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PREDICTIVE MODEL OF ROAD ACCIDENT COSTS INVOLVING OVERLOADED HEAVY VEHICLES IN THE CONTEXT OF WEIGH-IN-MOTION SYSTEM IMPLEMENTATION

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Purpose: The study aimed to develop a computational model to determine the projected costs arising from road accidents involving overloaded heavy goods vehicles within the framework of implementing the WIM automatic weight-in-motion system.
Design/methodology/approach: The research methodology employed is based on Method II, as presented in the publication (JASPERS, 2023). This method was developed as part of a cost-benefit analysis for planned investment projects in the transport sector in Poland. Additionally, the theoretical coefficient representing the proportion of overloaded vehicles in road incidents in Poland was calculated. Based on this, a calculation model was developed in a spreadsheet to ascertain the annual costs of road incidents involving overloaded trucks.
Findings: The realisation of the primary objective led to determining the value of costs resulting from the implementation of the system for weighing vehicles in traffic in Poland. The calculation model serves as the principal tool for the calculations conducted.
Research limitations/implications: The main limitation of the calculation results is the estimation of the proportion of overloaded trucks involved in traffic incidents. In the future, more accurate source data on this issue should be obtained to enhance the projected costs. Practical implications: Based on the adopted methodology, the proposed calculation model enables the determination of the forecasted costs of road accidents, which are integral to the model for assessing the economic efficiency of investments in the implementation of the WIM system in Poland.
Social implications: The results of the research indicate a significant social problem regarding the cost of road accidents. These costs are borne by state and local authorities, and the results of the research provide valuable information regarding the management of potential money in other areas of social activity. This also applies to increasing safety on the roads covered by the WIM system.
Originality/value: The model itself, along with the calculation result, represents the author's presentation of costs for the considered case of investment in the WIM system. The study was created as part of the work on the project ‘System of automatic weighing of vehicles in traffic’ (WIM-PL) GOSPOSTRATEG9/000X/2022.
Keywords: transport, management, cost modelling, WIM.
Category of the paper: Research paper.

1. Introduction

According to data from the European Commission (2024), the number of fatalities resulting from road traffic accidents decreased in 2023. Around 20,400 people lost their lives on EU roads, which is a slight decrease of 1 per cent compared to 2022. The reduction in motorway fatalities across the EU amounted to around 20 per cent between 2010 and 2017, which was slower than initially anticipated. In Poland, the number of road accidents has fluctuated significantly over the past 50 years (Symon, Rzepka, 2024). Figure 1 presents the distribution of road traffic accidents. Historical data indicate an upward trend in the number of accidents until 1975. Since then, a downward trend has been observed, albeit with minor annual increases.

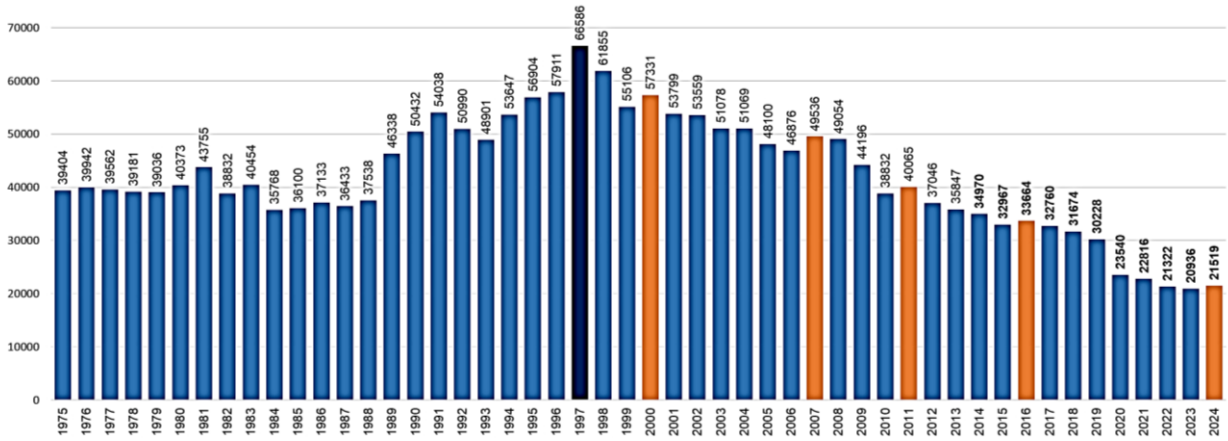


Figure 1. Trends in Road Traffic Accidents in Poland between 1975 and 2024.

Source: Wypadki drogowe - raporty roczne (statystyka.policja.pl).

Referring to the past decade, the highest number of road accidents was recorded in 2014. The downward trend continued in 2015, followed by a slight increase in 2016. The following four years saw a steady decline, with 30,288 accidents recorded in 2019. A significant decrease was observed in 2020, with the number of accidents falling by over 22 per cent compared to the previous year. While the downward trend has continued in recent years, the average annual rate of decline has slowed to 3.8%. According to analogous reports by the National Police Headquarters (KGP) on road accidents in the last decade (statystyka.policja.pl), the average proportion of heavy goods vehicles (above 3.5 tonnes) involved in road accidents in Poland was estimated at 3.15%. One of the key factors contributing to road accidents is the condition of the road infrastructure and traffic characteristics, such as the number of lanes, the quality of the road surface, and traffic density. The level of funding allocated for road maintenance directly impacts road quality and safety. At the same time, given that it is primarily heavy and overloaded vehicles that cause the greatest damage to infrastructure, it is these types of vehicles that bear the main cost of ensuring road safety (Ryś, Jaskuła, 2019).

