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Analysis of Risks and Safety Considerations in Oversize Transport, Incorporating an Original Concept for an Intelligent Driver Condition Monitoring System

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Abstract:

Purpose: *This paper aims to identify and evaluate the principal risk factors contributing to road accidents in oversize transport and to propose practical measures for improving transport safety. Particular attention is devoted to the influence of human, technical, infrastructural, and organisational factors on accident occurrence, as well as to the presentation of an original concept for an intelligent driver condition monitoring system integrated with modern vehicle telematics.*
Design/methodology/approach: *The study is based on a comprehensive review of the scientific literature, legal regulations, and statistical data concerning road accidents involving heavy goods vehicles in Poland and the European Union. The research includes an analysis of accident trends for the period 2019–2024, selected case studies of oversize transport accidents, and a conceptual proposal for an intelligent safety system integrating biometric monitoring of the driver with vehicle telematics and fleet management systems.*
Findings: *The results indicate that although the number of accidents involving heavy goods vehicles has declined in recent years, such incidents continue to produce disproportionately severe consequences, particularly in terms of fatalities. The dominant accident risk factors include driver errors, fatigue, inadequate route planning, technical failures, improper load securing, and infrastructural limitations. The proposed intelligent driver condition monitoring system, based on continuous analysis of physiological parameters collected by wearable devices and integrated with vehicle telematics, has the potential to enhance early hazard detection, support preventive decision-making, and improve the overall safety of oversize transport operations.*
Practical Implications: *The findings may support transport operators, logistics companies, public authorities, and policymakers in developing more effective safety management strategies for oversize transport. The proposed monitoring system may complement existing road safety procedures by enabling real-time assessment of driver fitness, improving operational supervision, reducing accident risk, and contributing to more efficient transport planning and fleet management.*

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Originality/Value: *The originality of this study lies in combining a comprehensive analysis of accident risk factors in oversize transport with the presentation of an original concept for an intelligent driver condition monitoring system. The proposed solution integrates wearable biometric technologies, telematics, GPS, digital tachographs, and fleet management platforms into a unified safety framework, offering a novel direction for the development of intelligent transport systems and proactive risk management in oversize road transport.*

Keywords: *Oversize transport, road safety, road accidents, heavy goods vehicles, risk factors, intelligent transport systems, telematics, driver monitoring, wearable technology, accident prevention.*

JEL Code: *R41, L91, O33.*

Paper Type: *Review article.*

1. Introduction

Road transport constitutes one of the fundamental components of the modern economic system, playing a significant role in the organisation and execution of logistics processes at both national and international levels. Its operational flexibility, widespread availability, and ability to deliver cargo directly to its final destination make it the predominant mode of freight transport.

The development of industry and technical infrastructure, together with the implementation of strategically significant investment projects, has led to growing demand for the transportation of loads of considerable dimensions and weight whose parameters exceed the permissible limits established under applicable legislation.

Such operations are carried out within the framework of oversize transport, which is regarded as one of the most complex and demanding areas of road freight transport. Oversize transport, due to its specific technical, organisational and legal conditions, is associated with an increased risk of events posing a threat to road traffic safety.

The non-standard dimensions of vehicles and transported loads, the considerable gross weight of transport combinations, limited manoeuvrability, and the need to use road infrastructure that is not fully adapted to the requirements of this type of transport constitute significant sources of hazards for road users.

This issue is of particular importance in international transport, where additional difficulties arise from differences in legal regulations, varying technical standards of infrastructure, and the need to coordinate the activities of multiple entities involved in the transport process.

Road accidents involving transport combinations carrying out oversize transport operations may result in serious consequences, including threats to the health and lives of road users, significant material losses, and damage to transport infrastructure.

Their consequences may include prolonged disruptions or a complete suspension of traffic on specific sections of roads, disruptions to the functioning of international supply chains, and an increase in the costs of implementing industrial and infrastructure projects.

In view of the above, ensuring an appropriate level of safety in oversize transport constitutes an important area of scientific research, encompassing both the identification and assessment of risk factors, as well as the development and implementation of technical, organisational, and technological solutions aimed at reducing the likelihood of road accidents and minimising their consequences.

2. Specific Characteristics of Oversize Transport

International oversize transport is a complex logistics process requiring the coordination of technical, organisational and administrative activities at all stages of transportation. Unlike standard transport, it requires individual planning that takes into account the characteristics of the load, the parameters of the means of transport, as well as the infrastructural and legal conditions encountered along the transport route. Proper coordination of these elements is crucial to ensuring the safety and efficiency of transport operations (Jacyna and Gołębiowski, 2018).

The fundamental stage in the preparation of oversize transport is a detailed route analysis, including an assessment of pavement load-bearing capacity, permissible axle loads, carriageway width, horizontal curve radii and vertical clearance. It is also essential to verify the technical condition of bridges, viaducts and culverts, which may constitute critical points along the route. Where infrastructural constraints occur, it is necessary to designate alternative routes or introduce temporary changes to traffic organisation.

The performance of international transport operations also requires compliance with the regulations applicable in the respective transit countries. Despite harmonisation efforts within the European Union, the procedures for obtaining permits for the passage of non-standard vehicles remain diverse. This applies, among other things, to requirements concerning escorting, vehicle marking, securing the passage, and permitted transport hours, which increases organisational complexity and extends the time required to prepare the transport operation (Bąk, 2014).

Another important element in the organisation of oversize transport is the proper planning of the transport schedule. Due to the considerable dimensions, high gross

weight and limited manoeuvrability of transport combinations, such operations are often carried out at night or with temporary restrictions on road traffic.

