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DETERMINANTS AND EFFECTS OF POLAND'S ROAD ACCIDENTS IN THE CONTEXT OF THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT – POVIAT LEVEL ANALYSIS FOR THE YEARS 2010-2019

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ABSTRACT: The objective of the research was to assess how selected factors influence road safety in Poland's poviats. To that end, an analysis was conducted of road accident determinants and effects in the poviats in the years 2010-2019. The time horizon fits in with Goal 3.6. of Agenda 2030, which is to halve the number of global deaths and injuries from road traffic accidents by 2020. The article presents the analysis results for the following determinants: the rate of car ownership by poviat, poviat spending on transport and length of the road network, and quality of road infrastructure. The research problem was to establish which of the poviats are closest to achieving Goal 3.6. of Agenda 2030 and how likely it is, and, as a consequence, which of the poviats should step up their road safety policies to align them to the targets set out in the Agenda. To identify groups of poviats sharing similar characteristics, they were grouped using the k-means method. Five groups of poviats were identified and anal-

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ysed for how their road safety indicators changed between 2010 and 2019. The results of the analysis show that the highest fatality reduction (-40%) was achieved by urban poviats with the highest per capita spending on transport. The same poviats, however, have the highest increases in serious injuries (+30%). The analyses show that Polish poviats are still far from achieving Goal 3.6 of Agenda 2030. The research results presented in the article are original for the poviat level.

KEYWORDS: Agenda 2030, sustainable development, road accidents, fatalities and injured, poviats

Introduction

Agenda 2030, also known as the resolution "Transforming our world: The 2030 Agenda for Sustainable Development", is designed to respond to global socio-economic and climate challenges (UN, 2015). Set out in Agenda 2030, its 17 sustainable development goals are assigned 169 targets in five areas: people, planet, prosperity, peace, and partnership. This article focuses on Goal 3: to ensure healthy lives and promote well-being for all ages. Its point 3.6. has the objective to halve the number of global deaths and injuries from road traffic accidents by 2020 (UNDP Global, 2022) compared to 2010.

In recent years each year, on average, road accidents have claimed about 1.3 million lives worldwide, of which 93% are people killed in low and medium income countries representing about 60% of the global vehicle fleet. This translates into nearly 3,700 victims daily. Car accidents also cause from 20 to 50 million severe injuries, the majority of which require long-term and costly treatments (WHO, 2018). In the EU, on average, 63 people are killed in road accidents, of which 8 people are killed on Poland's roads (Trzeciak, 2020).

Using road traffic entails enormous risks. The main reasons for the high number of fatalities and injuries in Poland include: speed not appropriate for the conditions of traffic, dangerous manoeuvres of drivers and incorrect pedestrian behaviour. The determinants of road accidents on Poland's roads also include the poor technical condition of vehicles and roads and the failure to ensure road infrastructure safety standards (Goniewicz et al., 2019).

Road accidents generate huge losses for the economy. The costs of road deaths to most national economies represent about 3% of their GDP (WHO, 2021). Road accidents are a consequence of a number of factors related to the user–vehicle–road system (Job et al., 2022)but it has been adopted pervasively to a substantially constrained extent. This paper argues that effec-

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tive adoption is hampered by two weaknesses in strategies for the implementation of Safe System: (1. In an effort to reduce road accidents and halve global injuries and deaths as set out in Goal 3 of Agenda 2030, measures have been taken such as intelligent speed assistance, driver attention warning systems (user-oriented measures) or emergency braking system (vehicle-oriented measures) and intelligent transport systems (ITS), traffic calming measures (infrastructure-oriented measures). Across the EU in 2020, the best performing country for road safety was Sweden (18 road deaths per 1 million population). The highest fatality rate was recorded in Romania at 85. In Poland, there were 65 fatalities per 1 million population, positioning our country among the EU's most dangerous road networks (Eurostat, 2022). To compare, the EU average was 42, with the world's average at 180 (European Parliament, 2021).

With a drop in fatalities at a mere 23% in the decade from 2010, the European Union has failed to reach Agenda 2030's Goal 3.6. Even considering the pandemic restrictions in 2020, the target has not been achieved either. The EU, however, now has a new target. As well as reaching zero fatalities on its roads until 2050, it also aims to halve severe injuries from road accidents by 2030 (Decae, 2021).

The authors have conducted analyses of Poland's road accident determinants and consequences at the level of poviats using the available data: car ownership rates in the poviats (passenger cars), poviat level spending on transport, the length of the road network including the quality of the road infrastructure and municipal and poviat roads with hard, improved and unpaved surfaces. As regards Goal 3.6. of Agenda 2030, the analysis looked at road deaths and injuries in the years 2010-2019. The research objective was to establish which of Poland's poviats were the closest to achieving Goal 3.6. of Agenda 2030 and the outlooks for the future considering some selected determinants of road accidents. The study covers all 314 of Poland's poviats and 66 urban poviats (formally referred to as poviats with city rights). The data come from Statistics Poland's Local Data Bank (GUS, 2022) and the SEWIK database (sewik.pl, 2020). The work was preceded with an overview of the literature. To set the context for the research problem, a short characteristic of Poland's 2019 road accident consequences is given by region.

Road accidents and their determinants

According to the Road Traffic Act (Parliament of the Republic of Poland, 2021), a road accident is an "incident which occurs in land traffic caused by an inadvertent violation of traffic regulations leading to the death of one of the people involved in the accident or to an injury involving a disability of a

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bodily organ or health impairment lasting longer than 7 days". Road traffic crimes which lead to accidents are covered in Article 177 of the Criminal Code (Parliament of the Republic of Poland, 1997). While road accidents take a split second to occur, their consequences may be life-long and include death and injury, including serious injury. Road accidents leave the victims, casualties and their families in distress and carry health, social, psychological and economic costs. The latter are a huge burden to national budgets.

