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Aleksandra PALCZEWSKA¹

IDENTIFICATION OF RISKS AND OPPORTUNITIES RELATED TO THE ROAD TRANSPORT OF DANGEROUS GOODS, FLAMMABLE LIQUIDS, AND GASES

Summary. Research on dangerous goods logistics encompasses three areas. The first concerns methodologies aimed at improving emergency responses based on road characteristics, weather conditions, and traffic factors. The second is based on human factors (i.e., methodologies for researching and analyzing accident risk based on historical data), aimed at revealing accident characteristics such as their frequency, consequences, and identification of causal factors. The final area focuses on decision-making aimed at improving decision-making and introducing opportunities for safe transport. The novelty of this article is the examination of the threats, risks and opportunities associated with the transport of hazardous materials. The current research indicates that the most frequently transported dangerous goods on national roads are Class 3 and 2 materials (i.e., flammable liquids and gases). It also demonstrates that qualified personnel and the periodic training of transport participants are the main enablers of safe transport.

1. INTRODUCTION

Solving theoretical problems and applying practical tools are important to the development of transport logistics. One factor contributing to the safe use of public roads is ensuring the safe transport of hazardous materials. It is necessary to guarantee the safety of transport processes, considering that hazardous substances pose a serious threat not only to the environment and people but also to the entire transport infrastructure. Risk often stems not only from the nature of transporting hazardous substances but also from human error. It depends on three main factors: the intensity of daily traffic, the frequency of accidents, and the length of the route traveled.

Janno and Koppel [5] found that up to 80% of accidents are caused by human error, and 8% are caused by technical failure. The importance of the human factor has always been underestimated. Parties involved in the dangerous goods transport chain are unaware of the operational hazards associated with their daily activities involving chemical substances. Although the transport of dangerous goods is risky, there is a need to learn how to manage and reduce risks.

Rada et al. [9] argued that it is necessary to examine the factors influencing transport risk in order to create an opportunity (i.e., ensure safety). Highly qualified personnel are required for the complete transport logistics, preparation of necessary documents and operations related to dangerous goods. It is necessary to ensure that everything is carried out without errors, thus avoiding the risk of an incident and leading to an opportunity.

Baterliene [4] stressed that special attention should be paid to the transport of dangerous goods not only during their preparation and loading, but also throughout the logistics until they reach their destination and are unloaded.

The importance of warning signs in the transport of dangerous goods was also noted. Dumlupinar and Öztürkoğlu [7] indicated that marking vehicles, packages, and tanks containing dangerous goods

¹ Wojskowe Zakłady Uzbrojenia S.A.; Parkowa 42, 86-300 Grudziądz, Poland; e-mail: a.palczewska@wzu.pl; orcid.org/0009-0008-4487-6916

with warning signs was the most important aspect of conveying information about a specific dangerous substance and, therefore, an opportunity for safe transport.

Conca et al. [8] analyzed accidents and concluded that it is crucial to utilize all theoretical and practical knowledge to make dangerous goods logistics safer. The preventive measures they identified are now widely used in the road transport sector and have become binding requirements and mandatory procedures throughout the dangerous goods logistics process. The results of Petrović et al. [6] confirm that the human factor is a key factor that causes road accidents.

The minimum requirement for safe transport is well-qualified and trained personnel. All transport participants must strictly adhere to general road traffic regulations and safety rules regarding dangerous goods.

The author's own research [3] conducted between 2018 and 2020 shows that the most common dangerous goods transported on national roads are flammable liquids and gases, as shown in Fig. 1. This is primarily due to their frequency of occurrence in road transport. Substantial amounts of these materials are supplied for daily public use. They are transported daily, for example, to gas stations, manufacturing plants, and for everyday household use.

