Risk Assessment of Emergencies During Transportation of Dangerous Goods by Rail

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Abstract

Based on the methods of comparative typology, expert assessment, and system analysis for the route running through the industrial districts in Kryvyi Rih, using the methods for analyzing the sources and consequences of a key event, the combined Ishikawa diagram of the key event tree, risk maps of a key event, the analysis of hidden and direct priorities, the risk indicator of the complex effect of negative factors in emergencies during the transportation of dangerous goods (DG) was determined. The authors identified the most likely sources of the emergency: 1) A rocket attack that damaged the track resulting in uncontrolled cars' derailment; 2) Exceeding the speed of a train with tanks; 3) Icy conditions, which led to an increase in the braking distance and an accident; 4) Oversight of traffic obstacles before moving tanks, which in turn can lead to a stoppage of the technological process, cargo spillage and financial losses. A probabilistic risk assessment was carried out based on an expert assessment of the operator's risk and measures to reduce the occurrence of emergencies were proposed with annual costs of thousand UAH. After that, a probabilistic risk assessment map and a probabilistic assessment map of risk management effects were created, which make it possible to effectively manage and control the probable sources of an emergency and choose financial investments for measures to reduce the occurrence of emergencies. After that, it was proposed to use the combined car model 17-975(01) with all the necessary equipment as a means for quick localizing and eliminating the consequences of spills of hazardous substances during their transportation by rail in the event of an accident. The economic feasibility of using the proposed technique was also substantiated. The scientific novelty lies in the creation of models for analyzing the risk assessment of an emergency, as well as identification of possible sources and factors in the occurrence of emergencies during the transportation of dangerous goods by rail, and also the development of recommendations for their reduction. The practical significance is the implementation of the developed recommendations, based on the created model to form a special car for operational needs, with the selection of the necessary equipment for the rapid implementation of the 1st stage in localization and liquidation measures.
KEY WORDS: *risk assessment, analysis of sources and consequences, Ishikawa diagram, key event tre,; environmental technologies, dangerous goods, localization of accidents, elimination of accidents, combined car model 17-975(01), cost of localization and liquidation measures*

1. Introduction

Recently, there has been a significant strengthening of technical standards and environmental requirements concerning the safety in the transportation of dangerous goods by all modes of transport. This is directly related to the environmental consequences of possible accidental or technological spills of dangerous goods as a result of violation of the rules for their transportation.

Unfortunately, due to the rapid development of social mobility, measures to ensure the transportation of dangerous goods by all modes of transport are not being developed sufficiently. Sometimes it is very difficult to analyze the sources and consequences of an emergency. Therefore, the development of principles for improving the safety of the procedure for transporting dangerous goods by rail is an urgent task.

The decision by the head of the corresponding emergency response center is the basis of force management while eliminating the consequences of emergencies in railway transport. Management of these forces is carried out under risk and uncertainty, which are sourced by incomplete information about the state of rolling stock and railway infrastructure facilities in an emergency, the development of dangerous factors of an emergency, their negative impact on the environment and people, as well as the time pressure necessary to reduce such impact and resumption of train traffic in the shortest possible time.

The problem of contradiction between the need to localize or eliminate the consequences of emergency spills of dangerous goods (DG) and the rapid resumption of the railway transport capacity is a pressing issue, especially besource of the current situation in the country.

2. An Analysis of Recent Research and Publications

Researchers engaged in research in the field of handling dangerous goods can be conventionally divided into 3 categories:

1. Researchers dealing with safety issues during cargo transportation.
2. Researchers dealing with issues of assessing the risks of an emergency during the transportation of such cargoes.
3. Researchers who are looking for different ways to localize and eliminate emergency spills of hazardous cargo emissions.

Domestic and foreign scientists have been working on these issues, such as M. O. Afonin [1, 2], Y. V. Bolzhelarskyi [3], R. V. Vernyhora, V. L. Horobets [4, 5], Yu. V. Zelenko [6, 7, 19, 20], D. M. Kozachenko, I. L. Zhuravel [8], D. O. Kulova, O. V. Lavrukhin [9], D. M. Kozadoi, D V. Lomotko [10], M, B. Drzewieniecka & M. Nowak [11], A. A. Conca [12], L. Szaciłło, M. Jacyna with colleagues [13], M. Šolc, M. Hovanec [14], F. Borghetti, G. Malavasi [15] and others.