Developed by Haddon (Haddon & Jr, 1980)sprinkler systems, electrical insulation, evacuation in the 1980s, the matrix identifies risk factors before, before, during and after an accident in relation to the person, vehicle and environment (road infrastructure and roadside, road traffic parameters) and forms the basis for road safety programmes. Current forecasts by the WHO suggest that by 2030 road accidents will be the fifth most common cause of death (WHO, 2018). Their determinants are divided into environmental, socio-demographic, technological, medical, political, organisational and the human factor (Yasmeen, 2019). The determinants of the road traffic environment (e.g. growing number of vehicles, increase in traffic) and road environment (e.g. poor technical condition of roads, inappropriate or no lighting) are positively correlated to the number of accidents, fatalities, and injuries (La Torre et al., 2007). Socio-demographic factors related to economic growth and the most synthetic measure of economic activity, i.e. GDP per capita (Orłowska & Pangsy-Kania, 2003), play the main role among road accident determinants (Van Beeck et al., 1991); (Hasselberg & Laflamme, 2008); (Jamroz & Smolarek, 2013) (Jamroz, 2012), (Jamroz et al., 2018). It is important to add that from the perspective of demographic determinants, the risk of becoming a road accident victim is the highest for men aged 15 to 29, who are responsible for nearly half of all road accidents worldwide (WHO, 2018). Technological factors have to do with vehicle manufacture and maintenance. This category includes also vehicle age and technical condition. Malfunctioning lights, tyres, brakes or steering, however, are not some of the main causes of road accidents. In Poland, the main causes of road accidents are user-related. As we know from statistics, road accidents usually occur in good weather, in the daytime and on straight stretches of road (Jędra, 2017). Driver's health, both physical and mental, belongs with the medical road accident determinants. Deteriorating cognitive capability as people age is a major factor. Driving experience and driver age affect reaction times when faced with the risk of accident (Stańczyk et al., 2011). Statistics, however, shows that it is young drivers who most frequently cause accidents and become accident victims (Neelakantan et al., 2017). According to European Union data, 38% of road accidents in the EU happen in the 25-49 age group, with 28% of accidents involving people aged 65 and over (European Parliament, 2021). Poland is no different, with every third accident involving someone

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from the 25-49 age group, made up mostly of men (Owczarek & Kowalska, 2014). Road accidents which involve working-age people, in particular, carry substantial economic consequences because they have an effect on the country's economic development (Decae, 2021; Nantulya & Reich, 2002; Mohan, 2002). Road accidents can also be caused by system-related factors when these determinants become road traffic hazards such as overdue road repairs leading to a worsening technical condition of roads. Other contributing factors may include poor enforcement, lack or insufficient monitoring or urban development without ensuring proper roads. These represent organisational factors (Yasmeen, 2019). Finally, the most important cause of road accidents is the human factor which applies to drivers, pedestrians and passengers. In Poland, in 2019, the human factor played a key role and accounted for 95.2% of transport accidents (Rosiak, 2020). The determinants include reckless driving and drunk road users, which increase the risk of a road accident. This group of factors also includes distractions when driving, in particular when using a mobile phone (Gis, 2018). Studies on driver distraction and mental load show that drivers talking on a mobile phone take 0.5–1.5 seconds longer to react (Monah et al., 2006). It should be stressed, however, that the condition of road infrastructure may have a critical effect on user mistakes and even generate them (Cafiso et al., 2017).

The literature usually distinguishes four groups of road accident theories: stochastic, causal, systemic and behavioural (Weszczak, 2018). In the stochastic approach, accidents are often purely random. In the causal theory, each road accident has a concrete cause which, if eliminated, will help to reduce accidents. The systemic approach stresses that road accidents are the effect of inappropriate interactions between the elements of the entire safety system. Behavioural theories, on the other hand, put the stress on driver risk assessment and risk acceptance defining it as a very important road accident factor (Jamroz, 2008).

Estimating the costs of road accidents may be problematic due to data credibility issues (Zalewski et al., 2009). According to data from the Centre for EU Transport Projects (CUPT), in 2019, the cost of a road death in Poland was PLN 2,539,224.806. The cost of a serious injury was higher and amounted to PLN 3,512,799.980. A slight injury cost PLN 51,126.828, and the average cost of an injury was PLN 1,066,954.949 (CUPT, 2022). The risk of becoming a fatality in Poland is high on regional roads, which represent 11% of all paved roads. These roads recorded 22.5% of fatalities and 15.2% of injuries, and 14.6% of all road accidents in Poland. No data are available on serious injuries by the poviat (Jamroz et al., 2015). There is no research on road accident determinants in poviats. Clearly, a gap in research which the results of the authors' work will partly fill.

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To summarise, the most frequent factors causing road accidents include: GDP *per capita*, car ownership rate and traffic load on the road network, length of the road network and its quality, spending on building and improving road infrastructure and improving road safety and the human factor. For reasons of data availability, this work does not focus on GDP due to problems with determining GDP figures at the poviat level in the Poland (Ciołek, 2017) or on the human factor despite the critical role of safety culture plays in road safety (Unarski, 2012). This would have to be covered separately. The Authors understand the width of the problems, and this article is only a starting point for more research on the subject.

Consequences of Poland's road accidents – fatalities and injuries

In 2019 there were 30,288 road accidents on Poland's roads, with 35,477 casualties and 2,909 people killed. Compared to 2010, accidents fell by 22%. The drop was observed in all regions except Wielkopolskie, where accidents went up by 32%. The region with the highest reduction in accidents over the analysed period was Śląskie (by 41%). Accidents were the highest in Mazowieckie at 13% of overall accidents. The share in Wielkopolskie was the same. Accidents were the lowest in the regions of Opolskie and Podlaskie, with 2% of overall accidents in Poland reported in each. Fatalities in Poland fell during this time by 25% (in 2010, there were 3,907 people killed and 2,909 people killed in 2019). The reduction was the highest in Śląskie (by 44%) and the lowest in Kujawsko-Pomorskie (by 7.5%). Mazowieckie continues to have the biggest share in overall fatalities in Poland at 16%, with the lowest figure in Opolskie at around 2.5% (Figure 1). Injuries from road accidents in 2019 compared to 2010 fell by 27.5%. In 2010 on Poland's roads, 48,952 people were injured, and 35,477 were injured in 2019. In all regions except Wielkopolskie, injuries fell in 2019 compared to 2010, with the biggest reductions in Lubelskie and Kujawsko-Pomorskie (the drop in both regions was 46%). The region of Wielkopolskie recorded an increase by 26%. In 2019 the highest share of injuries in overall injuries was observed in Wielkopolskie (13%) and Mazowieckie (12%), with the lowest share recorded in Podlaskie (1.7%).

