Method for determining the acceptability of transport operations involving dangerous goods

Vladimir Medvedev[1,*], *Igor* Teslenko[1], and *Sergey* Karasev[1]

[1]Siberian Transport University, 630049 Novosibirsk, Russia

Abstract. Due to transport incidents and accidents involving dangerous goods, which cause significant damage to the infrastructure and environment, there is a need to study ways of preventing losses from these accidents and minimizing their costs. The purpose of the paper is to develop a method for determining the acceptability of transport operations involving dangerous goods under normal conditions. The methods used in the study include analysis and synthesis, risk management and Delphi methods. The key outcome of the study is a developed method founded on an integrated generalized criterion for acceptability of the main transport operations involving dangerous goods. This criterion is based on risk assessment. It has been established that the safety of transportation is determined by the maximum level of dynamic loads, impact velocity, energy absorption efficiency, braking mode of railway cars, and degree of risk.

Introduction

The development of railway transport is determined by socio-economic needs of the country. As compared to more economically developed countries, the railway transport in Russia has a number of important features, primarily in terms of technical and economic parameters. Shunting operations constitute a significant part of the lifecycle of freight services, making up 1 to 10% of the total transportation time [1]. In the existing network structure of the federal railway transport, the possibility to increase freight traffic volumes is limited by handling capacities of classification yards. This limiting factor is expressed mainly in handling of car traffic volumes in hump yards. Handling of dangerous goods is the most complicated process.

Some studies [1–4] show that the most common cause of safety violations in transportation of dangerous goods is excessive dynamic loads on rolling stock, containers, packaging, and cargoes. Breaking up trains loaded with hazardous goods in hump yards is the most critical step in transportation of dangerous goods by rail, which accounts for the greatest number of safety violations [1, 5–7].

In order to ensure trouble-free and continuous transport operations, competent authorities have established standards and conditions [8–10] to govern classification

* Corresponding author: MedvedevVI2017@yandex.ru

operations. The Russian Railways have three shunting modes: the normal mode (with a maximum impact velocity of 5 km/h [8]); with special caution (with a maximum coupling velocity of 3 km/h); passage of cars through a hump yard only with a locomotive.

In foreign countries, there are no equivalents of these three shunting modes [5, 9]. This can be explained by the fact that a number of countries (USA, Canada, Australia) use cars with high-capacity draft gears, which allow safe impacts between cars at a speed of up to 10 km/h or more [1, 3–5]. In European countries [5], car handling volumes in hump yards are low; car fleets consist of lightweight two-axle cars. Shunting operations are carried out at a low rate, while the impact velocity does not reach threshold values. The problem of safety in handling cars with dangerous goods can be fundamentally solved through comprehensive routing of car traffic. In particular, such solutions are used in Japan [4–6]. At the same time, a worldwide trend towards increasing the traffic of dangerous goods [5] by high-capacity cars dictates the need to improve transportation safety even in these countries.

The subject of this study is transportation of dangerous goods by rail. The object of the study is linear facilities of the railway network. The scientific problem raised by this paper is a feasibility study of shunting conditions for cars with dangerous goods in the hump yards that support necessary parameters, such as train handling rate and acceptable level of accident risk. Dynamic and other loads can affect the technical condition of a car and initiate dangerous properties of goods.

The purpose of this study is to develop a method for determining the acceptability of shunting operations involving dangerous goods based on a feasibility study of shunting modes. Complex risk of transport operations involving dangerous goods is used as a criterion to assess a solution to the problem defined in this paper. A science-based approach proposed by the authors is based on a comprehensive risk assessment of transportation of dangerous goods by rail, taking into account technical and technological characteristics of rolling stock and infrastructure facilities. This approach is novel: no other research team has yet defined and solved this problem in such a broad setting.

Research methods

The research stages correspond to stages of a transportation process involving dangerous goods, from loading to unloading, since the risk can be expressed at any stage of transportation. The study focused on the factors that affect the transportation safety, such as rolling stock, cargo, and transportation procedure. Using an analysis and synthesis method, the authors studied a car fleet, dangerous goods transported by cars of appropriate types, and shunting modes. The analysis and synthesis method was used to review the regulatory documents governing the transportation of dangerous goods and operating procedures of hump yards [5, 7–11] to identify specific features in handling the cars with dangerous goods. The analysis of shunting modes was based on a sample of seven main classes, ten subclasses and 3,152 types of dangerous goods. The Delphi method was used to identify possible hazards of elements in the transportation procedure for dangerous goods. Risk management methods were applied in the final research stage to develop an integrated risk assessment method. For the purposes of this study, the risk is defined in a conventional way, as a combination of the probability of a hazardous event and the severity of damage [7, 12].