Their works cover the issues of determining the risk assessment of emergencies, safety protection in the transportation of dangerous goods (DG), the impact of various types of transport on the environment, and the integration of states in solving environmental problems in transport. Some scientists studied the ways to increase environmental safety, as well as environmental protection measures and management of environmental activities, the creation of an international system of transport corridors. Others studied ways to minimize the risks of emergencies, and the harmful impact of railway transport on the environment, etc. However, all of them are considered by scientists separately, according to the categories of researchers presented above, and they are not considered together as a single whole.

Analyzing the substantial problems, there is a need to improve the existing risk assessment methods for identifying source-and-effect relationships and eliminating emergency spills to increase efficiency, implementing the principles to minimize the consequences of the negative impact of transport on the environment.

That is why the scientific problem of finding new solutions to increase the level of safety, minimize negative consequences, ensure environmental friendliness and economy in transport, as well as the efficiency in the work of the relevant units in the event of emergencies during the transportation of dangerous goods, is topical.

3. Research Methodology

Taking into account the above-mentioned, the purpose of the research is to increase the safety of the procedure for the transportation of dangerous goods by railway transport by minimizing the risks of emergencies, and improving the system of prevention and elimination of their consequences.

Based on graphical and analytical tools and with the help of the theory of probability, the authors conducted the risk assessment of an emergency. The methods of statistical, system analysis and mathematical modeling were used in theoretical studies and numerical experiments.

To carry out an analysis of the risk assessment of an emergency, we first conducted the identification of dangerous goods, the assessment of the potential risks in transportation and storage of dangerous goods un 1790 under the conditions of a populated city, and the identification of potential scenarios of a dangerous event. The authors choose the dangerous substance "Chloric acid" as the predicted substance that will be transported by railway transport for the risk assessment of emergencies.

The risk assessment of an emergency was carried out near the inhabited area of Kryvyi Rih, namely: near the area with a probable damage radius of 1.0 km. Fig. 1 shows the geospatial site characterization of enterprises located in Kryvyi Rih.

The approximate amount of dangerous cargo that was conditionally spilled during the creation of the model is 160 tons, i.e. approximately 2 tanks with "Chloric acid".

The key event that was taken for modeling is the depressurization of tanks on access railroads due to violation of shunting operations, as one of the most common events, that leads to the occurrence of many accidents.

Fig. 1 The geospatial site characterization of enterprises located in Kryvyi Rih [16]. The red circle is the zone of probable damage, which is 1.0 km

Based on the analysis of the sources and consequences of the key event, which combines 2 methods: expert risk analysis and project sensitivity analysis. Sensitivity is the percentage change of the criterion divided by the percentage

change of the variable factor. Using special keys of the rating scale, risk maps of the key event were constructed (see Table 1).

Table 1

Maps of key event risks

		Consequences of the indoor environment						Consequences of the outdoor environment						
		C.1	C.2	C.3	C.4	C.5	ΣCI	C.6	C.7	C.8	C.9	C.10	ΣCO	ΣS
Sources of the indoor environment	S.1	80	90	60	65	65	360	30	65	35	75	65	270	630
	S.2	50	70	20	20	50	210	20	50	40	70	50	230	440
	S.3	50	90	20	20	50	230	30	10	10	50	40	140	370
	S.4	50	80	60	20	90	300	50	45	35	70	45	245	545
	S.5	30	70	70	80	85	335	70	60	35	70	75	310	645
	ΣSI	260	400	230	205	340	1435	200	230	155	335	275	1195	
Sources of the outdoor environment	S.6	40	30	10	10	20	110	30	60	40	60	55	245	355
	S.7	80	50	60	65	45	300	40	70	30	60	75	275	575
	S.8	30	80	40	60	35	245	30	10	10	40	40	130	375
	S.9	70	50	50	60	40	270	50	90	20	40	60	260	530
	S.10	90	90	55	70	90	395	55	90	45	85	80	355	750
	ΣSO	310	300	215	265	230	1320	205	320	145	285	310	1265	
	ΣC	570	700	445	470	570		405	550	300	620	585		5215

Note: S is the source of indoor or outdoor environment; C are consequences of the indoor or outdoor environment; ΣSI(O) is the sum of the source of the indoor or outdoor environment; ΣCI(O) is the sum of the consequences of the indoor or outdoor environment; ΣS is the total sum of sources; ΣC is the total sum of consequences.