The relevance of the aforementioned variables is supported by the literature. Research by J. Navarro-Moreno et al. (2023) demonstrated a significant relationship between road accidents involving casualties, related safety expenditure, and variables such as the unemployment rate, per capita income, and the penalty points system. Furthermore, a correlation was identified between the number of accidents and investment expenditure on infrastructure construction and development. The findings confirmed that spending on road maintenance could be an effective means of developing a safer and more sustainable road transport system. Increased investment in road infrastructure construction and maintenance - including Weigh-in-Motion (WIM) system installation (Michalski, Habura, Tekieli, 2015) - could contribute to safer road networks, reducing both accidents and associated costs (Ossowski, Burnos, 2015).

According to a CRS report (CRS, 2016), heavy goods vehicles (HGVs) in the United States are involved in road accidents in proportion to the distance travelled rather than their numerical presence on the road network. They account for approximately 10 per cent of all vehicles involved in fatal accidents. Furthermore, the data indicate that accident involvement varies by truck length. Combination trucks - vehicles with additional trailers - account for around 1.7 per cent of fatal accidents per 100 million miles (161 million kilometres), whereas single-unit trucks account for approximately 1.1 per cent (U.S. Department of Transportation, 2021). In China, 80 per cent of accidents involving trucks on mountainous roads are attributed to vehicle overloading (Wen et al., 2022). The Kentucky Traffic Collision Facts Report (2020) reveals that, of all heavy goods vehicles involved in accidents, 0.08 per cent were either overloaded or improperly loaded, and 0.43 per cent were transporting oversized loads (Green et al., 2021). However, a different perspective is provided in the report Large Truck and Bus Crash Facts 2019 (2021), which states that overloaded vehicles accounted for just 0.2 per cent of all heavy goods vehicles involved in accidents. Available research does not provide a definitive number or precise proportion of overloaded heavy goods vehicles involved in road accidents on a global scale. However, the existing data allow for the presentation of several significant findings.

2. Research Methodology

The study of the costs of road traffic accidents in the context of the planned WIM (Weigh-in-Motion) investment is based on Method II, as outlined in the Blue Book: Road Infrastructure, updated edition (JASPERS, 2023). This publication presents two methodologies for estimating accident-related costs. Both are grounded in the national method for forecasting road safety indicators, known as the Road Safety Indicator Method, which was developed as part of a research project commissioned by the General Directorate for National Roads and Motorways (GDDKiA) in 2012. This project was conducted by a consortium comprising the Foundation

for the Development of Civil Engineering in Gdańsk, Gdańsk University of Technology, and Cracow University of Technology.

The methodology adopted for the present study comprises a structured sequence of five stages designed to standardise calculations and organise the obtained data. Cost calculations (Stage III) were preceded by a data analysis to determine the coefficient representing the proportion of overloaded heavy goods vehicles involved in road incidents (Stage I). Next, accident density and accident frequency indicators were chosen for the selected potential WIM station locations (Stage II). Figure 2 illustrates the structure of the research methodology applied in this context.

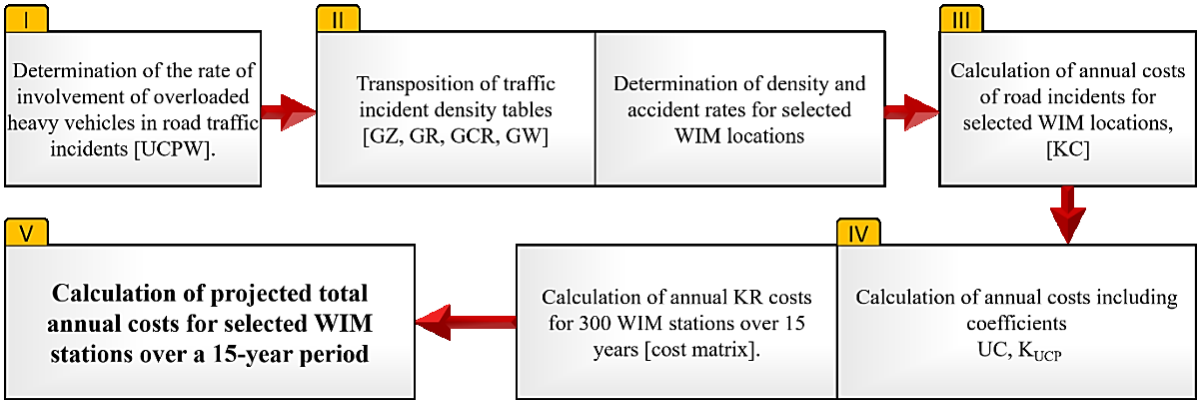


Figure 2. Structure of the adopted research methodology.

Source: Own study.

