E3S Web of Conferences **138**, 02019 (2019) https://doi.org/10.1051/e3sconf/201913802019
CATPID-2019

Dangerous zone during transportation of dangerous goods

Vladimir Medvedev [1,*], *Zakhar* Oshchepkov [1] , *Ekaterina* Bogomolova[1] and *Vladislav* Bogomolov [1]

[1] Siberian Transport University (STU), 191 Dusi Kovalchuk st., Novosibirsk, 630049 Russia

Abstract. The purpose of research is to develop elements of an integrated security system for zone of dangerous goods by federal railway transport with the possibility to employ them on international scale and in other modes of transport. Improving the concept of dangerous zone during transportation of dangerous goods stands in as the first-priority work stage of the development process. Solving the main tasks of the research was based on such proven and fruitful theoretical and experimental methods as computer modelling, comparative typology and circular expert estimations, statistical analysis, probability theory, theory of similarity, and others. The most meaningful results of the development are both of theoretical and practical importance. The theoretical result consists in development of a new approach to the concept of dangerous zone during transportation of dangerous goods by rail. The practical result involves development of proposals for improvement of the Railway Transport System of Emergency Prevention and Response; introduction of amendments into the Safety Rules for Response to Emergencies related to Dangerous Goods during Their Transportation by Rail; emergency cards for dangerous goods and a number of other technical guidance documents. Processing of the experimental data has established that the expected effectiveness of the development is 7.5–10%

1 Introduction

The transportation of dangerous goods has been and remains the most important component that determines the operating conditions of the manufacturing, extractive, defensive and other, virtually all, sectors of any economically developed country of the world. Depending on the infrastructure transportation development, the share of each mode of transport in a country is different. However, the railway transport is of particular importance for the Russian Federation, especially with respect to long-distance, international, and multimodal (mixed) transportation. Meanwhile, analysis of statistical data demonstrates that transportation of dangerous goods by all modes of transport does not ensure an adequate level of risk. The manifestation of risk causes considerable damage to the transport workers and passengers, transportation infrastructure, transported goods and

[*] Corresponding author: MedvedevVI2017@yandex.ru

freight units, natural environment, residents of neighbouring communities, and people who happened to be in a dangerous zone.

The global system that provides chemical, biological, radiation, and fire safety for people, property, infrastructure facilities, and natural environment is a "pyramidal" hierarchical structure. Its basic levels are: 1) UN specialized agencies (UN ECOSOC), 2) international transport organizations, 3) national governments, 4) specialized associations, ministries and agencies, and 5) economic entities in transportation area. The topicality of research is dictated by the necessity of further improving the methods for protection and damage prevention, reduction in social and economic costs and environmental damage, which is only possible with regard to the interaction between the above elements.

This research of the new approach to the concept of dangerous zone during transportation of dangerous goods by rail is an integral part of a draft Research and Development (R&D) Program for 2018–2022 approved by the management of the Siberian Transport University (STU) and by the founder (the Federal Railway Transport Agency). The purpose of the R&D Program with the working title Revision of the Regulations concerning Transportation of Dangerous Goods by Rail and Development of a Draft Decree of the Government of the Russian Federation concerning Enhancement of Safety of Transportation Activities involving Dangerous Goods is to achieve the targets stipulated by the Strategy of RZD Open Joint-Stock Company (RZD OJSC) [1].

The purpose of the research is to develop elements of an integrated security system for the transportation of dangerous goods by federal railway transport with the possibility to employ them on international scale and in other modes of transport. Improving the concept of dangerous zone during transportation of dangerous goods stands in as the first-priority work stage of the development process.

The timeliness, importance, and topicality of this development can be (perhaps, indirectly) confirmed by the fact that President of the Russian Federation signed Decree No. 97 of March 11, 2019 On the Fundamentals of the State Policy of the Russian Federation in the Area of Chemical and Biological Safety for the Period till 2025 and Beyond [2] during preparation of this publication. The document defines the objective, principles, key priorities, and the main tasks of the state policy in the area of chemical and biological safety for the period till 2025 and beyond, and this imparts the traits of a strategic direction to our development.