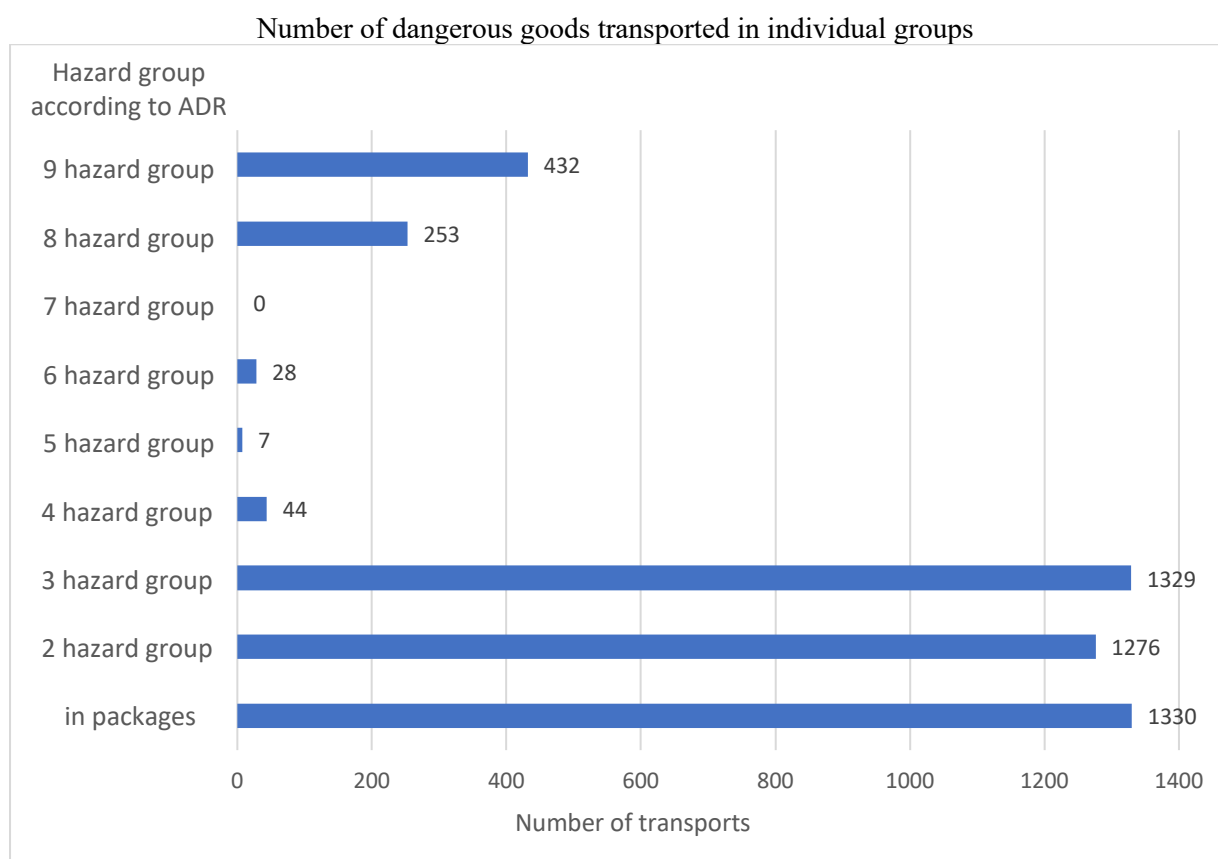


Fig. 1. Monitored number of dangerous goods transports in individual groups

The weekly structure of liquid fuel transport is presented in Fig. 2, which illustrates the weekly supply of liquid fuels. This reveals the nature of demand for these goods and, consequently, the risk structure posed by these types of hazardous materials.

Fig. 2 shows that Class 3 materials are most frequently transported on Tuesdays and Wednesdays. Studies show that the negligible transport of flammable liquids on Saturdays and Sundays is followed by a return to normal transport volumes. Transport activity increases noticeably during midweek.

The increasingly developed industry is driving the use of hazardous substances, such as flammable liquids and gases. This article focuses on these threats and identifies the risks and opportunities

associated with their transportation. It can be argued that as the transport of dangerous goods increases, so does the risk posed during transportation. Our task is to minimize this risk and ensure safe transport.

