RISK ASSESSMENT FOR THE TRANSPORT OF CLASS 1 HAZARDOUS MATERIALS BY ROAD

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Introduction/background: The paper outlines the importance of risk analysis in ensuring the safety of road transport of explosives and ammunition. The growing number of accidents makes it necessary to take a closer look at the safety of the transport of hazardous materials. The article is devoted to the risk assessment for the transport of class 1 hazardous materials by road.
Aim of the paper: The aim of this article is to assess the risk of transporting Class 1 hazardous materials by road.
Materials and methods: The paper uses a literature study of risks in the transport of hazardous materials. The empirical research covered the assessment of risk factors in the transport of class 1 dangerous goods with Bow-Tie Tree diagram, PHA method and risk map.
Results and conclusions: The result of the research is the identification of key categories that generate the main hazards in the transport of class 1 hazardous materials. An analysis of the volume and structure of transported hazardous substances on the domestic market was carried out. The Bow-Tie tree method of cause-effect analysis was used to identify risk factors. The individual risk factors were assessed and the category with the highest risk level was singled out. The results of the analysis were presented in a risk map.

Keywords: Hazardous goods, risk analysis, transport of ADR materials.

1. Introduction

A specific type of transport that requires the involvement of specialised material resources and the application of strict procedures is the transport of hazardous materials (ADR). A hazardous material is defined as a substance that may pose a risk to human or animal health and life (Fertsch, 2006). The transport of this type of goods is characterised by the possibility of a wide variety of hazards. These include those that could potentially occur in the transport of any group of goods, as well as those arising from the specific hazard characteristics of the product. Their type and level also depends on the class of goods being transported (according

to the accepted ADR classification of hazardous materials). The most common branch of transport of hazardous materials is road transport. It should be stressed that this is the most popular mode of transport, but at the same time has the highest accident rate and congestion. These aspects, in the context of hazardous materials, are a definite contributory factor to the hazards involved in transport. This can also be seen in the statistics, which show an increasing number of accidents involving this type of transport.

Currently, the safety of hazardous materials transport is an interesting and analysed research area in the literature (Conca et al., 2016). In the field of road transport, this problem has been addressed by, among others: Fabiano (Fabiano et al., 2021), Fornalchyk (Fornalchyk et al., 2021), Yang (Yang et al., 2010), Janno and Koppel (Janno, Koppel, 2017). A key aim of the analyses undertaken in the literature is to reduce the risks of transport, which can pose a threat both to the goods themselves and, on a wider scale, also to people and the environment. This issue thus fits in with the idea of sustainable development, in which, in addition to the economic pillar, the environmental and social pillars have also gained in importance. A specific group of hazardous materials, generating many risks in transport, are products of an explosive nature, which represent Class 1 ADR materials. These loads are characterised by low transportability due to their sensitivity to high temperatures. They also pose a significant risk given the scale of damage and the number of casualties they can cause during an accident. With reference to this, an assessment of the risks present in the transport of ADR Class 1 explosive goods was adopted as the aim of the paper. In relation to the aim, the authors adopted two research questions:

1. What hazards can be identified as key in the transport of Class 1 hazardous, explosive materials?
2. Which category (technical, natural, human, other aspects) generates the main hazards in the transport of Class 1 hazardous, explosive materials?

This paper is organised as follows. In section 2 and 3, literature studies on the risks associated with the transport of hazardous materials are presented and an analysis of the national market for ADR transport is carried out. The next section of the paper (4) describes the research methodology concerning the risk assessment of the transport of Class 1 hazardous materials. The results obtained from the research, conducted according to the adopted methodology, are presented in section 5 of the paper. The whole paper was concluded with the final conclusions indicating the answer to the research questions posed.

2. Risks in the transport of hazardous materials

When organising the transport of hazardous materials, a key element is ensuring safety. The concept of security should be understood as a state during which both the individual unit and the organisation as a whole are protected against various types of hazards and the achievement of their main objectives can take place without disruption (Romanow, 2017). However, in order to be able to ensure the security of ADR transport, it is necessary at the outset to understand the risks present in the process. Risks exist in any type of business. A risk can be the failure to achieve an adequate financial result or a material loss due to an unforeseen event. This concept particularly applies to the transport of hazardous materials. Risk is defined as the degree of potential damage that could result from the occurrence of an event (Janasz, 2009). In this case, it is expressed as the magnitude of the probability of the event and the severity of the loss. Risk can also be defined as the loss or lost expected value (Haixing, Qiangian, 2020).