The general assumptions adopted for Method II concerned a defined number of 300 vehicle weighing station locations for the future WIM system in Poland and a 15-year investment period for developing the system. Based on these parameters, a computational model was developed that encompasses both a fixed set of locations and a defined timeframe. The flexibility of the model allows these parameters to be adjusted according to the requirements of future investment projects.

3. Results

3.1. Stage I – Determination of the coefficient of participation of overloaded heavy vehicles (UCPW).

Based on the report 'Overweight Vehicles: Impact on Road Infrastructure and Safety (Special Project 2022SP01EN, PIARC, 2022), an analysis was conducted using data obtained through direct access to national collision statistics for the United Kingdom and Portugal. The survey yielded a response from one participant who provided data on accidents and incidents involving overloaded heavy goods vehicles in Scotland, constituting a subset of UK data. These findings are presented in Table 1.

Table 1.
Percentage of all incidents involving heavy goods vehicles in which overloading occurred (Portugal) or was a contributing factor (United Kingdom/Scotland).

Country	Road Collisions [%]
Portugal	0.3
United Kingdom	1.0
Scotland	1.3

Source: Based on (PIARC, 2022).

The report presents further analyses that provide information on the frequency with which improperly loaded or overloaded vehicles are involved in collisions. Two different reporting formats are used. In Portugal, overloading is recorded when one of the vehicles involved in a collision was overloaded, regardless of whether this played a role in causing or exacerbating the incident. In contrast, in the United Kingdom, overloading is only recorded when the attending police officer determines that it may have contributed to the collision's cause. A comparative summary is presented in Table 2.

Table 2.
Number of road incidents involving overloaded heavy goods vehicles in Portugal and the United Kingdom

Country (Period)	Collisions Involving CPP	Collisions Involving Overloaded CPP	Share of Overloaded Vehicles [%]
Portugal (2016-2018)	5.800	17	0.29
United Kingdom (2009-2018)	184.069	1.099	0.60

Source: Based on (PIARC, 2022).

The summary data was compiled from detailed tables showing the number of incidents involving overloaded heavy goods vehicles (CPP) during various research periods. This explains the significant discrepancy in the number of recorded incidents. However, in terms of subsequent cost calculations, the key finding is that the proportion of overloaded vehicles is relatively small compared to the overall issue of heavy vehicle safety on roads in each country. Nevertheless, despite this low proportion and the presence of high regulatory standards, it is important to acknowledge that the impact of overloading on road safety is not negligible.

The literature review conducted did not reveal a specific figure for the proportion of overloaded heavy goods vehicles involved in road accidents or incidents. Therefore, the most justifiable estimate appropriate for the Polish context must be adopted. According to the 2024 report by the National Police Headquarters (Symon, Rzepka, 2024), there were 1691 road incidents involving heavy goods vehicles in Poland, 648 of which involved vehicles over 3.5 tonnes. This corresponds to a share of 3.1 per cent. The PIARC 2022 report provides data on incidents involving CPP over 7.5 tonnes in the UK, of which there were 504 (1.13%), representing the highest proportion of all CPP incidents recorded in the country. Considering the total number of incidents involving CPP in the UK, which stands at 184,069, the share of overloaded vehicles is 0.27%, a figure that aligns closely with the results reported for Portugal.

A comparative analysis of key road transport indicators for Poland, Portugal and the United Kingdom was conducted for 2023.

Table 3.
Characteristics of Key Indicators (TK) for Road Transport in Selected European Countries

Country	**Domestic Transport** (DT) [million tonnes]	**Freight Transport Work** (FTW) [billion tkm]	**Import** (I) [million tonnes]	**Export** (E) [million tonnes]	**Length of Main Road Network** [km]	**Land Area** [km²]	**Road Network Density** (RND) [km/km²]
United Kingdom	1,550.0	164.00	3.20	2.50	31,900.00	243,610.00	0.13
Portugal	128.6	26.80	21.70	17.80	13,833.00	92,090.00	0.15
Poland	1,245.7	377.90	79.30	93.00	19,313.00	312,696.00	0.06

Source: stat.gov.pl, eurostat.com, www.gov.uk, www.ine.pt, infraestruturasdeportugal.pt

The above table presents selected fundamental data on road transport in various countries, obtained from online databases. This data is used to estimate the proportion of overloaded heavy goods vehicles (CPP) in Poland. Based on the data presented in the PIARC 2022 report regarding the CPP share in two selected European countries, it is important to consider the similarities and differences in relevant indicators for Poland. Analysis of the above figures shows that Poland and the United Kingdom have similar domestic transport volumes, but differ significantly in terms of international transport activity. By contrast, Portugal demonstrates somewhat more comparable international transport volumes to Poland, but diverges markedly in terms of domestic transport activity. These data do not allow for the CPP share in Poland to be determined directly. To this end, structural coefficients were calculated and applied in the analysis. These were derived by comparing selected Polish parameters to those of the reference countries and served as the basis for estimating Poland's participation rate. The structural coefficient was calculated using the following formula:

$$WP_{TK} = \frac{TK_{PL}}{TK_n} \tag{1}$$

where *n* – country compared with Poland.

This is an exemplary formula applied to the following indicators: FTW (Freight Transport Work), I (Import), E (Export) and RND (Road Network Density). The values of the proportionality coefficients are presented in Table 4.

