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Road freight transport safety in Poland: regional accident patterns and infrastructure damage costs

Abstract: The article examines the scale and structure of road incidents involving freight transport vehicles in Poland in 2022. Drawing on national statistical data, it investigates both accidents and collisions involving light and heavy trucks, focusing on their distribution by region, road type, incident category, and location. The analysis highlights noticeable regional differences, with the highest numbers of incidents occurring in central and southern Poland, particularly in voivodeships characterised by high traffic volumes and dense infrastructure. Particular attention is given to incidents on motorways and expressways, which, although representing a relatively small proportion of the total network, account for a disproportionate share of truck-related accidents. Furthermore, the study explores typical incident scenarios, showing that side and rear-end collisions are most common, whereas accidents involving pedestrians or head-on collisions are often more severe. The paper also addresses the financial consequences of such events, estimating the cost of road infrastructure restoration resulting from damage caused by heavy goods vehicles. The findings suggest the need for a more differentiated and spatially focused approach to safety management in freight transport, one that accounts for both traffic dynamics and the vulnerability of specific road users and infrastructure.

Keywords: freight transport, restoration costs, road accidents, road collisions, transport safety.

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1. INTRODUCTION

Freight road transport plays a crucial role in the logistics and economy of Poland, accounting for a dominant share of the total cargo movement. In 2022, road transport carried 86.8% of the total cargo volume, significantly outperforming other transport modes such as rail, maritime, and air transport [1]. However, the expansion of road transport is accompanied by growing concerns about road safety, especially concerning heavy goods vehicles (HGVs), which are involved in a considerable number of accidents and collisions each year.

This study focuses on road incidents involving freight vehicles in Poland, aiming to examine not only their frequency and primary causes, but also their broader consequences for safety and infrastructure. The analysis is based on datasets from the Accident and Collision Recording System (SEWiK), administered by the Polish National Police Headquarters, and complemented by statistical data from Statistics Poland (GUS). These sources provide a solid empirical foundation for evaluating the current state of safety in road freight transport.

A key element of the research is the identification of regional variations in the occurrence of accidents, with particular attention paid to areas that consistently report higher levels of risk. In addition to mapping the scale and distribution of these incidents, the paper explores their economic and infrastructural impact, notably, the financial costs associated with repairing damaged road infrastructure.

To support the spatial analysis, the study introduces several contextual indicators, including accident rates relative to road length, transported freight volume, and population. This approach makes it possible to identify structural patterns of risk and infrastructure vulnerability across Poland's voivodeships.

On this basis, the paper addresses the following research questions:

1. What is the share of freight vehicles in the total number of road incidents, including those on high-capacity roads, and how does the severity of these incidents compare to overall road safety outcomes?
2. What regional differences can be observed in the frequency and impact of these incidents, and what underlying factors may explain them?
3. What kinds of accidents involving freight vehicles occur most frequently, and how do they vary in terms of severity and consequences?
4. What are the estimated regional costs of infrastructure damage linked to freight transport, and how unevenly are these costs distributed?

In the authors' view, it is worth emphasizing that despite the dominant role of road transport in handling freight traffic, this sector has so far received relatively limited attention in road safety research. While numerous studies have focused on passenger transport, urban mobility, or vulnerable road users, the specific risks, operational conditions, and safety consequences of freight transport remain underexplored. This research gap is particularly important given the stable yet consistently high volume of freight transport, and its sustained impact on road infrastructure and traffic safety. A more systematic and data-driven approach to studying safety issues in freight transport is therefore both timely and necessary.

2. LITERATURE REVIEW

Improving road safety for all traffic participants is one of the main priorities of the national transport policy, as reflected in numerous government documents, including the National Road Safety Program 2021-2030 [1], the Safe Road Infrastructure Program 2021-2024 [2], and the Sustainable Transport Development Strategy 2030 [3].

Road Traffic Safety is a comprehensive set of actions, measures, and strategies aimed at minimizing the risk of traffic accidents and their consequences for road users [4-6]. In the literature, this concept is defined in various contexts: (i) as a state of risk reduction for accidents, directly referring to the level of hazards in road traffic and the consequences of these hazards, such as the number of fatalities and injuries [7], (ii) as a set of organizational and technical measures, including legal regulations, traffic management, preventive actions, and monitoring systems [8], (iii) as a culture of transport safety, which integrates social awareness, ethical norms, and the responsibility of road users [9].

The costs associated with accidents in passenger transport – both in individual and public road transport – have been extensively discussed in various thematic reports, available on the websites of the National Road Safety Council and the Polish Road Safety Observatory. However, the issue of costs related to road incidents in freight transport has not received as much attention from road safety experts. Meanwhile, due to the systematically increasing intensity of freight transport and its significant impact on the economy and society, this topic is of great importance and deserves thorough research and detailed analysis of the results [10].

Freight transport is one of the main sources of losses in supply chains, leading to a reduction in economic resources, both material and immaterial [11]. The pursuit of profit maximization by transport company owners often comes at the expense of compliance with road traffic regulations, particularly concerning driver working hours. Such practices frequently lead to dangerous road incidents, with driver fatigue being the primary cause of accidents. Studies suggest that integrating technology, such as telematics and AI-based predictive analytics, can enhance fleet management and reduce accident rates [12, 13].

Research by Adachi et al. [14] showed that mental and physical workload from different traffic environments induces distinct driver fatigue patterns. EEG-based experiments confirmed a significant increase in theta- and alpha-band spectral activity in urban and congested driving conditions, associated with cognitive and operational demands. This suggests a strong link between complex traffic conditions and reduced driver alertness.

In the Polish context, Jamroz and Smolarek [15] analysed fatigue-related accidents on national roads between 2003 and 2007. Their findings indicated that over 60% of such incidents occurred on national roads, especially in the morning and on weekends. Fatigue-related accidents accounted for up to 5% of all road fatalities and were most severe in head-on collisions and run-off-the-road events. The authors emphasized the lack of rest areas and the importance of proper scheduling and monitoring to mitigate fatigue.

These findings are well-aligned with the study of Mollicone et al. [16], who used a biomathematical model to predict driver fatigue and linked it with the incidence of hard-braking events – a proxy for accident risk. Their analysis of over 7300 hours of driving by 106 truck drivers revealed that a one-unit increase in predicted fatigue raised the risk of a hard-braking event by 7.8%. For the most fatigued drivers, the risk of a hard-braking event more than doubled. This study reinforces the evidence that fatigue significantly impairs driving performance and underlines the potential of data-driven fatigue management systems in commercial road transport.

Previous studies highlight the complex and multifaceted nature of freight transport safety, emphasizing the crucial role of infrastructure, education, weather conditions, and road user behaviour in mitigating risks [17-21]. According to Khadka et al. [22], the demanding nature of truck driving makes it one of the most high-risk professions in terms of fatality rates. Research by Koetse & Rietveld [23] indicates that extreme weather conditions, such as rain, snow, and fog, significantly increase the likelihood of accidents, particularly on highways and rural roads, while also causing delays and escalating operational risks for freight carriers. Similarly, Camp et al. [24] stress that poor road conditions, a lack of designated rest areas, and inadequate signage contribute to higher accident risks for heavy goods vehicles (HGVs). Their findings suggest that strategic infrastructure improvements, including dedicated truck lanes and smart road technologies, are essential for enhancing safety in freight transport and reducing accident rates.

These conclusions are supported by more recent studies focusing on specific high-risk categories in freight transport. Batarlienė [25] emphasizes the unique hazards associated with the transport of dangerous goods, where even isolated incidents can result in disproportionate economic and environmental damage. This is often due to inadequate vehicle equipment, improper routing, and insufficient training of drivers handling hazardous materials. Similarly, Davidović et al. [26] draw attention to the prevalence of driver fatigue as a major accident factor. Their studies highlight structural shortcomings such as overloaded or absent rest areas and long duty periods without adequate recovery, especially on national roads. Neurophysiological research by Adachi et al. [14] confirms these findings at the cognitive level, demonstrating that fatigue from monotonous or congested driving conditions severely impairs driver alertness and response times. Together, these findings reinforce the notion that improving safety in freight transport requires a systemic approach – targeting not only road and vehicle infrastructure but also organizational practices and human factors.

3. METHODS

Research on road accidents and collisions in freight transport was conducted using a three-stage research procedure, which included: 1) an analysis of road freight transport performance in 2022, 2) the identification and classification of road incidents involving road freight transport in 2022, 3) an estimation of the costs of restoring road infrastructure damaged due to road incidents in road freight transport in 2022.