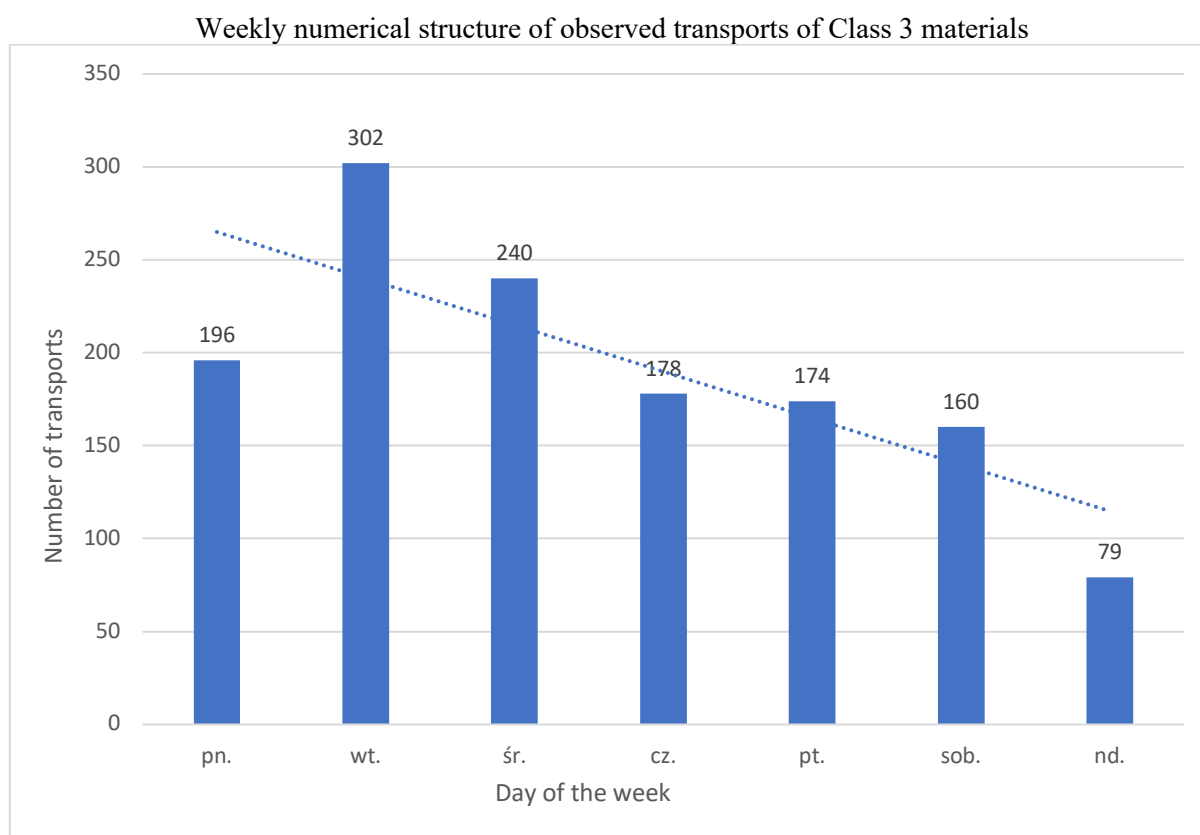


Fig. 2. Monitored weekly numerical structure of transport of materials from the third hazard group

2. LEGAL REQUIREMENTS FOR THE ROAD TRANSPORT OF DANGEROUS GOODS, FLAMMABLE LIQUIDS, AND GASES

The logistics of hazardous materials are regulated by the Act on the Transport of Dangerous Goods [1]. This act defines the principles of conducting business in the field of domestic and international road transport of dangerous goods, as well as the authorities and entities responsible for carrying out tasks related to this transport. The most important act in force in European Union countries is the ADR Agreement concerning the International Carriage of Dangerous Goods by Road, signed in Geneva on September 30, 1957, whose primary goal is to reduce the risk of transported hazardous materials. The provisions of the ADR Agreement are amended every two years. It currently applies to 44 countries. Table 1 below presents the structure of Annexes A and B to the European Agreement.

In terms of the degree and type of hazard, all dangerous goods are divided into 13 classes contained in Annex A of the ADR European Agreement, which were distinguished based on the dominant hazards [2]. They are presented in Table 2 below.

The provisions of the European Agreement list the classes of dangerous goods, while the headings of the groups of materials are based on the aforementioned dominant hazards. These are determined by physicochemical, biological-physiological, and chemical properties.

The list also includes goods that are definitely not approved for transport, approved for transport after meeting legal requirements, and fully or partially exempt from the regulations, depending on the possibilities dedicated to a given dangerous good in this respect.

