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INVESTIGATION OF SAFETY CONDITIONS IN THE TRANSPORT OF DANGEROUS GOODS BY RAILWAY

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Abstract. Safe transport of dangerous goods by railway is an important challenge for both national and international freight transport. The transport of dangerous goods is one of the most demanding transportation technologies. The aim of this article is to assess the conditions for the transport of dangerous goods by railway and to define the main factors, which affect the transport of such goods by railway. Scientific literature was analysed, statistics were provided, and a qualitative survey was conducted. The factors of 3 groupas that have the greatest impact on the safe transport of dangerous goods by railway were studied and identified. The obtained results were processed using the Kendall's rank correlation method, and the consistency of the expert opinions was clarified using the fit coefficient. Using the medium-distance transformation weights (Average Rank Transformation Into Weight – ARTIW) method, the main normalized subjective weighting factors that most influence the conditions of transport of dangerous goods for safe transport have been identified. The results of the study revealed that the main factors of Group I that have the greatest impact on the accident of dangerous goods by railway, are: complete preparation of the train, driver's confidence in the safety systems of the locomotive and improper loading of cargo. The most important technical-technological factors of Group II, which have the greatest impact on the accident occurring in the transportation of dangerous goods by railway, are: technical condition of the locomotive, tightness of railway tanks (wagons) and marking of wagons carrying dangerous goods. Key organizational factors for Group III to consider before dangerous goods are transported by railway are: risks related to freight forwarding, identification of chemical properties of freight and driver qualification. The key factors in these three groups can be used to develop models to make the transport of dangerous goods by railway safer and more efficient.

Keywords: dangerous goods, railway transport, accidents, risk, safety, transportation.

Introduction

Hundreds and thousands of tons of dangerous goods are transported by railway every day. Railways carry a wide range of types of goods, from petroleum products to non-standard goods. Any dangerous goods transported by railway are subject to strict rules so that the goods can reach their destination safely (OTIF 2021). The transportation of dangerous goods is considered to be one of the most demanding areas of transportation, since an accident involving dangerous goods can endanger human health and the environment because of its chemical or physical properties.

Güner-Özbek (2008) state that the types of harmful and dangerous goods are not very numerous, 9 classes of dangerous goods are distinguished depending on the chemical or physical properties of the materials. According to the authors, in practice, dangerous goods are thoroughly assessed only when incidents occur, so it is necessary to pay attention to the dangerousness of goods in advance. The analysis of accidents in the transport of dangerous goods shows that accidents or incidents in the transport of dangerous goods cause more problems than in the transport of conventional goods. The transport of dangerous goods poses an imminent risk and a potential danger to public and environmental safety.

The main aspects of the transport of dangerous goods differ from normal transport processes. The transport of harmful, dangerous to humans and the environment, toxic or self-igniting goods, which are considered dangerous, includes the preparation for transport, the acceptance of the goods from the consignor, the transport process and delivery to the final consignee. These actions include ensuring security both during loading, unloading or re-

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loading of cargo and during storage. The various security measures must also take into account the hazard class of the substances carried.

As the demand for dangerous goods increases, not only the flows of dangerous goods but also the likelihood of an accident risk increases. According to the Lithuanian Department of Statistics (LDS 2022), the transportation of dangerous goods is mostly carried out by road and railway. The volumes of transportation of dangerous goods in Lithuania by railway were grown from 2014 till 2017 and from 2017 till 2019 were decreased slightly. Although not a lot of goods are transported by road transport, the volume of dangerous goods has almost doubled in 5 years – 1712 thousands of tons. The amount of dangerous goods transported by railway in 2017 reached a volume of transportation – 13564 thousands of tons, but in 2019 decreased till 11497 thousand tons. It can be stated that the volumes of railway of transport increased steadily from 2014 till 2017, but decreased the last two years analysed. There are usually 3 classes of dangerous goods transported. These are flammable liquids. Diesel, varnish and petrol are mostly transported by railway. 2013–2019 the transportation of these materials was stable and amounted to about 9000…10000 thousands tons. In second place, according to the amount of cargo most often transported, are self-igniting substances such as phosphorus, activated carbon, and so on. Quantities of this class of dangerous goods, ranging from 17 thousand tonnes to 1300 thousand tonnes per year. In third place in terms of transport volume are oxidizing substances, which are transported by railway in the amount of approximately 650 thousand tons per year. It can be noted that in 2015, the volume of shipments of these materials started to decrease, and in 2019, their volume amounted to 621 thousand tons per year. The relatively smallest amount of dangerous goods according to the frequency of transportation belongs to Class 2 cargo. These are gases such as propane, butane or aerosols. The volumes of Class 2 dangerous goods transportation have increased since 2015 and in 2019 amounted to 1056 thousand tons.