These measures are intended to reduce hazards to other road users and limit the impact of the transport operation on traffic flow. The schedule should also take into account weather conditions, the availability of safety and support services, and the coordination of activities on cross-border sections (Tabor, 2014).

Modern oversize transport operations make use of information and telematics technologies, including GPS systems and specialised logistics software. These technologies enable route optimisation, monitoring of transport parameters, identification of infrastructural constraints, and rapid response to emergency situations.

The application of these solutions improves the flow of information, enhances transport safety, and reduces the risk of delays resulting from infrastructural and organisational problems (Eurostat 2026).

3. Safety in Oversize Transport

Road traffic safety constitutes an important area of transport engineering, encompassing technical, organisational and legal measures aimed at reducing the number of accidents and minimising their consequences. From a systems perspective, it takes into account the interaction between the human, the vehicle and the road infrastructure, each of which may constitute both a factor contributing to safety and a source of hazards (Jacyna and Gołębiowski, 2016).

In oversize transport, this issue is of particular importance due to the considerable dimensions and weight of transport combinations, their limited manoeuvrability, and the difficulty of responding to emergency situations. These factors may lead to reduced visibility, increased braking distances, and an increased risk of collisions with other vehicles and elements of road infrastructure (Police raport, 2024).

Significant hazards also include insufficient load-bearing capacity of road surfaces and engineering structures, restricted vertical clearance, narrow carriageways, small curve radii, and high traffic volumes. In international transport, differences in the legal regulations and infrastructure standards of individual countries constitute an additional challenge.

The specific characteristics of oversize transport are also associated with the need to carry out non-standard operations, such as temporary road closures, night-time transport operations, or modifications to infrastructure. Organisational errors and deviations from the approved transport plan may lead to serious road incidents, posing a threat to the life and health of road users, causing damage to infrastructure, and disrupting the functioning of the transport system. Mitigating these hazards

requires the application of specialised technical, organisational and technological solutions (Police raport, 2024).

4. Risk Factors for Road Accidents in Oversize Transport

Road accidents involving oversize transport result from the interaction of multiple factors of varying nature. In the relevant literature and road traffic safety analyses, four main groups of risk factors are most commonly distinguished: human, technical, infrastructural and organisational factors. Their simultaneous occurrence in oversize transport leads to an accumulation of hazards and a significant increase in the likelihood of road incidents with serious consequences (World Health Organization, 2023).

4.1 Human Factors

Human factors constitute one of the most frequently identified causes of road accidents, including those involving oversize transport. The most significant factors include driver fatigue, stress associated with responsibility for the transported load, and errors in assessing traffic situations. Oversize transport operations are often carried out at night, under changing weather conditions and time pressure, which may contribute to reduced concentration and increased driver reaction time (Police raport, 2024).

Another significant problem is insufficient driver experience in operating non-standard vehicles. Driving a transport combination of considerable dimensions and high weight requires specialised skills, including the ability to anticipate the vehicle's behaviour during manoeuvres, braking, or cornering.

A lack of appropriate training in the specific characteristics of oversize transport increases the risk of errors leading to hazardous situations (World Health Organization, 2023).

An additional risk factor is improper cooperation between the driver of the oversize vehicle and the transport escort personnel. Inadequate communication, a lack of unambiguous signals, or delayed responses may lead to hazardous situations, particularly on road sections with limited technical parameters.

4.2 Technical Factors

Technical factors affecting the safety of oversize transport primarily include the technical condition of vehicles and the design solutions employed. Of particular importance are braking systems, steering systems, suspension systems, and components responsible for the stability of the transport combination. The failure of any of these components may lead to a loss of control over the vehicle, particularly at high speeds or during emergency manoeuvres (Wicher, 2017).

Another significant technical hazard is the improper securing of the load. Incorrect weight distribution, insufficient securing, or a shift in the centre of gravity during transit may result in a loss of stability of the transport combination. In the case of loads with a high concentrated mass, even minor displacements may lead to serious consequences for road traffic safety (Police raport, 2024).

Driver assistance systems, such as stability control systems or axle load monitoring systems, are also of considerable importance. Their absence or malfunction increases the risk of road incidents, particularly on routes with varying infrastructure conditions (Wicher, 2017).

4.3 Infrastructural Factors

The condition and parameters of road infrastructure have a significant impact on the level of safety of oversize transport. Narrow carriageways, small horizontal curve radii, restricted vertical clearance, and insufficient pavement load-bearing capacity constitute significant sources of hazards for non-standard vehicles. In many cases, road infrastructure is not designed to accommodate the regular movement of oversize transport vehicles, which increases the risk of collisions and damage to engineering structures (Kacprzak, 2017).

An additional problem is inadequate road signage and the lack of up-to-date information on infrastructural constraints. Failure to adapt road signage to the specific characteristics of oversize transport may lead to incorrect decisions by drivers and to vehicles entering road sections that are not suitable for the passage of vehicles of considerable dimensions (Kacprzak, 2017).

4.4 Organisational Factors

Organisational factors play a key role in determining the level of safety in oversize transport. The most common factors include errors in route planning, a lack of up-to-date data on the condition of infrastructure, and improper coordination of activities between the participants involved in the transport process.

An improperly developed transport plan may result in the need to make ad hoc decisions, which significantly increases the risk of road incidents (Police raport, 2024). Another significant problem is non-compliance with the conditions specified in administrative permits, such as changes to the route or transport hours, or the absence of the required escort. Such violations not only increase the risk of accidents but may also result in legal liability for the carrier and other entities involved in carrying out the transport operation (Wicher, 2017).