Results

It has been established that special shunting modes for cars with dangerous goods in hump yards apply to special goods of various hazard classes. Shunting modes for cars with dangerous goods are summarized in Table 1.

Table 1. Structure of shunting modes for cars with dangerous goods.

Class, subclass according to GOST R57478-2017		Type of car				Unrestricted
		box car, general-purpose container		tank car, tank container		
		Prohibited	Caution	Prohibited	Caution	
Class 2, subclasses	2.1	2	61	73	0	7
	2.2	0	65	63	0	9
	2.3	24	56	52	0	14
Total for class:		26	182	187	0	30
Class 3		7	2	13	2	761
Class 4, subclasses	4.1	0	1	0	0	123
	4.2	2	0	3	0	74
	4.3	4	0	2	0	81
Total for class:		6	1	5	0	278
Class 5, subclasses	5.1	3	0	2	0	149
	5.2	152	0	10	0	0
Total for class:		155	0	12	0	149
Class 6, subclasses	6.1	7	19	3	17	570
	6.2	0	0	0	0	5
Total for class:		7	19	3	17	575
Class 8		2	1	3	0	400
Class 9		0	0	0	0	309
TOTAL		203	205	223	19	2,502
Share of goods subject to this mode, %		6.44	6.50	7.07	0.60	79.38

Thus, 20% of dangerous goods are subject to shunting restrictions, some of which are obviously excessive [3–5]. In international practice, instead of restrictions, a risk transfer method is used in the form of carrier liability insurance [9, 13]. Using the Delphi method, the authors have established that, in addition to dangerous properties of goods, such characteristics as rolling stock, technical parameters of hump yards, and a handling procedure influence the transportation safety. Types of railway cars accepted for the carriage of dangerous goods represent a wide range of vehicles [9, 11]. There is a variety of transportation options depending on types of vehicle, dangerous cargo, container and packaging (Fig. 1). Factors that affect dangerous goods can be classified into two groups:

1. depending on the level of technological development;
2. not depending on the level of technological development.

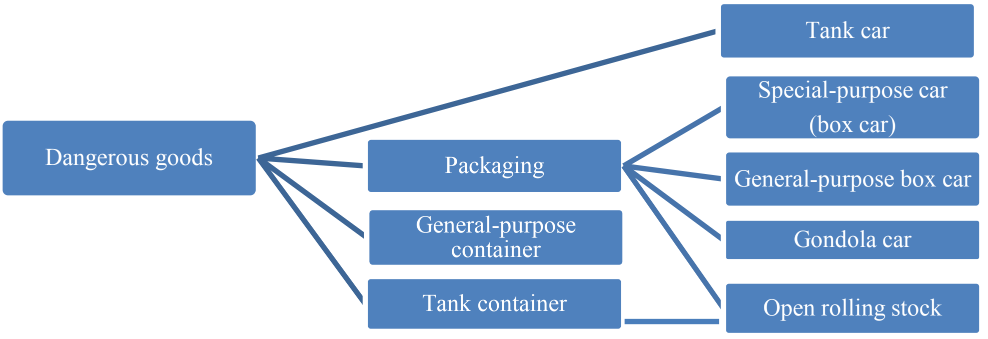

Fig. 1. Transport support options for dangerous goods.

The proposed classification of factors of the first category is presented in Figure 2.

