Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 149 (2019) 28–35

Procedia Computer Science

www.elsevier.com/locate/procedia

ICTE in Transportation and Logistics 2018 (ICTE 2018)

Formation of a model for the rational placement of cars with dangerous goods in a freight train

Oleksandr Lavrukhin[a,]*, Anton Kovalov[a], Daria Kulova[a], Artem Panchenko[b]

[a] *Ukranian State University of Railway Transport, Kharkov, Ukraine 61000*
[b] *The V.N. Karazin National University of Kharkov, Kharkov, Ukraine 61000*

Abstract

The article deals with a scientific approach towards the target function generation of a mathematical model intended for an effective make-up of freight trains with wagons transporting dangerous goods. The model considered possible economic expenditures on making-up such trains and taking into account additional expenditures on rearrangement. It can be fulfilled at sorting stations and at any railway stations as well. The principle proposed can be applied on the territory of the CIS countries and on the territory of the member-states of the International Union of Railways.
The academic value of the study lies in the fact that the target function suggests considering not only economic expenditures, but also ones for possible risks from transit of trains with dangerous goods under operational conditions. Considering the complexity of the model solution the authors propose the approach based on the genetic algorithm method; it allows obtaining efficient variants of freight train make-up in a comparatively short time. The approach can be further used as a computer-aided decision support system for operational staff on railway stations.

Keywords: Dangerous goods; Freight train; Genetic algorithm; Decision support system

1. Introduction

Integration of Ukraine into the European community requires solving multiple technical, technological, economic

* Corresponding author. Tel.: +380577301085.
E-mail address: tilavalval@gmail.com

10.1016/j.procs.2019.01.103

and legal problems. In these conditions, the railway transport should first of all react to the current requirements of the transport services market for domestic and foreign customers.

Historically, the same infrastructure has been used for transportation process of both passenger and freight traffic. In these conditions, the Public Joint Stock Company Ukrzaliznytsya faces a difficult task - ensuring the profitability of the industry while complying with the unprecedented security conditions. It should be noted that the risk of transport accidents will always exist, since the transportation process includes a significant number of technical and technological components and is under the significant influence of the human factor. Besides, it should be mentioned that the service life fleet of mobile technical equipment such as cars and locomotives has almost expired by 80%. Works and measures are being permanently performed to extend the lifetime of these transport units, but metal structures and principle traction nodes are known to have their own resource of failure-free operation, which has already been exhausted.

2. Analysis

2.1. Analysis of recent studies and publications

Transportation of dangerous goods takes a significant volume in the transport products. In Ukraine, about 70% of dangerous goods (DG) is transported by rail.

Certain additional requirements are imposed to the organization of the transportation process for ensuring an increased level of safety in the transportation of such cargo. However, in certain cases such requirements are applicable only locally, namely: according to regulatory documents [1] loading dangerous goods of certain classes into one vehicle is prohibited in order to reduce the possible negative consequences of occurrence of unforeseen circumstances (such as explosion, fire, poisoning, etc.); departure of trains and perform shunting without a car protecting the locomotive from the cars with dangerous goods is also prohibited [2]. Either empty cars or cars loaded with the usual category of goods can be used as such cars. However, currently, there are actually no requirements for the procedure of marshalling of trains with cars loaded with dangerous goods, which entails the risk of occurrence of much more significant consequences in the event of emergency situations during shunting work at stations and access roads, as well as during travelling. Thus, it implies the increased risks during operational work. At the same time, attempts to reduce risks by operational personnel through taking additional measures in marshalling of trains can lead to significant negative results in the performance of main operational indicators. This will lead to the decrease in economic efficiency of cargo transportation. In such conditions, operational personnel need to solve the complicated tasks of obtaining maximum profit by minimizing operating costs with the allowable low level of risk.

It should be noted that this problem becomes particularly relevant to take advantage of the favorable geographic location of Ukraine. In the aspect of this issue, it is worth mentioning that in the framework of the implementation of the Twinning institutional tool [3], the European community became interested in the opportunities of the PJSC Ukrzaliznytsya concerning the transit of dangerous goods through the territory of Ukraine. For this purpose, funds are allocated for harmonization of the legal and technological foundations of the transport industry with European standards.

Contributions to the promotion of study on the development and improvement of technology for the transport of dangerous goods by rail were made by such researchers as T.V. Butko, A.V. Prokhorchenko, S.I. Muzykina, A.M. Kotenko, V.M. Ostrovsky, L.A. Grebenyuk, M. Solc, A. Conca, R. Macciotta, T. Luan et al.