In the first stage, the performance results of road freight transport, as published by the Statistics Poland [1], were analysed. The analysis covered freight transport in both commercial and business operations, considering the structure of transported commodity groups, transport directions, and the share of transport across different distance zones.

In the second stage, a desk research study was conducted to provide a detailed characterisation of road incidents involving road freight transport. The analysis was based on data from the Accident and Collision Records System for 2022, covering three groups of vehicles: 1) trucks with a *GVW* of up to 3.5 tons, 2) vehicles exceeding 3.5 tons, and 3) vehicles transporting hazardous materials. The analysis was carried out in the following sequence: 1) general characteristics of road incidents, 2) characteristics of road accidents, 3) characteristics of road collisions, and 4) typology and location of road incidents. Spatial and indicator-based approaches were used to identify regional disparities and evaluate infrastructure-related risks. These included: the number of incidents per 1,000 km of public roads, the number of incidents per million tons of transported freight and the number of incidents per 100,000 inhabitants. In addition, the share of freight-related incidents in the total number of national road accidents and collisions was calculated. Key safety indicators such as fatality rate and injury rate were also included to assess the relative severity of incidents involving freight vehicles. Additionally, traffic intensity indicators were calculated to contextualise the frequency of freight-related road incidents. A correlation analysis using Pearson's coefficient was performed in SPSS software (significance threshold $p < 0.05$).

In the third stage, data on infrastructure damage caused by freight-related incidents were collected directly from road authorities through formal public information requests. Each authority received a detailed inventory of recorded infrastructure damage and was asked to provide associated cost estimates. Despite a high number of refusals or incomplete responses, data were successfully obtained from 34 road authorities. These responses formed the basis for calculating infrastructure restoration costs.

To ensure the reliability of the cost assessment, descriptive statistical analysis was performed on the collected cost data. This included measures of central tendency (mean, median), dispersion (standard deviation, quartiles), and range. Due to high variability and the presence of outliers, a trimmed mean (excluding 5% of extreme values from both ends of the distribution) was also calculated. This adjusted cost formed the basis for estimating total national damage costs. In addition, two contextual unit indicators were calculated for each voivodeship: cost of infrastructure restoration per 1,000 tons of transported freight, and cost per 1,000 km of public roads. These indicators allowed for a comparative evaluation of infrastructure vulnerability and exposure relative to regional transport activity and network scale.

All contextual indicators were based on official data from Statistics Poland, including freight volumes, road network length, and population figures [1, 28]. Spatial data analysis and map generation were supported by QGIS.

4. RESEARCH RESULTS

4.1. ROAD FREIGHT TRANSPORT OPERATIONS IN 2022

According to data from the Statistics Poland, in 2022, a total of 2,277.1 million tons of cargo was transported across all modes of transport, marking a 1.1% increase compared to the previous year. The transport performance reached 497.8 billion ton-kilometres, reflecting a 1.3% growth compared to 2021.

Analysis of Table 1 indicates an increase in the volume of transported cargo in road, pipeline, and air transport, while declines were recorded in rail, maritime, and inland waterway transport. In terms of transport performance, a decrease was observed in road transport and inland waterway shipping.

Despite the decline in transport performance in road freight transport, it remains the dominant mode of transport. In 2022, road transport accounted for 86.8% of the total transported cargo mass and 81.7% of the total transport performance. Compared to other modes of transport, road freight carried over 8 times more cargo (in thousand tons) than rail transport, 230 times more than maritime transport, and nearly 17,000 times more than air transport.

Table 1. Freight transport by mode of transport; source: [1]

No.	Mode of transport	2021	2022	2021 = 100	2021	2022	2021 = 100
		Thousand tons		%	Million ton-km		%
1	Rail transport	237,915	237,587	99.9	54,387	59,306	109.0
2	Road transport	1,952,465	1,976,278	101.2	410,224	406,902	99.2
3	Pipeline transport	49,854	52,591	105.4	18,428	19,132	103.8
4	Maritime transport	9,587	8,442	88.0	7,554	11,602	153.6
5	Inland waterway transport	3,465	2,076	59.9	493	445	90.3
6	Air transport	91	119	131.2	341	445	130.6
7	Total	2,253,377	2,277,093	101.1	491,427	497,832	101.3

The data presented in Table 1 pertain to road transport in both economic and commercial activities. Economic transport refers to freight transport carried out for a company's own needs, with the costs included in its operational expenses. Commercial transport involves the paid provision of transport services to other business entities. Since 2003, this category has also included services provided by companies for which freight transport is not the primary business activity. Within commercial transport, data have been specifically separated for road transport enterprises, referring to companies whose core business is transportation services.

In 2022, compared to the previous year, domestic transport recorded an increase of 1.2% in tons and 1.4% in ton-kilometers. On the other hand, international transport recorded a 0.4% decline in tonnage, while transport performance remained at a similar level. Domestic transport accounted for approximately 79% of the total tonnage handled in road transport in 2022.

An analysis of 2022 freight transport data by distance zones for domestic transport indicates that the largest share of transport (46.3%) occurred over distances of up to 49 km, representing nearly half of the total transported cargo mass. The smallest share of transported goods was recorded for distances of 500 km or more, accounting for only 2.5% of the total volume.

The distribution of freight transport by distance zones in 2022 is illustrated in Fig. 1. Based on this graph, it can be concluded that the share of transported cargo (measured in tonnage) decreases as the distance between the loading and unloading points increases.

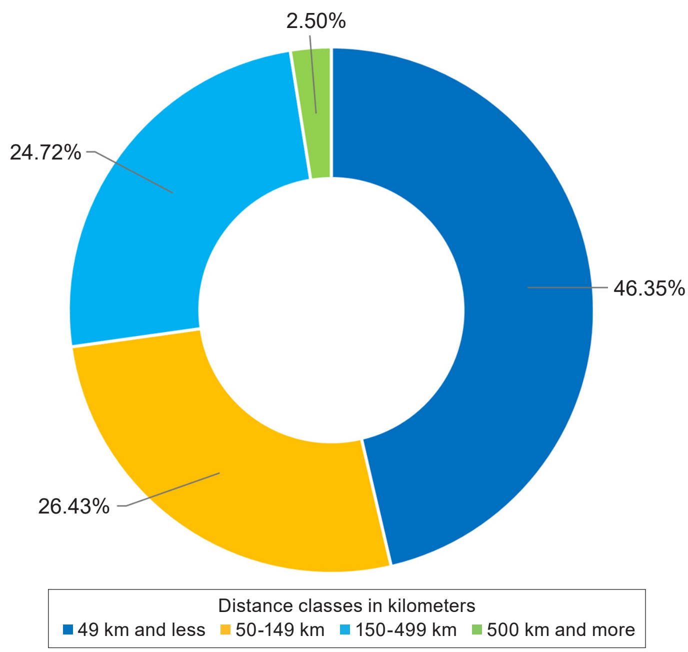

Fig. 1. Share of freight transport in domestic transport by distance zones in 2022; source: [1]

4.2. ROAD ACCIDENTS AND COLLISIONS IN 2022

4.2.1. General characteristics of road incidents

Based on the analysed data, in 2022, there were 61,929 collisions and 3,016 road accidents involving trucks with a gross vehicle weight *GVW* of up to 3.5 tons and over 3.5 tons in Poland. As a result of these accidents: 123 people lost their lives and 1,114 people were injured. Detailed data on road incidents involving trucks are presented in Fig. 2.