A central aspect in an organisation involved in the transport of dangerous goods is appropriate risk management. It is understood as an activity relating to the management and control of risks in an organisation (Sidorova, 2022). According to the principles of risk management, this process should be systematic and an integral part of the company's activities. It is also important to designate specific individuals responsible for the correct functioning of the process. It is also worth emphasising that risk management in the transport of dangerous substances is a system that is subject to change over time. It is important that the level of risk is constantly monitored and that new risks in transport are addressed on an ongoing basis (Wróblewski, 2015). The ISO 31000:2009 standard defines framework structures for risk management that are applicable to various industries, including ADR transport. According to the standard, risk management consists of three basic elements: principles, a framework structure and a process (Hopkin, 2017). The relationship between the different elements in risk management is shown in Figure 1.

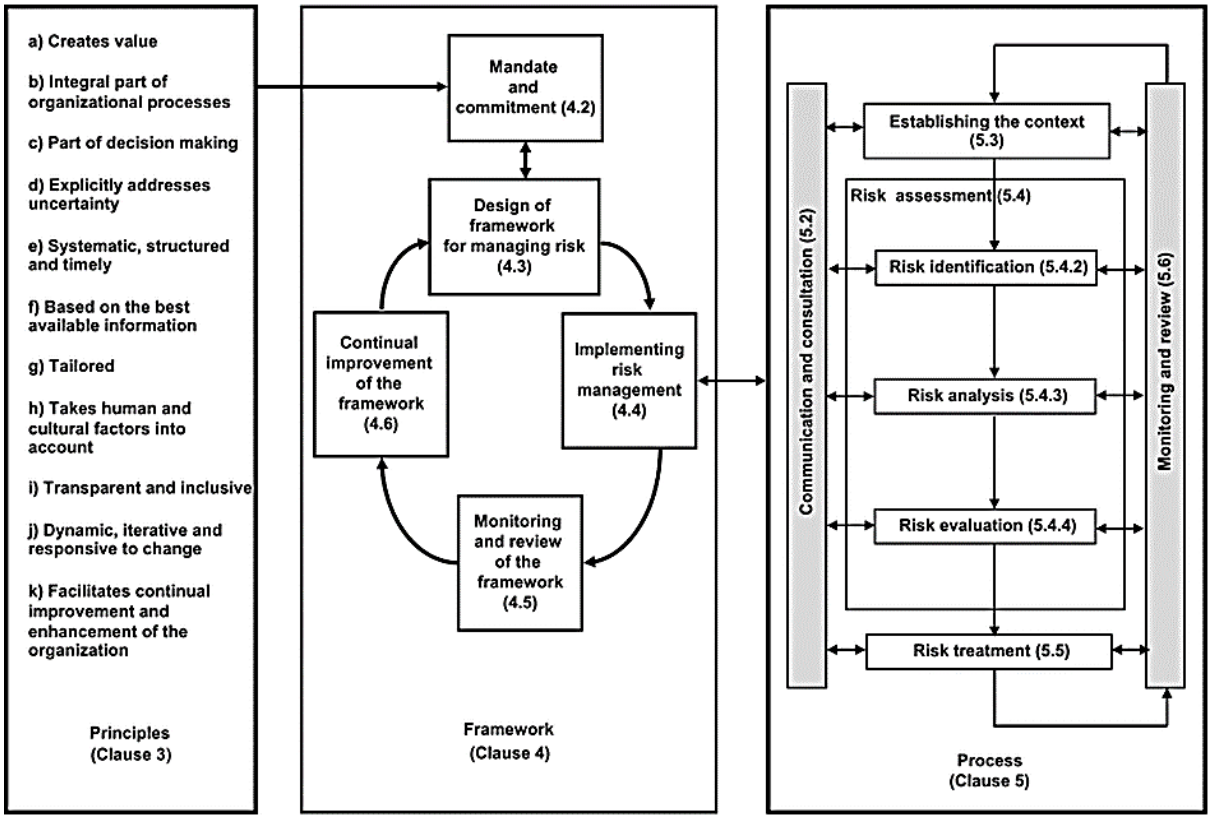

Figure 1. Relationships in risk management. Source: Wróblewski, D. (2015). *Zarządzanie ryzykiem*. Józefów: CNBOP-PIB.