Table 1

Structure of Annexes A and B to the ADR European Agreement

ADR AGREEMENT		
1	2	3
Attachments	Parts	Description
A	1	General provisions regarding, among other things, the obligations of participants, training of persons transporting dangerous goods, control principles and transport restrictions
	2	Criteria and methods for classifying dangerous goods
	3	List by goods identification numbers
	4	Regulations regarding the use of packaging
	5	Shipping procedures, such as marking and the proper placement of warning labels
	6	Packaging design requirements
	7	Regulations related to operations during transport, including carriage, loading, unloading, and cargo manipulation
B	8	Requirements for equipment, vehicle crew, and technical documentation, restrictions on the passage of transport units in the scope of carrying out dangerous goods logistics through tunnels
	9	Requirements for the approval of vehicles and their construction

Table 2

Classes for the transport of dangerous goods according to ADR

Class	Danger
1	Explosive materials and items
2	Gases
3	Flammable liquids
4.1	Flammable solids, self-reactive materials and explosives
4.2	Pyrophoric materials
4.3	Materials that produce flammable gases when in contact with water
5.1	Oxidizing materials
5.2	Organic peroxides
6.1	Poisonous materials
6.2	Infectious materials
7	Radioactive materials
8	Corrosive materials
9	Various hazardous materials and items

The ADR Agreement mandates the use of warning labels and stickers as part of warning and information marking. These labels should be placed on both packaging and vehicles. Each dangerous good listed in the ADR is identified by a UN letter and a four-digit number (e.g., UN 1965 or UN 0209). This number is called the dangerous goods identification number. Besides the informative value of the individual goods number, it also specifies the precise conditions for transporting a given load. The goal of all these requirements is to minimize the risk caused by the objectivity of dangerous goods and to eliminate the impact of human-induced hazards and uncertainty on the safety of transporting dangerous goods. In this way, vehicles traveling on roads can be identified for the transport of a given dangerous substance and its hazards.

3. IDENTIFICATION OF RISKS RELATED TO THE ROAD TRANSPORT OF DANGEROUS GOODS, FLAMMABLE LIQUIDS, AND GASES

Road, rail, sea, and air connections improve the quality of life for society and ensure the availability of goods in distant locations. The efficient operation of individual infrastructure elements does not guarantee internal security. Effective and efficient methods of management, monitoring, and control are also needed to ultimately ensure the safety of people and the environment.

Dangerous goods logistics in Poland and across the EU encompass more than just road accidents, which can lead to explosions, chemical poisoning, and environmental hazards. Terrorist attacks involving hazardous materials also significantly impact safety. This is because each terrorist attack impacts key elements of transport infrastructure and can have a significant, long-term effect on the functioning of the European economy.

Risks associated with the road transport of dangerous goods may also result from technical defects in vehicles, failure to adhere to road safety regulations, improper use of means of transport, and poor road conditions. Hazardous substances are released into the environment in approximately 20% of cases. It turns out that over 80% of these incidents involve the transport of liquid fuels.

Road accidents occurring during the transport of dangerous goods pose a particularly serious threat to the environment, as illustrated in Fig. 3. The associated fire, explosion, toxic, and radioactive hazards can directly threaten the health and lives of many people. They may require the immediate evacuation of people and animals, cause contamination, environmental degradation, and significant material losses.

Examples of road incidents involving flammable liquids and gases



Fig. 3. Examples of the consequences of incidents in the road transport of flammable liquid goods and gases

The main causes of hazards in the transport of dangerous materials include the inadequate technical condition of packaging and loading units, means of transport, non-compliant technical instructions, and inappropriate kinds and types of packaging. Other causes of risk include inadequate equipment at transshipment points and the poor technical condition of infrastructure and transshipment equipment, as well as improper organization or technology of hazardous materials logistics [7].

By analyzing accidents involving dangerous goods between 2015 and 2020, the author showed that the majority of road accidents and incidents involved vehicles transporting flammable gases and liquids, as these were the most frequently transported materials. After examining the incidents and assessing the failures, the most common risks involving vehicles transporting hazardous materials can be identified. The key criteria for selecting accidents were those that caused the most severe consequences for people and the environment.

The direct causes of these incidents are most often human factors, such as recklessness and a lack of caution on the road, which, combined with difficult weather conditions, resulted in the majority of accidents. Cases of drunk drivers were also observed. It should be emphasized that some of these accidents were also caused by technical faults. However, these should be considered in the context of

human negligence, as it is the individual who decides whether to continue driving. Fig. 4 presents a classification of the causes of road accidents involving dangerous goods.

As the research shows, there is also a risk of accidents due to physical, mental, and health-related overload. Drivers experience health problems related to prolonged sitting in their cabins, manifesting as back, circulatory, and digestive disorders. At the same time, they must contend with unfavorable weather conditions and physical hazards such as noise, vibration, high and low temperatures, and hazardous substances. Time pressure, along with poor eating habits, sleep deprivation, inadequate driving breaks, and insufficient rest between shifts, also negatively impacts drivers' mental health. Long working hours, loneliness, and separation from family and friends also impact drivers' well-being.