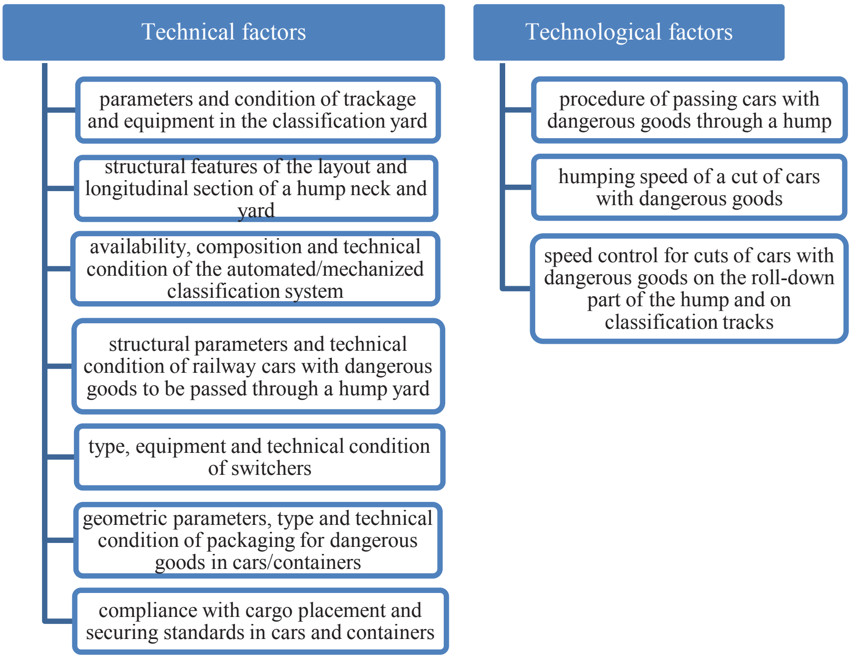

Fig. 2. Classification of technical and technological factors that determine the safe conditions for the transportation of dangerous goods.

The second category includes physicochemical (physical, chemical and hazardous properties, aggregate state of a dangerous cargo) and other factors that characterize a dangerous cargo. Other factors influencing the safety of shunting the cars with dangerous goods include parameters of the natural environment and human factor [1, 2].

All these factors have a significant influence on a combination of energy impacts that accompany the carriage of dangerous goods. Most transport operations are significantly influenced by kinetic, potential and thermal energy. Normal carriage conditions are the conditions under which a deviation in changes of all types of energy influencing transport operations does not exceed the maximum permissible levels (MPL).

$$\Delta E^{0}_{en-i} \leq \Delta E_{en-i}(t) \leq \Delta E^{MPL}_{en-i}, \tag{1}$$

where ΔE^{0}_{en-i} is the value of the ith type of energy in the initial condition of the transportation process (before loading into a car);

$\Delta E_{en-i}(t)$ is the change in the ith type of energy in transport operations during the entire period of (t) transportation;

ΔE^{MPL}_{en-i} is the maximum permissible levels of change in the ith type of energy.

The expression (1) corresponds to the risk management principle according to which the actual degree of risk should not exceed the permissible level [7, 12]. When implementing a sequence N of transport operations, it is obvious that the degree of level R_j $(j=\overline{1,N})$ at each jth stage should not exceed the acceptable level of risk for this stage. Taking into account that a hazardous situation may occur (regardless of a transportation stage) due to the exceeded permissible level of energy impact on a dangerous cargo, we can assume that the acceptable level of risk is equal for all stages and determined by tolerance of the maximum permissible level. Then, critical risks are those risks that correspond to the exceeded maximum permissible level. Risk management activities should be implemented for the relevant transportation stages. They should be aimed at minimizing the probability of a hazardous event and/or the severity of its consequences/damage.

During the transportation, the energy changes $\Delta E_{en-i}(t)$ in a certain time interval t_k under the influence of a short-term impact $W_i^{en}(t_k)$. In most cases, this impact is caused by technical and technological factors. The probability of changing the state in the jth stage of transportation process can be defined as:

$$P_j(t) = P_{i,j} ln \frac{W_i^{en}(t)}{W_{i,j}}, \tag{2}$$

where $P_{i,j}$ is the probability that the ith type of energy will influence the jth stage of transportation;

$W_{i,j}$ is the time of impact of the ith type of energy during the transportation of goods.

The risk of violation of safety conditions is determined by the formula:

$$R_j = У^* \cdot P_j(t) = У^* \cdot P_{i,j} \cdot ln \frac{W_i^{en}(t)}{W_i}, \tag{3}$$

where $У^*$ is the severity of the consequences of a hazardous situation/damage.

Safety targets are presented in Table 2.