The risk management process makes it possible to implement appropriate responses to the risk factors present in ADR transports, which make it possible to reduce the likelihood of an accident occurring or to reduce the severity of its consequences. Risk identification is the first step that is carried out during the risk assessment of a process. The main objective of risk identification is to identify areas where the carrier is at risk of suffering loss or causing an accident involving a dangerous substance. Risk identification most often illustrates the causes of the risk, the type of hazardous event and its effects and consequences (Voicu et al., 2018). Risk factors are the circumstances under which the risk of a hazardous event may or may not arise. In addition to considering natural and technical factors, special attention should also be paid to the increasing relevance of the human factor in ensuring the safety of the transport process (Chengwu et al., 2022). The main categories of methods for the identification of risk factors include: expert, heuristic, systematic and computer software-based methods (Korombel, 2007). Expert methods involve assembling a panel of experts and having them select and evaluate risk factors. Participants in this method can be specialists in the organisation of the transport of hazardous materials and ADR safety advisors. Heuristic methods, on the other hand, allow a large number of risk factors to be generated by people involved in the transport industry and stakeholders. The systemic category allows risk identification using holistic methods and error analysis. The last category is methods using IT tools to identify risk factors.

They allow the collection of information on the number of potentially hazardous events. The classification of risk identification methods is shown in Table 1.

Table 1.
Classification of risk identification methods

Expert	Heuristic	Systematic	Using computer programmes
- checklist method, - the Delphi method, - nominal group process method.	- the brainstorming method, - synthetic method, - public debate, - scenario building method.	- holistic method, - mystical register, - systemic error analysis.	- review of documentation, - information-gathering techniques, checklists, - diagrammatic techniques (Bow-Tie tree).

Source: Korombel, A. (2007). Ryzyko w finansowaniu działalności inwestycyjnej. Warsaw: Difin.

The next step in the risk management process for the transport of dangerous goods is to assess the risk of individual factors. The assessment of the identified factors can be made in terms of the magnitude of the probability and the scale of the effect of the hazard associated with the transport of hazardous materials. The magnitude of the effect depends on the number of casualties and injured persons, the amount of material damage and environmental damage (Curtis et al., 2012). The results of the risk analysis are presented on a risk map. It allows decisions to be made on the order in which risks should be dealt with. Particular priority should be given to risks in the red zone of the map, i.e. factors with the highest risk level. For these, immediate action should be taken to reduce the current level of risk. The risk map should be updated once mitigating actions have been taken and risk assessments of the ADR transport process should be carried out regularly to maintain a high level of safety (Wróblewski, 2015).

3. Transport of hazardous materials in Poland

The market for the transport of dangerous goods by road in the European Union has been characterised by stable growth and slight fluctuations over recent years. Poland ranks 5th in terms of the volume of hazardous materials transported compared to other EU Member States. A graph showing the volume of ADR transport in the EU in 2020 is presented in Figure 2.

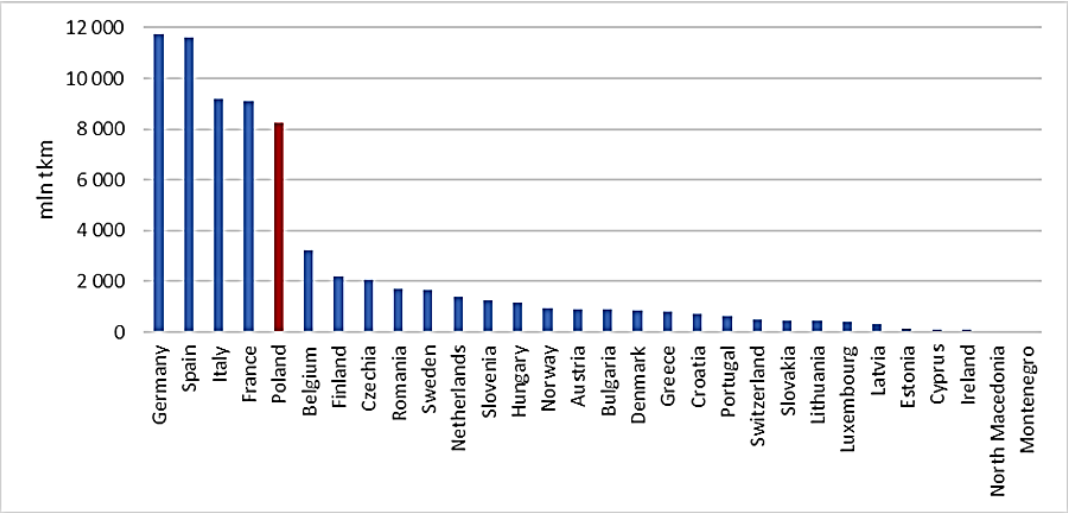

Figure 2. ADR transport in the EU in 2020 (million tonne-kilometres). Source: own study based on Eurostat data.