The above risk map makes it possible to analyze direct and hidden priorities (see Table 2, Table 3)

Table 2

Results of the weighted assessment for the priority of sources and consequences

Source	Estimated weight	Priority (rank)	Consequence	Estimated weight	Priority (rank)
S.1	0.12	2	C.1	0.11	3
S.2	0.08	5	C.2	0.13	1
S.3	0.07	6	C.3	0.09	4
S.4	0.10	4	C.4	0.09	4
S.5	0.12	2	C.5	0.11	3
S.6	0.07	6	C.6	0.08	5
S.7	0.11	3	C.7	0.11	3
S.8	0.07	6	C.8	0.06	6
S.9	0.10	4	C.9	0.12	2
S.10	0.14	1	C.10	0.11	3

Table 3

Revealed hidden priorities

Comparison criterion:			The proposed risk coping strategy
1	S1-C2	0.070	The locomotive crew must undergo unplanned, repeated, and targeted briefings with a detailed explaination of the safety requirements when working in emergencies
2	S5-C9	0.073	
3	S10-C1	0.070	Conducting briefings, control of knowledge regarding the rules of shunting works, and transporting dangerous goods under conditions of rocket attack with a detailed analysis of all possible consequences of an emergency (E)
4	S10-C7	0.071	
5	S10-C10	0.069	

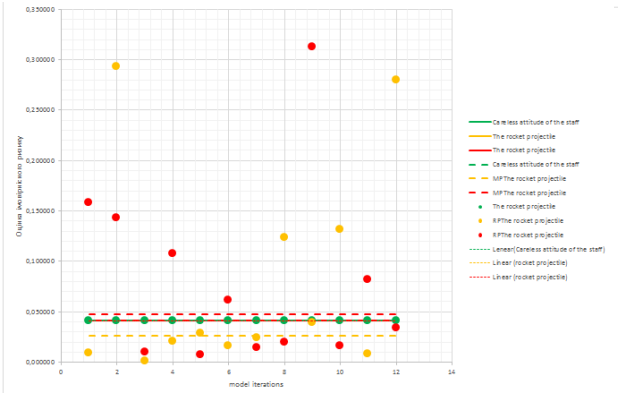
The most likely sources of an emergency are:

- a rocket projectile that damaged the track resulting in uncontrolled cars' derailment;
- exceeding the speed of the locomotive;
- icy conditions, which led to an increase in the braking distance and an accident;
- oversight of traffic obstacles before moving tanks, which in turn can lead to a stoppage of the technological process, cargo spillage and financial losses.

The indoor environment of the enterprise is the main risk factor and source of an emergency with dangerous cargo. We also have to take into account the outdoor risk, which involves the close location of other dangerous objects (power plants, factories, artificial lakes) to our enterprise, which can significantly increase the scale of the accident.

It has been proven that the location of objects such as product pipelines, high-risk enterprises, and natural protection objects next to a railway can significantly increase the scale and consequences of an accident.

Using simulation modeling of the proposed scenarios for the potential risk prevention (impact factors; incident damage, thousand UAH; analysis of measures to reduce the impact and annual costs to reduce the impact, thousand UAH), the authors constructed graphs, on which we show a map of probabilistic risk assessment and a map of the probability assessment of the effects of risk management (see Fig. 2, Fig. 3).