In order to further justify the appropriateness and relevance of this research, the best practices in organizing the transportation process with dangerous goods should be analyzed.

In [4], the information system Global Integrated Information System was created, which has the management functions for the risk analysis model and assessment of human and environmental vulnerability during the transportation of dangerous substances and materials. This information system provides more efficient use of rolling stock, taking into account the specific landscape of certain areas and improves the data exchange technology between the countries of the European Union (Italy and Switzerland) concerning transportation of dangerous goods.

Work [5] represents the development of a system for monitoring and control of transportation of dangerous goods, the National System of Monitoring Dangerous Goods in Poland, which will function in real time and provide better security by improving the data exchange system between employees of the station and rescue services, developing methods for rapid response and cooperation at the site of an emergency situation, and developing methods for minimizing operating costs.

Scientific development [6] proposes the developed methods for risk management during transportation of dangerous goods, including the identification of individual risks, the identification of areas of the highest risk, and the assessment of risks through certain procedures. Using the developed methods will minimize the degree of risk to an acceptable level. One of the presented methods is a risk matrix that is used to assess risk, identify main areas with a high level of risk, and identify risks which can be neglected.

In [7] the decision-making tool developed on the basis of the model of risk assessment and optimization of routes is presented. The implementation of this tool will allow calculating the quantitative risk assessment for each individual cruise and the operating costs, depending on the chosen mode of transport for transportation of dangerous goods.

In [8] a tool was developed for assessing and systematizing risks in transportation of dangerous goods by rail, associated with the most common reasons for the derailment of rolling stock and other emergencies on the way registered in Canada based on the frequency of trains, the speed of movement, characteristics of the rail and other factors.

In [9] a three-level system was developed for indexing the prevention of risks when transporting dangerous goods by rail. Combined with the characteristics of each index and the current situation in safety management of the transportation process, the subjective and objective method of analysis and selection of the combination were integrated into the dynamic model of railway risk prevention during transportation of dangerous goods.

According to the performed analysis, powerful tools for assessment, prevention and minimization of risks in transportation of dangerous goods by rail are developed in the presented works. However, it should be noted that none of the authors had the purpose of developing a model to search for a rational marshalling option for dangerous goods of various classes, that is, insufficient attention was paid to the "safe" marshalling of rolling stock with such cars.

2.2 Analysis of statistical data

In 2017, the regional branches of PJSC Ukrzaliznytsya transported 339.5 million tonnes of cargo [10]. In connection with the growing quantitative and qualitative indicators of the use of rolling stock, the volumes of transportation of the main types of cargo increased in all types of transportations. In 2017, the volume of transported chemicals increased on average from 15% to 18% vs. 2016, chemical and mineral fertilizers from 8% to 13% [11] (see Fig. 1).

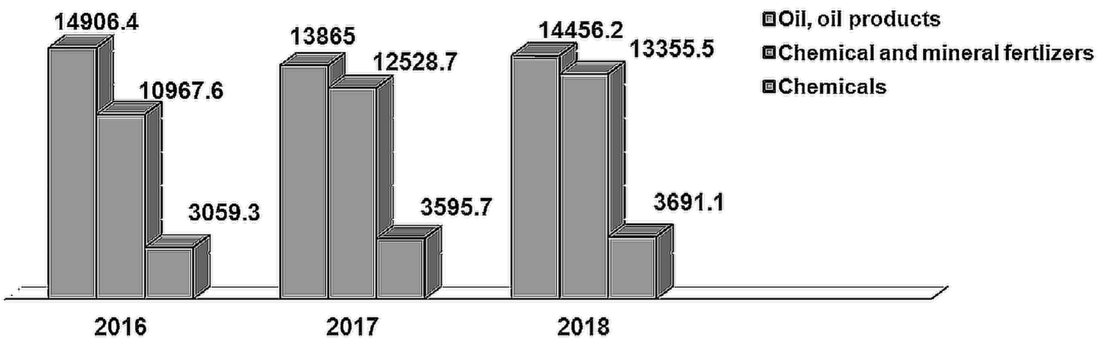

Fig. 1. Total amount of transported goods for 2016-2018 (2018 - forecast).