In 16 years, the volume of ADR cargo transported in Poland has more than doubled. The increase in transport volumes is closely linked to the country's economic development and increased demand for specialised transport services. Despite periodic decreases, further development of the hazardous cargo transport industry is expected. A graph of the volume of domestic transport of hazardous materials in million tonne-kilometres between 2004 and 2020 is shown in Figure 3.

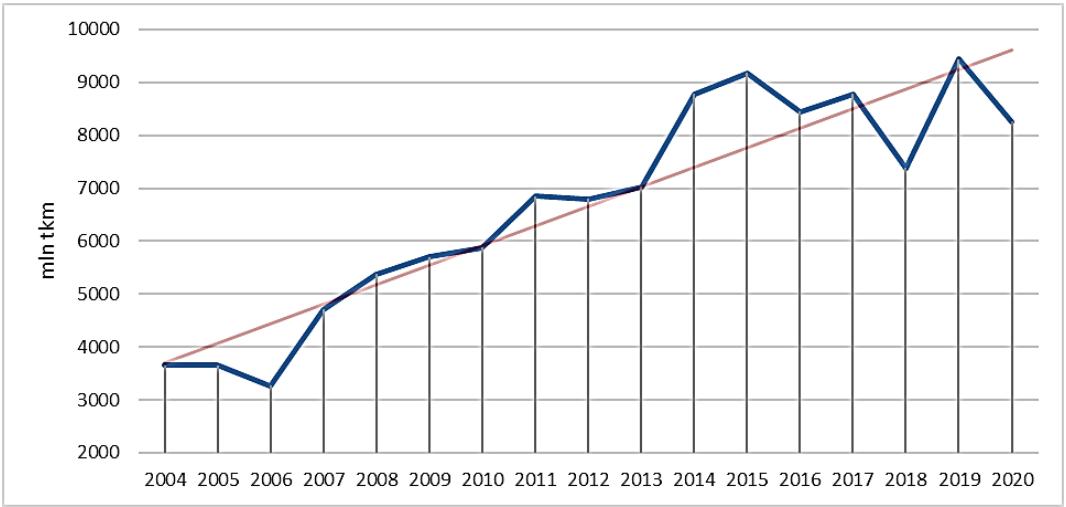

Figure 3. ADR transport in Poland between 2004 and 2020 (million tonne-kilometres) Source: own study based on Eurostat data.

As the volume of hazardous materials transported increases, so does the number of accidents involving ADR transport. Their number is shown in the range of 2010-2017 in Figure 4.

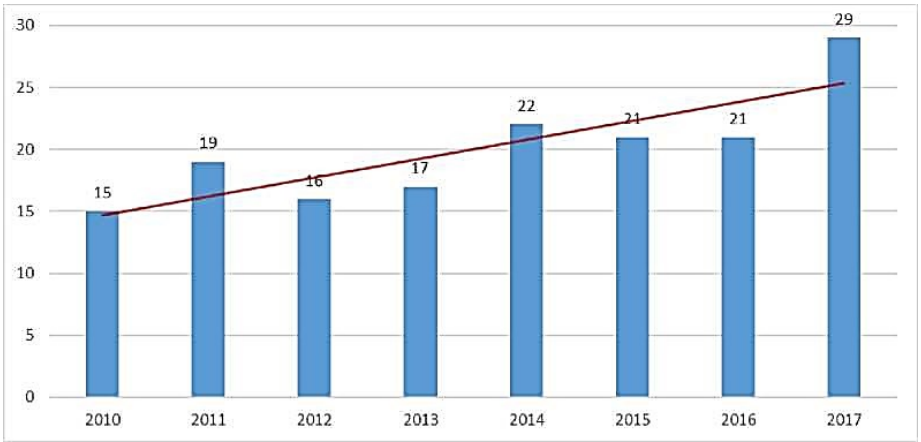

Figure 4. Number of accidents involving transport of hazardous materials in Poland between 2010 and 2017. Source: own study based on: Pajak M. (2019). Ograniczanie ryzyka zagrożeń w transporcie drogowym przez zastosowanie systemu monitorowania towarów niebezpiecznych. Poznań.

The increase in accidents involving hazardous materials is a serious problem in transport. They definitely pose a significant risk to the safety of the cargo itself, as well as to people and the environment. It is therefore important to identify and assess the risks of transporting hazardous materials and consequently to implement risk management procedures to minimise potential hazards.

4. Research methodology

With reference to the aim adopted and presented in the introduction of the paper and the research questions formulated, a methodology was adopted which consists of 3 main phases. It is presented in Figure 5.