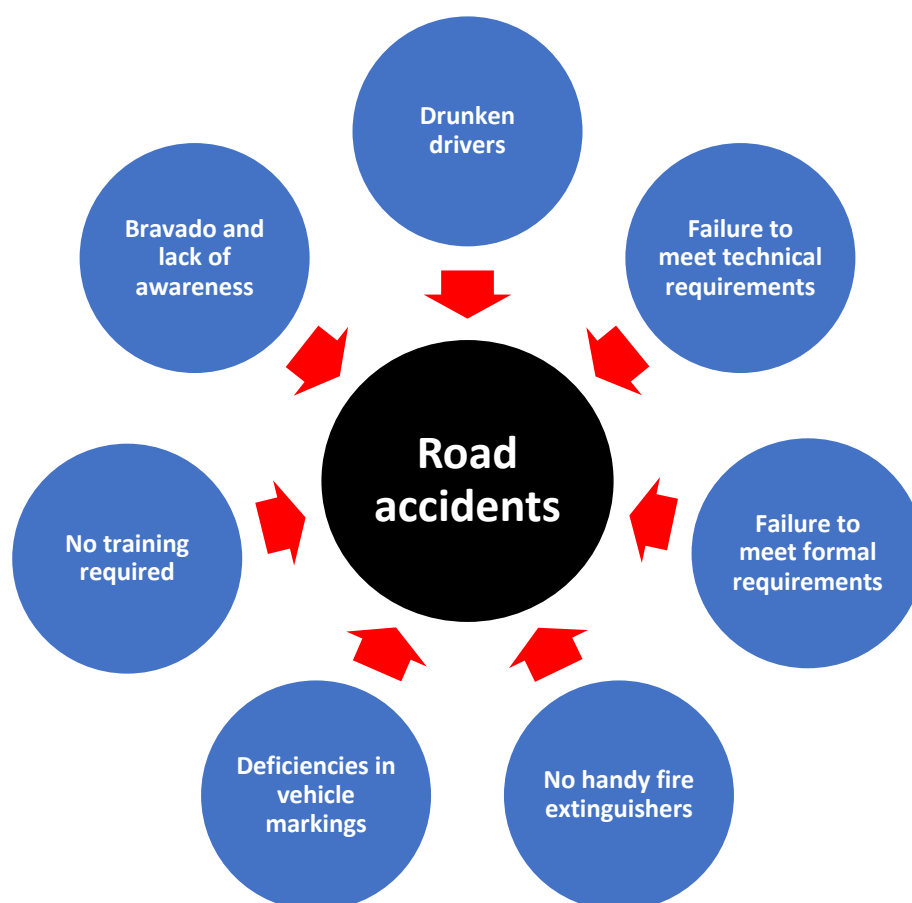


Fig. 4. Classification of causes of road accidents involving dangerous goods

The human factor has a significant impact on ensuring safety in the transport of dangerous goods. Accidents in the hazardous goods transport chain are primarily caused by the number of people involved, the repetitive nature of operational risks among the parties involved, and the possible consequences of an incident. Probability is a secondary consideration when assessing the operational risk of dangerous goods.

Appropriate procedures to improve drivers' health and safety must include a risk assessment and preventive measures. This should precede the implementation of preventive measures for both the driver and their vehicle. Technical measures for risk control and monitoring should be part of the company's management process, not a separate element. Since drivers are experienced and independent workers, it is crucial to engage them in identifying and analyzing risks and opportunities, as well as determining the best ways to manage them. These factors, in the context of drivers' health and psychomotor skills, can negatively impact driving behavior. Risks arise from excessive speed, driving through red lights,

failing to yield to pedestrians, overtaking in prohibited areas, failure to use vehicle safety devices (e.g., seatbelts), using cell phones while driving, etc.

The number of accidents involving the transport of dangerous goods is increasing worldwide. Awareness of their potential negative impact on people and the environment should translate into motivation and, consequently, raise awareness among government representatives, industry, and society at large. The most developed transport of flammable liquid hazardous materials, including all types of fuels, also poses a significant threat.

The liquid fuel supply chain comprises links consisting of refineries and loading terminals during transport from the supplier to the customer. It also includes fuel depots serving as intermediate storage points. However, the weakest link impacting both the quality and quantity of safety is road transport in tankers.