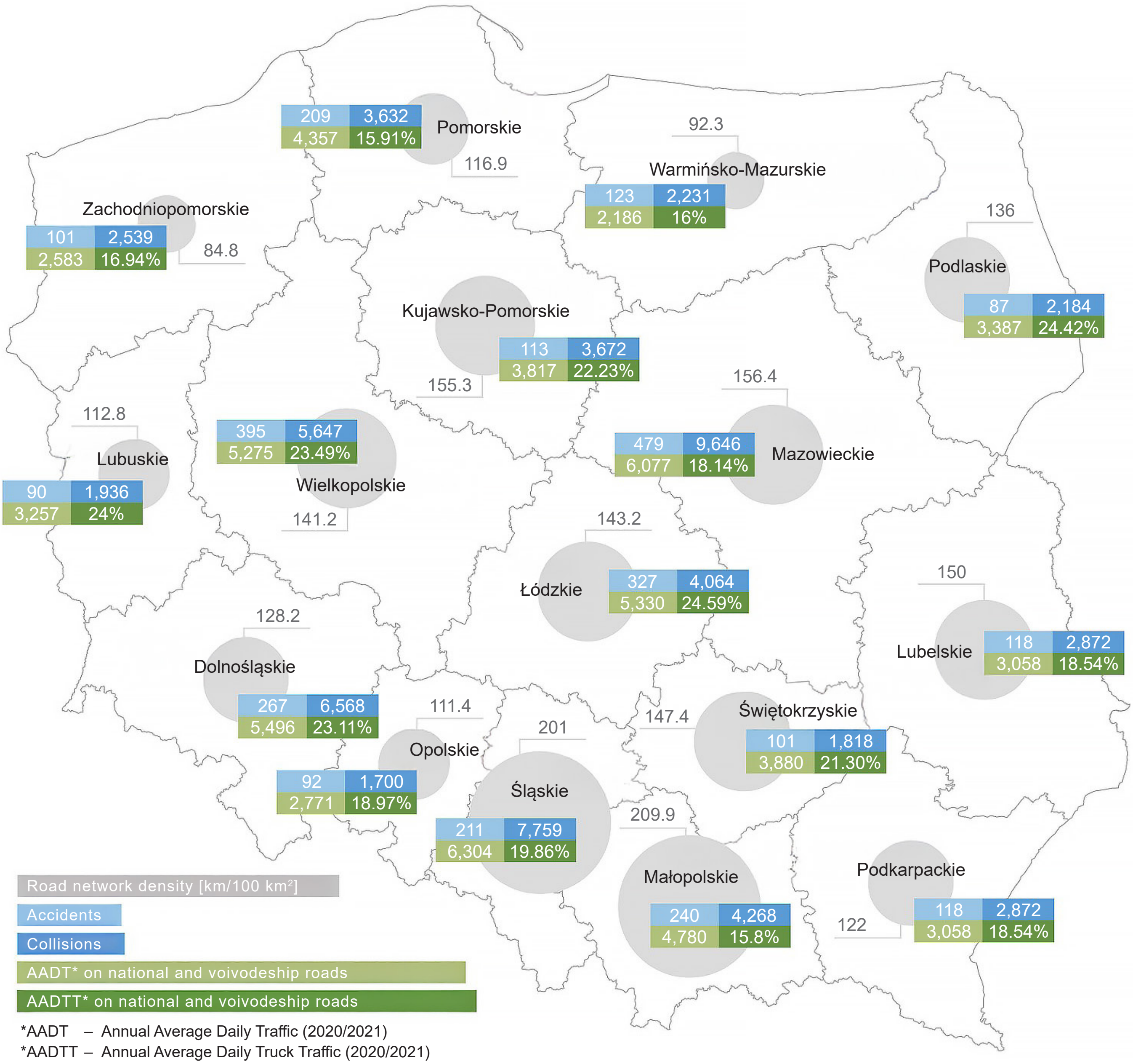

Fig. 2. Road accidents, collisions, traffic volume, share of heavy vehicles in total traffic, and road network density in Poland by voivodeship; source: [1, 29]

The analysis by voivodeships (provinces) revealed significant disparities. Mazowieckie Voivodeship recorded both the highest number of accidents (479) and collisions (9,646). In contrast, Podkarpackie Voivodeship had the lowest number of accidents (63), meaning the difference between these two regions was more than sixfold. A similar trend was observed for collisions, with Mazowieckie having over five times more incidents than Podkarpackie (1,393 collisions).

The highest number of fatalities was recorded in Śląskie Voivodeship (25 deaths). In contrast, Lubuskie Voivodeship had the lowest number of fatalities (only 2 deaths). This represents a more than tenfold difference, highlighting significant disparities in road safety across different regions.

The highest number of injuries was also recorded in Śląskie Voivodeship (189 injuries), making it the leading region in both fatalities and injuries. In contrast, the lowest number of injuries was reported in Podlaskie Voivodeship (20 injuries), which is eight times fewer than in Śląskie.

Mazowieckie and Śląskie Voivodeships clearly dominate in terms of the number of accidents and casualties, which may be linked to their high population density and heavy traffic volume. On the other hand, Podkarpackie, Lubuskie, and Podlaskie Voivodeships recorded the lowest values in the analysed categories, suggesting a relatively higher level of road safety in these regions.

Beyond the number of incidents, the analysed data also reveal significant differences in traffic structure and infrastructure conditions across regions. Voivodeships such as Łódzkie, Lubuskie, and Wielkopolskie show a particularly high share of heavy vehicles in total traffic, exceeding 23%, which underlines their importance in freight transit. At the same time, regions with the densest road networks (e.g., Śląskie, Małopolskie) often report higher numbers of incidents, possibly due to more complex traffic systems and urban congestion. In contrast, areas such as Warmińsko-Mazurskie or Podlaskie, with sparse networks and low traffic volumes, register fewer accidents but may face challenges related to accessibility and emergency response.

The data presented in Table 2 illustrate the scale and characteristics of road traffic incidents involving freight transport vehicles in 2022. These vehicles were involved in a notable share of incidents, accounting for 14.16% of all accidents and 17.09% of all collisions. However, their share in total fatalities (6.49%) and injuries (4.50%) was much lower compared to their overall involvement in road incidents. This indicates that, while freight vehicles are frequently involved in road crashes, such incidents are generally less injurious or fatal than those involving other vehicle categories, particularly passenger cars. This conclusion is supported by the relative indicators presented: the fatality rate and the injury rate. In comparison to the overall road traffic data, accidents involving freight transport vehicles show a more than twofold lower fatality rate and over three times lower injury rate per accident. One possible explanation for these findings is that freight vehicles tend to operate more often on national roads, expressways, and motorways, routes characterized by a higher technical standard, limited access, and grade-separated intersections, often subject to enhanced monitoring and enforcement. This traffic pattern reduces exposure to high-risk scenarios, especially head-on and side-impact collisions at intersections, which are statistically among the most severe types of road accidents.

Table 2. Structure of road traffic incidents involving freight transport vehicles compared to all road incidents in 2022; source: [27].

No.	Specification	Road incidents in freight transport	Total road incidents	Share in total incidents [%]
1	Road accidents	3,016	21,322	14.16
2	Road collisions	61,929	362,266	17.09
3	Number of fatalities	123	1,896	6.49
4	Number of injured persons	1,114	24,743	4.50
5	Fatality rate*)	4.07	8.89	–
6	Injury rate**)	36.91	116.08	–

Explanatory notes:
*) Fatality rate =
= (number of fatalities / number of accidents) × 100
**) Injury rate =
= (number of injured persons / number of accidents) × 100

Table 3 presents data related to the occurrence of road accidents and collisions on motorways and expressways in Poland. In total, 403 accidents and 7,451 collisions were reported on these two types of roads, which together comprise nearly 4,900 km of the national road network. When related to all truck-involved road incidents recorded in 2022, it is worth noting that motorways and expressways accounted for 13.4% of all truck-related accidents and 12% of all truck-related collisions, despite their relatively limited share in the total road length. Particularly insightful data are provided by the analysis normalised per 1,000 km of road length. In this perspective, motorways exhibit significantly higher rates of both accidents and collisions compared to expressways. In 2022, there were 118 accidents and over 2,260 collisions per 1,000 km of motorway, while expressways recorded only 62 accidents and approximately 1,100 collisions per 1,000 km.

Although these figures may initially appear to contradict the earlier conclusion regarding the relative safety of roads used by freight vehicles, they in fact reflect different aspects of road safety. Table 3 highlights the density of incidents per road length, which tends to be higher on motorways, likely due to greater traffic volumes and higher operating speeds.

Table 3. Number of road accidents and collisions on motorways and expressways in Poland in 2022 and their intensity per 1,000 km of network length

No.	Type of road	Total lenght [km]	Total accidents	Total collisions	Accidents per 1,000 km type of road[*)]	Collisions per 1,000 km type of road[**)]
1	Motorway	1,801.8	213	4,079	118.22	2,263.85
2	Expressway	3,070.2	190	3,372	61.89	1,098.30
3	Total	4,872	403	7,451	82.72	1,529.35

Explanatory notes:
[*)] Accidents per 1,000 km type of road = (number of accidents / total length) × 1,000;
[**)] Collisions per 1,000 km type of road = (number of collisions / total length) × 1,000;

However, Table 2 focuses on the severity of incidents, namely, the fatality and injury rates, which remain significantly lower for freight-related accidents. This suggests that, while incidents may be more frequent on high-standard roads, their outcomes tend to be less severe. Features such as controlled access, median separation, and higher design standards contribute to mitigating the consequences of crashes involving freight vehicles, thus supporting the earlier conclusion that the technical characteristics of roads play a crucial role in reducing the risk of serious injury or death.