In 2019 Poland's daily average was 83 accidents, 8 road deaths and 97 injuries, with almost every third accident occurring in a built-up area and nearly 60% of all fatalities reported in non-built-up areas. Poland's fatalities usually occur on single carriageways with two directions of traffic, at night-time and on unlit roads, although more accidents are observed in the daytime. In every fourth night-time accident, one person is killed. In the daytime,

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fatalities occur in every thirteenth accident. In 75% of the cases, accidents were caused by car drivers, the most common cause being failure to give way (27% of all accidents), speed not appropriate for the conditions (24%) and failure to yield to a pedestrian on a pedestrian crossing (11%). Accidents are caused by drivers in 90% of the cases. Drivers are also killed in road accidents, most often (Kalisz, 2020).

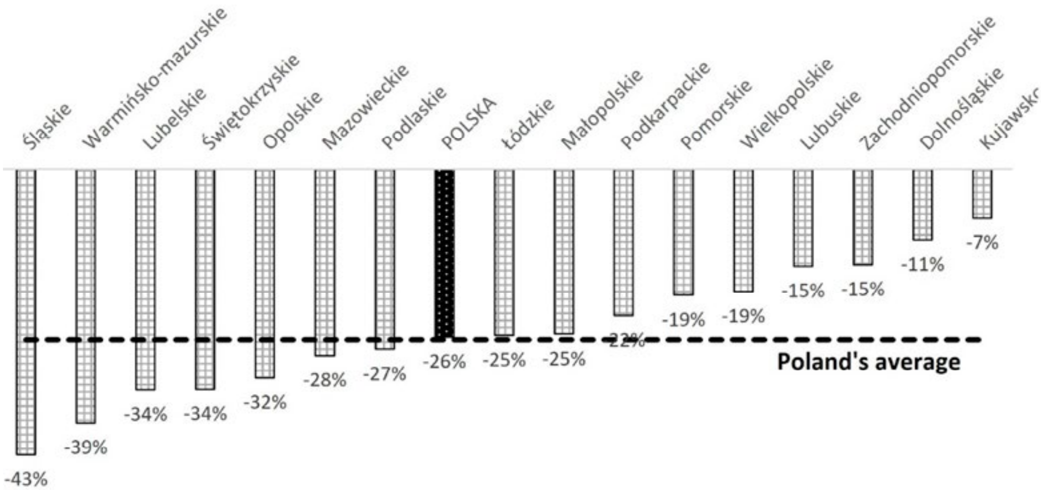

Figure 1. Change in fatalities in the regions between 2010 and 2019

Source: author's work.

To take account of the differences between the regions, such as population, area or traffic volume, fatality and injury rates are calculated for over 100 road accidents. The fatality rate per 100 residents is the highest in the regions of Kujawsko-Pomorskie (22.4), Podlaskie (18.1) and Lubelskie (14.9). Mazowieckie takes fifth place. The regions with the lowest rates include Pomorskie (7), Śląskie (6.7) and Małopolskie (5.6). The injury rate is the highest in the regions of Warmińsko-Mazurskie (122), Łódzkie (120.8) and Pomorskie (120.8), with the lowest rates observed in Lubelskie (108.3), Podlaskie (106) and Kujawsko-Pomorskie (103.6) (Symon, 2020). Figure 2 shows a map of the regions by the total number of fatalities and serious injuries per 100,000 population (NF_NSI/100 thous. H).

In terms of road class, in 2019, there were 70 road deaths and 594 injuries on motorways. On national roads, there were 991 and 8,650 cases, respectively, and 713 and 7,037 on regional roads (Symon, 2020). This means that in 2019 1,135 people were killed and 19,196 were injured in road accidents in Poland which occurred on roads other than those mentioned above.

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Despite the fall in road deaths and injuries in Poland in the years 2010-2019, the goal of Agenda 2030 has not been reached. The EU is similar – according to data from the European Commission in 2019, on the roads of the EU, 22,800 people were killed, which was a mere 23% reduction compared to the 2010 (Eurostat, 2022). *Nota bene*, even though 2020 was a special year on Poland's roads because of the Covid-19 pandemic, the number of road deaths was still high at 2,491 fatalities. This was, however, less by 14.4% compared to 2019.

Figure 2 Map of the regions by fatalities and serious injuries per 100,000 population
Source: author's work.

Research methods

The data comes from Statistics Poland's Local Data Bank (GUS, 2022) and the road accident database (sewik.pl, 2020). Because the problems covered in this article are related to Goal 3.6. of Agenda 2030, the data cover the years 2010-2019 and the main indicators of socio-economic development and road safety in the poviats.

To assess safety at the poviat level, a risk-based approach was applied (Jamroz et al., 2019). Societal risk in strategic terms refers to all road traffic behaviour of entire groups in a selected area (poviat or city with poviat rights). The consequences (casualties and costs) are caused by road acci-

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dents within an agreed time interval (usually a year) which may occur as a result of hazardous events caused by the operation of the road transport system. The normalised risk (FAT_INJH_POP) was calculated as the total number of fatalities and serious injuries per 10,000 population in a given poviat. A regular fatality rate could not be used because many of the poviats recorded several road deaths in a year, and the number itself may have been random (it is difficult to assess a trend when rates change, e.g. from 9 to 5 over a period of ten years).