The volume of transport of dangerous goods is increasing every year. According to Kondratov and Novikov (2015), not only are corporate transport fleets expanding, but the risk of accidents is also increasing. The number of accidents related to the transport of dangerous goods by railway was the highest in 2017–2019 – from 27 to 152 accidents per year in European Union countries. In drawing conclusions, it should be noted that these figures do not include accidents during which there were no consequences of the accident.

The object of the work is the factors that have the greatest impact on the safe transport of dangerous goods by railway. The aim of this article is to assess the conditions for the transport of dangerous goods by railway and to define the main factors, which affect the transport of such goods by railway.

1. Review of the scientific literature on the transportation of dangerous goods

Foreign and Lithuanian scientists emphasize that great attention must be paid to the transportation of dangerous goods not only during the preparation of such cargo, but also in its loading and unloading, and especially in the transportation of cargo to its final destination. Conca *et al.* (2016) state that the safety of the transportation of dangerous goods is an important task in transport planning. This concerns road safety, storage, prevention and safety of goods. The main objective is to reduce the risk of dangerous goods accidents. The consequences of accidents involving dangerous goods can be very tragic for people, especially when they occur in urban areas; as well as to the environment of the surrounding cities, property and all forms of life.

During transportation, there are various risks of safety, cargo stability and ensuring the required condition, so there is a need to properly ensure all actions of the dangerous goods transportation process (Janno, Koppel 2017). The topic of dangerous goods was analysed by Lithuanian authors: Motiejūnaitė, Batarlienė (2012); Pikūnas, Pumputis (2005); Batarlienė, Jarašūnienė (2014); Batarlienė (2020a, 2020b), etc., and foreign authors: Drewek (2010); Ghazinoory, Kheirkhah (2008); Šolc, Hovanec (2015); Nowacki *et al.* (2016); Gamero *et al.* (2018); Drzewieniecka, Nowak (2018); Ren *et al.* (2018); Loprencipe *et al.* (2018), etc., however, insufficient attention is paid to the factors affecting the safe transportation of dangerous goods by railway.

Odincov *et al.* (2009) states that dangerous goods include any substance, industrial or other waste, which by its intrinsic properties may endanger human life and health as well as harm the environment. Dangerous goods are classified according to direct physical or chemical effects, which may affect human health, property or the environment, such as explosive, flammable, corrosive, chemically reactive, acute toxic, radioactive or infectious substances. Freight transport by railway often poses a high risk of accidents. When transporting dangerous goods, there is always the risk of events such as cargo spills, fire, explosion, chemical burns or environmental damage (Erkut *et al.* 2007; Kršák *et al.* 2012).

Dangerous goods are divided into 9 categories of dangerous goods (OTIF 2021):

- »» explosives;
- »» gas;
- »» flammable liquids;
- »» flammable solids;
- »» oxidizing agents;
- »» toxic substances;
- »» radioactive substances;
- »» edible substances;
- »» other hazardous substances and products.

Ensuring safety and developing risk management strategies as a prevention to mitigate the potential consequences of the transport of dangerous goods is essential, but according to Laarabi *et al.* (2014), there is no uniform model for risk management internationally. Although the transportation of dangerous goods is always a risky procedure, the possibility to manage and reduce the risks is a very important factor. The authors believe that this issue will be resolved in the future, as research is already being carried out, advanced technologies are being developed, and the need to manage the transport of dangerous goods is emerging.

Special safety requirements for the transport of dangerous goods by railway must be complied with, both internationally and nationally. International requirements apply to the transport of dangerous goods, packaging and marking of wagons. The main document that regulates the transport of dangerous goods by railway is the *Regulations Concerning the International Carriage of Dangerous Goods by Rail* (*RID*), which is adjusted and supplemented every two years (OTIF 2021). It is necessary to regulate, control and inspect the transport of dangerous goods by railway because of their characteristics and real risks.