Effective organisation of oversize transport therefore requires close cooperation between the carrier, freight forwarder, transport escort personnel, and public administration authorities. A lack of coordination between these parties or

insufficient organisational supervision constitutes one of the most serious risk factors for road accidents in this segment of transport (Police raport, 2024).

5. Consequences of Road Accidents Involving Oversize Transport

Road accidents involving oversize transport generally result in more serious consequences than incidents involving standard vehicles. This is due to the considerable weight and dimensions of transport combinations, as well as the specific characteristics of the loads being transported.

The consequences may include human, material, infrastructural, organisational and social losses, extending beyond the immediate location of the incident (World Health Organization, 2023).

Due to the high kinetic energy involved, collisions with non-standard vehicles often result in serious injuries or fatalities. Pedestrians, cyclists and passenger car drivers are particularly at risk, as their vehicles provide less protection in collisions with heavy transport combinations (World Health Organization, 2023).

Accidents may also cause damage to vehicles, loads and infrastructure, including barriers, road signs, traffic signals, bridges and viaducts. This results in high repair costs and, in some cases, the prolonged closure of a road to traffic (European Transport Safety, 2023).

Another significant consequence is the disruption of the functioning of the transport system. Road blockages, the need to carry out rescue operations, and the removal of the consequences of an incident lead to delays, increased transport costs, and disruption of supply chains. In international transport, particularly along TEN-T corridors, these consequences may have a cross-border dimension and adversely affect the implementation of infrastructure, energy, and production projects (Eurostat, 2026).

Accidents also generate indirect costs associated with the activities of emergency services, infrastructure repairs, transport and production downtime, placing a financial burden on the budgets of national governments, local authorities and businesses. They may also lead to administrative, civil or criminal proceedings, financial penalties, loss of authorisations, and restrictions on the activities of carriers (European Transport Safety, 2023).

The consequences of accidents involving oversize transport are therefore multidimensional and encompass social, economic, infrastructural, organisational and legal aspects. Reducing the number of such accidents is of key importance for road traffic safety, the stability of supply chains, and the efficiency of the transport system as a whole.

6. Statistical Analysis of Road Accidents in Oversize Transport

The statistical analysis of road accidents in oversize transport was conducted on the basis of data concerning accidents involving heavy vehicles, which, due to their technical parameters and the nature of their use, most closely reflect the specific characteristics of non-standard transport operations. Oversize transport is most commonly carried out using transport combinations characterised by a high gross weight, limited manoeuvrability and an extended braking distance, which makes the analysis of incidents involving heavy vehicles a justified research approach.

Table 1 presents a comparison of the number of road accidents involving heavy vehicles in Poland between 2019 and 2023.

Table 1. *Road Accidents Caused by Heavy Goods Vehicles with a Gross Vehicle Weight Exceeding 3.5 t in Poland in 2019–2023*

Year	Number of Accidents	Share of Accidents Caused by Drivers	Number of Fatalities	Percentage Share of Fatalities	Number of Injured People	Percentage Share of Injured People
2019	802	3,0%	113	5,1%	953	3,0%
2020	648	3,1%	96	4,8%	786	3,3%
2021	685	3,3%	103	5,4%	751	3,1%
2022	648	3,3%	102	6,3%	766	3,4%
2023	537	2,8%	82	5,1%	593	2,7%

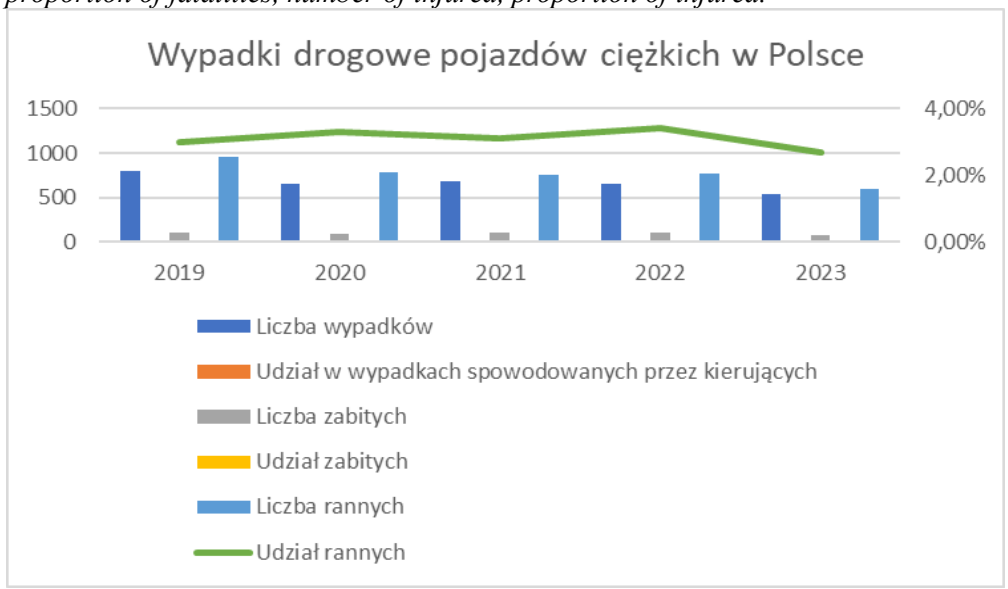
Source: *Authors' own elaboration.*

The data indicate that between 2019 and 2023, the number of accidents caused by drivers of heavy goods vehicles with a gross vehicle weight exceeding 3.5 t decreased from 802 to 537, representing a reduction of 265 incidents. This corresponds to a decrease of approximately 33.0%.