In 2016, 550 accidents occurred, 16 of them were serious. In 2017, 541 transport events occurred, of which 1 fatal one and 540 accidents, 32 of them were serious. In average, 1.48 accidents occurred every day vs. 1.51 in 2016 [12] (see Fig. 2). Analysis of statistical data has shown that the volume of transportation of dangerous goods tends to increase, while the number of transport incidents remains quite high, which can lead to more fatal consequences in each emergency situation.

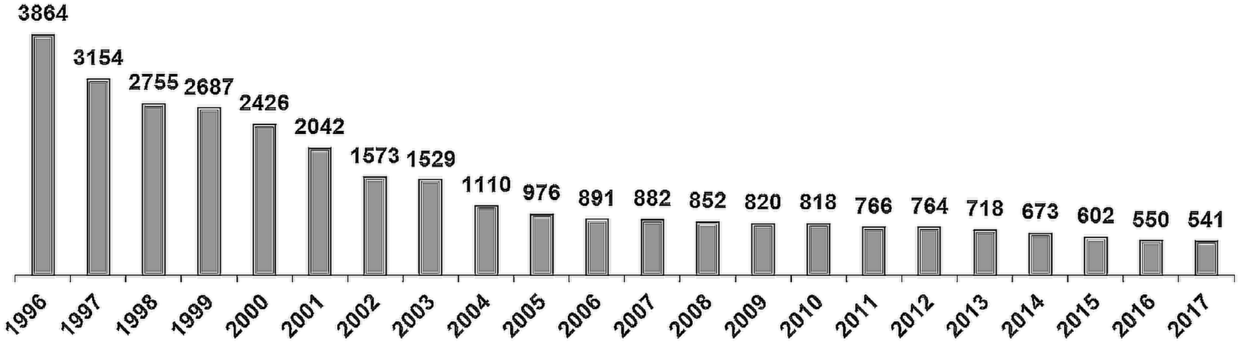

Fig. 2. Total number of transport events in the structure of Ukrzaliznytsya.

In view of the aforesaid, the scientific and applied problem of forming a model for determining the rational marshalling of freight trains with a dangerous cargo arises which would help minimizing risks and operating costs.

3. The main part of study

The technology of the marshalling of freight trains and their passing through railway units is now practically identical throughout the Commonwealth of Independent States (CIS). This statement is true also for freight and sorting stations, equipped with gravity sorting yards of various capacities. The process of breaking up and marshalling trains is a rather complex engineering task, which at the Ukrainian railways is solved by the operational staff of the station, such as shunting dispatchers, station duty officers, the employee in charge of the gravity sorting yard. The technology for marshalling freight trains is based on the parameter of minimal operation costs, which in turn depends on the time which the freight cars spend at the railway station for different operations (processing on arrival, waiting for breaking up, accumulation, etc.), the time of operation of hump and shunting locomotives, which affects the costs of fuel and energy resources, etc. At the same time, the category of goods contained in the cars of a newly formed train is practically not taken into account. First of all, this refers to the cars loaded with dangerous goods of various classes. In [4, 8] the existence of immediate danger if dangerous goods are included in the train, as well as possible consequences of accidents with such cars is mentioned. In [5] the assessment of the risk of functioning of the switchyard is focused on, provided that cars with dangerous goods are included into trains. At the same time, certain works pay insufficient attention to systemic accounting of operating costs related to marshalling of trains with DG and possible risks in their movement, expressed in terms of money. It is logical to assume that the risk of the occurrence of a traffic accident with a train which contains cars with DG depends not only on their presence, but also on their number, class and order of arrangement in the train. This assumption is based on the basic requirements of existing national and international rules, standards and agreements [1, 6, 7], which state that the DG of certain compatibility groups are prohibited to be loaded into one car because of the increased danger of the impact of one dangerous cargo to another. That is, the initiation of some dangerous goods may lead to the initiation of other DG, which together can lead to more serious consequences with an increased damage area. However, such situations, at the so-called global level, that is not within a single freight car, but within the whole train are not defined in technological documents and the corresponding rules. This requirement should be taken into account due to the relatively small amount of airspace that separates one car from another. If certain goods of hazard class I are initiated, such a distance is of only slight importance. Also, if tanks with a substance of hazard class II explode, such an explosion will spread to the nearby cars, thus creating a chain reaction that may increase the extent and area of the attack. The most striking example of such a situation may be the arrangement of cars loaded with hazard class I cargo (explosives) next to the hazard class VII cargo (radioactive materials). In this case, radioactive damage with spreading effect is added to the affecting factor of the explosion [8].