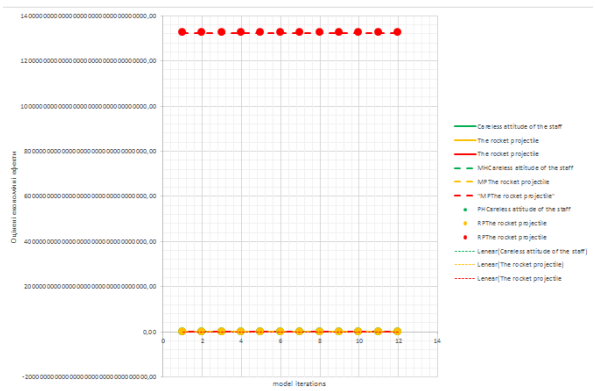


Fig. 2. The map of probabilistic risk assessment Fig. 3. The map of probabilistic risk management effects

Analyzing the hidden priorities, we can see from Table 3 that scenario 2 "Overspeeding" has the most probable priority.

The risk according to scenarios 1 and 4 has a low priority and requires organization-wide management measures.

Scenarios 3, 4, and 5 have an uncertain result due to a lack of objective data. We recommend clarifying information about the number of missiles, their flight path, and keeping statistics on the number of emergencies. This may allow for the revision of probabilistic risk characteristics

The "rocket projectile" factor is in some cases underestimated and in some cases overestimated. The factor "negligent attitude of the staff" was assessed correctly.

Scenario 3 (the result due to the rocket attack, there was tank damage leading to spills of dangerous cargo) is a priority. Its probability characteristic is in the 3rd Pareto quartile. This risk requires prompt and ongoing management.

The "rocket projectile" factor is in some cases underestimated from an economic viewpoint, this factor has a positive value and economic profit. The analysis of the scope is quite large, it is necessary to invest capital costs.

This factor is currently very common and likely to occur, but not predictable, but its economic effect will be positive. With regard to the factor of careless attitude of employees, the scenario 1 (before moving the freight train, the driver did not make sure that there were no obstacles to movement), is not very common, and the probability of its occurrence is not very high percentage, and the economic effect there is negative, that is, we will go into the red.

That is why the recommendation is to pay attention to scenario 3 (the consequence due to a rocket attack should become a priority, but it should be solved comprehensively. Regarding the factor of careless attitude of employees, it is better to pay attention to scenario 2, which is a priority among the 5 selected factors, and which, unlike scenario 1 has a positive economic effect.

The presented models for assessing the risks of an emergencies can be used to select equipment and equip cars for operational needs.

4. Ways to Solve Problems

Based on the analyzed data, a strategy was proposed using a combined car model 19-795. and 19-795-01. [17, 18].

Fig. 4 [18] gives an example of the developed procedure for eliminating the consequences of an accident during the transportation of petroleum products using sorption methods.

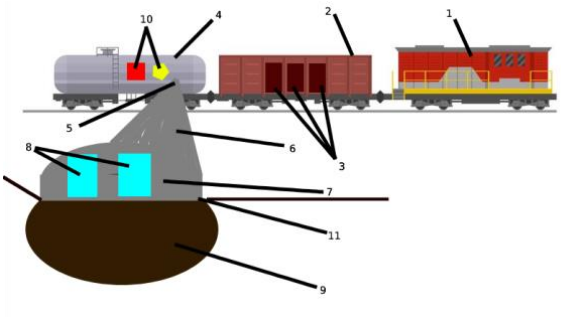


Fig. 4 The scheme of placement of equipment and materials during the liquidation of consequences of an accident during the transportation of dangerous goods (petroleum products): 1 – locomotive; 2 – a car with an absorbent cloth (8); 3 – containers with an absorbent cloth (8); 4 – a tank with liquid hazardous cargo (10); 5 – an opening through which a leak of dangerous goods (10) occurs; 6 – the surface runoff of liquid hazardous cargo (10) according to the topography of the area; 7 – a zone of formation of the mirror (11) of the leak; 8 – an absorbent cloth; 9 – the zone of the affected soil layer; 10 – dangerous cargo; 11 – a leakage mirror

According to the scheme, the procedure for localization and liquidation of emergency spills of dangerous goods takes place as follows. A combined car (2) with containers (3) with "Universal Absorbent Cloth" (UAC) (8) is attached to the locomotive (1). In the event of an emergency during the transportation of liquid hazardous cargo (10), the containers (3) with the "UAC" (8) are retrieved from the combined car (2). Taking out from the container "UAC" (8), they throw the zone of formation of the mirror (11) of the leak (7), to prevent the dangerous cargo (10) from entering the soil layer and reducing the zone of damage to the soil layer (9). Then the spent absorbent cloth (8) is put back in the container (3), and upon the arrival of the locomotive (1) to its permanent location, the absorbent cloth (8) is regenerated, and after regeneration, it can be used again.