Diernhofer *et al.* (2010) state that most accidents involving the transport of dangerous goods do not occur due to the characteristics of the dangerous goods themselves, but due to organizational errors in the production and transport processes. Motiejūnaitė and Batarlienė (2012) point out that safe and efficient transportation of dangerous goods requires a good information system, which should include such components as labelling, packaging, transportation and storage of dangerous goods.

Container transport of dangerous goods is widespread not only by railway, but also by road and sea. Intermodal transport is particularly popular, in which dangerous goods remain in containers as modes of transport change, so it is essential for each operator to monitor the condition of the goods being transported. Ding *et al.* (2016) suggest the use of Internet of Things (IoT) technology. According to the authors, it combines various information collection, analysis and transmission technologies, such as Radio-Frequency IDentification (RFID), Global Positioning System (GPS), laser, infrared sensors.

Ghazinoory and Kheirkhah (2008) argue that the description of the optimal state of the transportation system for hazardous materials focuses on the risk of transportation. Nowacki *et al.* (2016) and Gamero *et al.* (2018) have emphasized that special attention needs to be paid to the transport of dangerous goods not only during the preparation and loading of such cargo, but also during transportation until the cargo reaches its destination.

Sun *et al.* (2018) proposed a weight optimization approach to improve railway safety assessment. They used a branch-constrained algorithm, which is an algorithm for solving a quadratic programming model. Ren *et al.* (2018) examined the causes of deaths due to accidents involving the transport of dangerous goods by land (railway and road) and found a relationship between cumulative frequency and deaths in a different vehicle, in a different country, and at different times. This study provided insights into the evolution of the severity of accidents with the development of the social economy and safety requirements. The safety and efficiency of international railway freight have also been studied by Loprencipe *et al.* (2018), who proposed to define an innovative methodology for the design of tunnel structures, the inspection of free space conditions, and the design of modernization works.

Hazardous materials transportation should consider risk equity and transportation risk and cost. This has been examined by the researches Chai *et al.* (2018). They proposed a risk-sharing equity model to reduce the risk gap between populated areas by adjusting the road frequency for transporting hazardous materials. The model they propose is appropriate to reduce the complexity of the transportation process and increase its portability.

The effects of fires and explosions on the transport of hazardous materials were modelled by Assael *et al.* (2015). They described losses in road transport, accidents involving tankers transporting Liquefied Natural Gas (LNG) or Liquefied Petroleum Gas (LPG), and pipeline transport, which can ignite and explode. Their article presents a simulated effect of explosion-induced overpressure and heat radiated by fires.

Cieśla *et al.* (2020) presented the idea of modelling the decision-making process in the field of the metropolitan areas transport system. They developed a model that was implemented in the Silesian metropolis of Poland, with a special focus on the sharing of mobile vehicle users. Jacyna and Semenov (2020) presented problems related to decision-making planning and implementation of the vehicle service system with spare parts, providing incomplete information. In the study by Jacyna and Wasiak (2015) indicated decision-making problems related to the development of transport systems in the face of planning challenges of sustainable urban mobility. They examined multi-criteria decision support in designing transport systems. Jacyna and Krześniak (2018) presented what computer aids are used to make decisions when planning the movement of freight wagons on the railway network. However, they did not address safety issues in the transport of dangerous goods.

Before planning any transport of goods by railway, it is necessary to take into account not only the skills and qualifications of the driver of the locomotive, but also the technical condition of the train wagon or tank and other requirements necessary to ensure maximum safe transport.

After the analysis of the scientific literature, accident risk factors were grouped into 3 groups:

- *Group I* – factors having the greatest impact on the occurrence of accidents;
- *Group II* – technical-technological factors to be considered before the shipment;
- *Group III* – organizational factors to be considered before the shipment.

Limitation of the research. Actually, there are a lot of factors that have the impact on the safe transportation of dangerous goods by railway, but this research target is evaluate the factors that most often lead to traffic accidents or accidents while transporting dangerous goods. In addition, the method used is completely inappropriate when a large number of factors are present, since it is difficult for an expert to determine the correct relationships between the factors in relation to the phenomenon under consideration.