So, the principles of achieving minimum operating costs and risks should be the basis for formation of technology for marshalling of uniform trains. Accordingly, the objective function of a mathematical model that would describe a particular technology can be formed. Implicitly, the objective function can be represented as follows:

$$E(n, m_n) = \left(\sum_{i=1}^{\kappa} C(n, m_n), R(n, m_n), M(n, m_n) \right) \to \min, \quad (1)$$

where n - parameter responsible for the number of groups of cars with dangerous cargo as part of a single-cargo freight train, m_n - variable parameter corresponding to the number of cars with DG in each group, n cars, $\sum_{i=1}^{\kappa} C$ - total operating costs related to: breaking up of trains from the sorting gravity sorting yard, marshalling of the train from the turnout tracks, idle time of cars awaiting certain technological operations, UAH, R - value of the risk which depends on a certain composition of the freight train with DG, UAH, M - parameter that corresponds to the rational rearrangement of groups n with cars m_n. The search for a solution of the proposed model by standard methods that involve a exhaustive search from the field of possible solutions is not effective, since, as it was noted earlier, the result of this solution will be used in the changing circumstances of the operation of the railway station and railway units. The complexity of the task is illustrated in Fig. 3, which reflects an arbitrary possible operational situation at the railway station, as a result of which trains are located at the station and access tracks (shown in the left part of the figure) containing cars with dangerous goods (indicated in orange). The result of functioning of the model is the definition of a rational composition of a freight train, which includes cars with DG of various compatibility groups (shown in the right part of the figure).

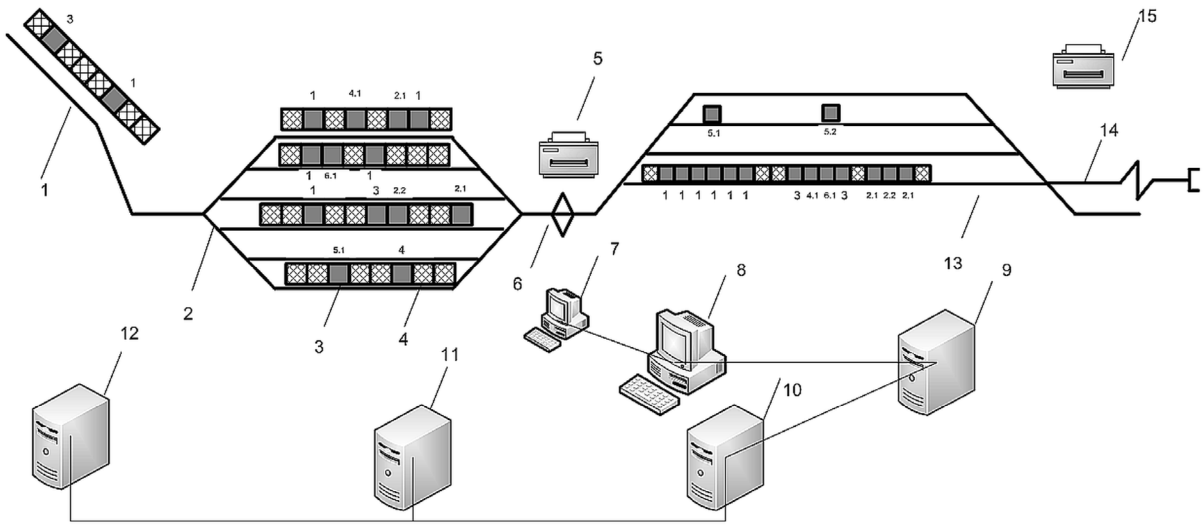

Fig. 3. Visualization of the procedure of marshalling of a single-cargo train with cars loaded with dangerous goods.

Conventions:
1 - path of the railway section adjacent to the station; 2 - rail receiving yard; 3 - car with DG; 4 - car with ordinary cargo or empty car; 5 – printer located at the gravity sorting yard; 6 - sorting yard; 7 - automated workstation (AWS) of the sorting yard operator; 8 - AWS of the shunting controller; 9 - station server; 10 - server of the Directorate of Railway Transport; 11 - server of the regional branch of PJSC Ukrzaliznytsya; 12 - server of the main computer center of PJSC Ukrzaliznytsya; 13 - sorting yard; 14 - shunting turnout tracks; 15 - printer located in the "tail" area of the sorting yard.