Table 4.
Proportionality Coefficients [WP] of Transport Indicators for Poland Compared with the United Kingdom and Portugal

		United Kingdom CPP = 0.27	**Portugal CPP = 0.3**
Poland	$WP_{[DT]}$	0.80	9.69
	$WP_{[FTW]}$	2.30	14.10
	$WP_{[I]}$	24.78	3.65
	$WP_{[E]}$	37.20	5.22
	$WP_{[RND]}$	0.47	0.41

Source: own study.

Next, proportional values were calculated for each of the transport indicators based on the adopted values of the share of overloaded heavy goods vehicles in road incidents (UCPW). The median values for the United Kingdom and Portugal were then determined. The results are presented in Table 5.

Table 5.
UCPW Indicator Values for Selected Transport Metrics in the Analysed Countries

		United Kingdom CPP = 0.27	**Portugal CPP = 0.3**
Poland	DT	0.22	2.91
	FTW	0.62	4.23
	I	6.69	1.10
	E	10.04	1.57
	RND	0.13	0.12
	Median value	0.62	1.57
		UCPW value for Poland	**1,1**

Source: Own study.

Ultimately, the average UCPW indicator for Poland was estimated at 1.1%, based on the calculated median CPP values. This figure represents the proportion of overloaded heavy goods vehicles that potentially contribute to road incidents within Polish territory. This indicates a higher level than in the other analysed countries, which can be attributed to the considerable disparity in transport indicators presented in Table 3. It should be acknowledged that the calculations may be subject to a margin of error due to the limited dataset analysed. An additional important factor is that Poland lies along key east–west European transport corridors, significantly increasing the volume of transit traffic. This, in turn, increases the risk of incidents involving overloaded foreign heavy goods vehicles.

3.2. Stage II – Determination of density coefficients and number of accidents

The costs of road traffic accidents include direct expenses such as vehicle repair and medical treatment for the injured, as well as indirect costs including economic losses related to reduced transport efficiency and societal impacts. When analysing road infrastructure investments, it is crucial to consider not only current accident rates but also projected changes, as this provides a more comprehensive assessment of the financial and social consequences of infrastructure projects (JASPERS, 2023).

The following categories of road accident costs are distinguished:

- costs related to fatalities in road traffic accidents (kzt),
- costs related to minor injuries in road traffic accidents (krt),
- costs related to serious injuries in road traffic accidents (krct),
- costs of material losses (kmt) (incurred in accidents involving injuries and/or fatalities).

The cost analysis incorporates various financial aspects, including administrative and legal expenses, loss of productivity, employer costs, material damage and expenditures related to hospitalisation, funerals and compensation.

After considering all the variables and the available input data, it was decided to reject this method in favour of Method II. Method II is more suitable for further analysis due to the availability of relevant data and the broad range of variables applied at each stage of the methodology. In this method, the primary measures of road safety are the values of social losses, expressed as the number of accidents and categorised as follows:

- total number of accidents (LW),
- total number of injured persons (LR),
- total number of seriously injured persons (LCR),
- total number of fatalities (LZ).

Estimates of the current and projected number of road traffic accidents, as well as the number of fatalities and injuries in a given year, are based on the determination of auxiliary risk measures, which are expressed in the form of accident density indicators.

- accident density (GW),
- injury density (GR),
- serious injury density (GCR),
- fatality density (GZ).

These indicators are presented in table format in the Blue Book (JASPERS, 2023). They were developed using the Road Safety Indicator Method (BRD Method) and are based on input data including:

- type of investment (road section, bypass),
- number of carriageways (dual or single carriageway),
- road classification (distinguishing the following classes: A, S (and S2+1), GP, G,
- traffic forecast – Annual Average Daily Traffic (SSDR),
- location (voivodeship) – applies to single-carriageway sections,
- area type – urban (z) / non-urban (n).

This format enables the calculation of accident-related costs for a given year, depending on the number of actual or projected road traffic incidents. The next step is to estimate the number of accidents, fatalities, injuries and serious injuries. To achieve this, accident density indicators must be determined for the selected road sections with planned WIM station locations.

The accident density indicators selected (GZ, GR, GCR and GW) were based on the input parameters of the road section intended for investment. To facilitate calculation, the accident density tables (JASPERS, Blue Book, Tables 14, 15, 16 and 17, pp. 193-194) were reorganised and condensed into two cumulative tables for single and dual carriageways. The accident density indicator is presented below.

Table 6.
Fatality, Injury and Serious Injury Density Coefficients for Single-Carriageway Road Sections

SSDR	GZ	S		GP. G	
		GR	GCR	GR	GCR
(0- 5,000>	0.06	0.175	0.023	0.323	0.06
(5,000- 10,000>	0.103	0.404	0.077	0.804	0.199
(10,000- 20,000>	0.193	0.742	0.157	1.527	0.408
higher 20,000	0.291	1.113	0.217	2.246	0.562

Source: own study based on (JASPERS, 2023).

For single-carriageway road sections, the accident density (GW) should be calculated according to the following formula:

$$GW = gw \cdot f_{LDW} \tag{2}$$

where:

gw – road accident density coefficient for single carriageway road sections [persons/km/year],
fLDW – road location factor; an indicator dependent on the voivodeship for location.