4.2.2. Characteristics of road accidents in 2022

The total number of accidents involving freight vehicles across all provinces in 2022 was 3,016, with an average of approximately 73.6 incidents per province. The highest number of accidents was recorded in the Mazowieckie province, where 479 accidents were reported, accounting for nearly 16% of all accidents in Poland. The Wielkopolskie province accounted for over 13% of the total number of accidents, placing it second in the country. Among all vehicle categories, light trucks with a *GVW* of up to 3.5 tons were the most frequently involved in accidents, accounting for over 55%. Heavy trucks with a *GVW* of more than 3.5 tons constituted nearly 45%, while accidents involving vehicles transporting hazardous materials accounted for only 0.3%. It should be noted that the last group of vehicles does not fully reflect the actual scale of accidents due to incomplete available data.

The analysis of road accidents by voivodeship and vehicle type, presented in Table 4, indicates that the highest number of incidents was recorded in the Mazowieckie Voivodeship, with a total of 479 accidents. This figure is significantly higher compared to other provinces, which may be attributed to high traffic volume and the presence of numerous major transportation routes. The Dolnośląskie province recorded 267 accidents, also placing it among the top regions with a high incidence of road accidents. Despite its smaller area, the traffic volume in this region is considerably higher.

The analysis shows that light trucks with *GVW* of up to 3.5 tons are the most frequently involved in accidents across all provinces. In Mazowieckie, the number of such accidents reached as high as 284, while in Dolnośląskie, it amounted to 130. This category of vehicles is particularly important from a road safety perspective, as they play a crucial role in the transportation of goods over short and medium distances.

Heavy trucks with a *GVW* of more than 3.5 tons also have a significant share in accident statistics. In the Mazowieckie province, 193 such incidents were recorded, while in Dolnośląskie, the number reached 137. Their involvement may be linked to the high volume of heavy vehicle traffic on both international and national roads. Vehicles transporting hazardous materials were involved in accidents only sporadically, with the highest number – two incidents – recorded in both the Mazowieckie and Pomorskie Voivodeships.

The distribution of accidents across provinces and vehicle categories highlights regional differences in traffic intensity and the types of vehicles in use. Smaller provinces, such as Lubuskie and Kujawsko-Pomorskie, have a lower number of accidents, which may be a result of lower road infrastructure congestion. However, in these regions, the share of accidents involving heavy vehicles remains noticeable.

Table 4. Road accident statistics by voivodeship and type of vehicle

No.	Voivodeship	Vehicle transporting dangerous goods	Truck with *GVW**) up to 3.5 t	Truck with *GVW**) over 3.5 t	Total accidents
1	Dolnośląskie	n/a	130	137	267
2	Kujawsko-Pomorskie	n/a	53	60	113
3	Lubelskie	0	69	49	118
4	Lubuskie	n/a	43	47	90
5	Łódzkie	n/a	172	155	327
6	Małopolskie	0	153	87	240
7	Mazowieckie	2	284	193	479
8	Opolskie	1	42	49	92
9	Podkarpackie	n/a	47	16	63
10	Podlaskie	1	44	42	87
11	Pomorskie	2	109	98	209
12	Śląskie	0	133	78	211
13	Świętokrzyskie	n/a	47	54	101
14	Warmińsko-Mazurskie	1	67	55	123
15	Wielkopolskie	n/a	223	172	395
16	Zachodniopomorskie	1	57	43	101

Explanatory notes:
*) *GVW* – Gross Vehicle Weight; n/a – not applicable

Table 5. Regional distribution of road freight accidents in Poland in 2022 and accident rates per 1,000 km of public roads; source: own research and [1]

No.	Voivodeship	Total accidents	Public roads in absolute numbers	Accidents per 1,000 km of roads*)
1	Dolnośląskie	267	25,562.7	10.44
2	Kujawsko-Pomorskie	113	27,911.6	4.05
3	Lubelskie	118	37,695.0	3.13
4	Lubuskie	90	15,778.0	5.70
5	Łódzkie	327	22,306.6	14.66
6	Małopolskie	240	31,870.0	7,53
7	Mazowieckie	479	55,616.8	8,61
8	Opolskie	92	10,487.7	8.77
9	Podkarpackie	63	21,770.2	2.89
10	Podlaskie	87	27,452.3	3.17
11	Pomorskie	209	21,442.4	9.75
12	Śląskie	211	24,797.1	8.51
13	Świętokrzyskie	101	17,261.2	5.85
14	Warmińsko-Mazurskie	123	22,306.6	5.51
15	Wielkopolskie	395	42,127.3	9.38
16	Zachodniopomorskie	101	19,416.1	5.20
17	Total	3,016	427,580.30	7.05

Explanatory notes:
*) Accidents per 1,000 km of roads = (Total number of accidents / Total length of public roads in km) × 1,000

Table 5 presents the regional distribution of road freight accidents in Poland in 2022, along with standardized accident rates per 1,000 kilometers of public roads. The calculated indicator allows for the assessment of accident intensity relative to the extent of road infrastructure across voivodeships, enabling fairer comparisons regardless of region size. It is worth noting that the Pearson correlation coefficient revealed a strong positive relationship ($r = 0.730$, $p < 0.001$) between the length of national roads and the total number of accidents involving freight vehicles. This supports the conclusion that the number of such incidents increases with the expansion of road infrastructure. This relationship is most likely driven by higher traffic volumes and the strategic transport role of regions with more developed road networks.

The national average rate was 7.05 accidents per 1,000 km, with significant variation among regions. The highest accident rate was observed in the Łódzkie Voivodeship (14.66), followed by Dolnośląskie (10.44), Pomorskie (9.75), and Wielkopolskie (9.38) voivodeships. These values may reflect a combination of heavy freight traffic, infrastructure congestion, and high exposure on major transport corridors.

In contrast, the lowest accident rates were recorded in Podkarpackie (2.89), Lubuskie (3.13), and Podlaskie (3.17) voivodeships. These regions may benefit from lower traffic volumes, less intensive freight movement, or more dispersed infrastructure.

Notably, Mazowieckie Voivodeship, despite recording the highest absolute number of accidents (479), remained only moderately above the national average in terms of relative intensity (8.61), likely due to its extensive road network. This highlights the importance of using standardized indicators for balanced regional assessment.

Fig. 3 illustrates the relationship between the volume of freight transported (in thousand tons), based on the voivodeship-level balance of goods road transport in 2022 [1], and the number of road accidents involving freight vehicles across Polish voivodeships. A clear positive association is visible: regions with higher freight activity tend to report more accidents. This visual trend is confirmed by Pearson's correlation coefficient, which indicates a very strong and statistically significant linear relationship ($r = 0.899$, $p < 0.001$) between the two variables. The result suggests that increased freight activity is closely linked to a higher frequency of road incidents. However, despite the strength of this monotonic relationship, certain regions deviate from the general pattern. Notably, Śląskie Voivodeship demonstrates a lower-than-expected accident count given its high freight transport volume (over 136 million tons and only 211 accidents). This may reflect better traffic management, infrastructure efficiency, or urban transport planning, which reduce exposure to risk despite high freight intensity. In contrast, Łódzkie Voivodeship exhibits a disproportionately high number of accidents (327) compared to its freight volume, which may be attributed to network congestion, central logistical location, or urban exposure. These exceptions highlight that, although freight volume is a key explanatory factor, road safety outcomes are also shaped by regional characteristics such as infrastructure quality, enforcement policies, and spatial distribution of traffic.

The data in Table 6 reveal noticeable regional differences in the number of freight-related road accidents when adjusted for both freight volume and population size. Nationally, the average number of accidents per million tons of transported freight was 2.23, while the average number of accidents per 100,000 inhabitants stood at 7.99.

The indicator of accidents per million tons of transported freight complements the earlier analysis, in which the absolute number of accidents was compared against the volume of freight transported (in thousand tons). This normalization enables a more precise assessment of accident intensity in relation to transport activity, allowing for the identification of regions where safety risks are disproportionately high relative to the volume of cargo moved. The conducted analysis shows that the highest values of the indicator of accidents per million tons of transported freight were recorded in the Lubuskie (3.68), Dolnośląskie (2.87), and Śląskie (2.64) voivodeships. These elevated figures indicate that the frequency of accidents in these regions is disproportionately high relative to the volume of freight transported. This may be attributed to infrastructure overload, challenging terrain, or high traffic density along major industrial and transit corridors. In contrast, the lowest values were observed in the Podkarpackie (1.06) and Świętokrzyskie (1.61) voivodeships, which may suggest lower freight transport intensity or more favorable safety conditions in relation to the scale of cargo operations.