The following section of this article will discuss the methodology used for the study.

2. Research methodology

2.1. Expert assessment method

Expert evaluation was used to conduct the study. Expert evaluation is taken as a generalized opinion of the expert team, which is based on the knowledge, intuition and experience of specialist experts. It is a procedure for reconciling the opinions of individual experts and forming a common solution. An expert is called a specialist who has knowledge and experience in a particular field (Sėrikovienė 2013). The reliability of an expert evaluation depends on the size of the expert group, the composition of the experts according to their specialty and the characteristics of the experts.

Expert assessment methods are usually used when there is a lot of information about the object, but it is multi-criteria or qualitative in nature (Maknickienė 2015).

The main ethical requirements of social research that apply to expert evaluation are the following (Kardelis 2016):

- respondents must agree to participate in the survey;
- the researcher cannot influence the respondents in answering the questions;
- respondents must be chosen in such a way that they have sufficient competence to answer the questions.

The problem of the selection of experts is emphasized in the scientific literature. From a statistical point of view, the more experts you use, the better. Depending on the circumstances and objectives of the study, in some cases there may be only one or two experts who observe the same phenomenon. Their decisions are then compared statistically.

The expert review conducted in autumn of 2019 involved 10 respondents who participated in it. According to the formulated methodological assumptions, the number of experts was determined in accordance with the theory of classical tests. These theories state that the reliability of solutions and the number of experts is linked by a rapidly extinguishing nonlinear relationship.

It has been shown that in models of aggregated expert review with equal weights, the accuracy of judgments and evaluations of a small group of experts does not outweigh a large group of experts (Libby, Blashfield 1978), see Figure.

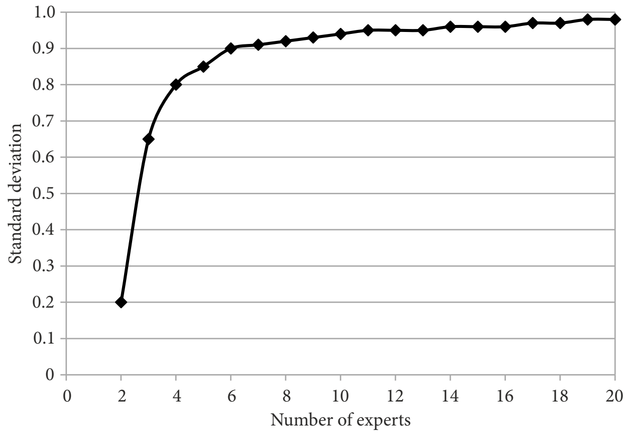

Figure. Dependence of expert standard deviation on number of experts (Libby, Blashfield 1978)

If there are more than 7 experts, the accuracy is over 90%. If the number of experts is increased, the accuracy increases very little. Hence, the 10 is a sufficient number of experts for this study.

It was very important to find suitable experts for the research in all the analysed companies. The questionnaires were distributed to 16 employees of JSC "Lithuanian Railways" (in Lithuanian: *AB „Lietuvos geležinkeliai"*) who work directly with the transportation of dangerous goods. The survey was conducted by sending questionnaires by e-mail or in meetings with railway staff. 10 questionnaires were received.

During a qualitative study in a railway company, the team was composed of experts with a 10-to-15-year experience in dealing with dangerous goods. 5 experts hold senior positions in the companies and are closely involved in top-level strategic decision-making. 5 experts conduct research in areas of scientific interest such as the effectiveness of railway transportation, safety of transportation.

A questionnaire was developed to find out which factors most often cause accidents or incidents and which factors have the greatest impact on the safe transport of dangerous goods by railway.

Results showed, that Kendall coefficient of concordance is statistically significant (range from 0.8 till 1). It is important to consider the number of factors to choose the appropriate methodology for determining the significance of factors. For a small number of factors, it is simplest and most rational, according to Ginevičius (2006), to apply direct estimation, where experts report on a unit-by-unit basis the significance of the factors. According to this method, the sum of the materiality of all evaluations of each expert must be equal to one (Podvezko 2008). The practice of using this method has shown that it is easy to understand and gives a relatively accurate result of the materiality assessment when the expert group agrees. However, according to Ginevičius (2006), such a method is completely inappropriate when a large number of factors are present, since it is difficult for an expert to determine the correct relationships between the factors in relation to the phenomenon under consideration. This increases the field of disagreement, often beyond the legal limits, and invalidates the results of the expert survey for further calculations. The experts were interviewed by questionnaire. The questionnaire was compiled in order to find out the experts' attitude towards the factors, which have the greatest impact on the safe transportation of dangerous goods by railway. Closed-ended questions were used to obtain the required information because it facilitates the comparison and analysis of the data.