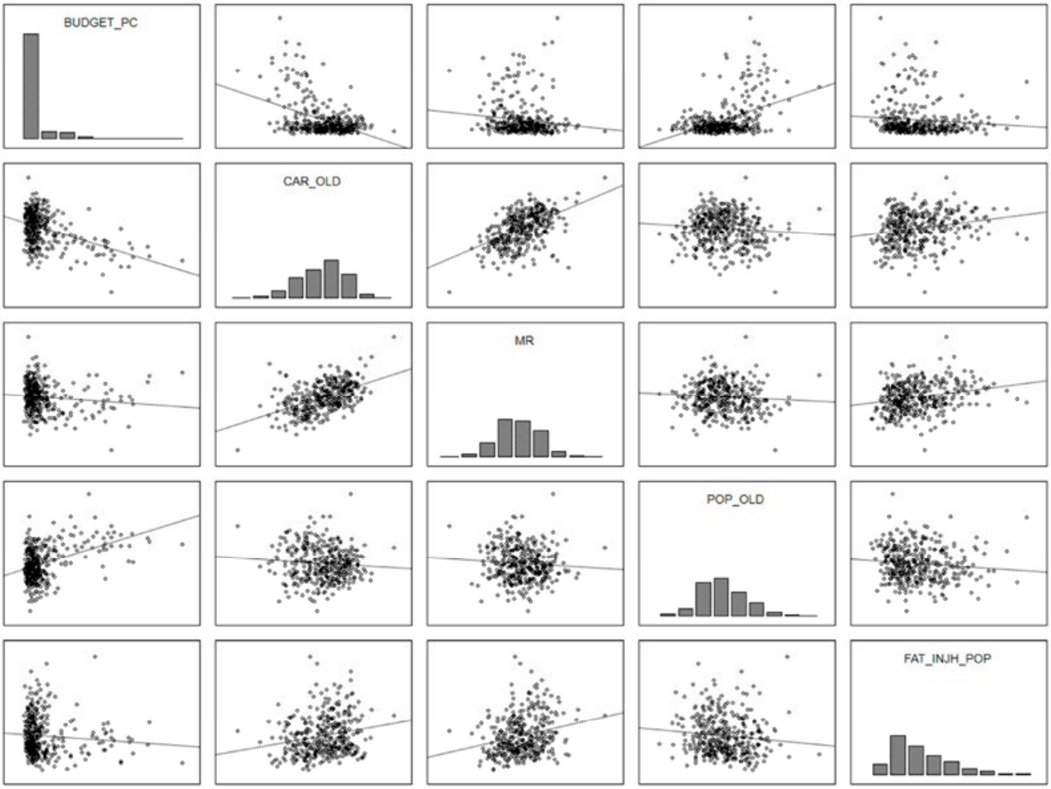

Figure 3. Multivariate scatterplot of selected variables
Source: author's work.

Before selecting variables to characterise the poviats' socio-economic situation, a correlation analysis was conducted due to the high sensitivity of clustering algorithms to multi-collinearity of variables (Nowakowska, 2012). It was assumed that bivariate correlation is strong if it exceeds 0.6. The following variables were used in further analyses: a number of passenger cars per 1,000 inhabitants (MR), budget spending in the transport sector per cap-

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ita (BUDGET_ PC), the share of passenger cars that are over 20 years of age (CAR_OLD), the share of post-working age population (POP_OLD). All of the selected variables are quantitative. The data were preliminary processed: the observed outliers were removed, and the variables were checked against the missing data and standardised.

Figure 3 shows a multivariate scatterplot between selected pairs of variables. The illustration was made using TIBCO Statistica 13.0 (TIBCO Software Inc, 2022).

The k-means method was used for the analyses. It is a clustering method which uses unsupervised machine learning algorithms to assign observations to clusters based on similarities between them and differences between other observations (Hartigan and Wong, 1979). In the initial phase, the algorithm generates centroids at random for a pre-defined number of clusters and assigns observations to the clusters based on the geometric distance from those centroids. Subsequent iterations calculate the centroids of each cluster again and assign observations to them. The algorithm ends when subsequent iterations do not lead to a new position of the centroids, and the resulting system is considered optimal for the given number of clusters. To determine the geometric distance between observations and cluster centroids, the following formula can be used:

$$d(x, y) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}, \tag{1}$$

where d is an Euclidean distance between two vectors x and y of length n.

The elbow method was used to determine the optimal number of clusters in a data set. In the method, the mean squared error (MSE) of the observation distances from cluster centroids is calculated for a given number of clusters from a specific range (e.g. from 1 to 15 clusters). Next, the sum of squares (SS) within clusters is plotted as a function of the number of clusters. The optimal number of clusters is determined as the number which lies in the elbow of the curve. The clustering analysis was performed in RStudio (RStudio, 2022).

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Results of the research

Road safety in the poviats

There are 314 poviats and 66 cities with poviats rights (urban poviats) in Poland. Urban poviats are inhabited by 33% of the population (12.58 million), with the rest of the population living in rural poviats (67%; 25.74 million). Table 1 shows general statistics of the socio-economic characteristics of the poviats in 2019. Figure 4 shows maps of the poviats by selected measures (number of accidents NA, number of fatalities and serious injuries NF_NSI, number of accidents per 100,000 population NA/100 thous. H, number of fatalities and serious injuries per 100,000 population NF_NSI/100 thous. H). In 2019 poviats and urban poviats with the highest number of accidents included: Łódź (1376), Poznań (940), Warszawa (892), Kraków (886), Wałbrzych (508), Szczecin (496), Gdańsk (462), Poznański poviat (462), Rzeszów (328) and Częstochowa (318). It is noteworthy that except for the Poznański poviat, all of the cities are urban poviats. The highest accident rate per 100,000 population was recorded in: Wrocław (208.3), Łódź (115.7), and the poviats of Wyszkowski (97), Olsztyński (89.3), Kaliski (77.1), Kozienicki (76.7), Kutnowski (76.6), Ostródzki (76.6), Kamieński (74.5), Nowomiejski (73.2). Except for the worst performing cities of Wrocław and Łódź in this category, the other areas are rural poverty. The highest total number of fatalities and serious injuries was recorded in: Łódź (810), Kraków (305), Poznań (267), Wrocław (235), poviat of Poznański (193), Szczecin (172), Gdańsk (139), Warszawa (139), poviats of Wrocławski (124) and Wejherowski (120). The very high rate in Łódź is noteworthy. This may be indicative either of very high risk in this city or that it classifies its serious injuries differently. The highest rate of fatalities and serious injuries per 100,000 population was recorded in: Wrocław (211), Łódź (119,1), and poviats of Wyszkowski (111.8), Opatowski (103.7), Olsztyński (97.9), Włocławski (94.1), Nowomiejski (90.8), Międzychodzki (89.8), Ostródzki (89.1), Kutnowski (88.0).