At the same time, the number of fatalities in these accidents decreased from 113 in 2019 to 82 in 2023, representing a reduction of approximately 27.4%. This decrease should be regarded as a positive development; however, the share of fatalities in accidents caused by heavy goods vehicles remains relatively high in relation to the share of these vehicles in the total number of accidents.

The year 2022 is particularly significant, as heavy goods vehicles with a gross vehicle weight exceeding 3.5 t accounted for 3.3% of accidents caused by drivers but for 6.3% of fatalities. This indicates that the consequences of accidents involving heavy vehicles are disproportionately severe relative to the number of such accidents. This conclusion is important for the analysis of oversize transport, as vehicles used for non-standard transport operations are characterised by even greater weight, limited manoeuvrability, and longer braking distances (Police raport, 2024).

Figure 1. *Number of Road Accidents Involving Heavy Vehicles in Poland, number of accidents, involvement in accidents caused by drivers, number of fatalities, proportion of fatalities, number of injured, proportion of injured.*



Source: *Authors' own elaboration.*

Table 2 presents an assessment of changes in the number of accidents and accident casualties involving heavy goods vehicles with a gross vehicle weight exceeding 3.5 t in Poland.

Table 2. *Changes in the Number of Accidents and Accident Casualties Involving Heavy Goods Vehicles with a Gross Vehicle Weight Exceeding 3.5 t in Poland*

Comparison Period	Change in the Number of Accidents	Change in the Number of Fatalities	Number of Injured People
2019-2023	-33,0%	-27,4%	-37,8%
2020-2023	-17,1%	-14,6%	-24,6%
2022-2023	-17,1%	-19,6%	-22,6%

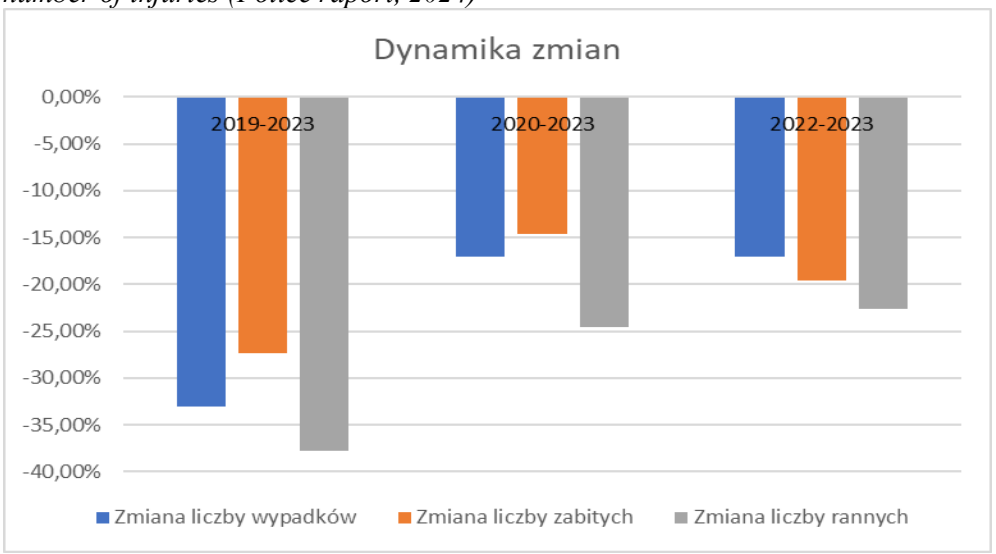
Source: *Authors' own elaboration (Police raport, 2024).*

Analysis of the dynamics of change confirms an overall improvement in safety in the heavy vehicle segment in Poland. The largest decrease was recorded in the number of injured persons, which fell by 37.8% between 2019 and 2023. At the same time, it should be noted that the decrease in the number of fatalities was smaller than the decrease in the number of injured persons. This may indicate that, despite the reduction in the overall number of incidents, accidents involving heavy vehicles continue to be characterised by a high severity of consequences.

From the perspective of oversize transport, this indicates the need to focus preventive measures not only on reducing the number of accidents but also on

mitigating their consequences. Of particular importance in this respect are appropriate route selection, axle load monitoring, the technical condition of the vehicle, the quality of escorting, and precise coordination of all participants involved in the transport process (Police raport, 2024).

Figure 2. *Changes in the Number of Accidents and Accident Casualties Involving Heavy Goods Vehicles with a Gross Vehicle Weight Exceeding 3.5 t in Poland, change in the number of accidents, change in the number of fatalities, change in the number of injuries (Police raport, 2024)*



Source: *Own study.*

In the subsequent part of the analysis, the number of fatalities in accidents involving HGVs in the EU27 was assessed. The indicator presented in Table 3 makes it possible to determine the significance of heavy goods transport in the overall structure of road accidents and to assess the impact of the development of international transport operations on the level of road traffic safety.