Table 7.
Road Accident Density Coefficient for Single-Carriageway Road Sections

SSDR	S	GP. G1	
		Non-urban area	Urban area
(0-5.000>	0.07	0.113	0.17
(5.000-10.000>	0.152	0.244	0.369
(10.000- 20.000>	0.27	0.435	0.656
higher 20.000	0.413	0.665	1.004

Source: (JASPERS, 2023).

Table 8.
Road Location Coefficient

Voiv. No	Voivodeship	f_{LDW}	Voiv. No	Voivodeship	f_{LDW}
2	dolnośląskie	2.342	18	podkarpackie	2.43
4	kujawsko-pomorskie	1.696	20	podlaskie	1.76
6	lubelskie	2.405	22	pomorskie	2.317
8	lubuskie	1.742	24	śląskie	2.833
10	łódzkie	2.701	26	świętokrzyskie	2.43
12	małopolskie	2.788	28	warmińsko-mazurskie	2.617
14	mazowieckie	2.096	30	wielkopolskie	1.936
16	opolskie	2.063	32	zachodniopomorskie	1.886

Source: (JASPERS, 2023).

Table 9.
Accident Density Coefficients for Dual Carriageway Road Sections

	S1/2+1				S,A				GPn				GPz			
SSDR	GZ	GR	GCR	GW	GZ	GR	GCR	GW	GZ	GR	GCR	GW	GZ	GR	GCR	GW
(0-,5000>	0.036	0.051	0.044	0.04	0.022	0.034	0.027	0.029	0.179	0.519	0.198	0.396	0.113	0.981	0.264	0.739
(5,000-10,000>	0.073	0.144	0.078	0.113	0.052	0.096	0.055	0.081	0.189	0.604	0.212	0.46	0.117	1.09	0.278	0.819
(10,000-20,000>	0.104	0.381	0.122	0.294	0.083	0.256	0.093	0.22	0.209	0.797	0.238	0.603	0.124	1.303	0.301	0.974
(20,000-30,000>	0.135	0.953	0.167	0.554	0.104	0.504	0.125	0.396	0.233	1.303	0.275	0.81	0.131	1.559	0.325	1.161
(30,000-40,000>	0.154	1.058	0.199	0.8	0.118	0.713	0.148	0.571	0.254	1.407	0.306	1.016	0.137	1.657	0.343	1.309
higher 40,000	0.177	1.631	0.242	1.255	0.141	1.12	0.187	0.877	0.28	1.956	0.359	1.447	0.143	2.075	0.368	1.535

Source: Own study based on (JASPERS, 2023).

The determination of accident density coefficients depends on parameters such as:

- number of carriageways,
- road classification,
- traffic forecast (SSDR),
- location.

These parameters were defined as part of a project task carried out by a separate scientific research unit within the framework of the Gospostrateg project, 'Automatic Weigh-in-Motion System for Vehicles in Motion' (WIM-PL). They were made available in the form of a list of planned WIM station locations.

A proprietary spreadsheet tool was developed to calculate the density coefficients, allowing for the automatic selection of individual coefficients based on the adopted criteria for any number of WIM station locations. Subsequent analysis involved performing calculations for 300 identified and ranked locations.

3.3. Stage III – Annual Costs of Road Traffic Incidents

The calculation of total road traffic accident costs, broken down by cost category, refers to the fifteen-year analysis period adopted for the study. The following formula was used to estimate the total cost of road accidents over the study period.

$$K_W = \sum_{t=1}^{n}[(k_{zt} \cdot a_{zt}) + (k_{rt} \cdot a_{rt}) + (k_{crt} \cdot a_{crt}) + (k_{mt} \cdot a_{mt})] \quad (3)$$

where:

KW – total cost of road traffic accidents, including injuries and fatalities, over the entire analysis period [PLN],
kzt – unit cost of fatalities in a given year [PLN],
krt – unit cost of minor injuries in a given year [PLN],
kcrt – unit cost of serious injuries in a given year [PLN],
kmt – unit cost of material losses in a given year [PLN],
azt – number of fatalities in a given year,
art – number of minor injuries in a given year,
acrt – number of serious injuries in a given year,
amt – number of road traffic accidents involving material losses in a given year,
t – year of the analysis (analysis period n = 15 years).

In Method II, the sum of the individual cost categories is calculated for each year of the analysis. First, the number of incidents is determined and then multiplied by the unit cost of road traffic incidents (PLN per incident). These unit costs are presented in Table 10. These are forecast values developed based on the publication Estimation of the Costs of Road Accidents and Collisions on the Polish Road Network at the End of 2018, Including Average Socio-Economic Costs of Accidents on the Trans-European Transport Network. Following the

authors' recommendations (Jaździk-Osmólska, Korneć, 2019), the consumer price index (CPI) was taken into account for the first year of analysis (2024); in July, the inflation rate was 4.2% (NBP, 2024). The cost values assigned to individual years were increased by the corresponding CPI value. The primary criterion for selecting the base year for calculations was the availability of actual statistical and economic data. Calculations for subsequent years of the investment period are derived from real data and treated as forecast values.