Compared to rural poviats, urban poviats spend more both in overall numbers and per capita (Table 1). Unlike rural poviats, urban poviats have a higher share of relatively new cars (up to 5 years of age) and fewer old cars (over 20 years of age). In addition, the share of post-working age people is higher, and that of working age people is lower in the overall population.

Poviats have a significantly higher accident severity rate (per each 100 accidents in 2019, there were 13 deaths and 3.3 in urban poviats). The change in fatalities (-23%) in poviats was closer to the national statistics for all of Poland (-26%). Fatalities in urban poviats fell by 40% (Figure 5).

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Table 1. General poviat statistics in 2019

Variables	Poviat (n=314)				Urban poviats* (n=66)			
	min	max	avg	st. dev.	min	max	avg	st. dev.
Population (thous.)	19.9	399.3	82.2	44.7	35.7	1,790.7	190.6	253.7
Post-working age population (%)	14	29	21	2	19	32	24	2
Area (km^2)	158	2,975	973	445	13	517	113	92
Population density (people per 1 km^2)	19	674	101	79	202	3,723	1,639	685
Motorisation rate (cars per 1 thous. people)	430	972	646	74	340	813	587	86
Share of new cars (<5 years old)	2	31	5	3	3	32	15	6
Share of old cars (>20 years old)	23	64	42	7	12	50	33	6
Budget per capita (PLN)	664.4	2,017.4	1,198.9	247.4	4,982.0	11,605.7	7087.0	1096.5
Budget for transport (m. PLN)	1.16	114.29	15.63	12.42	8.46	4,674.08	267.87	605.81

* including the capital city
Source: author's work based on GUS. (2022, March 30).

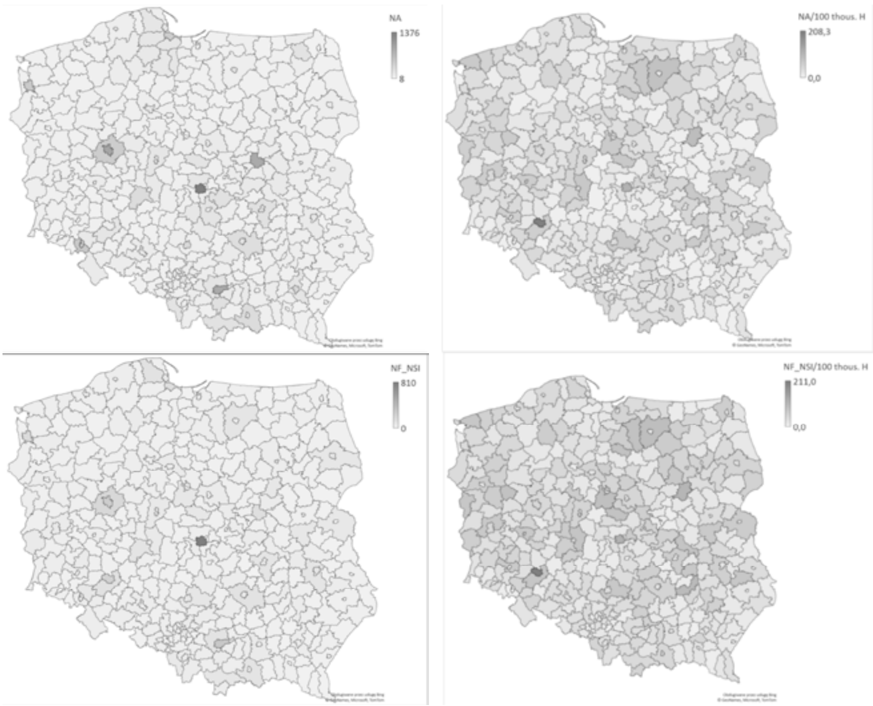

Figure 4. Map of poviats by selected measures of safety
Source: author's work.

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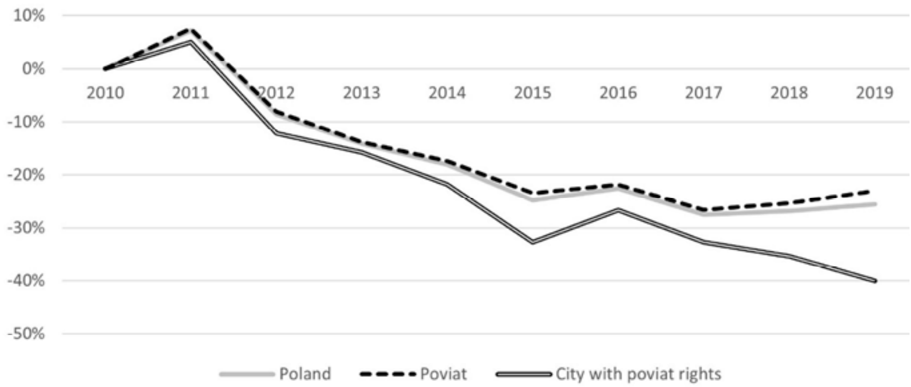

Figure 5. Change in fatalities in the years 2010-2019 – comparison of rural and urban poviats

Source: author's work.

Clustering of poviats according to socio-economic characteristics and the road safety

Poland's poviats were divided into groups (clusters) based on their socio-economic characteristics and road safety rates. Each poviat was assigned to one of 5 clusters. The number of clusters was predefined using the elbow method. Figure 6 shows poviat classification in a two-dimensional space. Table 2 shows the results of clustering.