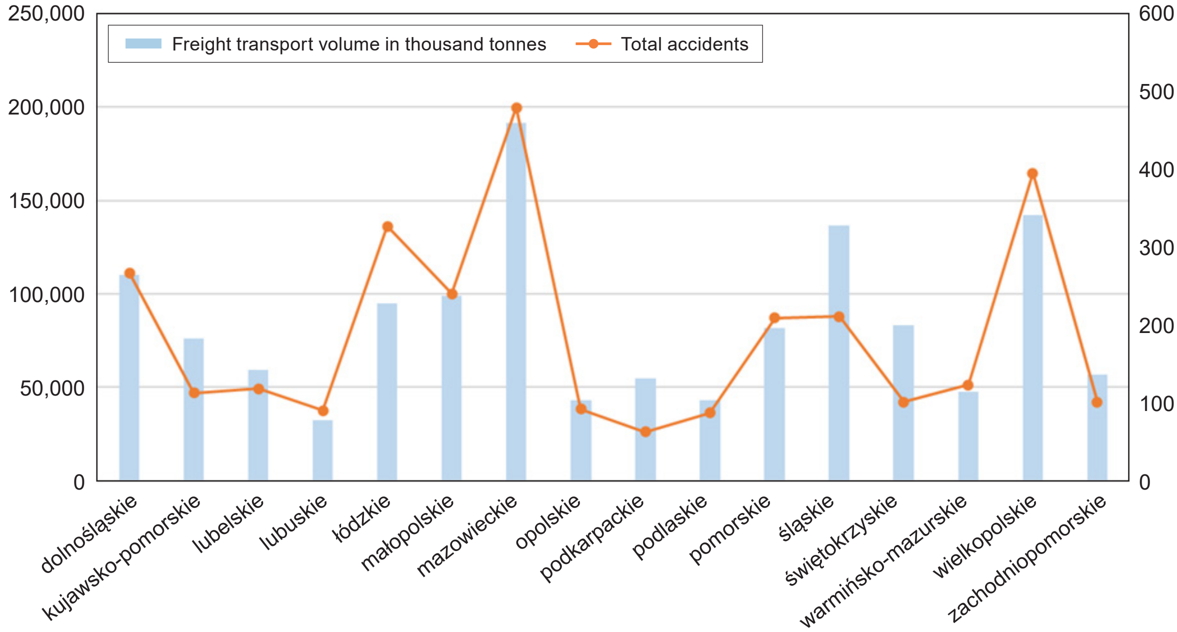

Fig. 3. Freight transport volume and road accident counts by voivodeship

Table 6. Regional distribution of road accidents involving freight vehicles in 2022 by voivodeship, including rates per million tons of freight and per 100,000 inhabitants

No.	Voivodeship	Total accidents	Accidents per million tons of freight*)	Accidents per 100,000 people**)
1	Dolnośląskie	267	2.87	10.94
2	Kujawsko-Pomorskie	113	2.32	8.77
3	Lubelskie	118	2.37	6.96
4	Lubuskie	90	3.68	12.25
5	Łódzkie	327	2.53	10.13
6	Małopolskie	240	2.25	6.50
7	Mazowieckie	479	2.20	7.64
8	Opolskie	92	2.02	9.23
9	Podkarpackie	63	1.06	2.79
10	Podlaskie	87	2.25	8.48
11	Pomorskie	209	2.45	8.48
12	Śląskie	211	2.64	8.28
13	Świętokrzyskie	101	1.61	11.37
14	Warmińsko-Mazurskie	123	2.57	9.00
15	Wielkopolskie	395	2.24	9.10
16	Zachodniopomorskie	101	2.40	8.29
17	Total	3,016	2.23	7.99

Explanatory notes:
*) Accidents per million tons of freight = (Total number of accidents / Freight volume) × 1,000,000
**) Accidents per 100,000 people = (Total Number of Accidents / Population) × 100,000

When population is taken into account, Lubuskie (12.25), Dolnośląskie (10.94), and Świętokrzyskie (11.37) voivodeships show the highest accident rates per 100,000 residents, highlighting potential risks in regions with relatively smaller populations but significant freight traffic. On the other hand, Podkarpackie (2.79), Lubelskie (6.96), and Małopolskie (6.50) demonstrate the lowest per capita accident ratios, suggesting either less exposure to freight-related incidents or more distributed traffic networks.

4.2.3. Characteristics of road collisions

Table 7 presents the number of road collisions involving freight vehicles in Poland in 2022, broken down by voivodeship and vehicle type. The analysis reveals significant regional disparities in collision frequency, both in absolute terms and in relation to the national average.

The mean number of collisions per voivodeship was 3,870.6, while the median was lower at 3,252, indicating a right-skewed distribution. The highest number of collisions was recorded in the Mazowieckie Voivodeship (9,646), exceeding the national average by nearly 150%, followed by the Śląskie Voivodeship (7,759), which also exceeded the average by about 100%. In contrast, the Podkarpackie Voivodeship had the lowest number of collisions (1,393), representing a value 64% below the national mean. These differences may reflect diverse factors such as freight traffic intensity, infrastructure design, and regional economic and transport structures.

Regarding vehicle type, Table 7 indicates that: light trucks ($GVW \leq 3.5$ tons) were involved in 32,308 collisions, accounting for 52.2% of all recorded incidents, heavy trucks ($GVW > 3.5$ tons) were involved in 29,461 collisions, representing 47.6% of the total and vehicles transporting dangerous goods were involved in only 160 collisions (0.3%), with no incidents reported in several voivodeships (e.g., Kujawsko-Pomorskie, Lubuskie, Podkarpackie).

Although hazardous materials vehicles appear only marginally in the statistics, they require particular attention due to their potentially serious consequences in case of accidents. It is also likely that the low figures reflect underreporting or limited availability of disaggregated data for this category.

Table 7. Number of road collisions involving freight vehicles by voivodeship and vehicle type in 2022

No.	Voivodeship	Vehicle transporting dangerous goods	Truck with *GVW* up to 3.5 t	Truck with *GVW* over 3.5 t	Total collisions
1	Dolnośląskie	n/a	3,168	3,400	6,568
2	Kujawsko-Pomorskie	n/a	2,014	1,658	3,672
3	Lubelskie	n/a	1,505	1,367	2,872
4	Lubuskie	4	957	975	1,936
5	Łódzkie	n/a	2,061	2,003	4,064
6	Małopolskie	22	2,355	1,891	4,268
7	Mazowieckie	54	4,987	4,605	9,646
8	Opolskie	9	801	890	1,700
9	Podkarpackie	n/a	730	663	1,393
10	Podlaskie	19	943	1,222	2,184
11	Pomorskie	27	2,054	1,551	3,632
12	Śląskie	13	4,112	3,634	7,759
13	Świętokrzyskie	n/a	943	875	1,818
14	Warmińsko-Mazurskie	2	1,232	997	2,231
15	Wielkopolskie	n/a	3,087	2,560	5,647
16	Zachodniopomorskie	10	1,359	1,170	2,539
17	Total	160	32,308	29,461	61,929

Explanatory notes:
n/a – not applicable

The findings suggest that collision risk is not evenly distributed, and the type of vehicle plays an important role in shaping the overall collision profile across the country. This highlights the need for regionally tailored road safety policies, especially in high-density logistics hubs such as Mazowieckie and Śląskie Voivodeships.

Table 8 presents regional data on road collisions involving freight vehicles, based on three contextual indicators: the number of collisions per 1,000 km of public roads, the number of collisions per million tons of transported freight, and the number of collisions per 100,000 inhabitants. The first indicator allows for the assessment of the intensity of traffic incidents in relation to the size of road infrastructure. The national average for this measure was 146.13, with considerable variation across voivodeships. The highest values were observed in Śląskie (312.90), Dolnośląskie (256.94), and Łódzkie (182.19) voivodeships, which may indicate heavy freight traffic volumes and overstressed road networks. In contrast, the lowest values were recorded in Podkarpackie (63.99), Lubelskie (76.19), and Podlaskie (79.56), suggesting lower traffic intensity or more evenly distributed flows.

The third indicator (the number of collisions per 100,000 inhabitants) provides insight into the scale of road freight-related incidents from a social perspective, reflecting the potential exposure of local populations to such events. The national average was 163.98, but significant variation is observed across regions. The highest values were recorded in Dolnośląskie (227.42), Lubuskie (197.56), and Podlaskie (191.02) voivodeships. In the case of Dolnośląskie, this result is consistent with other contextual indicators: it also recorded a high number of collisions per 1,000 km of roads (256.94) and the highest national rate of collisions per million tons of transported freight (59.59). This convergence suggests a cumulative risk arising from intensive infrastructure use, a large freight volume, and high population exposure to incidents.