2 Research Methods

Solving the main tasks of the research was based on such proven and fruitful theoretical and experimental methods as computer modelling, comparative typology and circular expert estimations, statistical analysis, probability theory, theory of similarity, and others. The most meaningful results of the development are both of theoretical and practical importance because, as will be confirmed by the relevant data, they allow increasing the accuracy of response operations and decreasing the accident damage and the cost of response.

The following elements, among other things, served as the initial methodological assumptions:

− investments in prevention measures ensuring safety of complex technogenic systems make economic sense, as the estimate of prevented damage is, on the average, generally 5–10 times larger than the losses [3, 4];

− investments in the "new technological paradigm measures" are most efficient in social and economic aspects since they create synergy in the interaction between all components of the following complex: man → rolling stock → infrastructure → natural environment.

3 Topicality, Practical and Scientific Importance of Research

The topicality of research is dictated by the necessity of further improving the methods for protection and damage prevention, reduction in social and economic costs and environmental damage during transportation operations involving dangerous goods.

The prerequisites to the scientific and practical importance of research are, among others, the following:

1. The basic results of development of emergency cards for dangerous goods were obtained more than 20 years ago [5]; since then, considerable changes were made in the organizational and technical support of prevention and response to emergencies related to dangerous goods.
2. Substantial results were obtained in the technological support of emergency recovery work, especially in the information and telecommunication area, and a program of innovative development of RZD OJSC were launched [1].
3. The list of UN dangerous goods (UNDG) [6] that can circulate within the railway operating domain of member states of the Organization of Railway Cooperation and of the Council for Rail Transport of the Commonwealth of Independent States (CIS) member states, the Latvian Republic, the Lithuanian Republic, and the Estonian Republic has been extended significantly.
4. A certain array of information regarding hazardous, physical and chemical, and other properties of substances, materials, and products have been gained over the past period of time, so it is expedient to correct not only the isolation radii but, possibly, other sections of the emergency cards, respectively.

4 Research Results. Theoretical Prerequisites

Research on the key problems of transport safety, for example, those described in [4, 7] are based on the first noxology axiom that defines the potential hazard of techno-sphere, an infinity of sources of danger (SD) and the principal inaccessibility both of 100% safety of a facility to be protected (FP) and of 100% reliability of a safety system (SS) or protection system (PS) as a basic methodological principle. Theoretical and methodological background of design of SSs and PSs in technogenic systems [7] is a purposeful reduction of a negative hazardous impact (Wfact) at a FP. This impact is identified and localized in space (X, Y, Z) at certain times, Δt, to meet the permissible conditions of hazard or safety as follows:

$$W_{fact}\{X(\Delta t)\cdot Y(\Delta t)\cdot Z(\Delta t)\}<W_{PDU}, \qquad (1)$$

where W_{PDU} is a certain level of impact accepted as maximum allowable or specified.

Any technical system employs a combination of danger parrying methods including active methods (ASS) directed at the sources of danger (SD ← ASS) and passive ones (PSS) directed at the facility to be protected (PSS → FP). It is a common practice to use the concept of risk R [4, 7] as a quantitative measure of danger in technogenic systems. Among the passive risk reduction methods, the method of removal (isolation, containment) is most universal. In practice, it is not always possible to draw a clear line between them, since some protective means can have the features of ASS and PSS to different extents.

With the advancement of the methods for prediction and prevention of risks [4, 7, 8], a growing number of researchers place a particular emphasis on redundancy of the passive protection standards. Thus, for example, the authors of publication [8] propose to make amendments in SP 36.13330.2012 Trunk Pipelines. Revised edition. SNiP 2.05.06-85, which provide that the tabulated values of the minimal distances from the axis of liquefied petroleum gas trunk pipelines to communities should be reduced by 40–60%. A conceptual study [4] postulates that all safety aspects of railway transport provide for an excessive safety margin, so its reasonable reduction is one of the tasks set before the transportation science. This article, which, as stated in the introduction, is performed according to the integrated program aimed at improvement of safety during transportation of dangerous goods by rail attempts to conduct a critical analysis of the existing isolation standards for the sources of danger in the events of emergencies. Such approach, which we consider to be new, requires a correct definition of initial concepts. A dangerous zone is an accident area within which there is a threat of damage caused by explosion, fire, toxic exposure, radiation, burns, freezing injuries of people and animals [9]. Its standard size, the so-called specified isolation radius (SIR), is established by emergency cards for dangerous goods [5, 9]. Our scientific hypothesis consists in the assumption that the SIRs in a considerable number of emergency cards were established in accordance with an out-of-date scientific and methodological base that needs a certain revision. Based on this, a new approach to the concept of dangerous zone during the transportation of dangerous goods with subsequent development of practical recommendations can be proposed.