An important role is assigned to the issue of reducing the threat of an emergency with DGs transported on the territory of Ukraine. Fines for environmental damage are quite high (sometimes reaching hundreds of thousands of US dollars). In addition, there are significant costs for the implementation of reconstruction works related to the removal and cleaning of contaminated soil. For example, in case of spillage of one tanker with fuel oil, the air, surface water bodies and soil are polluted on an area of up to 6...10 thousand m^2 and to a depth of 0.1...0.3 m. The volume of contaminated soil is 1...3 thousand m^3 or 2...6 thousand tons. And if the accident happened near a waterbody, then taking into account the fine for environmental damage, the amount of expenses can reach about 1 million US dollars [19].

5. Conclusions

1) Based on the analysis of literary sources and the risk map of the key event, an analysis of the risk assessment of the emergencies was carried out.

2) The possible sources and factors of the occurrence of emergencies during the transportation of dangerous goods by railway transport were identified and the priority of events was determined.

3) Recommendations have been developed to reduce the risk of accidents (increasing labor discipline, control of traffic safety, and occupational safety knowledge).

4) The map of probabilistic risk assessment and the map of probabilistic assessment of risk management effects are given. (Scenarios 2 and 3 are the most prioritized and probable from the viewpoint of occurrence.).

5) Proposals have been developed to improve the process of localization and liquidation of emergency spills of dangerous goods, namely:

– it is proposed to use certain types of cars (combined cars of models 19-795 and 19-795-01) for the transportation of the necessary special equipment as part of a freight train, which will provide convenient access to liquidation materials and reduce the time spent on liquidation measures due to the rapid deployment of the cloth in to 30–35 min.;

– the use of "UAC", fire extinguishers, shovels, and other special equipment is recommended as a means of localization and liquidation of emergency spills, which ensures the speed of deployment of liquidation means, coverage of a significant area of emission, and minimization of environmental consequences and loss of cargo;

The proposed stages of modeling and assessment of the risks of emergencies will simplify the procedure for making management decisions, and reduce the response time to dangerous emergencies, and the developed recommendations for their localization and elimination will minimize possible negative consequences, and comply with all safety rules.

References

1. **Afonin, M.** 2022. Change of drivers functional condition during dangerous goods transportation. Transport Technologies. 1 (3): 5–64.
2. **Fornalchyk, Y.; Afonin, M.; Postranskyy, T.; Boikiv, M.** 2021. Risk Assessment during the Transportation of Dangerous Goods Considering the Functional State of the Driver. Transp. Probl. 16: 139–152.