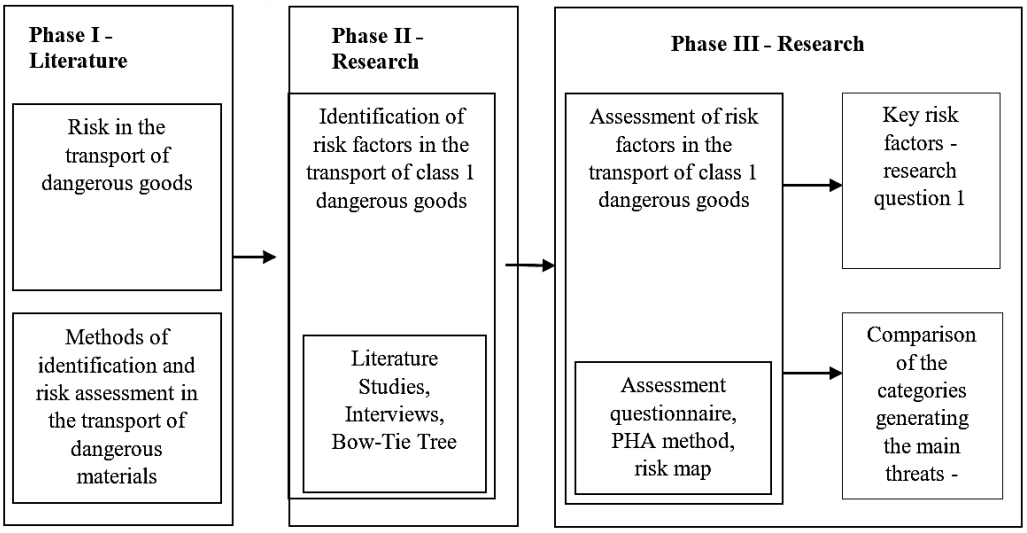

Figure 5. Test methodology. Source: own study.

As shown in Figure 5, the research conducted involved three main phases. In the first, literature studies were carried out. These were aimed at showing the risk of various hazards as factors adversely affecting transport safety. This is particularly important in view of the significant volume of hazardous materials transport work carried out in Poland in comparison with other European countries, as shown in point 3 of the paper, and because of the increase in the number of accidents involving these materials. In addition, the study identified methods used to identify and assess risks. They can also be applied in the area of hazardous materials transport. As part of the second phase of the research, the identification of potential risk factors in the transport of Class 1 hazardous materials was carried out. The risk factors can be divided according to different categories, but in the conducted research a division into four categories was adopted: 1) Natural factors, 2) Technical factors, 3) Human factors, and 4) Other factors. The identification of individual factors within these four categories was made as a result of literature analyses and interviews with experts in the field of hazardous materials transport. A group of 12 Polish experts was appointed for the research. They were representatives of the world of science and business practice in the field of transport of hazardous materials (with particular emphasis on class I ADR loads). The basic criterion for the selection of experts was their knowledge and experience within the research area in question. Scientific publications were considered in the case of experts representing science as well as the position held and seniority in the transport activity, in the case of experts representing business practice. The presentation of the identified factors was made using a Bow-Tie tree. This method consists of a visual representation of the cause-and-effect relationship of risks in the process (Voicu et al., 2018). In the third phase of the research conducted, the identified risk factors were assessed using the PHA method. For this purpose, a questionnaire was prepared, addressed to the above-mentioned group of experts. This research was conducted in March 2022. As part of the questionnaire, the experts assessed the identified risks in terms of two criteria: the probability of the risk occurring and the effect generated by the risk. A five-point scale was adopted, where: a score of 1 meant a very low probability of occurrence/a very low effect generated by the risk. The remaining scores (2, 3, 4, 5) showed an increasing trend up to a score of 5, which meant a very high probability of occurrence / a very high effect generated by the risk. Based on the results obtained, the identified risks were assessed. The final score was the product of the probability and the effect assigned to each risk separately. A risk map was used to show the individual risk levels. The results obtained for each risk individually and the juxtaposition of risks within each category allowed answers to the two research questions posed in the introduction.

5. Identification and risk assessment in the transport of ADR Class 1 dangerous goods – research results

When identifying the risks in the transport of ADR Class 1 dangerous goods, the risk factors were divided into four categories: natural, technical, human and other hazardous factors. A total of 20 main risk factors affecting transport safety were identified and assessed. A Bow-Tie tree diagram also shows the cause-and-effect relationships that exist between the risk factors and the consequences in the transport process. The identified factors affect the risk of an accident involving a vehicle transporting hazardous materials and the possibility of vehicle hijacking. The consequences of these events can be the explosion of a hazardous material and environmental contamination. The identification of risk factors in the road transport of explosives using the Bow-Tie tree method is shown in Figure 6.