Table 3. *Fatalities in Accidents Involving Heavy Goods Vehicles (HGVs) in the EU27 in 2019–2023*

Year	Number of Fatalities in Accidents Involving HGVs in the EU27	Share of the Total Number of Fatalities in the EU27
2019	3178	14,0%
2020	2564	13,6%
2021	2922	14,7%
2022	2950	14,3%
2023	2829	13,8%

Source: *Authors' own elaboration.*

European data indicate that accidents involving heavy goods vehicles (HGVs) account for approximately one-seventh of all road traffic fatalities in the EU. In 2023, 2,829 people were killed in accidents involving HGVs, accounting for 13.8% of all road fatalities in the European Union. It is worth noting that, despite the decrease in the number of fatalities compared with 2019, the percentage share of fatalities in accidents involving HGVs in the total number of road fatalities remains stable, at approximately 13.6–14.7%.

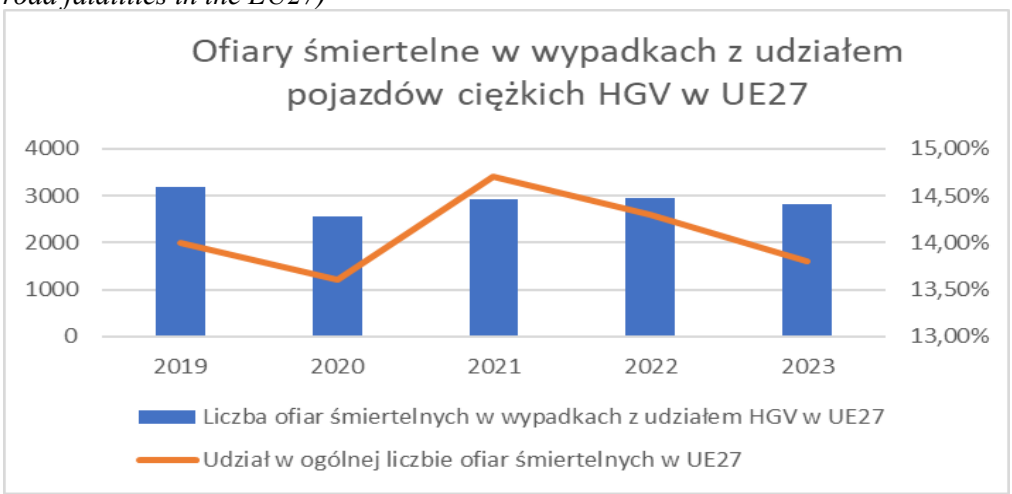
This means that improvements in road traffic safety in the EU do not fully eliminate the risks associated with heavy goods transport. From the perspective of this study, this constitutes an important argument confirming that heavy goods transport, including oversize transport, requires separate safety procedures, detailed planning, and effective organisational supervision.

The distribution of fatalities indicates that accidents involving heavy vehicles are particularly dangerous for other road users. The largest group consists of drivers and passengers of passenger cars, who account for approximately 50%.

These findings are directly relevant to oversize transport. Non-standard transport combinations, due to their dimensions, limited visibility, and the greater space required for manoeuvring, may pose a particular hazard to passenger cars, pedestrians, and cyclists.

Therefore, when organising oversize transport operations, particular attention should be paid to ensuring safe passage through built-up areas, intersections, roundabouts, pedestrian crossings, and road sections with high volumes of local traffic.

Figure 3. *Fatalities in Accidents Involving Heavy Goods Vehicles (HGVs) in the EU27 (Number of fatalities in accidents involving HGVs in the EU27, Share of total road fatalities in the EU27)*



Source: *Own study.*

Table 4 presents the distribution of fatalities in accidents involving heavy goods vehicles (HGVs) in the EU27.

Table 4. *Distribution of Fatalities in Accidents Involving Heavy Goods Vehicles (HGVs) in the EU27*

Road User Group	**Estimated Share of Fatalities in Accidents Involving HGVs**
Drivers and Passengers of Passenger Cars	approx. 50%
Pedestrians	approx. 15%
Cyclists	approx. 6%
Other or Unidentified Road Users	approx. 29 %

Source: *Authors' own elaboration.*

Table 5. *Main causes of accidents caused by drivers in Poland in 2023.*

Cause	Amount of accidents	Significance for Oversize Transport
Failure to Give Way	4594	Particularly High Risk at Intersections and Roundabouts
Failure to Adjust Speed to Traffic Conditions	4216	Crucial Due to the Longer Braking Distance
Failure to Give Way to a Pedestrian at a Pedestrian Crossing	1 823	Significant When Travelling Through Built-Up Areas
Failure to Maintain a Safe Distance Between Vehicles	1 324	Particularly Dangerous Due to the High Weight of the Transport Combination
Improper Overtaking	813	The Risk Increases with Limited Visibility and the Considerable Length of the Transport Combination
Fatigue, Falling Asleep	487	Important Due to Some Oversize Transport Operations Being Carried Out at Night
Sudden Deterioration in the Driver's Health, Including Myocardial Infarction, Stroke, or Loss of Consciousness	3	May Lead to a Complete Loss of Control over the Vehicle and Cause Catastrophic Consequences Due to the High Weight and Large Dimensions of the Transport Combination

Source: *Authors' own elaboration.*

The most common causes of accidents caused by drivers in Poland indicate the predominant importance of the human factor. In 2023, the largest number of accidents was caused by failure to give way and failure to adjust speed to traffic conditions. With regard to oversize transport, the latter cause is particularly significant, as non-standard vehicles require longer braking distances, have limited manoeuvrability, and are more susceptible to the consequences of an incorrect assessment of the traffic situation.

Driver fatigue is also of considerable importance. Although the number of such accidents is lower than in the case of errors related to right of way or speed, this risk is particularly significant in oversize transport because many transport operations are carried out at night, with limited visibility and increased psychological strain on the driver. Table 6 presents road freight transport in the EU in 2022–2024.