Table 2. Traffic safety indicators.

Deviation indicator	Deviation from normal carriage conditions		
	incident	accident	emergency situation
Standard risk, R	10^{-5}	10^{-6}	10^{-7}
Minimum possible risk, R_{min}	10^{-4}	10^{-5}	10^{-6}

Expression (3) can be used as an integrated generalized criterion for acceptability of main transport operations involving dangerous goods. Thus, the key outcome of the study is the method that includes the following components: the integrated generalized criterion (indicator) of acceptability of the main transport operations involving dangerous goods, such as loading, shunting operations, including hump shunting, movement in the train, unloading; risk assessment for transportation of dangerous goods. This method can be used to draft a technical regulatory document to govern changes in the current rules and conditions of transportation.

Conclusion

The proposed classification of the factors that determine the safe transportation of dangerous goods can be a basis for comprehensive risk assessment. Based on the solution to the scientific problem considered in this paper, this approach can be used to take into account the influence of technical and technological factors on car handling conditions and to review hump shunting conditions for 20% of cars loaded with dangerous goods which do not pose a significant danger to personnel, infrastructure and environment. The risk assessment method is applicable not only to railway, but also to other modes of transport, as well as to multimodal transportation.

By developing engineering solutions using condition (1), research teams and manufacturing enterprises will be able to focus on the creation of effective technical and technological proposals. This approach will significantly reduce risks in transportation of dangerous goods. Adoption of the relevant amendments to the Rules for Transportation of Dangerous Goods will reduce the time of classification by 2.5–5%. Complex risks, including risks of failure on hump yards and late delivery, will be reduced.

Further research will be aimed at quantifying the risks of transport operations with all dangerous goods. As a result, science-based solutions for the Russian rail carrier, as well as carriers of the United Nations member states will be developed.

The authors are grateful to the University's administration, including Rector A.L. Manakov and Vice-Rector of Academic Affairs S.A. Bokarev, for their assistance in this research.

References

1. V.I. Medvedev, I.O. Teslenko, V. D. Sumina, Proceedings of the VIII International Scientific and Technical Conference within the Russia – EU year « Scientific problems of the implementation of transport projects in Siberia and the Far East», 263-265 (STU, Novosibirsk, 2017). (in Russian)
2. J. Forigua, L.L. Barrera, Transportation Research Procedia, **Vol. 12,** 842-850 (2016).
3. X. Liu, M.R. Saat, C.P. Barkan, Journal of Hazardous Materials, **260**,131-140 (2013).
4. M.R. Saat, C.J. Werth, D. Schaeffer, H. Yoon, C.P.L. Barkan, Journal of Hazardous Materials, **264**, 560-569 (2014).
5. ST/SG/AC.10/1 l/Rev.5. UN Recommendations on the transport of dangerous goods. Manual of Tests and Criteria (United Nations, Geneva, 2009).
6. E. Zio, T. Aven, Process Safety and Environmental Protection, **91** (2013).
7. GOST 33433-2015. Functional safety. Risk Management in Railway Transport (Standartinform, Moscow, 2016). (in Russian)
8. Pravila tehnicheskoj ekspluatacii zheleznyh dorog Rossijskoj Federacii [Rules for Technical Operation of Railways in the Russian Federation] (RZD JSC, Moscow, 2011). (in Russian)
9. ST/SG/AC.10/1/Rev. 18. UN Recommendations on the Transport of Dangerous Goods – Model Regulations (United Nations, Geneva, 2013).
10. Pravila perevozok opasnyh gruzov po zheleznym dorogam [Rules for the transportation of dangerous goods by railways (Transport, Moscow, 2009). (in Russian)

11. Tehnicheskie uslovija razmeshhenija i kreplenija gruzov v vagonah i kontejnerah [Technic specifications for the placement and fastening of goods in wagons and containers] (Transport, Moscow, 2003). (in Russian)
12. ISO/IEC 31010:2009. Ed. 1.0. Risk Management – Risk Assessment Techniques. (International Organization for Standardization, Geneva, 2009).
13. S. Dekker, E. Hollnagel, D. Woods, R. Cook, *Resilience Engineering: New directions for measuring and maintaining safety in complex systems*. Final Report (Lund University School of Aviation, 2008).