Obtaining a rational composition of a freight train with cars with DG after breaking up of trains in the rail receiving yard receiving of the station from sorting yard 6 is very complicated. Using the free tracks of sorting yard 13 and turnout shunting track 14 is expedient for final marshalling of such a train. Here it is assumed that operational information on the breaking up order will be provided to the shunting teams as a sorting sheet through printing devices 5 and 15. This information is the result of application of a mathematical model with objective function (1). Preliminary information for application of the mathematical model will be transferred via the channels of the automated freight management system of Ukrzaliznytsya (ASK VP UZ-E), which is represented in the figure by devices 7 -12. In accordance with the defined, the method of search for a solution of the proposed objective function should be chosen. One of such methods is a based on a genetic algorithm. If the determined method is a used, rational solutions can be obtained in a relatively short time, which is a necessary condition for performing operational work under operational conditions, which were mentioned above.

Giving the main phases of the work of the genetic algorithm (GA) in relation to the task is advisable. At the first phase of application of GA, the so-called parent pair of chromosomes should be formed. In this context, the chromosome refers to a certain sequence of freight cars with DG and without them in the train. In general, for a given task, the chromosome will consist of a certain number of genes g , which will be equal to the total number of cars of a certain purpose V (these cars can be located both at the station and on the access tracks), that is $ch_i = \{g_1, g_2, ..., g_v\}$, $v \in V$. Fig. 4 shows a graphical visualization of the operation of the three-point crossing over operator with the parent pair of chromosomes ch_1 and ch_2 , which are necessary for formation of the following populations. Numerical values that are recorded in the cells correspond to compatibility group (hazard number) [1], and the cell itself corresponds to the concept of gene.

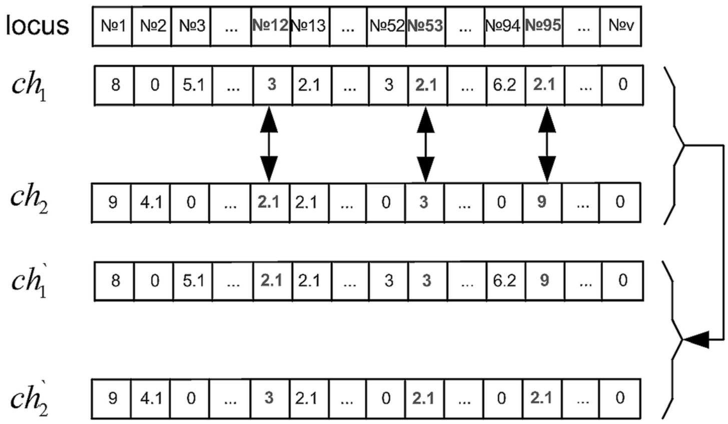

Fig. 4. Visualization of the operation of the three-point crossing over operator.

According to the main provisions of the theory of GA, each gene of the chromosome has its own specific place called locus [9], which corresponds to the order of arrangement of the cars in the freight train. As a result of the operation of the presented crossing over operator, three genes of the parent pair of chromosomes are immediately exchanged, resulting in the formation of the following pair of chromosomes $ch_1^`$ and $ch_2^`$.

It should be noted that the preliminary formation of the parent pair of chromosomes ch_1 and ch_2 should be based on the condition of including only those compatibility group values that correspond to the actual presence of such cars at the station for a certain direction or on the access tracks with the addition of an arbitrary number of cars without DGs. For this case, $g \in G$, where g is the value of the gene of the chromosome, G - the range of admissible values, which corresponds to the array of cars with DG. At the same time, an adjacency matrix should be formed for functioning of GA that will correspond to the possibility of setting freight cars with DGs with the corresponding danger signs. The basis of such a matrix will be Table 5 paragraph 7.5 [1] with the addition of the zero value, which will correspond to a freight car loaded with ordinary cargo (see Table 1). Determining the rational sequence of arranging cars with DG in a freight train is complicated by the necessary to provide for separation of such cars with cars with ordinary cargo or empty ones, which are defined in Table 1 with the zero value. In this article, such groups of cars with DG are proposed to be divided with three cars of the zero category. This assumption is based on the observance of the cover conditions, the maximum value of which, according to [1], is three cars. To implement this condition, using such operators as "delete" and “paste” in application of GA is reasonable.

Table 1. Basis for formation of an adjacency matrix for cars with DG.