An analysis of the risks and causes of road accidents indicates inappropriate driver behavior. The most common causes of accidents include excessive speed and failure to adjust speed to road conditions, improper passing, failure to yield the right of way, and insufficient safe distance from other vehicles.

Despite severe penalties for failing to meet transport requirements for both shippers and recipients, a significant number of accidents involving hazardous materials occur each year. Driver error, including non-compliance with regulations, can be caused by many factors. Analyses also highlight “fatigue,” which stems from factors such as the nature of the job and work organization. Excessive driving hours and a lack of breaks prevent the body from recovering and impair the driver’s psychomotor skills.

A driver’s careless behavior on the road may also stem from their personality traits, and this should be taken into account during job selection and training. Fatigue can be caused by many factors related to working conditions, such as the ergonomics of the driver’s cabin, monotony, the physical conditions of the working environment in the cabin, and road conditions. Accidents resulting from improper and insufficient securing of cargo on the vehicle or the overfilling of tanks against legal regulations occur just as frequently [2].

Removing the effects of road accidents involving dangerous goods is costly. It also involves significant road disruptions, numerous specialized services, and the securing and protection of the contaminated area. The goal of all these initiatives is to restore the natural environment to its pre-accident state.

This chapter identifies risks in the logistics of dangerous goods. The types of risks vary, with human-related causes predominating. These considerations are important in the context of assessing the safety status of hazardous goods logistics.

In summary, the enormous risks associated with dangerous goods logistics require a high level of ergonomics and safety between the driver, vehicle, and environment. The road transport of hazardous materials can pose a threat to the environment and the people involved in their transport. Compliance with applicable ADR regulations, road traffic regulations, and the responsibility of participants in the transport of dangerous goods can minimize the risk of hazards and contribute to increased safety.

4. IDENTIFICATION OF OPPORTUNITIES RELATED TO THE ROAD TRANSPORT OF DANGEROUS GOODS, FLAMMABLE LIQUIDS, AND GASES

Road safety is a complex and interdisciplinary issue. Road accidents can be caused by many factors, including traffic volume, the number of vehicles, and technical and organizational solutions. Most simply, road traffic safety under specific conditions can be defined as a function of the human-vehicle-road system. The most crucial (and unreliable) element of the system is the human being.

Analyzing the road transport of dangerous goods is one of the factors necessary to estimate how safety levels will change in Poland and globally in the coming years. The lack of systematic solutions for detailed monitoring of road transport of dangerous goods hinders a reliable assessment of the current safety level and the development of such a forecast.

Based on the analysis, it was estimated that the transport of dangerous goods worldwide in the coming years will increase to approximately 32%.

This represents an average annual growth of approximately 4.8%. Considering the transport of individual classes of dangerous goods, it can be concluded that the transport of Class 2 (gases), Class 3 (flammable liquids), and Class 8 (corrosives) materials will experience the most dynamic growth in the coming years. To develop a more reliable forecast for the future transport of dangerous goods by road, it is necessary to implement systematic monitoring of their transport as soon as possible and continuously monitor the movement of vehicles carrying specific dangerous goods.

Factors affecting the safety of the transported product include:

- the variety of means of transport used,
- tank loading method (bottom or top),
- unloading method (gravity or forced, with a measuring system),
- structure of the share of transported cargo,
- human factor (the level of training of staff, especially drivers, and their awareness of hazards and the impact of their own correct work on the level of achieved safety of the products they transport),
- procedures connecting all the links involved in the described dangerous goods logistics chain.

The ADR Agreement [2] regulates the basic activities that should be performed by participants in the transport of hazardous materials. The carrier's primary responsibilities are to ensure that:

- dangerous goods intended for transport are permitted for transport in accordance with ADR,
- all information required by the ADR Agreement regarding dangerous goods intended for transport is delivered by the sender before the commencement of transport,
- the required documentation is in the transport unit,
- The carrier should visually check whether:
- vehicles and cargo have no obvious defects and are free from leaks, leaks or defects in equipment, etc.,
- the deadline for the next test for tank vehicles has not expired,
- vehicles are not overloaded,
- the required warning stickers, signs and orange-colored plates have been placed on the vehicles,
- the transport unit contains the equipment required by the ADR Agreement for the unit transport, vehicle crew, and specific warning stickers.