Table 8. Road collisions involving freight transport by voivodeship with relative safety indicators in 2022

No.	Voivodeship	Total collisions	Collisions per 1,000 km of roads*)	Collsions per million tons of freight**)	Collisions per 100,000 people***)
1	Dolnośląskie	6,568	256.94	59.59	227.42
2	Kujawsko-Pomorskie	3,672	131.56	48.41	182.97
3	Lubelskie	2,872	76.19	48.37	141.85
4	Lubuskie	1,936	122.70	59.29	197.56
5	Łódzkie	4,064	182.19	42.73	170.87
6	Małopolskie	4,268	133.92	43.12	124.47
7	Mazowieckie	9,646	173.44	50.40	175.04
8	Opolskie	1,700	162.09	39.47	180.38
9	Podkarpackie	1,393	63.99	25.45	67.00
10	Podlaskie	2,184	79.56	50.57	191.02
11	Pomorskie	3,632	169.38	44.48	154.01
12	Śląskie	7,759	312.90	56.80	178.59
13	Świętokrzyskie	1,818	105.32	21.81	154.31
14	Warmińsko-Mazurskie	2,231	100.02	46.60	163.27
15	Wielkopolskie	5,647	134.05	39.74	161.64
16	Zachodniopomorskie	2,539	130.77	44.81	154.76
17	Total	61,929	146.13	45.78	163.98

Explanatory notes:
*) Collisions per 1,000 km of roads = (Total Number of Collisions / Length of Public Roads in km) × 1,000
**) Collisions per million tons of freight = (Total number of collisions / Freight volume) × 1,000,000
***) Collisions per 100,000 people = (Total number of collisions / Population) × 100,000

In Lubuskie and Podlaskie, although these are not major industrial or logistics hubs, elevated collision rates per capita may be driven by relatively low population levels combined with high transit traffic, particularly along international corridors such as A2, S3, and S19. In such cases, even a moderate absolute number of collisions results in a high per capita ratio, disproportionately affecting local communities.

At the opposite end of the spectrum, the lowest collision rates per 100,000 inhabitants were noted in Podlaskie (67.00), Małopolskie (124.47), and Lubelskie (141.85) voivodeships. These regions also recorded relatively low values in the other two indicators, which may reflect a more balanced transport structure, lower share of heavy freight traffic, or more dispersed infrastructure networks. This indicator helps highlight areas where road safety issues have a particularly strong social impact and where safety interventions should be tailored to local demographic and spatial conditions.

4.2.4. Typology and location of road incidents

To gain deeper insights into road safety risks associated with freight transport, a detailed analysis was conducted of the types and locations of road incidents involving this type of vehicles. The analysis covers both accidents and collisions involving trucks with a *GVW* of up to 3.5 tons and over 3.5 tons, based on nationwide data from 2022.

Table 9 presents data on the types of road incidents involving freight vehicles in Poland in 2022. The analysis shows that the majority of incidents involving freight vehicles were classified as side collisions, accounting for 28.9% of all accidents and 39.4% of all collisions. These events most frequently occur during lane-changing, merging, or overtaking manoeuvres, particularly in congested traffic conditions and high-speed environments such as expressways and urban arterials. Other common types of incidents included rear-end collisions (25.8% of all incidents) and head-on collisions, which, although less frequent, were disproportionately represented among serious accidents due to their typically high severity. A significant share of accidents involving pedestrians (13.2%) highlights the elevated risk posed to vulnerable road users in interactions with freight vehicles, especially in urban areas. Additionally, frequent minor collisions were recorded in incidents involving stationary vehicles, guardrails, road signs, and animals, typically less severe in consequence, yet indicative of issues related to spatial awareness, fatigue, or limited manoeuvrability in constrained environments.

Table 9. Types of road incidents involving freight vehicles by *GVW*

No.	Type of incident	*HGV* of *GVW* ≤ 3.5 t		*HGV* of *GVW* > 3.5 t		*HGV*	
		Accidents	Collisions	Accidents	Collisions	Accidents	Collisions
1	Collision with a guardrail/barrier	12	386	20	762	32	1,148
2	Collision with a tree	49	195	11	135	60	330
3	Collision with a pothole, bump, hump	0	213	0	105	0	318
4	Collision with a pedestrian	282	238	116	68	398	306
5	Collision with a stationary vehicle	39	3,722	41	2,317	80	6,039
6	Collision with a pole, sign	5	628	5	1,072	10	1,700
7	Collision with a railway barrier	0	99	0	231	0	330
8	Collision with an animal	1	924	1	419	2	1,343
9	Vehicle overturn	61	384	43	571	104	955
10	Incident involving a user of a PMD	1	6	0	1	1	7
11	Incident involving a passenger	6	17	7	5	13	22
12	Side collision of vehicles	458	11,923	415	12,488	873	24,411
13	Head-on collision of vehicles	253	1,005	338	699	591	1,704
14	Rear-end collision of vehicles	412	9,764	327	5,643	739	15,407
15	Other	28	2,335	34	4,928	62	7,263
16	n/a**	18	255	33	391	51	646
17	Total	1,625	32,094	1,391	29,835	3,016	61,929

Explanatory notes: *) PMD – Personal Mobility Device; **) n/a – in this case, the circumstances of the incidents are unknown

Table 10 provides data on the locations of road incidents involving freight vehicles. The vast majority of both accidents and collisions occurred on the carriageway, accounting for 86.5% of all accidents and 88.8% of all collisions. This finding confirms that the main area of risk for freight vehicles lies in dynamic traffic flow situations, such as lane changes, overtaking, and braking, rather than at intersections or other conflict zones. A notable number of collisions also occurred in parking lots, squares, and motorway service areas (5.5% of all collisions), although these locations accounted for only a small number of accidents, indicating that incidents in these environments are generally minor and related to low-speed manoeuvring. In contrast, pedestrian crossings and sidewalks, while representing a smaller share of total incidents, were overrepresented in serious accidents, underscoring the vulnerability of pedestrians in freight transport environments. Additional incident locations of concern included road shoulders, temporary construction zones, and railway crossings, areas where limited space, changing road conditions, or multimodal interactions increase the likelihood of error or loss of control.

4.3. ROAD INCIDENTS RESULTING IN DAMAGE TO ROAD INFRASTRUCTURE

Fig. 4 presents data on the number of cases of road infrastructure damage resulting from road incidents in freight transport in 2022 across different provinces of Poland. Additionally, it includes information on the percentage share of damaged infrastructure in the total number of road incidents. Data analysis shows that the total number of infrastructure damage cases amounted to 7,532, which accounts for 12.12% of all road incidents. The highest number of road incidents leading to infrastructure damage was recorded in the Śląskie, Dolnośląskie, and Wielkopolskie provinces. Conversely, the lowest occurrence of such damage was noted in the Podkarpackie, Opolskie, and Pomorskie provinces. The results of the analysis indicate a strong and highly statistically significant correlation between the number of road incidents and the number of infrastructure damage cases (Pearson correlation = 0.91, $p < 0.001$). This high correlation suggests that in regions with a higher number of road incidents, the number of infrastructure damage cases also increases automatically. This may be due to both higher traffic intensity and the characteristics of local road infrastructure, which in some regions may be more susceptible to damage.