Table 10.
Unit Costs of Road Traffic Incidents (PLN/incident)

Year	Fatalities [kzt]	Minor Injuries [krt]	Serious Injuries[crt]	Material Losses [kmt]
2024	3 136 622	63 156	4 339 247	20 173
2025	3 217 726	64 788	4 451 448	20 695
2026	3 303 984	66 525	4 570 779	21 250
2027	3 390 399	68 265	4 690 326	21 806
2028	3 479 584	70 061	4 813 706	22 379
2029	3 568 842	71 858	4 937 187	22 953
2030	3 658 046	73 654	5 060 594	23 527
2031	3 747 060	75 446	5 183 736	24 099
2032	3 838 834	77 295	5 310 698	24 689
2033	3 930 345	79 137	5 437 295	25 278
2034	4 024 578	81 034	5 567 659	25 884
2035	4 118 343	82 922	5 697 376	26 488
2036	4 211 437	84 797	5 826 162	27 086
2037	4 303 708	86 655	5 953 812	27 680
2038	4 394 955	88 492	6 080 044	28 266

Source: (JASPERS, 2023).

The calculations were based on the assumptions adopted from the descriptions and recommendations provided in the Blue Book. The first stage of the cost calculations involves determining the individual costs related to fatalities, injuries, serious injuries and material losses for the first year.

3.4. Stage IV – Development of the cost matrix

The adopted calculation method does not categorise costs according to the types of vehicles involved in a given incident. However, it is important to specify the costs incurred by the target group of heavy goods vehicles and overloaded vehicles. To this end, the coefficient of heavy vehicle participation (UC) was employed. This variable is location-dependent and therefore differs for each of the 300 individual locations. It was developed specifically for this project, along with the list of locations. In addition, the coefficient of overloaded vehicle participation (UCP), as determined by the forecast calculations conducted within the project tasks, was applied. It is assumed that there will be a decreasing trend in the share of overloaded vehicles, starting at 23% in the first year of investment and gradually falling to a stable level of 5% by year six (see Table 12). The total annual costs of all types of incidents were calculated, and then reduced based on the share of heavy and overloaded vehicles. This figure was further adjusted using a dedicated coefficient. This ultimately yields the potential cost of accidents

caused by overloaded vehicles on a given road section (at a specific location). The calculation results for the first year and the first ten locations from the list are presented below as an example.

Table 11.
Example of Annual Accident Cost (AC) Calculation for Overloaded Vehicles in the First Year, for the First 10 Locations from the List

	Year 1								**KR1**		**4212870.727**
	f_{hp}=0,7								UCP=23 %		UCPW=1,1%
	Number of Accidents/ km/year				**Accident Costs**				**All cost**		**UCP cost**
No	**azt**	**art.**	**acrt**	**awt**	**kz*azt**	**krt*art.**	**kcrt*acrt**	**kmt*awt**	**KC**	**UC**	**KUCP**
1	1.6296	0.6328	3.1472	7.8055	5111439.452	39964.876	13656479.701	157461.369	18965345.398	0.127	6100.75871969
2	1.0225	8.1222	1.3561	6.36	3207296.518	512965.103	5884557.663	128301.124	9733120.408	0.163	4003.31015714
3	1.4463	5.673	2.7944	7.1814	4536578.165	358279.811	12125410.938	144871.563	17165140.477	0.253	10971.51880831
4	3.3651	1.3067	6.499	16.118	10555122.469	82527.470	28200630.582	325157.727	39163438.247	0.318	31521.30771121
5	1.2018	0.4667	2.3211	5.7566	3769686.596	29474.096	10071653.779	116127.760	13986942.231	0.291	10314.91954575
6	3.6381	1.4127	7.0261	17.426	11411288.577	89221.586	30488090.931	351532.506	42340133.601	0.400	42831.48415597
7	1.87	0.7261	3.6114	8.9568	5865376.772	45859.696	15670810.456	180686.921	21762733.844	0.354	19479.46378292
8	2.4566	0.9539	4.7444	11.767	7705494.974	60247.051	20587143.149	237373.014	28590258.188	0.331	23933.38086479
9	0.9753	5.4544	1.1512	3.3907	3059266.773	344473.361	4995124.748	68400.191	8467265.073	0.314	6727.80502366
10	2.0905	16.605	2.7725	13.002	6557001.955	1048706.649	12030398.775	262299.016	19898406.394	0.150	7573.40987250

Source: Own study.

The values shown in the final column ('UCP Cost') represent the total cost for a given location. This figure reflects accident costs, adjusted for the proportion of heavy and overloaded vehicles involved in incidents. In the first year, the time horizon coefficient was set at fHP = 0.7, with UCP = 23% and UCPW = 1.1%. The total cost for a given year and location can be calculated using the following equation:

$$K_{UCP\,t} = KC_t \cdot UC_t \cdot UCP \cdot UCPW \tag{4}$$

where:

t – index number of the location,

KC – total accident cost for the location,

UC – share of heavy goods vehicles in the traffic stream,

UCP – share of overloaded heavy goods vehicles relative to UC,

UCPW – share of overloaded heavy goods vehicles involved in road incidents, relative to UC.

4. Results: Stage V–Annual Cost Calculations (KR)

The annual road accident cost value (Table 11) represents the sum of all calculated costs across the 300 locations. The total yearly cost for all locations can be obtained by summing the values in the UCP Costs column and is expressed as follows:

$$KR_i = \sum_{t=1}^{n} K_{UCP\,t} \quad (5)$$

where:

i – subsequent years,

t – index number of the location,

n – total number of locations.