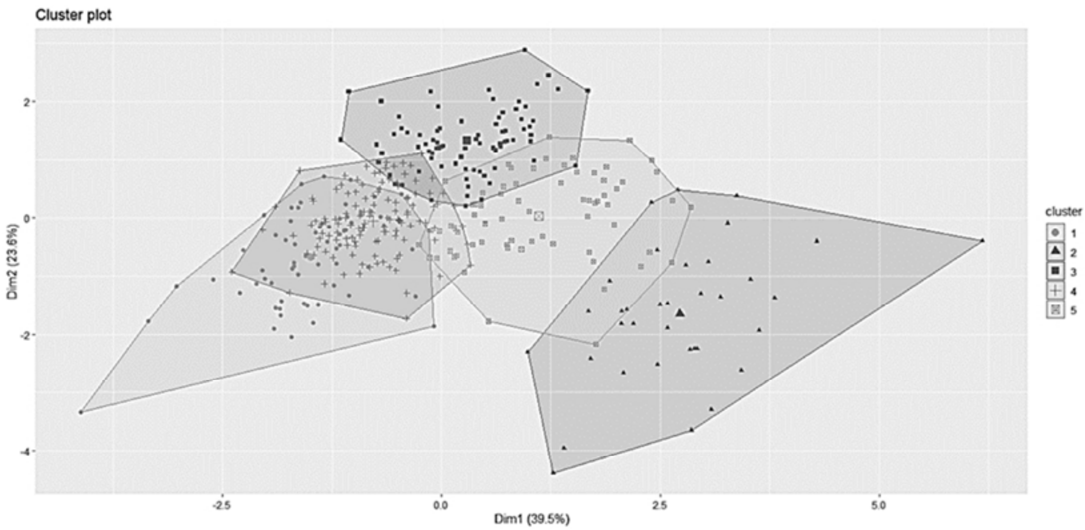

Figure 6. Cluster plot of the data

Source: author's work.

Table 2. The results of clustering using the k-means algorithm

	Clusters				
	1	2	3	4	5
Number of observations	65	35	80	127	70
Within cluster SS	156.34	158.77	156.24	189.06	148.58
Between cluster SS / total SS	57%				
Silhouette score (0÷1)	0.20	0.25	0.22	0.28	0.17
Average BUDGET_PC	208.12	1323.90	170.63	205.37	315.06
Average CAR_OLD	0.45	0.31	0.35	0.46	0.38
Average MR	700.16	610.65	587.82	675.23	570.61
Average POP_OLD	0.21	0.25	0.19	0.21	0.24
Average FAT_INJH_POP	67.22	34.75	29.43	29.46	24.62
Number of poviats	65	0	79	125	44
Number of urban poviats	0	35	1	2	26

Source: author's work.

Cluster 1: This group of poviats features the highest number of fatalities and serious injuries in relation to the population. In 2019 per 10,000 population, there were on average 67 fatalities and serious injuries in these poviats. Poviat characteristics include low spending on transport, a high average share of old vehicles and a relatively high car ownership rate (Figure 7). In 2019, the poviats' fatality rate was the highest (1.3 killed per 10,000 population and 1.9 killed per 10,000 cars) with accident severity also high compared to the other poviats (13 fatalities per 100 accidents) (Table 3).

Cluster 2: This cluster includes solely urban poviats. Their characteristics includes high spending on transport, several times more than in the other clusters, the lowest average car ownership rate, a low share of old vehicles and a higher average share of older people in the population in relation to the other clusters (Figure 7). In 2019 these poviats had the highest number of accidents, but accident severity was several times lower than severity in the other poviats (3 fatalities per 100 accidents). Similarly, these poviats reached the lowest fatality rates compared to other poviats (Table 3).

Cluster 3: This group of poviats features a high car ownership rate and a high share of old vehicles, low spending on transport and a relatively low number of fatalities and serious injuries per 10,000 population (Figure 7). This group is made up mostly of rural poviats. Road safety in these poviats places them in the middle of the other clusters, i.e. in 2019, per 100 acci-

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dents, there were 11 fatalities with fatality rates at 0.8 and 1.3 deaths per 10,000 population and 10,000 cars, respectively (Table 3).

Cluster 4: This cluster has the highest number of poviats, with regular poviats prevailing. The poviats feature a low share of old vehicles and a low car ownership rate, but the share of older people in the population is higher than in the other poviats but lower than in the cities (cluster 2) (Figure 7). While the average fatality and serious injury rate is relatively low in these poviats, accident severity is the highest from all the poviats with 15 fatalities per 100 accidents (Table 3).

Cluster 5: This group is made up of poviats and urban poviats whose car ownership, the share of old vehicles and the share of post-working age people is the lowest compared to the other clusters. In addition, spending on transport per capita is low (Figure 7). While these poviats perform better on road safety than cluster 2, they are significantly below the other clusters, i.e. in 2019, per 100 accidents, there were 11 fatalities, and fatality rates were 0.7 and 1.2 deaths per 10,000 population and 10,000 cars respectively (Table 3).

