQ%3d%3d, available: 15.03.2024

[33] Eismo įvykių Lietuvoje statistika. Lietuvos Kelių Policijos Tarnyba, https://policija.lrv.lt/lt/veiklos-sritys/eismo-saugumas-1/eismo-statistika/eismo-ivykiu-lietuvoje-statistika/, available: 15.03.2024

[34] Rázcestník štatistík dopravnej nehodovosti – kompletná štatistika. Ministerstvo Vnútra Slovenskej Republiky, https://www.minv.sk/?kompletna-statistika, available: 15.03.2024

[35] Gesellschaft und Umwelt – Verkehrsunfälle. Statistisches Bundesamt, https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Verkehrsunfaelle/_inhalt.html#sprg230562, available: 15.03.2024

[36] SCPR – dane z roku 2022. Generalna Dyrekcja Dróg Krajowych i Autostrad, https://www.gov.pl/web/gddkia/scpr-dane-z-roku-2022, available: 15.03.2024

[37] Badania kosztów zdarzeń drogowych. Krajowa Rada Bezpieczeństwa Ruchu Drogowego, https://www.krbrd.gov.pl/baza-wiedzy/badania-kosztow-zdarzen-drogowych/, available: 15.03.2024

Analiza wpływu zmian prawnych na liczbę wypadków drogowych i ofiar śmiertelnych w Polsce w 2022 roku

Streszczenie: Celem artykułu jest ocena wpływu zaostrzenia przepisów ruchu drogowego w Polsce w 2022 roku na liczbę zarejestrowanych wypadków drogowych oraz ofiar śmiertelnych. W analizowanym okresie wprowadzono szereg zmian legislacyjnych, które istotnie zwiększyły sankcje – głównie finansowe – za wykroczenia i przestępstwa drogowe. Jednocześnie odnotowano wyraźny spadek liczby wypadków w porównaniu z rokiem 2021. W opisanych w artykule badaniach przeanalizowano statystyczną istotność wpływu wprowadzonych regulacji na poziom bezpieczeństwa ruchu drogowego oraz oszacowano skalę redukcji liczby wypadków i ofiar śmiertelnych będącą efektem działań legislacyjnych. Podstawowym narzędziem analitycznym była analiza przerywanych szeregów czasowych. Ponadto wyniki dla Polski zestawiono z danymi pochodzącymi z wybranych państw sąsiednich. Uzyskane rezultaty wskazują na istotny statystycznie oraz znaczący wpływ zmian prawnych. W oparciu o zaproponowany model oszacowano, że liczba wypadków uległa zmniejszeniu o około 6–8%, a liczba ofiar śmiertelnych – o około 22%.

Słowa kluczowe: egzekwowanie prawa, przerywane szeregi czasowe, wpływ pandemii COVID-19, zaostrzanie prawa, zapobieganie wypadkom.