Table 6. *Road Freight Transport in the EU in 2022–2024*

Year	Volume of Road Freight Transport in the EU	Change Compared with the Previous Year
2022	1 919 mld tkm	-
2023	1 857 mld tkm	-3,2%
2024	1 869 mld tkm	+0,6%

Source: *Authors' own elaboration (Jacyna, 2018).*

Eurostat data indicate that road freight transport in the EU remains at a very high level, exceeding 1,800 billion tonne-kilometres annually. Following a decrease of 3.2% in 2023, an increase of 0.6% was recorded in 2024, confirming the importance of road transport within the European transport system. The high volume of heavy vehicle traffic increases the importance of proper planning of oversize transport, particularly on international routes, bridges, roads with limited capacity, and in urban areas.

In Poland, between 2019 and 2023, the number of accidents caused by heavy goods vehicles with a gross vehicle weight exceeding 3.5 t decreased from 802 to 537, while the number of fatalities fell from 113 to 82. In 2023, 2,829 people were killed in accidents involving heavy vehicles in the EU27, accounting for 13.8% of all road accident fatalities.

Despite the decrease in the number of incidents, accidents involving heavy vehicles are characterised by a high severity of consequences. In oversize transport, this risk is intensified by the considerable weight and dimensions of transport combinations, limited manoeuvrability, longer braking distances, greater loads imposed on infrastructure, and the need for detailed route planning. The most significant hazards arise from human factors, such as failure to adjust speed to traffic conditions, errors related to right of way, and driver fatigue. Improving the safety of oversize transport therefore requires the development of road infrastructure, ITS systems, and effective logistics planning for non-standard transport operations.

7. Examples of Selected Road Accidents in Oversize Transport

The statistical analysis of road accidents presented in the previous subsections makes it possible to assess the scale and structure of road incidents associated with heavy transport. However, in order to provide a more comprehensive illustration of safety issues in oversize transport, it is also appropriate to refer to actual road accident cases that illustrate the consequences of technical, organisational and

infrastructural errors. This subsection presents selected examples of road incidents involving oversize transport operations or vehicles carrying loads of considerable dimensions.

7.1 Case 1 – Collision of an Oversize Transport Vehicle with the I-5 Bridge (USA)

On 23 May 2013, a section of the bridge over the Skagit River on Interstate 5 in the state of Washington collapsed. The incident was caused by a vehicle carrying an oversize load striking structural elements of the bridge. As a result of the collision, the steel load-bearing beams were damaged, leading to the immediate collapse of one of the bridge spans. The incident caused serious disruptions to road traffic along one of the key transport corridors and also highlighted the risks arising from infrastructure that is insufficiently adapted to oversize transport operations.

7.2 Case 2 – Detachment of a Heavy Load During Road Transport (Texas, USA)

In April 2024, a tragic accident occurred in the state of Texas involving a truck transporting a load weighing more than 150 tonnes. While the vehicle was in motion, part of the load became detached and fell onto a passenger car travelling behind the truck. As a result of the accident, two people were killed and one person was seriously injured. This case demonstrates the importance of properly securing an oversize load and monitoring its stability during transport. The consequences of the road accident caused by the detachment of the oversize load are presented in Figure 5.

Figure 4. *Consequences of an Oversize Transport Collision with the I-5 Bridge in Washington State (USA),*

Source: *https://pacificpile.com/project/i-5-skagit-bridge-collapse/*

Figure 5. *Consequences of a Road Accident Caused by the Detachment of an Oversize Load (Texas, USA),*

Source: *https://www.fox7austin.com/news/temple-texas-deadly-crash*

7.3 Case 3 – Collision Involving the Transport of Wind Turbine Components (Spain)

In July 2022, a collision involving several heavy goods vehicles transporting wind turbine components occurred on the A4 motorway in Spain. As a result of the incident, one of the long wind turbine blades struck the cab of a vehicle, causing serious injuries to the driver and significant damage to road infrastructure.

This incident highlights the hazards associated with transporting loads of non-standard shapes and lengths, particularly under conditions of heavy road traffic.

7.4 Case 4 – Load Shift and Cab Detachment – Netherlands (A4)

In March 2025, a serious accident occurred on the A4 motorway in the Netherlands involving a truck transporting long metal pipes. As a result of sudden braking, the load shifted, broke through its restraints, and struck the vehicle cab directly, causing the cab to detach from the chassis and resulting in the driver's death.

This incident is an example of the risks arising from the improper securing of an oversize load, even when the weight and dimensions of the load comply with the relevant permits.

Dynamic forces acting during transit and emergency manoeuvres may lead to tragic consequences. Figure 6 presents the consequences of the displacement of an oversize load during road transport.

Figure 6. *Consequences of Oversize Load Displacement During Road Transport – Damage to the Cab of a Heavy Goods Vehicle (Netherlands)*

Source: *Own elaboration.*

The examples presented confirm that road accidents in oversize transport often have serious social, economic and infrastructural consequences. The study of actual incidents constitutes an important complement to the statistical analysis and enables a better understanding of the mechanisms leading to road accidents in this segment of transport.

8. Recommendations for Improving Safety in Oversize Transport

Oversize transport is one of the most demanding segments of road transport. The safety of transport operations depends not only on the technical condition of vehicles, but also on proper route planning, the organisation of the transport process, and cooperation between its participants. Of particular importance is the analysis of infrastructure, taking into account the parameters of roads and engineering structures, roadworks, traffic organisation, weather conditions, and potential disruptions.