Prior to conducting the survey, the experts were individually introduced to the purpose of the study and the evaluation methodology. Experts were given the task of evaluating the factors that most often lead to traffic accidents or accidents while transporting dangerous goods by giving rating values in the range [1, 10], with 10 being the best rating and 1 being the worst rating. During the evaluation, the experts were able to communicate with the initiators of the study, but they had to evaluate it individually, indicating their estimates in a questionnaire prepared by the authors. The expert survey was conducted by sending questionnaires by e-mail or by visiting an expert. Questionnaire data was processed and analysed using *Microsoft Excel*.

2.2. Methodology for calculating expert opinions

The overall consistency of the expert judgment is determined by applying a concordance coefficient, which allows to estimate the experts' opinions degree of agreement. The correlation between two experts can be quantified by a correlation coefficient. If the number of experts is greater than two, the concordance factor is defined by the concordance coefficient of the experts in the group. In order to calculate the concordance coefficient, it is first necessary to rank the factors in order of importance. After factoring the factors, the concordance coefficient is calculated according to the equation (Podvezko 2008):

$$W = \frac{12 \cdot S}{r^2 \cdot n \cdot \left(n^2 - 1\right)}, \quad (1)$$

where: W – concordance coefficient; r – the number of experts; n – the number of indicators to be evaluated; S – the sum of the squared deviations of the totals of the grades, calculated using the equation:

$$S = \sum_{j=1}^{n} \left(e_i - \overline{e}\right)^2, \quad (2)$$

where: e – random variable; $\overline{e}$ – expected value (the average) of random variable.

If the value of the concordance coefficient is close to a unit, this indicates that there is no contradiction between the experts' estimates. The concordance coefficient can only be applied when it has a threshold value indicating that the expert assessments can still be considered as concordant. Concordance coefficient W values are in the range of 0 till 1, where $0 \leq W \leq 1$. The higher the value of W, the less the respondents' opinions differ on the analysed question. If the experts agree on the subject being evaluated, then the W value is 1. The concordance coefficient is used to obtain the highest quality results, and to determine how much each factor is more important than the other.

When the quality of an object is assessed and can be described by a single value and compared with the quality of other similar objects, the normalized criterion weight w_j should be used. The significances (weight) of the criteria can be defined by Average Rank Transformation Into Weight (ARTIW) method by which the relative importance of all 10 factors is defined.

3. Results of the study of factors, which have the greatest impact on the safe transportation of dangerous goods by railway

Having analysed the scientific literature, the factors that have the greatest impact on the safe transportation of dangerous goods by railway were grouped and evaluated by experts according to 3 groups.

The experts first assessed the factors contributing to the occurrence of accidents involving the carriage of dangerous goods by railway, which are factors contributing to Group I:

- A1 – railway track condition;
- A2 – complete preparation of the train;
- A3 – secondary occupation of locomotive driver;
- A4 – improper loading of cargo;
- A5 – delivery speed;
- A6 – time of day;
- A7 – lack of locomotive driver knowledge;
- A8 – driver's confidence in the safety systems of the locomotive;
- A9 – locomotive driver fatigue;
- A10 – route selection.

After assessing the importance of Group I factors contributing to the occurrence of accidents involving the carriage of dangerous goods by railway, the significance weights indicator w_j was calculated according to the ARTIW method, which allows to determine how much one factor is more important than another.