The results presented in Table 12 were obtained using the general calculation model for the entire fifteen-year investment period and assuming the implementation of 300 roadside Weigh-in-Motion (WIM) stations across Poland. These results are shown alongside the time horizon coefficient (f_{HP}) and the overloaded vehicle share indicator (UCP).

Table 12.
Forecast of Annual Road Accident Costs Over 15 Years [PLN]

Year	f_{HP}	UCP	Cost PLN
1	70.00%	23.00%	4212870.727
2	70.00%	16.50%	3100424.557
3	60.00%	15.50%	2563368.111
4	60.00%	11.00%	1866744.121
5	60.00%	7.20%	1254010.301
6	60.00%	5.00%	893179.3736
7	50.00%	5.00%	762920.5256
8	50.00%	5.00%	781485.0064
9	50.00%	5.00%	800625.4203
10	50.00%	5.00%	819710.7518
11	40.00%	5.00%	671491.4073
12	40.00%	5.00%	687136.0626
13	40.00%	5.00%	702668.2836
14	40.00%	5.00%	718063.724
15	40.00%	5.00%	733287.9271
		SUM:	**20 567 986.299**

Source: Own study.

Table 12 summarises the costs aggregated for each year of the investment period, based on the assumptions previously adopted. Juxtaposing cost data with the f_{HP} and UCP coefficients enables cost value changes over time to be observed. The result obtained from the accident cost calculations using Method II amounts to approximately PLN 20.6 million. This figure represents the potential cost of accidents occurring within the analysed timeframe and is calculated for 300 selected locations in Poland. The computational model assumes the maximum number of stations planned for the national Weigh-in-Motion (WIM) system. All of these stations are established in the first year of investment and remain operational for the full 15-year period. This is a forecasted value of accident-related costs estimated under fixed boundary conditions, including the number of weighing stations, their locations along road sections and the implementation strategy adopted. Figure 3 illustrates the distribution of annual costs across the investment period.

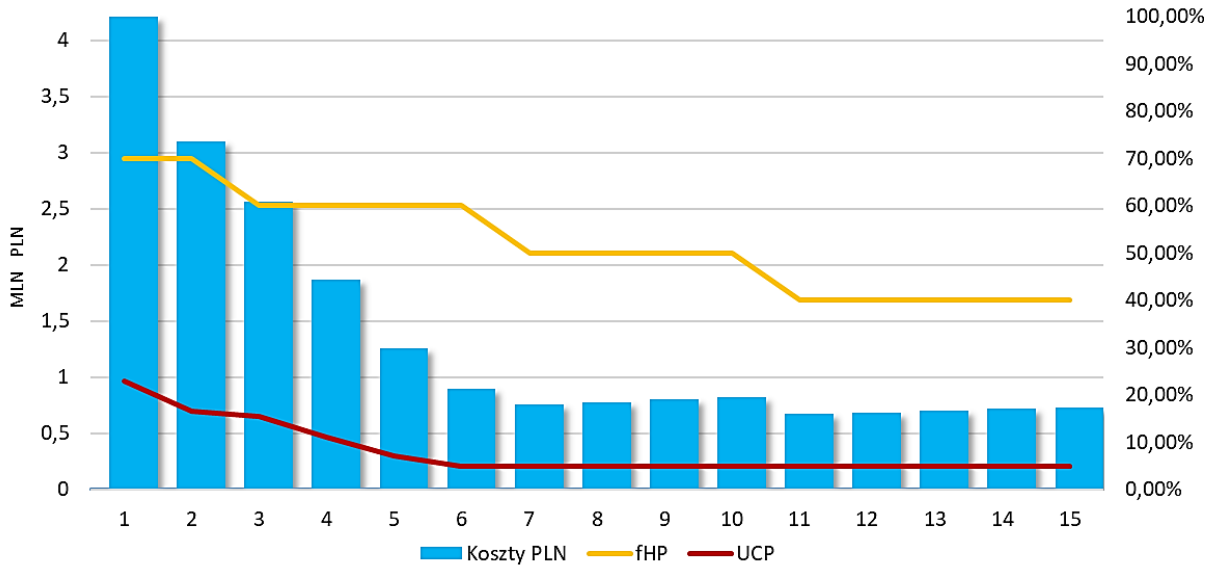


Figure 3. Total annual accident costs for the planned number of WIM stations over the 15-year investment period.

Source: Own study.

The figure above clearly shows a downward trend in annual accident costs over time. This corresponds with the projected decrease in the number of overloaded heavy goods vehicles, particularly during the first six years of the investment period. In subsequent years, cost levels stabilise, with minor increases occurring within periods defined by a single time influence coefficient. The decisive factor behind this forecast is undoubtedly the assumed reduction in the number of overloaded vehicles and the potential to maintain this level in subsequent years. The accident cost results presented for the selected analysis period are based on a computational model that demonstrates stabilisation of costs after the seventh year of investment. Assuming the continued application of the adopted modelling formula, the visible trend suggests that cost values in years beyond the fifteenth year are likely to continue decreasing. The calculated annual cost values indicate variation in the year-on-year dynamics of accident numbers. These changes are illustrated in Figure 4. The visible trends highlight the critical importance of the first seven years of investment, during which the rate of cost reduction is at its highest.