Transport safety depends largely on the shipper, the carrier, and, above all, the driver. A safe driver should possess not only the appropriate physical and mental predispositions but also be properly trained. The goal of training drivers who transport dangerous goods is to familiarize them with the hazards involved in transport, raise awareness of the consequences of careless driving, and provide them with the information necessary to minimize the likelihood of an accident. Drivers should also be prepared to take actions to mitigate the consequences of accidents and counteract terrorist attacks. Systematic training for participants in the transport of dangerous goods increases the probability of the safe road transport of hazardous materials.

The transport of dangerous goods involves not only transporting them from point A to point B but also a range of other activities related to transport preparation. These include filling the tanker and preparing it for use on public roads, as well as unloading and handing the empty tanker over to the carrier. Therefore, it involves the forwarder, the carrier, and the recipient.

Properly filling and preparing a tanker truck with liquid fuel for transport, as well as transporting and emptying it at unloading points, ensures the safety of other road users, bystanders, and the environment. Marking vehicles transporting liquid fuels provides information not only to the carriers themselves, but also to other road users, and above all, to emergency services.

Drivers encountering a vehicle marked with orange plates should exercise extreme caution. They must be aware that causing traffic disruptions with such a vehicle, or even a minor collision, can lead to an accident, which could have serious consequences for people and the environment. For emergency services, orange plates and stickers provide information regarding the threat posed by the transported goods and the necessary rescue measures.

Appropriate transport conditions should ensure an appropriate level of safety. This is not only a legal requirement but also a paramount consideration when modernizing and developing infrastructure. Because the transport of dangerous goods covered by the ADR Agreement is a particularly dangerous

and sensitive process, all transport participants must take preventive measures to minimize the risk of situations threatening human life or health, as well as the environment.

Defining the impact of transport infrastructure on the safety of transporting goods covered by the ADR Agreement enables the identification of risk criteria and the development of action strategies and opportunities.

The transport of hazardous materials is permitted after meeting several regulations and standards [2], including appropriate technical preparation of the means of transport, including labeling and ensuring proper equipment. These factors reduce hazards and ensure safe transport. A key aspect of the safe transport of hazardous materials is the designation of the route and parking areas. This requires many aspects to be considered, including traffic volume, building density, and road surface quality.

5. CONCLUSIONS

The road transport of hazardous goods will continue to grow worldwide in the coming years. According to the author's research [3], the dominant threats are primarily flammable liquids and gases used in everyday life by society and businesses. The most common cause of accidents on public roads is the human factor.

Table 3

Risks and opportunities during road transport of flammable liquids and gases

Area impact	Risks	Cause	Chances
- people (vehicle crew and bystanders), - natural environment (soil, water, sewage, air).	- leakage of a hazardous substance inside and outside the vehicle, - gas leakage into the atmosphere, - explosion, - inflammation.	- leakage of the packaging or valves due to an accident, packaging defect or failure.	- compliance with applicable law and ADR driver instructions, - use of approved packaging and means of transport, - securing the vehicle using mats and sorbents, - evacuation of people, - rescue operation, - sealing of the vehicle or packaging valve, - determining the danger zone, - turning off the electricity supply, - securing the load and using handy fire extinguishing agents.

This article identified and discussed risks and opportunities related to the transport of flammable liquids and gases. It demonstrates that road accidents involving hazardous materials are largely caused by human factors. Table 3 presents the risks and opportunities related to the road transport of flammable liquids and gases.

The frequency and impact of road incidents depend on various factors, including the duration of the event, the type and level of hazard posed by the transported goods, the nature of the accident, the type of road (motorway, urban road, etc.), specific road features (curved, tunnels, bridges, etc.), the surrounding areas through which they pass, the surface structure, and vehicle speed. A crucial issue is the relationship between traffic volume and the frequency or consequences of road accidents. Road crashes generate substantial costs and have significant consequences for road users and society. Reducing their impact is one of the main goals of transport policymakers.

Although some industrial sectors have made significant efforts to improve the safety and security of dangerous goods logistics, further improvements are still necessary. Public authorities must improve control and monitoring activities, which will require a significant investment of public economic resources.

Minimizing the negative impacts of the hazardous materials logistics chain is a critical task for communities, governments, hazardous materials producers, and carriers. Systems have been developed globally in recent years to help find appropriate solutions, but in the long term, this may not be sufficient.

The opportunities associated with the transport of hazardous goods include appropriate driver predispositions and qualifications, as well as systematic training and procedures. All of this will improve the safety of the hazardous materials logistics chain.

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