Table 10. Locations of road incidents involving freight vehicles by *GVW*

No.	Incident location	*HGV* of *GVW* ≤ 3.5 t		*HGV* of *GVW* > 3.5 t		*HGV*	
		Accidents	Collisions	Accidents	Collisions	Accidents	Collisions
1	Sidewalk, pedestrian path	30	331	6	183	36	514
2	Road, bicycle lane, bicycle box	10	153	4	142	14	295
3	Carriageway / Roadway	1,328	27,267	1281	27,704	2,609	54,971
4	Bridge, overpass, ramp, tunnel	11	190	3	223	14	413
5	Parking lot, square, motorway service area	13	1,677	0	1,759	13	3,436
6	Road median	2	33	2	74	4	107
7	Road shoulder	39	196	15	895	54	1,091
8	Bicycle crossing	25	40	13	10	38	50
9	Unprotected (unmanned) railway crossing	2	16	2	35	4	51
10	Protected (manned) railway crossing	1	90	0	195	1	285
11	Tram crossing, tram tracks	4	21	2	7	6	28
12	Pedestrian crossing	147	108	64	46	211	154
13	Crossover on dual carriageway	0	3	0	5	0	8
14	Public transport stop	1	19	1	30	2	49
15	Roadworks, temporary road signs	4	116	9	181	13	297
16	Embankment, ditch	11	118	6	175	17	293
17	Entrance/exit from property, field	11	181	5	220	16	401
18	Total	1,639	30,559	1,413	31,884	3,016	61,929

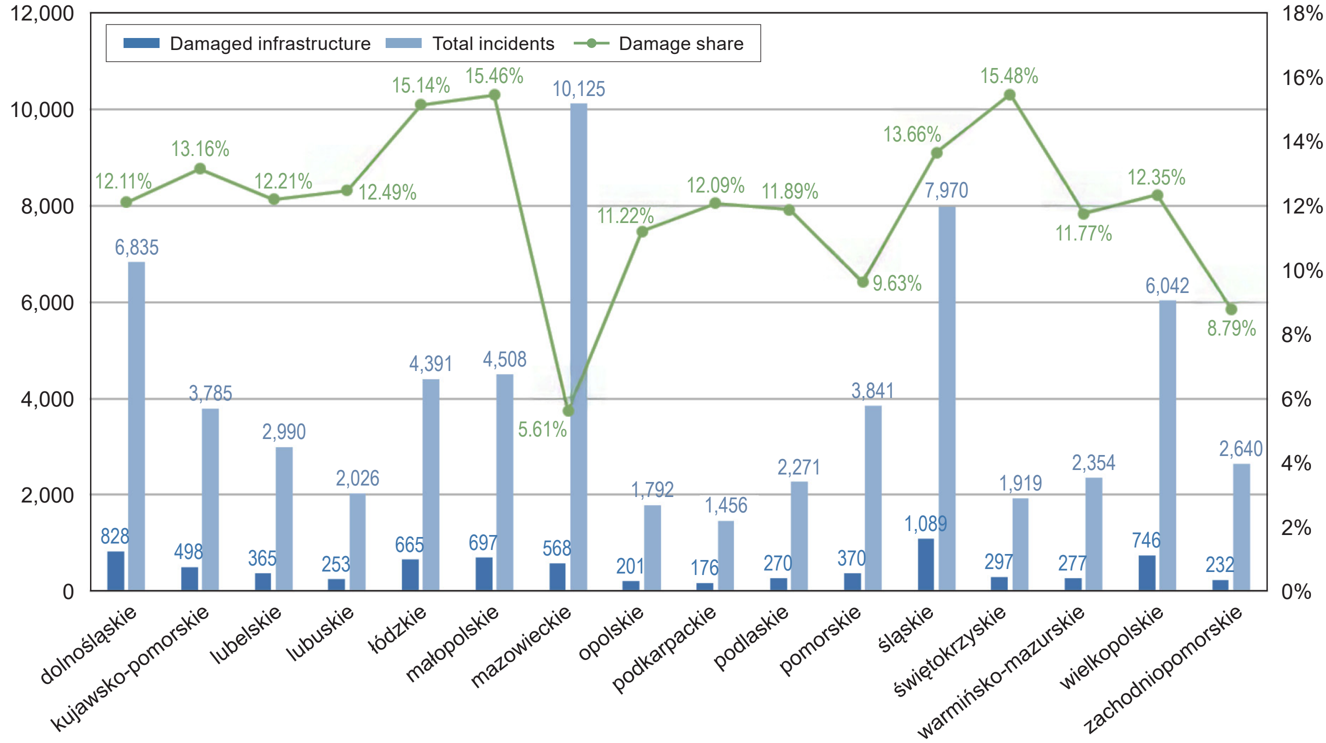

Fig. 4. Road incidents and damaged infrastructure by voivodeship in 2022

The research results indicate clear regional differences in the share of damaged road infrastructure in the total number of road incidents. The highest rates, significantly exceeding the national average (12.12%), were observed in the following provinces: Świętokrzyskie (15.48%), Małopolskie (15.46%) and Łódzkie (15.14%). On the other hand, the lowest rates, well below the national average, were recorded in: Mazowieckie (5.61%), Zachodniopomorskie (8.79%) and Pomorskie (9.63%). This suggests that the nature of road incidents and the frequency of infrastructure damage vary by region, which may be related to: differences in traffic intensity, varying road conditions and accompanying infrastructure, different levels of adaptation of infrastructure to heavy freight transport.

The study found that in 46% of analysed cases, road equipment was damaged. Additionally: 30% of cases involved damage to fences or other structures, 12% of cases reported damage to poles or masts. Due to imprecise descriptions in police reports, conducting more detailed analyses was not feasible.

Table 11 presents key descriptive statistics regarding the distribution of cost data. The study determined that the total cost of restoring road infrastructure for 342 incidents amounted to 1,672,344 PLN. The average cost of restoration was 4,890 PLN. However, the high standard deviation (9,541.48 PLN) indicates significant variability in the data distribution, suggesting that costs are highly dispersed around the mean. These findings emphasize the economic burden of road infrastructure damage and the necessity for targeted strategies to reduce such incidents and their financial impact.

The median restoration cost was 1,731.23 PLN, meaning that half of the incidents incurred costs not exceeding this amount. The first quartile ($Q1 = 572.71$ PLN) indicates that 25% of the costs were very low. The third quartile ($Q3 = 5{,}576.99$ PLN) shows that 75% of the costs were below this value. The interquartile range ($IQR = 5{,}004.28$ PLN) highlights high variability in costs within the middle 50% of cases. It is important to note that the maximum restoration cost (83,000 PLN) significantly deviates from other values, suggesting the presence of outliers that could substantially affect the mean cost calculation.

Table 11. Descriptive statistics of road infrastructure restoration costs

Specification	*N*	Range	Minimum	Maximum	Sum	Mean	Standard deviation	Quartiles		
								Q1	Q2	Q3
Costs	342	82,958.18	41.82	83,000.00	1,672,344.12	4,889.90	9,541.48	572.71	1731.23	5576.99

Due to the high cost variability, the analysis adopted an adjusted unit restoration cost, calculated by removing 5% of extreme values from both ends of the dataset. This resulted in a trimmed mean of 3,290 PLN. Based on this adjusted cost, the total estimated infrastructure damage costs were calculated at 24,783,570 PLN. This approach ensures a more reliable cost estimation, minimizing the impact of extreme outliers on the final assessment.

Table 12 presents the distribution of road infrastructure restoration costs across Polish voivodeships, including absolute values and two contextual indicators: cost per 1,000 tons of freight and cost per 1,000 kilometres of public roads. These measures allow for a comparative assessment of infrastructure strain relative to transport volume and network size.

The total costs of road infrastructure restoration vary markedly between voivodeships, reflecting regional differences in exposure to damage. The Śląskie voivodeship incurs the highest overall cost, amounting to over 3.58 million PLN, which accounts for a significant share of the national total. Other high-cost regions include Dolnośląskie (2.72 million PLN), Wielkopolskie (2.45 million PLN), Małopolskie (2.29 million PLN), and Łódzkie (2.19 million PLN). These voivodeships form the core industrial and logistical zones of the country, where freight intensity and urban density likely accelerate infrastructure degradation.

Table 12. Unit costs of road infrastructure restoration in Polish voivodeships in 2024 in relation to freight volume and road network length (per 1,000 tons of freight and per 1,000 km of public roads)

No.	Voivodeship	Damaged infrastructure	Restoration cost [PLN]	Cost per 1,000 tons[*)] [PLN]	Cost per 1,000 km roads[**)] [PLN]
1	Dolnośląskie	828	2,724,120	24.71	106,566.20
2	Kujawsko-Pomorskie	498	1,638,420	21.60	58,700.33
3	Lubelskie	365	1,200,850	20.23	31,857.01
4	Lubuskie	253	832,370	25.49	52,755.10
5	Łódzkie	665	2,187,850	22.30	83,872.91
6	Małopolskie	697	2,293,130	23.17	71,952.62
7	Mazowieckie	568	1,868,720	9.76	33,599.92
8	Opolskie	201	661,290	15.35	63,053.86
9	Podkarpackie	176	579,040	10.58	26,597.83
10	Podlaskie	270	888,300	20.57	32,357.94
11	Pomorskie	370	1,217,300	14.91	56,770.70
12	Śląskie	1,089	3,582,810	26.23	144,485.04
13	Świętokrzyskie	297	977,130	11.72	56,608.46
14	Warmińsko-Mazurskie	277	911,330	19.04	40,854.72
15	Wielkopolskie	746	2,454,340	17.27	58,260.08
16	Zachodniopomorskie	232	763,280	13.47	39,311.71
17	Total	7,532	24,780,280	18.32	57,954.68

Explanatory notes:
[*)] Cost per 1,000 tons [PLN] = (Restoration Cost / Freight volume) × 1,000
[**)] Cost per 1,000 km roads [PLN] = (Restoration Cost / Road network length) × 1,000

At the opposite end of the spectrum, the Podkarpackie (579,040 PLN), Opolskie (661,290 PLN), and Lubuskie (832,370 PLN) voivodeships report the lowest absolute restoration costs. These regions tend to have lower freight volumes, fewer urban freight corridors, or more dispersed traffic flows, which may result in fewer high-impact incidents requiring costly repairs.