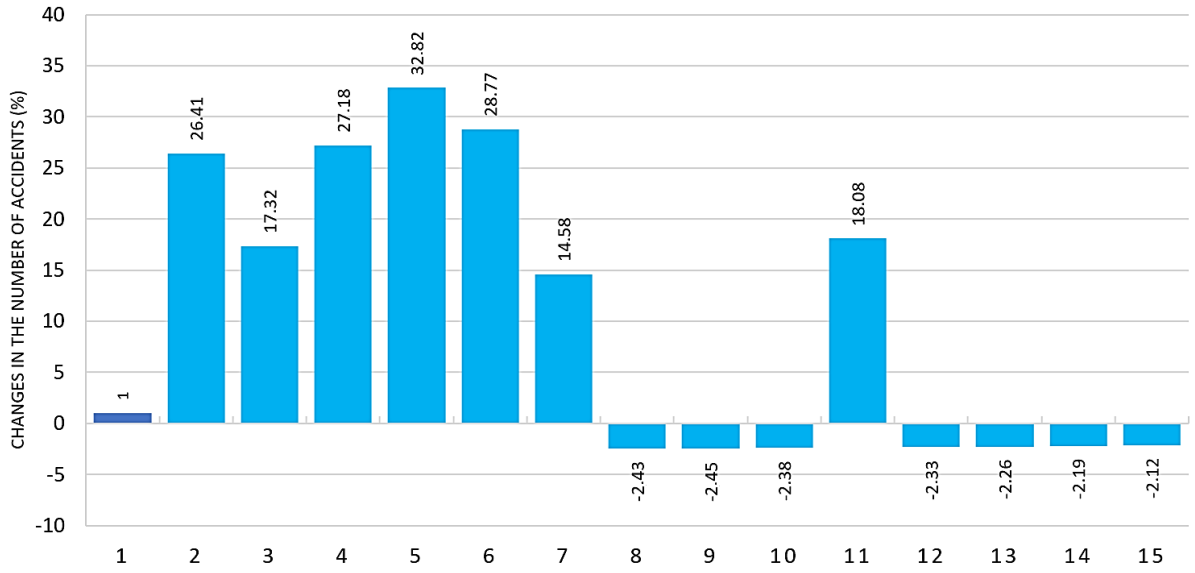


Figure 4. Dynamics of annual reductions in road accident costs involving overloaded vehicles during the planned investment period.

Source: Own study.

Positive percentage values indicate a high rate of reduction in accident costs involving overloaded heavy goods vehicles. This suggests that the initial seven years of the investment period could generate the greatest annual benefits due to a decrease in accidents. Conversely, negative values reflect a declining trend in the rate of change. Figure 4 illustrates this with periodic increases in costs during the 7-10 and 11-15 year intervals. Furthermore, during the final phase of the analysis period, a single increase in the rate of change was observed in year 11. This was due to a smaller year-on-year reduction in costs between years 10 and 11. The information presented is a synthesis of complex cost calculations based on selected data concerning the locations of individual weigh-in-motion (WIM) stations. The spreadsheet model was constructed adaptively to allow calculations to be carried out for any number of locations. Therefore, it can be concluded that the accident cost estimate of PLN 20.6 million corresponds to the assumed number of WIM stations nationwide. This value refers to the entire WIM system (300 stations), the development of which is planned over subsequent years of the investment period.

5. Summary

The planned national Weigh-in-Motion (WIM) system is intended primarily to reduce the number of overloaded heavy goods vehicles on Polish roads. This is expected to lead to a decrease in road surface degradation and associated maintenance and repair costs. Another key benefit of reducing overloaded vehicles is enhancing road safety by lowering the number

of accidents involving them. According to the adopted research methodology, the cost of each road incident is the total result of the emergency response, including personnel, technical resources and material losses. Reducing road incidents corresponds to avoiding these costs, which can be considered measurable savings. The scale of these savings is one of the main factors influencing the cost-effectiveness of the WIM system. While the method for determining the amount of potential savings is based on the accident cost calculation approach, it is not included in the present analysis.

The research conducted to forecast potential costs resulting from the non-occurrence of road traffic incidents is based directly on Method II of the Blue Book: Accident Cost Calculation, as developed and presented in the publication. Road Infrastructure (JASPERS, 2023). This document is the main source of methodology for preparing cost–benefit analyses in the transport sector, and it supplements and refines the guidelines issued by the European Commission and national authorities. Based on this, a computational model comprising successive stages for estimating road accident costs was developed.

This model formed the core analytical tool for the cost calculations presented in the study. The cost matrix implemented in the spreadsheet provides a basis for estimating road accident costs in any planned deployment scenario of the WIM system throughout the investment period. The intended implementation strategy should define the criteria for selected road traffic factors that most significantly influence the number of accidents at a given location or road section. These may include parameters such as average annual daily traffic (SDDR) share of heavy goods vehicles, accident rate, voivodeship (region), road classification or number of recorded road incidents. The flexibility of the developed matrix also enables the estimation of annual road accident costs for an increasing number of WIM stations as the system expands.

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