4.1 Central ideas of the initial concept

1. The existing SIRs were established based on the analysis of a certain number of emergencies (critical situations, incidents) that actually happened to dangerous goods in the past, with regard to the experience of containment and remediation of consequences, and the estimation of damage. With this, the “you can never be too safe” rule taken from everyday practice was followed, and so attempts were made to model situations and to predict scenarios proceeding from possible combinations of the worst factors.
2. Based on the analysis of international experience, a concept of group emergency cards was adopted. This concept stipulates that dangerous goods are grouped ac-cording to certain classification criteria and combined in an emergency card for which an isolation radius RSIR of dangerous section is established.
3. The isolation radius, RSIR, of dangerous zone is established as the maximum value under the worst-case scenario typical for the goods being most dangerous and most unfavorable in this respect. As for the other goods of this emergency card, this margin is further increased thus reaching a considerable value for the least dangerous goods.
4. This problem got substantially complicated after making a decision (1998−2000) on development of emergency cards for dangerous goods transported under generalized shipping names. Generalized shipping names specify the characteristic properties of a group of goods and contain the “not otherwise specified” (n.o.s.) definition. The necessity of developing emergency cards for the “dangerous goods, n.o.s.” stock items (that exist not only at the regulatory level but in the international transportation practices as well, and, consequently, need both SSs and PSs) has determined such measures as their inclusion into cards for specific goods or development of new cards that contain only generalized names. In both situations, it was necessary to proceed from a combination of the most unfavorable conditions when establishing R_{SIR}.

4.2 Central ideas of the new concept

1. All R_{SIR} specified in the emergency cards should be revised and objectified, which can imply not only a change in the standard size but also a number of substantial changes, for example, in the number and layout of emergency cards and in the indications contained therein.

2. The uncertainty related to establishing R_{SIR} for emergency cards containing dangerous goods under generalized shipping names, "dangerous goods, n.o.s." and related possible errors should be reduced by certain methods. Refusal to include such goods that have the greatest transportation danger into the UNDG is among these methods. One of the transportation danger criteria is a packaging group referred to as packaging group I for such dangerous goods. In our opinion, such goods should be fully classified in a mandatory order with subsequent inclusion into respective databases and registers of hazardous substances including the UNDG under a specific name with assignment of a unique number.

3. The R_{SIR} radii should be left as reference amounts, since these standards, even if allowance is made for a certain degree of subjectivity in their definition in individual emergency cards, were agreed and approved by a large number of competent authorities, such as more than 25 ministries, agencies, and major corporations, including the Ministry of Railways, in the Russian Federation; and 14 railway administrations being the Council for Rail Transport of the Commonwealth members, at the international level. These standards were adopted, virtually without discussion or amendments, when confirming the Regulations concerning Transportation of Dangerous Goods by Rail as Appendix 2 to the Agreement on International Goods Transport by Rail.

4. Along with the specified isolation radius, we introduce the concept of the refined isolation radius R_{RIR} related to the basic standard R_{SIR} by means of refinement or adjustment coefficient, $K_{RIR.}$ Within the concept under development, this is the parameter that allows for reasonable changes in the basic standard having regard to the factors that affect the emergency propagation and corresponding response measures. As for the basic standard, this can be either a decrease (which is most probable) or an increase (in a number of cases concerning dangerous goods of classes 1 and 2) within the following limits: $K_{RIR} = 10^{-2} \ldots 10^{2} R_{SIR.}$

5. The structure of this coefficient, just like the entire concept of the new approach, is based on the deterministic and probabilistic approach, so refinement or adjustment of the standard parameter is carried out on the basis of expression (2):

$$R_{RIR} = K_{RIR} \cdot R_{SIR} = k_0 \prod\nolimits^{n}_{i=1} \cdot k_i \cdot R_{SIR} \tag{2}$$

where K_0 is a dimensionless coefficient related to the features of the transportation route and the mode of transport (it is taken equal to 1 as the first approximation for railway transportation);

k_i are dimensionless refinement coefficients (DRC) that take meaningful emergency propagation factors into account;

n is the number of dimensionless refinement coefficients that increases as the model gets refined and complicated. In this respect, the model reflected by equation (2) is characterized by an "open" type that allows taking a large number of factors into account.