When normalized to freight volume and road network length, signific ant regional disparities in infrastructure restoration costs become evident. The Śląskie, Lubuskie, and Dolnośląskie voivodeships record the highest unit costs per 1,000 tons of transported goods: 26.23 PLN, 25.49 PLN, and 24.72 PLN, respectively. All of these values clearly surpass the national average of 18.32 PLN. This indicates accelerated infrastructure wear relative to transport intensity, potentially due to high axle loads, concentrated freight activity, or structural limitations within regional road networks.

In terms of cost per 1,000 km of roads, Śląskie again stands out with 144,485 PLN, which is more than 2.5 times the national average of 57,955 PLN. Dolnośląskie (106,566 PLN) and Łódzkie (98,081 PLN) also show elevated values, suggesting the presence of densely developed and heavily loaded road systems, where usage intensity may exceed the networks' design and maintenance capacity.

On the other hand, the Mazowieckie voivodeship, which has both the highest freight volume and the longest road network, maintains one of the lowest unit costs in both categories: 9.76 PLN per 1,000 tons and 33,600 PLN per 1,000 km. This suggests a relatively efficient and resilient infrastructure, capable of absorbing high transport demand without disproportionate degradation.

The Świętokrzyskie and Podkarpackie voivodeships also report low unit burdens, possibly resulting from lower traffic densities, more balanced freight flows, or less aggressive vehicle dynamics, which contribute to more sustainable infrastructure usage.

5. CONCLUSIONS

The aim of this study was to examine selected characteristics of road incidents involving freight vehicles in Poland, with particular attention to their scale, regional variation, typology, and the costs of infrastructure damage. The analysis was guided by four research questions concerning the general profile of these incidents, their geographical distribution, the types of accidents and their severity, and the economic consequences taking into account infrastructure restoration costs.

The results of the analysis can be summarised as follows:

1. Freight vehicles are involved in a noticeable share of road incidents relative to their presence in overall traffic. In 2022, they accounted for over 14% of all accidents and 17% of collisions. On motorways and expressways, despite comprising only a small fraction of the national road network, freight-related incidents represented over 13% of all truck accidents. When related to road length, the number of incidents per kilometre was particularly high on motorways. At the same time, these incidents were generally less severe in terms of personal consequences. The fatality and injury rates for freight-related incidents remained well below national averages. Similar distinctions between frequency and severity of truck crashes were also observed in probabilistic analyses by Tsai and Su [30].
2. Significant differences were observed across regions. The highest numbers of incidents and infrastructure repair costs were reported in Mazowieckie and Śląskie voivodeships, where freight activity is intensive. In contrast, eastern regions recorded much lower values. This uneven distribution reflects, at least partly, differences in traffic density and logistics functions. The results indicate that regions with higher traffic volumes (AADT and AADTT) tend to report more incidents, which is consistent with the concentration of freight flows on the main economic corridors. However, exceptions exist: in voivodeships such as Podlaskie and Lubuskie, the share of heavy vehicles in total traffic exceeded 24%, but the absolute number of incidents remained relatively low due to smaller overall traffic volumes. Comparable spatial disparities have been reported in Chile, where hot spots of truck crashes were concentrated on specific highway corridors with intensive freight flows [31].
3. The most frequent types of incidents were rear-end and side collisions. Although they occurred regularly, they typically resulted in limited injuries. Less frequent but more severe incidents, such as head-on collisions and pedestrian involvement, accounted for a smaller proportion of cases but had greater consequences. These

findings are consistent with international evidence linking inattentive driving, fatigue, and truck-trailer combinations to the most severe outcomes [32].

4. The costs of restoring road infrastructure damaged in freight-related incidents in 2022 were estimated at nearly PLN 25 million. These costs were not evenly distributed. Regions with higher freight intensity incurred much greater expenses, highlighting the financial dimension of road safety in freight transport. Addressing these outcomes requires a systemic approach that goes beyond attributing responsibility solely to drivers and includes regulatory, organizational, and fleet management factors [33].
5. In light of these findings, further improvements in safety should consider both the spatial context and the specific conditions of freight operations. Infrastructure investment, traffic management, and preventive measures should take into account not only the frequency but also the severity and cost implications of freight-related incidents.

6. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This study is based on data from 2022, offering a detailed overview of road incidents involving freight vehicles in Poland. However, its temporal scope is limited. Cost estimates for infrastructure damage and the analysis of incident patterns both refer to a single year, which restricts the ability to identify long-term trends. Future studies should therefore include multi-year data, particularly to capture changes surrounding the COVID-19 period, when both traffic volume and freight logistics were significantly affected.

Another limitation lies in the structure of the SEWiK database. While it remains the most comprehensive national source of road incident data, it lacks several key variables. Notably, it does not allow for the reliable identification of incidents involving the transport of dangerous goods (ADR), making it difficult to assess the safety risks associated with this critical segment of freight transport. The database also does not incorporate telematics or early-warning information, which in other contexts have been successfully used to predict and mitigate freight-related risks [32].

Further research could explore the influence of road configuration, such as straight sections versus intersections, on the occurrence and severity of incidents. A full comparative analysis with passenger vehicle incidents, focusing on causes and outcomes, would also offer a more complete picture of traffic safety. The use of more advanced statistical methods could support the identification of underlying risk factors and improve the targeting of preventive measures. Finally, future studies may address the broader economic consequences of freight incidents, especially in cases where cargo damage disrupts manufacturing or retail operations.

Finally, future studies should explore advanced analytical methods for forecasting freight-related road incidents using a broader range of data sources. As highlighted in recent studies, state-of-the-art techniques, such as machine learning algorithms, integrated forecasting models, and probabilistic approaches, have the potential to enhance predictive accuracy and compensate for limitations in SEWiK [34]. Such approaches would allow the identification of high-risk segments and periods, supporting more effective, evidence-based interventions.

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Bezpieczeństwo towarowego transportu drogowego w Polsce: regionalne wzorce wypadków i koszty uszkodzeń infrastruktury

Streszczenie: Artykuł prezentuje wyniki analizy skali i struktury zdarzeń drogowych z udziałem pojazdów transportu towarowego w Polsce w 2022 roku. Na podstawie krajowych danych statystycznych przeprowadzono szczegółowe badania wypadków i kolizji obejmujących zarówno samochody dostawcze, jak i ciężarowe, ze szczególnym uwzględnieniem ich rozmieszczenia w ujęciu regionalnym, według kategorii dróg, rodzaju zdarzeń oraz lokalizacji. Uzyskane wyniki wskazują na wyraźne różnice regionalne: największą liczbę zdarzeń odnotowano w Polsce centralnej i południowej, zwłaszcza w województwach o dużym natężeniu ruchu i gęstej sieci drogowej. Na szczególne podkreślenie zasługują zdarzenia występujące na autostradach i drogach ekspresowych, które, mimo że stanowią stosunkowo niewielki odsetek całej sieci, generują nieproporcjonalnie wysoki udział wypadków z udziałem pojazdów ciężarowych. Przeprowadzona w pracy analiza pozwoliła również zidentyfikować typowe scenariusze zdarzeń, wśród których najczęściej występują zderzenia boczne oraz najechania na tył, podczas gdy wypadki z udziałem pieszych czy zderzenia czołowe wiążą się zazwyczaj z poważniejszymi skutkami. Artykuł odnosi się także do konsekwencji finansowych omawianych zdarzeń, koncentrując się na kosztach odtworzenia infrastruktury drogowej uszkodzonej przez pojazdy ciężarowe. Wyniki badań wskazują na potrzebę bardziej zróżnicowanego i przestrzennie ukierunkowanego podejścia do zarządzania bezpieczeństwem w transporcie towarowym, które uwzględnia zarówno dynamikę ruchu, jak i podatność poszczególnych użytkowników dróg oraz odporność elementów infrastruktury.

Słowa kluczowe: bezpieczeństwo transportu, kolizje drogowe, koszty odtworzenia, transport towarowy, wypadki drogowe.