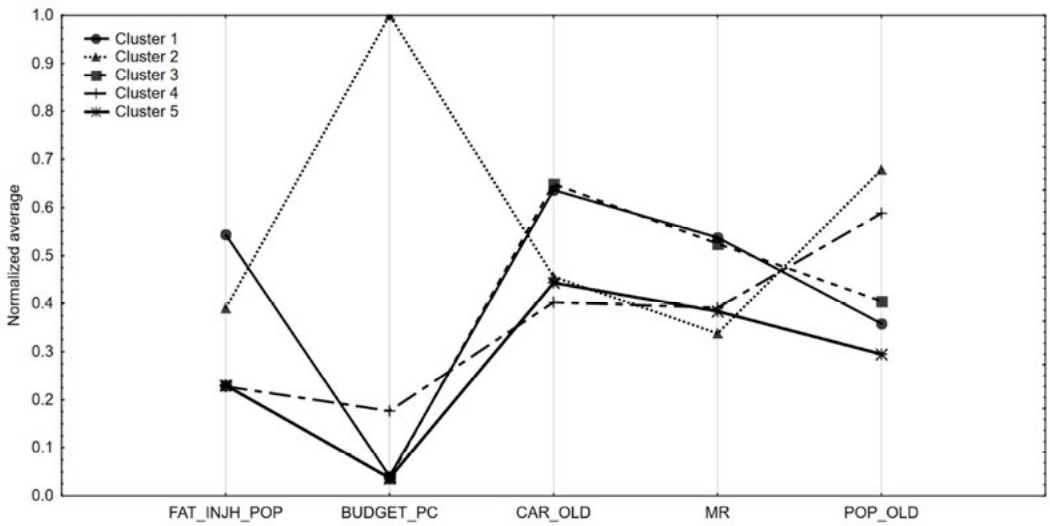

Figure 7. The normalised average of variable in clusters

Source: author's work.

Table 3. Road safety statistics in clusters

	All poviats	Clusters				
		1	2	3	4	5
Number of accidents	30,289	5019	8299	6378	5677	3952
Number of injuries	35,478	6123	9447	7664	6570	4576
Number of serious injuries	10,634	2584	3085	2000	1673	1156
Number of fatalities	2909	636	235	699	874	421
Fatality rate (per 10 thous. inhabitants)	0.76	1.33	0.29	0.80	1.03	0.67
Fatality rate (per 10 thous. cars)	1.19	1.91	0.46	1.34	1.54	1.18
Severity of accidents (fatalities per 100 accidents)	9.6	12.67	2.83	10.96	15.40	10.65

Source: author's work.

Figure 8 presents the road accident fatality trend in the particular clusters versus changes in fatalities over the same period in Poland. While the trend in cluster 5 is similar to that of Poland as a whole, clusters 1 and 4 have seen a much bigger fatality reduction relative to the national trend. The highest fatality reduction was achieved in cluster 2 poviats, i.e. in urban poviats (-40%).

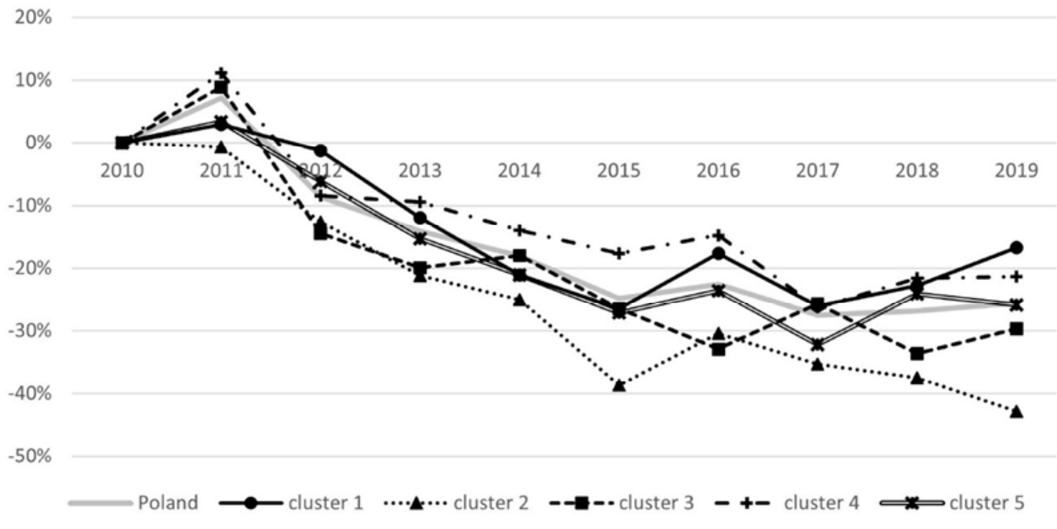

Figure 8. Changes in the number of road fatalities in clusters in 2010-2019

Source: author's work.

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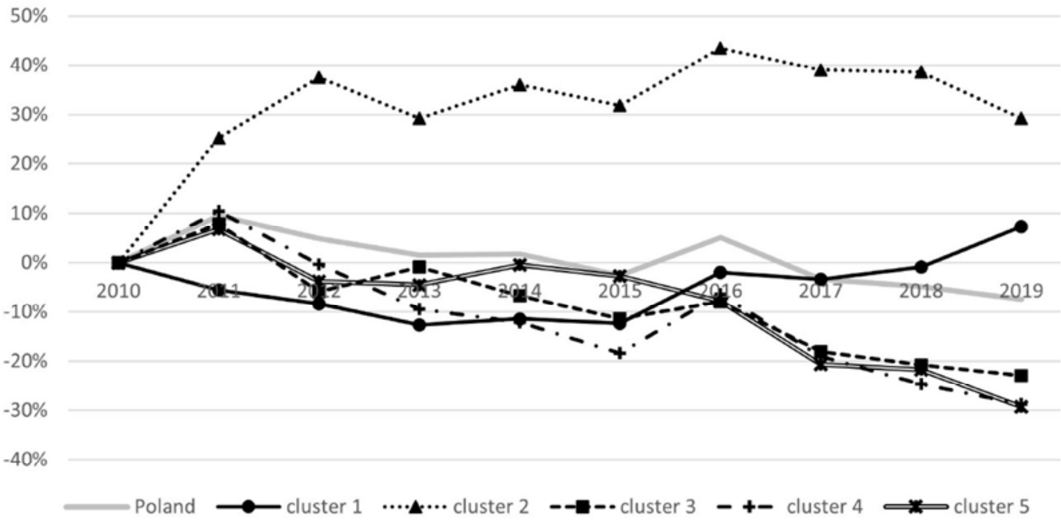

Figure 9. Changes in the number of serious injuries in clusters in 2010-2019

Source: author's work.