3. **Я. Болжеларський; В. Джус; О. Джус; О. Клецька; О. Кіріцева.** 2022. Оцінка вимог інтероперабельності до українських вагонів-цистерн, які призначені для перевезення небезпечних вантажів залізничним транспортом / Вісник Приазовського державного технічного університету. Серія: Технічні науки. 44: 89–100. Available from: https://doi.org/10.32782/2225-6733.44.2022.11 (in Ukrainian)
4. **Колективна монографія**. 2021. Інжиніринг криз та ризиків транспортних послуг: Київ: Талком, 312 р.
5. **Горобець, В.Л.; Козаченко, Д.М.; Вернигора Р.В.** 2022. Інжиніринг криз та ризиків перевезення небезпечних речовин. Транспортні системи та технології перевезень. 24. Available from: https://doi.org/10.15802/tstt2022/272063 (in Ukrainian)
6. **Зеленько, Ю.В.; Черкудінов, В.Е.; Левицька, С.І.** 2022. Концепція екологізації мультимодальних перевезень. Транспортні системи та технології перевезень. № 24. Available from: https://doi.org/10.15802/tstt2022/272065 (in Ukrainian)
7. **Zelenko, Yu.; Myamlin S.; Sandovskiy M.** 2014. Scientific foundation of management of the environmental safety of oil product turnover in railway transport. Д.: Литограф, 332 p.
8. **Kozachenko, D.M.; Zhuravel, I.L.; Zhuravel, V.V.** 2016. Especially the Functioning of Railway Stations in the Conditions of the Organization of Transport Dangerous Goods. Транспортні системи та технології перевезень: зб. наук. пр. Дніпропетр. нац. ун-ту залізн. трансп. ім. акад. Лазаряна. Дніпропетровськ, 12: 38–44. DOI: 10.15802/tstt2016/8595.
9. **Кульова, Д.О.; Лаврухін, О.В.** 2021. Моделювання поїзних станів при просуванні поїздопотоків з небезпечними вантажами на основі абстрактних поїзних конструкцій. Міжнародна транспортна інфраструктура, індустріальні центри та корпоративна логістика: матеріали сімнадцятої міжнар. науково-практ. конф. (3-4 червня 2021). Харків: УкрДУЗТ: 42–43. (online cit: 20.02.2024). Available from: http://lib.kart.edu.ua/handle/123456789/12660 (in Ukrainian)
10. **Lomotko, D.; Ohar, O.; Kozodoi, D.; Barbashyn, V.; Lomotko, M.** 2023. Prospects for the use “green” logistics as a safety factor in multimodal transportation of dangerous goods. AIP Conference Proceedings. AIP Publishing. T. 2684. №. 1. https://doi.org/10.1063/5.0120066.
11. **Drzewieniecka, B.; Nowak, M.** 2018. Safety Aspect in Carriage of Dangerous Goods by Railway Transport. New Trends in Production Engineering. 1: 35-41. https://doi.org/10.2478/ntpe-2018-0004
12. **Conca, A.; Ridella, C.; Sapori, E.** 2016. Risk Assessment for Road Transportation of Dangerous Goods: A Routing Solution. Transportation Research Procedia. 14: 2890–2899. DOI: 10.1016/j.trpro.2016.05.407
13. **Szaciłło, L.; Jacyna, M.; Szczepański, E.; Izdebski, M.** 2021. Risk assessment for rail freight transport operations. Eksploatacja i Niezawodnosc. 23(3):476-488. DOI:10.17531/ein.2021.3.8
14. **Šolc, M.; Hovanec, M.** 2015. The Importance of Dangerous Goods. Naše more. 62:
15. **Borghetti, F.; Malavasi, G.** 2016. Road accessibility model to the rail network in emergency conditions. Journal of Rail Transport Planning & Management. 6 (3): 237–254. DOI: 10.1016/j.jrtpm.2016.10.001
16. Google maps. Available from: https://maps.app.goo.gl/zYxF2mkGo1oo6TxE8
17. Комбінований вагон модель 19-795-01 [online cit: 25.02.2024]. Available from: https://www.kvsz.com/index.php/ua/produktsiya/vantazhne-vagonobuduvannya/vagoni-khoperi/item/1957-kombinovanyi-vahon-model-19-795-01.
18. **Zelenko, Y.; Calimbet N.** 2022. Improving a method for eliminating the spill of hazardous substances by using «Universal Absorbent Cloth». Eastern-European Journal of Enterprise Technologies. 4(10(118)): 30-37. DOI: https://doi.org/10.15587/1729-4061.2022.263583
19. **Переста, І.Я.; Яришкіна, Л.О.; Музикіна, С.І.; Зеленько, Ю.В.; Журавель, І.Л.** 2011. Забезпечення вдосконалення профілактичних заходів під час перевезень небезпечних вантажів // Транспортные системы и технологии перевозок. 1 [online cit: 28.09.2023]. Available from: https://cyberleninka.ru/article/n/zabezpechennya-vdoskonalennya-profilaktichnih-zahodiv-pid-chas-perevezen-nebezpechnih-vantazhiv
20. **Zelenko, Y.; Bezovska, M.; Kuznetsov, V.; Muntian. A.** 2021. Technological and Ecological Aspects of Disposal of Spent Cutting Fluids // Journal of Ecological Engineering // 22 (2021/4/1): 207-212.