The appropriate preparation of drivers is also of considerable importance. In addition to experience, they should possess specialised skills in assessing traffic situations, anticipating the behaviour of the transport combination, cooperating with escort personnel, and responding to emergency situations. Another important element of safety is monitoring the psychophysical condition of drivers, particularly fatigue, concentration, and health status.

Improving safety also requires effective cooperation between carriers, road authorities, and public administration authorities. The exchange of information concerning planned transport operations, infrastructural constraints, and changes in traffic organisation makes it possible to reduce the risk of emergency situations.

Technological development creates new opportunities to improve the safety of oversize transport. Advanced Driver Assistance Systems (ADAS), including automatic emergency braking, lane-keeping assistance, blind-spot monitoring, and distance monitoring, are of particular importance. Systems for monitoring the technical condition of the vehicle, including tyres, the braking system, axle loads, and the stability of the transport combination, are also significant.

Telematics systems using GPS and real-time data transmission also play an important role. They enable vehicle location monitoring, analysis of driving parameters, and rapid exchange of information between the driver and the dispatcher. The use of 360° cameras and environmental sensors, in turn, increases safety during manoeuvring, particularly in urban areas.

The most promising solution is the integration of telematics systems with monitoring of the driver's psychophysical condition. Combining data concerning the vehicle, traffic conditions, and the driver's physiological parameters may enable earlier detection of hazards and more effective safety management in oversize transport.

9. Original Concept for an Intelligent Driver Condition Monitoring System

The contemporary development of digital technologies and devices for monitoring human vital signs creates new opportunities to improve safety in road transport. Solutions of this type may be of particular importance in oversize transport, where the driver's responsibility for the safety of the transported load and other road users is exceptionally high. The analysis conducted in this study has shown that some of the most common factors increasing the risk of road accidents are driver fatigue, reduced concentration, and sudden deterioration in health. Therefore, it appears justified to seek new solutions enabling continuous monitoring of drivers' psychophysical condition while carrying out transport operations.

One possible solution is the development of an intelligent system for monitoring the driver's vital signs using a modern smartwatch equipped with biometric sensors. Such a solution could complement currently used safety systems and serve as a tool supporting the risk management process in transport companies. The fundamental principle of the system is the continuous analysis of selected physiological parameters of the driver and the automatic notification of abnormalities that may indicate a reduced ability to drive safely.

10. System Assumptions

The fundamental element of the proposed solution is a smartwatch worn by the driver while performing professional duties. The device would be equipped with a set of sensors enabling continuous measurement of vital signs and their real-time analysis. The monitored indicators would primarily include heart rate, blood oxygen

saturation, body temperature, heart rate variability, and parameters enabling the detection of cardiac arrhythmias, such as atrial fibrillation.

The selection of these parameters is not arbitrary. Changes in the functioning of the human body very often precede the onset of symptoms experienced by an individual. This means that a properly programmed system could detect concerning signals even before the driver begins to experience a deterioration in well-being.

This is particularly important during long-distance journeys undertaken by drivers of oversize vehicles, where maintaining a high level of concentration is a prerequisite for the safe performance of transport operations.

Another important assumption of the system is the possibility of monitoring the driver's level of fatigue. Modern biometric devices are capable of analysing heart rate variability and the level of physiological activity, making it possible to determine the user's level of physical and psychological strain. This information could be used to identify situations in which the driver should take a break or discontinue driving.

The proposed system could also support the detection of sudden health problems. Particularly dangerous conditions include myocardial infarction, stroke, cardiac arrhythmias, and loss of consciousness. In the case of a driver operating a vehicle carrying out an oversize transport operation, the consequences of such an event may be considerably more serious than in the case of standard vehicles. Therefore, the rapid detection of concerning changes could contribute to reducing the number of road incidents and mitigating their consequences.

In order to assess the driver's current condition, the proposed original model can be applied, combining information obtained from several physiological sensors. The proposed model takes into account heart rate, heart rate variability, blood oxygen saturation, signals that may indicate episodes of sleep apnoea, skin temperature, and stress level, i.e. functions that can be found in the latest products offered by leading smartwatch manufacturers.

$$W_k = W_{HR} \cdot X_{HR} + W_{sp}O_2 \cdot X_{sp}O_2$$

which:
W_k – driver condition indicator;
X_{HR} – normalised heart rate abnormality indicator;
$X_{sp}O_2$ – normalised blood oxygen saturation reduction indicator;
w_i – weights of the individual parameters

Parameter weights determine the importance of each parameter in calculating the final driver condition indicator.

For example:

Parameter	**Weight**	**Significance**
Heat Rate	0,50	50% contribution to the final result
Blood Oxygen Saturation	0,50	50% contribution to the final result

The weights must satisfy the following condition:

$$\sum_{i-1}^{6} w_i = 1$$

All components of the indicator should be normalised to a common range, e.g. 0–1 (0–100%), where 0 indicates no significant deviation and 1 represents the highest predefined risk level.

10.1 Integration of the System with the Vehicle

The essence of the proposed solution is not merely to monitor the driver's vital signs, but above all to integrate this process with the systems used in modern heavy goods vehicles. This would make it possible to create a comprehensive safety system integrating information concerning both the driver's condition and the progress of the transport operation being carried out.