As with the traditional approach (the initial concept), the DRC coefficients account for the meaningful factors of emergency development. Typically, the most important factors among them are: weight and volume of the transported goods (a rail tank car, a container, a cylinder, a tank, etc.), the aggregate state of goods (gas, liquid, powder, crystals), the degree and types of cargo-related danger (explosion hazard, inflammability, toxicity, corrosiveness, and other properties). The objectified relationship of factors and quantitative assessment of the DRCs are the new elements.

6. Isolation of the dangerous zone assumes that rescuers (provided with relevant personal protective equipment) should be located along the FP perimeter to ensure the containment of emergency and protection of people who happened to be for various reasons in the territory affected by the emergency. Reduction in the RSIR size entails reduction in the cost of emergency response procedures, primarily due to a decrease in the number of

involved rescuers. The cost reduction can be assessed from a simple relationship (assuming that the dangerous zone has a circular shape) that takes the decrease in the number of rescuers into account as follows:

$$\Delta N = N_1 - N_2 = 2\pi\, R_{SIR} / L_{is.s.} - 2\pi\, R_{RIR} / L_{is.s.} = 2\pi / L_{is.s} \cdot (R_{SIR} - R_{RIR}) = (2\pi \cdot R_{SIR}) / L_{is.s} (1 - K_{RIR}) \quad 3)$$

where ΔN is the reduction in the number of rescuers;

N1, N2 are the numbers of rescuers that provide isolation of dangerous section of size R_{SIR} *and* R_{RIR}, respectively;

Lis.s. is a statutory length of an area (perimeter of the zone to be isolated) controlled by a single rescuer.

5 Research Results. Practical Results and Their Discussion

We have conducted a statistical analysis of a dangerous zone statutory isolation radii provided in the emergency cards for dangerous goods of classes 1, 2, 3, 4, 5, 6, 8, and 9, and in the regulatory and technical documents that contain references to the numbers of emergency cards [5, 9, 10]. It has been established that emergency cards for a number of hazardous goods selections are absent, which creates a high-level threat of related emergencies in implementation of actual transportation by rail.

The regulations [10] outline the transportation conditions of new dangerous goods under UN 3499-3526 numbers; however, they are not included into the group [5] or individual emergency cards, and the isolation radius is not determined for them. As a result of the conducted work, isolation radii have been determined for new dangerous goods based on relationship (2), proceeding from the coefficient being equal to 0.9: RRIR = KRIR RSIR = 0.9 RSIR.

The characteristics of dangerous goods that do not have corresponding emergency cards in the national and international rules, isolation radii and numbers of the recommended (existing) emergency cards are provided in Table 1.

Table 1. The characteristics of dangerous goods that do not have the corresponding emergency cards in the national and international rules.

Main and Additional Types of Hazards	UN Numbers of New Dangerous Goods	Characteristics of Cargo-Related Hazards	R_{RIR}, m	Numbers of Emergency Cards (Forecast)
2, 2.1	3501, 3510	Flammable gases	45, 180, 270	204, 205, 206, 214, 218
2, 2.1+8	3505	Flammable, corrosive gases	180	220
2, 2.2	3500, 3511	Non-flammable, non-toxic gases	45	201, 213, 215
2, 2.2+5.1	3513	Non-flammable, oxidizing gases	45	202
2, 2.2 +6.1	3502, 3504	Non-flammable, toxic gases	180	220
2, 2.2+8	3503	Non-flammable, corrosive gases	180	211
2, 2.3	3512	Toxic gases	180	203
2, 2.3+2.1	3514, 3522, 3523, 3525, 3526	Toxic, flammable gases	180, 270	207, 208, 209, 210, 212, 219
2.3+2.1+8	3517	Toxic, flammable, corrosive gases	180	220
2.3+5.1	3515	Toxic, oxidizing gases	180	220
2.3+5.1+8	3518, 3520	Toxic, oxidizing,	180	220

		corrosive gases		
2, 2.3 +8	3516, 3519, 3521, 3524	Toxic, corrosive gases	180	220
8	3507	Corrosive substances	45	815
8+6.1	3506	Corrosive, toxic substances	45	811
9	3499, 3508, 3509	Other hazardous substances	45	906

It follows from Formula (3) and Table 1 that the determined effect is (1 − KRIR)*100%, which is equivalent to the reduction of costs by 7.5–10% (only at the first approximation, with the possibility of further reducing the standards and costs).