Table 1 presents the results of the expert evaluation of Group I factors. The main factors of Group I having the greatest impact on the accident of dangerous goods transportation by railway are: A2 "complete preparation of the train" (rating – 0.220), A8 "driver's confidence in the safety systems of the locomotive" (rating – 0.219) and A4 "improper loading of cargo" (rating – 0.196). Less important are: A9 "locomotive driver fatigue" (rating – 0.169), A7 "lack of locomotive driver knowledge" (rating – 0.162), A1 "railway track condition" (rating – 0.147) and A3 "secondary occupation of locomotive driver" (rating – 0.107). The least impact on accidents is: A5 "delivery speed" (rating – 0.091), A10 "route selection" (rating – 0.089) and A6 "time of day" (rating – 0.044).

The experts evaluated Group II technical-technological factors affecting the transportation of dangerous goods by railway:

- B1 – infrastructure for the place of loading and unloading;
- B2 – chemical properties of the cargo;
- B3 – correct filling of tanks;
- B4 – marking of wagons carrying dangerous goods;
- B5 – security control during cargo transportation;
- B6 – possible transhipment/transfusions of dangerous goods;
- B7 – provision of additional safety equipment onboard and wagons;
- B8 – packaging of dangerous goods;
- B9 – technical condition of the locomotive;
- B10 – tightness of railway tanks (wagons).

After assessing the importance of Group II factors, the significance weights indicator w_j was calculated according to the ARTIW method, which allows to determine how much one factor is more important than another.

Table 2 presents the results of the expert evaluation of Group II factors. The most important technical-technological factors of Group II, which have the greatest impact on the accident occurring in the transportation of dangerous goods by railway are: B10 "tightness of railway tanks (wagons)" (rating – 0.222), B9 "technical condition of the locomotive" (rating – 0.220) and B4 – marking of wagons carrying dangerous goods (rating – 0.194). Less important: B3 – correct filling of tanks (rating – 0.187), B8 "packaging of dangerous goods" (rating – 0.133), B5 "security control during cargo transportation" (rating – 0.115) and B6 "possible transhipment/transfusions of dangerous goods" (rating – 0.111). And the least impact on accidents is made by: B2 "chemical properties of the cargo" (rating – 0.107), B1 "infrastructure for the place of loading and unloading" (rating – 0.059) and B7 "provision of additional safety equipment on-board and wagons" (rating – 0.05).

The experts assess the organizational factors of Group III, which influence the transport of dangerous goods by railway:

- C1 – information identifying the chemical properties of the cargo being carried;
- C2 – time of day for the transportation of dangerous goods;
- C3 – driver's qualification;
- C4 – necessity of escorting the cargo;
- C5 – risks related to freight forwarding;
- C6 – speed limit;
- C7 – exact arrival at the place of loading or unloading at the specified time;
- C8 – cargo delivery distance;
- C9 – liaising with emergency services;
- C10 – routing.

After assessing the importance of Group III factors, the significance weights indicator w_j was calculated according to the ARTIW method.

Table 3 shows the results of the expert Group III factors assessment. Key organizational factors for Group III to consider before dangerous goods are transported by railway: C5 "risks related to freight forwarding" (rating – 0.227), C1 "information identifying the chemical properties of the cargo being carried" (rating – 0.220) and C3 "driver's qualification" (rating – 0.164). Less important: C8 "cargo delivery distance" (rating – 0.160), C10 "routing" (rating – 0.157), C9 "liaising with emergency services" (rating – 0.142) and C4 "necessity of escorting cargo" (rating – 0.127). The least influence is made by: C6 "speed limit" (rating – 0.118), C2 "time of day for the transporta-

Table 1. Results of the calculation of Group I factors, which have the greatest impact on the occurrence of dangerous goods

Indicator marker	Character encryption symbol									
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
w_j	0.147	0.220	0.107	0.196	0.091	0.044	0.162	0.219	0.169	0.089
Ranking of factors in order of importance	6	1	7	3	8	10	5	2	4	9

Table 2. Results of the calculation of Group II technical-technological factors, which have the greatest impact on the occurrence of dangerous goods

Indicator marker	Character encryption symbol									
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
w_j	0.059	0.107	0.187	0.194	0.115	0.111	0.05	0.133	0.220	0.222
Ranking of factors in order of importance	9	8	4	3	6	7	10	5	2	1

Table 3. Results of the calculation of Group III organizational factors, which have the greatest impact on the occurrence of dangerous goods

Indicator marker	Character encryption symbol									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
w_j	0.220	0.084	0.164	0.127	0.227	0.118	0.047	0.160	0.142	0.157
Ranking of factors in order of importance	2	9	3	7	1	8	10	4	6	5

tion of dangerous goods" (rating – 0.084) and C7 "exact arrival at the place of loading or unloading at the specified time" (rating – 0.047).