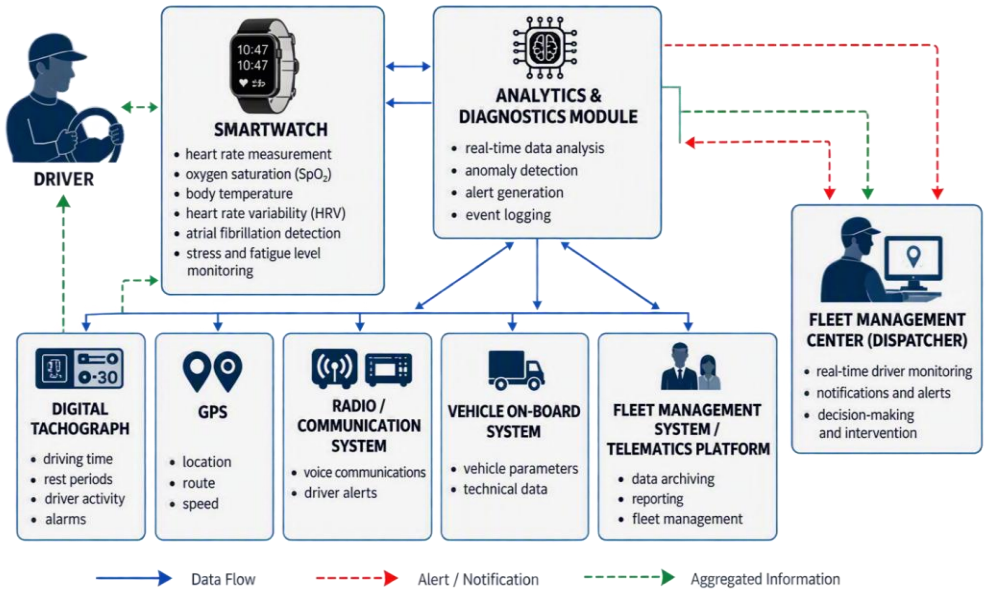
The data collected by the smartwatch would be transmitted to an analytical module located in the vehicle. This module would be responsible for analysing the parameters and identifying potential hazards. The information could then be transmitted to the digital tachograph, onboard computer, GPS system, and the transport company's telematics platform.

If concerning changes were detected, the system would automatically generate a warning for the driver. The warning could take the form of an audible signal, a voice message, or information displayed on the onboard computer screen. The purpose of such an action would be to draw the driver's attention to a deterioration in their psychophysical condition and encourage them to take a break.

At the same time, information concerning the detected hazard could be transmitted to the dispatcher or fleet management centre. This would enable the transport company to continuously monitor the safety of ongoing transport operations and take organisational measures aimed at reducing the risk of an accident.

The proposed solution could also support the identification of situations associated with the use of alcohol or psychoactive substances. Many such substances cause an increase in heart rate, cardiac arrhythmias, and changes in body temperature. Although the system itself would not replace sobriety testing, it could indicate the occurrence of unusual physiological parameters requiring additional verification.

Figure 7. *Concept of an Intelligent Driver Condition Monitoring System Integrated with Vehicle Systems.*



Source: *Authors' own elaboration.*

Figure 7 presents a schematic diagram of the proposed system for monitoring the driver's vital signs. The biometric smartwatch constitutes the fundamental element of the solution and is responsible for the continuous measurement of the driver's physiological parameters.

The collected data are transmitted to an analytical module, which integrates the information with the vehicle systems, including the digital tachograph, GPS system, and the transport company's telematics platform. If abnormalities are detected, the system generates a warning for the driver and transmits the information to the dispatcher responsible for supervising the transport operation.

10.2 Benefits of Implementing the System

The implementation of an intelligent system for monitoring the driver's vital signs could provide a range of benefits both for transport companies and for the road traffic safety system as a whole.

The most important advantage of the proposed solution would be an enhanced ability to detect risks associated with driver fatigue and deteriorating health at an early stage.

The system would enable concerning changes to be identified before a hazardous situation occurs. This would make it possible to take preventive measures in the form of additional rest, a change of driver, or the temporary suspension of the transport operation. Such an approach could contribute to reducing the number of road incidents resulting from human error.

An additional benefit would be an increase in the effectiveness of driver occupational safety management. Transport companies would gain access to information enabling them to assess the impact of working conditions on employees' psychophysical condition. These data could be used for route planning, work scheduling, and preventive measures.

The implementation of the system could also contribute to reducing the costs associated with road accidents. A lower number of incidents would result in lower vehicle repair costs, reduced losses associated with damage to transported loads, and lower expenses resulting from transport downtime. In the longer term, this could improve the economic efficiency of companies carrying out oversize transport operations.

It should also be emphasised that the proposed concept does not require the development of entirely new technologies. Most of the necessary solutions are already available on the market in the form of smartwatches, telematics systems, and fleet monitoring platforms.

The innovative aspect of the proposed concept lies in integrating these technologies into a single coherent system aimed at improving the safety of oversize transport.

In the authors' assessment, the implementation of such a solution could constitute an important step towards the further development of intelligent road transport safety systems.

Combining the monitoring of the driver's vital signs with modern telematics systems enables a more comprehensive approach to risk management and may contribute to reducing the number of road incidents in oversize transport.

The presented concept constitutes the author's original proposal for addressing the issue of safety in oversize transport. Unlike the methods currently used to monitor drivers' working time, the proposed solution focuses on the continuous analysis of the driver's psychophysical condition and the integration of this information with the systems used during transport operations.

This makes it possible to detect hazards at an earlier stage and take preventive measures before a hazardous situation occurs. The proposed system may complement existing safety procedures and provide a direction for the further development of intelligent transport systems.

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