The results of the conducted assessment of risk factors in the examined process are presented in Table 2. The level of probability and the level of losses are the averaged assessments assigned by the experts (on the basis of the applied assessment questionnaire). The magnitudes of the probability level and the loss level were assessed on a 5-degree scale. The final risk rating is the product of the probability level and the loss level.

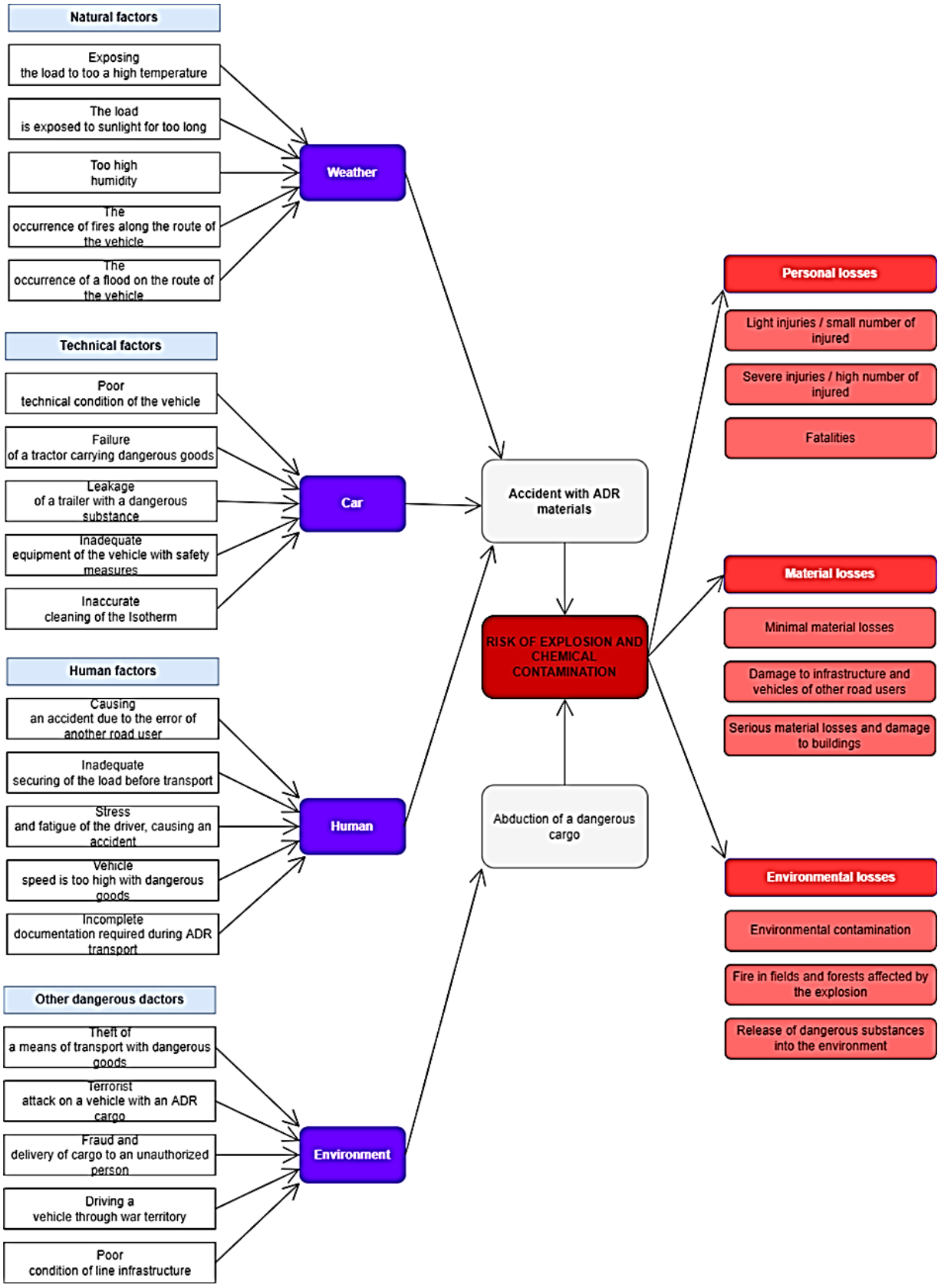

Figure 6. Identification of risk factors in the transport of ADR Class 1 materials using a Bow-Tie tree. Source: own study based on interviews with experts and Voicu et al., 2018.