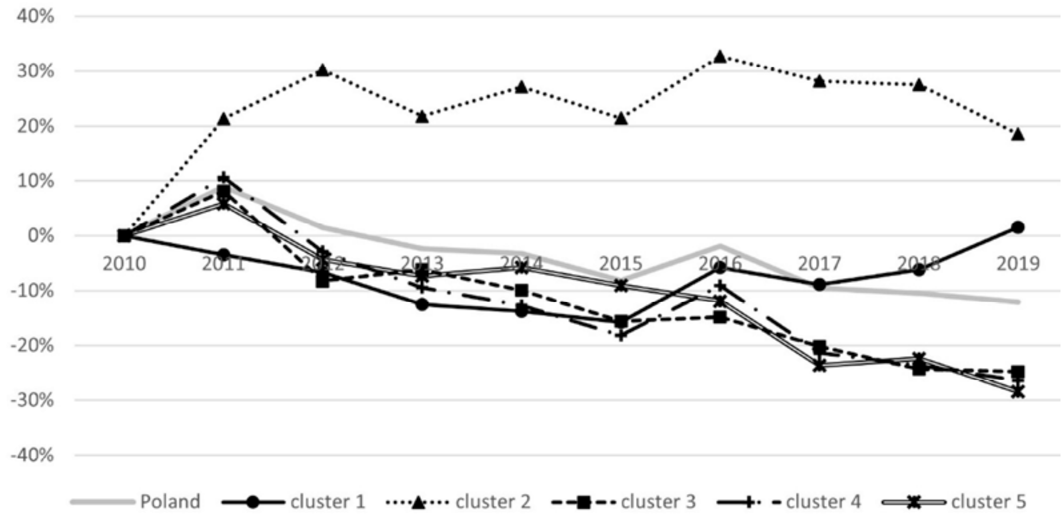

Figure 10. Changes in the total number of fatalities and serious injuries in clusters in 2010-2019

Source: author's work.

In the same period, serious injuries did not fall in all clusters. In clusters 3-5, a similar reduction is observed by about 25%, in cluster 1, however, within this time, casualties fell only to rise again and return to the baseline in

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2020. In cluster 2, which featured the highest fatality reduction, serious injuries increased by about 30% (Figure 9, Table 3). Figure 10 presents the trend for fatalities and serious injuries combined. It is similar to the serious injury trend.

Figure 11 shows a map of the poviats assigned to the clusters. Please note that a high number of poviats are assigned to cluster 3 in the south of Poland, and poviats assigned to cluster 4 form large groupings.

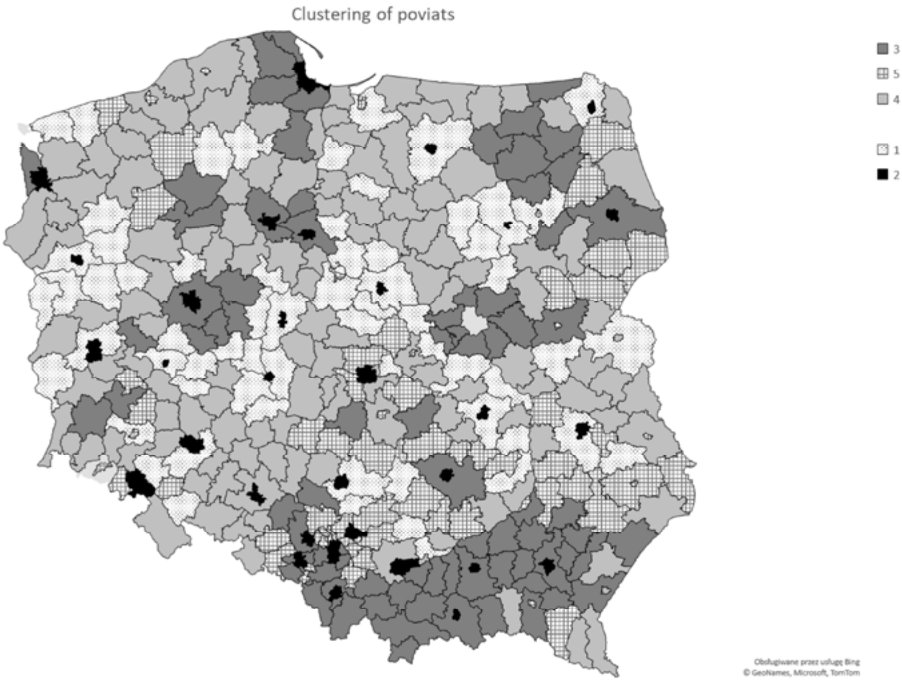

Figure 11. Clustering of poviats

Source: author's work.

Conclusions

The results of the analyses show that Poland as a whole and Poland's poviats on their own have not achieved Agenda 2030's goal, which is to halve fatalities by 2020 (compared to 2010). By dividing poviats into clusters, areas of similar parameters could be identified. This helps to suggest similar solutions to reduce the risk of fatalities and serious injuries in road traffic accidents.

Fatalities fell the most in cluster 2 (urban poviats) (-40%). Yet the decline is not sufficient to meet the 50% reduction set out in Agenda 2030. One area

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of concern, however, is the growing serious injury trend in cities. As a consequence, fatalities and serious injuries combined show that all groups of poviats are far from reaching the target, with clusters 1 and 2 having moved even further away from the goal compared to where they were in 2010. It is important to establish the reasons behind this and intensify treatment in areas that are most at risk.

Considering the complexity of the problem and how the different factors influence road safety, the authors will continue the work presented in the article to include infrastructure factors as well. Future work will take into account the types of roads (fast traffic, other dual carriageways, single carriageways) and types of accidents: head-on, side and rear collisions, hitting a pedestrian and cyclist, and roadside-related accidents). The results will help to implement the most effective road safety measures.

The contribution of the authors

Aleksandra Romanowska: conception – 30%, literature review – 35%, writing – 35%.
Sylwia Pangsy-Kania: conception – 30%, literature review – 35%, writing – 35%.
Marcin Budzyński: conception – 30%, literature review – 20%, writing – 20%.
Katarzyna Wierzbicka: conception – 5%, literature review – 5%, writing – 5%.
Joanna Prystrom: conception – 5%, literature review – 5%, writing – 5%.

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