4. Discussion

Examining the scientific articles, it can be stated that it is very important to use all theoretical and practical knowledge to make the transport of dangerous goods safer. However, the analytical solution of problems is complicated by the cost and duration of formalization and experimental research of dangerous goods transportation processes. The articles mainly analyse the requirements for land transport in general, but do not distinguish between the main hazards and the main factors determining the likelihood of dangerous goods accidents by railway, nor do they provide recommendations on how to ensure the safety of dangerous goods by railway.

The volume of transport of dangerous goods by railway is increasing every year. The transport of dangerous goods by railway can lead to the risk of accidents. The number of accidents related to the transport of dangerous goods by railway was the highest in 2019 – 152 accidents per year in European Union countries. Accidents can occur for a variety of reasons – not only through the fault of the locomotive driver, but also through the fault of other road users or for technical reasons. Therefore, after analysis of the scientific literature, it is very important to find the main factors that have the greatest impact on the occurrence of accidents in order to reduce their volume.

After analysing the scientific literature, the factors that have the greatest impact on the safe transport of dangerous goods by railway were grouped and evaluated by ten experts according to 3 groups. A qualitative survey of experts identified the most important factors. The analysis of these main factors that have the greatest impact on the safe transport of dangerous goods by railway has identified the human factor that usually determines the consequences of all events.

In order to reduce the number of accidents occurring, a coherent information system capable of investigating accidents and incidents and providing access to the results of investigations should be established. Risk reduction measures for the transportation of dangerous goods could include:

- maintenance of vehicle and tanks technical condition;
- a better and qualified recruitment of truck and locomotive drivers;
- compliance with set requirements and instructions;
- tracking of truck and locomotive drivers while freight is being carried;
- use of information systems for the transportation of dangerous goods;
- investment in vehicles specially designed for the transportation of dangerous goods;
- proper completion of documents and provision of instructions to truck and locomotive drivers.

After creating such a system, more general information on the causes and consequences of accidents would appear.

Conclusions

After the analysis of the scientific literature, accident risk factors by railway were grouped into 3 groups: Group I factors having the greatest impact on the occurrence of accidents, Group II technical-technological factors to be considered before the shipment and Group III organizational factors to be considered before the shipment.

After assessing the importance of all three groups of factors influencing the reduction of risk in the transport of dangerous goods by railway, the significance weights indicator w_j was calculated according to the ARTIW method, which allows to determine how much one factor is more important than another.

The major factors in Group I, which have the greatest impact on the accident occurring in the transportation of dangerous goods by railway, are: "complete preparation of the train" (rating – 0.220), "driver's confidence in the safety systems of the locomotive" (rating – 0.219) and "improper loading of cargo" (rating – 0.196). The least significant contributors to accidents for the transportation of dangerous goods by railway are: "delivery speed" (rating – 0.091), "route selection" (rating – 0.089) and "time of day" (rating – 0.044).

The major technical-technological factors of Group II that should be considered before the transportation of dangerous goods by railway are: "tightness of the railway tank (wagons)" (rating – 0.222), "technical condition of the locomotive" (rating – 0.220) and "marking of the wagons carrying dangerous goods" (rating – 0.194). Minor effects are: "chemical properties of the cargo" (rating – 0.107), "infrastructure for the place of loading and unloading" (rating –0.059) and "provision of additional safety equipment on-board and wagons" (rating – 0.05).

The main organizational factors for Group III to consider before the transportation of dangerous goods by railway are: "risks related to freight forwarding" (rating – 0.227), "information identifying the chemical properties of the cargo being carried" (rating – 0.220) and "driver's qualification" (rating – 0.164). Accidents are minimized by: "speed limit" (rating – 0.118), "time of day for transportation of dangerous goods" (rating – 0.084) and "exact arrival at the place of loading or unloading at the specified time" (rating – 0.047).

In the next stages of research, the key factors of the three identified groups should be used to develop models to make the transport of dangerous goods by railway safer.

Disclosure statement

We do not have any potential conflict of interest to disclose.

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