Table 2.
ADR Class 1 transport process risk assessment

No.	Risk characteristics	Probability level (i)	Loss level (j)	Product (i * j)	Level of risk
Natural factors					
1.	Exposure of cargo to excessive heat	2	5	10	Medium
2.	Exposure of cargo to sunlight for too long	3	4	12	Medium
3.	Too high humidity	2	1	2	Very low
4.	Occurrence of fires along the vehicle route	4	3	12	Medium
5.	Occurrence of flooding along the vehicle route	1	1	1	Very low
Technical factors					
6.	Poor technical condition of the vehicle	1	4	4	Very low
7.	Breakdown of a tractor carrying hazardous materials	2	2	4	Very low
8.	Leaking semi-trailer with hazardous substance	1	3	3	Very low
9.	Inadequate safety equipment on the vehicle	3	3	9	Low
10.	Inaccurate cleaning of the Isotherm	2	2	4	Very low
Human factors					
11.	Causing an accident due to the fault of another road user	2	5	10	Medium
12.	Inadequate load securing prior to transport	4	4	16	High
13.	Stress and exhaustion of the driver, causing an accident	4	5	20	Very high
14.	Excessive speed of vehicle with hazardous material	2	3	6	Low
15.	Incomplete documentation required for ADR transport	3	3	9	Low
Other hazardous factors					
16.	Theft of a means of transport with a hazardous material	2	4	8	Low
17.	Terrorist attack on an ADR laden vehicle	2	5	10	Medium
18.	Fraud and the release of cargo to an unauthorised person	2	4	8	Low
19.	Passage of a vehicle through a territory subject to war	1	5	5	Low
20.	Poor condition of line infrastructure	3	2	6	Low

Source: own study.

The risk map for the transport process of ADR Class 1 materials is shown in Figure 7. According to the results, seven factors were considered to be of medium or high risk. The factor considered to be the most dangerous (critical) is driver error due to fatigue and stress. The transport of ADR Class 1 explosives often takes place over considerable distances. Despite regular breaks, the driver may feel fatigued, which reduces his/her ability to react to situations on the road and increases the risk of causing an accident. Inadequate securing of the load by the customer for the transport of Class 1 explosives is also an important factor that affects the level of risk. The risk factor relates to the loading units themselves in which the explosive is stored. There is a risk that containers designed to hold explosives and ammunition may be worn or damaged, which directly affects the level of transport security. Consideration should also be given to factors associated with exposure of explosives to excessive heat and sunlight. Cargoes are particularly vulnerable to these factors during handling. On the other hand, factors such as the effect of moisture on transported loads and the risk of flooding along the route pose little risk. Transporting hazardous materials in isotherms significantly minimises the likelihood of an explosion resulting from natural factors.

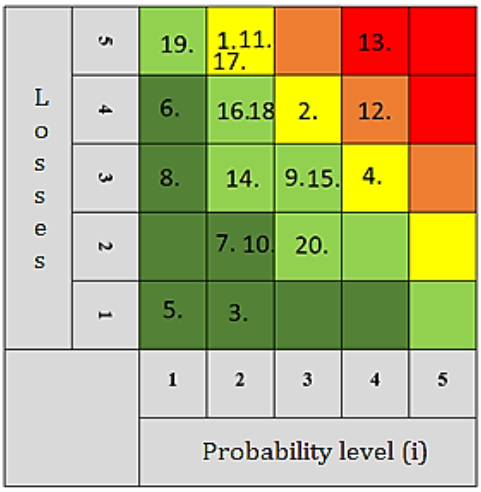

Figure 7. Risk map for the transport of dangerous goods of ADR Class 1. Source: own study.

A comparison of the average risk level of the Class 1 hazardous materials transport process by category is shown in Figure 8.