The practical outcome consists in improving the transportation process safety management methods for dangerous goods on rail. Proposals for improving the safety during transportation of dangerous goods by rail have been developed. Among them, most promising are as follows:

1. adjustment of the existing emergency cards and development of new ones for dangerous goods along with extension of the list of goods admitted to international traffic;

making amendments in the Safety Rules for Response to Emergencies related to Dangerous Goods during Their Transportation by Rail;

development of proposals for improving the Railway Transport System of Emergency Prevention and Response;

making considerable amendments in a number of other regulatory and technical guidance documents on transportation of dangerous goods, provision of process safety, application of collective and personal protective equipment, and substantiation of the list that will be provided in the next paper.

When discussing the main provisions of the new concept presented in this work, it is said that the development, determination of the conditions for the carriage of goods presented under generalized “not specifically indicated” names presents certain methodological difficulties, since the set of initial parameters is small (they are all contained in the name). These methodological difficulties increase both in determining the standard isolation radius and in solving the broader task of developing emergency cards. The problem that arouses our concern and our attention concerns, of course, not only and not so much scientific and methodological correctness, but the justification for achieving the necessary level of security. The security level is determined, first of all, by the development of specific practical recommendations in the emergency card for the protection of railway personnel, railway infrastructure and environmental objects (in the accident zone). The lack of relevant information causes uncertainty and, possibly, a certain subjectivity. Table 2 presents examples of two goods and the logical difficulties of “deciphering” the properties for the design of protective equipment (emergency cards).

Table 2. Examples of dangerous goods of generalized transport names and a set of parameters that impede the adoption of practical recommendations: (1) - identifiable properties with the possibility of modelling; (2) - hardly or completely unidentifiable properties and uncertainty of the recommended protective measures.

UN number, name	Basic properties and measures arising from them	Suggested personal protective equipment	The need for fire and explosion protection	Proposed first aid measures
2810 Liquid poisonous, organic, n.o.s.	Liquid state (1), therefore, spreads (at positive temperatures),	Requires respiratory, eye, skin protection (1), Recommended brands, types, samples of	Flammability (2) explosion hazard (2), emission of toxic combustion	Intake of water and antidotes inside (2). Skin flushing with water (2)

	isolation of the danger zone by technical means is required. Volatility, evaporation (2).	personal protective equipment (2)	products (2)	
2811 Solid substance, organic, n.o.s.	Solid state (1) - isolation of the danger zone with improvised means	Requires respiratory, eye, skin protection (1), Recommended brands, types, samples of personal protective equipment (2)	Flammability (2) explosion hazard (2), emission of toxic combustion products (2)	Intake of water and antidotes inside (2). Skin flushing with water (2)

Thus, at least 50% of the signs and associated protective measures are difficult to identify. The proposed measures should cover the entire range of possible negative consequences. The data presented above indicate that the proposed measures in existing emergency cards should be subjected to additional verification on a new methodological basis.

6 Conclusion

This stage of research allows drawing the following main implications and proposing recommendations:

1. State of the art for the analysis methods of technogenic hazards and risks for the rail transport facilities requires critical re-evaluation of the entire set of issues, theory and practices, railway traffic stability and safety promotion experience during response to emergency situations related to transportation of dangerous goods.
2. Reduction in frequencies of incidents, emergencies and critical situations during transportation of dangerous goods remains a priority task of state policy, and the Ministry of Transport of the Russian Federation and RZD OJSC play the critical part in solving this task. Solving this task requires an insistent search for new solutions and their implementation including systematization, objectification, and improvement of emergency cards.
3. The uncertainty related to establishing isolation radii RSIR of dangerous sections for emergency cards containing dangerous goods under generalized shipping names, “dangerous goods, n.o.s.” and resulting possible errors should be reduced by certain methods. Refusal to include such goods that have the greatest transportation danger into the UNDG is among these methods. One of the transportation danger criteria is a packaging group referred to as packaging group I for such dangerous goods. In our opinion, such goods should be fully classified in a mandatory order with subsequent inclusion into respective databases and registers of hazardous substances including the UNDG under a specific name with assignment of a unique number.
4. Development and introduction of the second version of the Response to Emergencies Related to Dangerous Goods information management system as an element of information technologies in transport seems to be an objective challenge in the light of optimization of labor and financial resources. It is necessary to increase the rate of reduction in the frequency of emergencies to an acceptable level and to decrease social and economic costs related to these emergencies and response operations. Among other things, these objectives can be achieved by increasing expenses for R&D.

According to the assessment obtained by processing experimental data, the expected effectiveness of introduction on a company or country basis is 7.5–10%. Currently, we are preparing a proposal for the Ministry of Transport of the Russian Federation regarding the creation of a mechanism by means of which the statutory cost saving will be aimed at technology upgrading and liquidation of potential and actual dangerous zones with dangerous goods. Within the approach under development, its universal character has been substantiated, which opens up potential for application in other modes of transport and transport and logistics companies. We will describe the attempt to extend the approach under development in our next paper.

References

1. Strategy of Scientific and Technological Development of RZD Holding for the Period Until 2025 and for Further Extension Until 2030 (White Book). Approved by Order of RZD OJSC of April 17, No. 769/p (2018). (In Russian).
2. On the Fundamentals of the State Policy of the Russian Federation in the Area of Chemical and Biological Safety for the Period Until 2025 and Beyond. Decree of the President of the Russian Federation No. 97 of March 11 (2019). (In Russian).
3. Public Declaration of the Goals and Objectives of the Ministry of Emergency Situations of Russia for 2017. URL: http://www.mchs.gov.ru/dop/opendata/dop/Publichnaja_deklaracija (In Russian).
4. Makhutov, N.A., Gadenin, M.M., Sokolov, A.M., Titov, E.Yu.:. Bulletin of the Railway Research Institute 6, 3–12 (2014). (In Russian).
5. Emergency Cards for Dangerous Goods Carried by Rail of the CIS, the Latvian Republic, the Lithuanian Republic, and the Estonian Republic. Approved by a decision of the forty-eighth meeting of the Council for Rail Transport of May 29–30, 2008. Manuscript, Novosibirsk (2010). (In Russian).
6. UN Recommendations on the Transportation of Dangerous Goods “Orange Book”. Model Regulations on the Transportation of Dangerous Goods. http://zakonrus.ru/asmap/rec_oon/toc_oon.htm
7. Medvedev, V.I., Strykov, P.G., Basalaeva, A.A.: Comprehensive Approach to Motivation of Safe Labor in the Rail Transport. In: System Support of Decent Working Conditions: Proceedings of the 1st All-Russian Research-to-Practice, pp. 77–85. SGUPSa, STU (2017). (In Russian).
8. Zaikin, I.A., Aleshin, Yu.V., Lisanov, M.V., Agapov, A.A., Sofyin, A.S., Sumskoy, S. I.: Studying the Influence of the Process Parameters of Trunk Pipelines on the Emergency Risk Indicators for Substantiation of Safe Distances. Labor Safety in the Industry 12, (2018). (In Russian).
9. Safety Rules for Response to Emergencies related to Dangerous Goods during Their Transportation by Rail. Moscow (1997). (In Russian).
10. Regulations Concerning Transportation of Dangerous Goods by Rail. Appendix 2 to the Agreement on International Goods Transport by Rail. https://www.mintrans.ru/documents/8/4293. (In Russian).
11. Instructional Guidelines for Organization of Emergency Recovery Work on Railways of RZD OJSC. Approved by Order of RZD OJSC of December 26, 2011 No. 2792p. (2011). (In Russian).
12. Basalaeva, A., Medvedev, V., Strykov, P.: MATEC Web of Conferences Siberian Transport Forum - TransSiberia 2018, vol. **239**, 02007 Novosibirsk (2018). DOI: https://doi.org/10.1051/matecconf/201823902007.