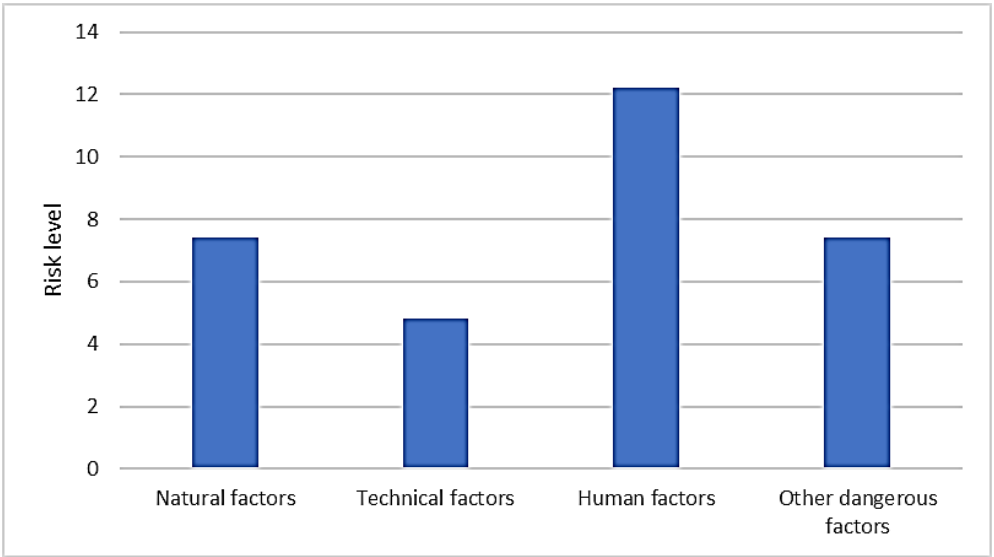

Figure 8. Comparison of the average risk level per category. Source: own study.

The average risk level for the transport of explosives was 7.95. The maximum achievable risk level was 25. This means that this transport has a relatively low risk level. The category with the lowest risk level with a score of 4.8 was technical factors. Due to the widespread use of modern technical solutions in the transport of explosive loads, high quality load securing measures and the stringent requirements for the approval of vehicles for the transport of loads in this class, this category had the lowest risk level. The natural factors category, with a score of 7.4, has a medium impact on the occurrence of risks for the transport of explosives. As the study showed, the risk factors associated with excessive outdoor temperatures and exposure to sunlight are the most significant influences in this category. The risk of fire along the route of travel is also an important factor. This factor is particularly possible due to the changing climate, droughts and the increased frequency of fires in Europe. In the case of

transporting explosive cargo, contact with fire can lead to an explosion. Other risk factors mainly related to criminal activities received an average score of 7.4, which means that they also strongly influence the process of transporting explosives. This is mainly due to the threat of hijacking of a vehicle transporting explosives, ammunition and weapons. Transports of this kind are often the target of a terrorist attack. Weapons transports can also be targeted by thieves and fraudsters. The human factors category received the highest average risk level of 12.2 points. Despite the highest standards and procedures in place, the key factor to ensure security is human. The safety of the transported cargo depends directly on the driver's skills, knowledge and experience.

6. Conclusions

The study made it possible to identify and assess the main risk factors in the road transport of ADR Class 1 explosives. Of the 20 factors analysed, one factor was identified as critical (with the highest risk level) - driver stress and exhaustion, causing an accident. A high risk level was identified for one factor - inadequate load securing prior to transport. In addition, five factors with a medium level of risk were identified. Thus, the first research question posed was answered. The risk analysis also made it possible to compare the four identified risk categories. This allowed the second research question posed to be answered. The human factor category received the highest mean risk score. As a result of stress and fatigue, the driver's ability to react quickly decreases and the risk of accidents and high levels of material and human loss increases. The safety level of the transport of hazardous materials depends directly on the skills, experience and knowledge of the driver. Thus, it must be recognised that the most important factor in ensuring the safety of the process under study is human. The identified and assessed risk factors will allow further research on risk evaluation in the transport of explosives and a comparison of the obtained results with the risks of other groups of hazardous materials.

The study has certain limitations including: 1) Small number of responses in the survey due to the limited number of experts in the field of transport of ADR Class 1. 2) The limitation of the research is not only the number of experts, but also the fact that only Polish representatives were the experts. It is not possible to relate the research results to other countries where experts could assess probability and effect differently. It may also generate the direction of further research, in which these results can be compared with the results of other countries, extending them to foreign experts. The selection of experts for research is a very important and even critical stage of research. 3) The risk of incorrectly assessing the level of loss or the probability of a risk factors due to different experiences of experts depending on the size of the company in which the expert works. 4) The survey might not cover all the hazards that may occur during the transport of ADR Class 1.

The implementation of the research will allow the companies involved in the transport of hazardous materials to focus on the key risk categories that cause a high level of the risk in the process, especially considering the human factor. Transport companies should pay particular attention to reducing the level of stress and driver exhaustion as a key risk factor in ADR transport. The research will allow for the development of numerously improvements that will increase the efficiency and safety of the process of transporting hazardous materials.

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