Danger symbol number	0	1	1.4	1.5	1.6	2	3	4.1	…	9
0	1	1	1	1	1	1	1	1	…	1
1	1	0	0	0	0	0	0	0	…	0
1.4	1	0	0	0	0	0	0	0	…	0
1.5	1	0	0	0	0	0	0	0	…	0
1.6	1	0	0	0	0	0	0	0	…	0
2	1	0	0	0	0	1	0	0	…	1
3	1	0	0	0	0	0	1	1	…	1
	…	…	…	…	…	…	…	…	…	…
9	1	0	0	0	0	1	1	1	…	1

That is, at certain points of application of the algorithm, the length of the chromosome may change, but finally it must satisfy the condition:

$$50 \leq locus \leq 60 \tag{2}$$

This expression corresponds to the condition of forming a train of standard length. It should be noted that for the correct function of "delete" and "paste" operators, the following condition should be provided: probability of using the "delete" operator should approximately be twice more than “paste”, that is:

$$P(paste) = P(delete) \cdot 0{,}5 , \tag{3}$$

Thus, expression (3) is responsible for the fulfillment of condition (2) and simultaneously for the increased number of options. Usually for solving optimization problems, probability of use of "delete" operator is within the range $P(delete) \in (0{,}6; 0{,}99)$ [9]. The basis for obtaining results when applying the genetic algorithm is the fitness function. In this case, objective function (1) will be used as a fitness function which determines the degree of adjustment of the obtained solution, which can be represented as follows:

$$Fit(n, m_n) = C(n, m_n) + R(n, m_n) \rightarrow \min \quad , \tag{4}$$

Thus, it is assumed that parameter M will be realized as a chromosome transformation, which will reflect the rational sequence of the arrangement of groups of cars with DG in the train. The visual result of GA is shown in Fig. 5.

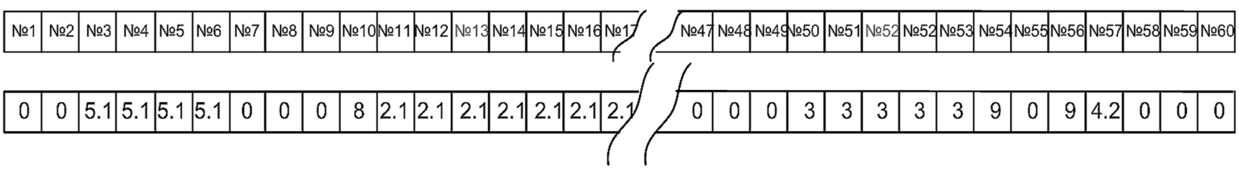

Fig. 5. Visual interpretation of the chromosome, which corresponds to the rational composition of the freight train with DG.

According to the figure above, the resulting chromosome has 60 loci. This in turn corresponds to 60 freight cars. At the same time, it is clear that the option of the train formation fully corresponds to Table 1 and the previously defined restriction (2). It should be noted that the obtained result can be considered almost perfect, but in practice, such a sequence can be achieved only by detailed adjustment of the model by selecting the appropriate genetic operators and the probability of their implementation.

4. Conclusion

In this research, an approach was proposed to forming a mathematical model and the method of solving it, which is responsible for the rational organization of freight trains with dangerous goods at sorting yard. It should be noted that the use of the proposed approach is possible at other stations provided shunting railways are available there. In prospect, the finalization of a mathematical model is planned to use it as the basis for the automated technology for determining the rational composition of freight trains with dangerous goods. However, the complexity of the formation of this model should be noted because one of its components is the value of risk, which is usually based on processing of statistical data. For adequate functioning of the proposed technology in the operational mode, this approach is not effective, so in future studies it is reasonable to consider the use of non-classical methods for determining the probability of occurrence of transport accidents with dangerous goods en route from the formation station to the destination station.

References

[1] *Rules for transportation of dangerous goods. Order of the Ministry of Infrastructure of Ukraine dd. 25.04.2017 No. 156.* Available: https://www.uz.gov.ua/cargo_transportation/legal_documents/terms_of_freight/page-2/454923/. [Accessed July 01, 2018].

[2] Instruction on the movement of trains and shunting work on the railways of Ukraine: approved. by order of the Ministry of Transport and Communications of Ukraine of August 31, 2005, No. 507 (as amended by the order of August 11, 2010, No. 584). Kyiv: 2010, 454 .

[3] Materials of the conference of the Ministry of Infrastructure dd. 27.09.2016, in the implementation of the European Union Twinning project "Support in improving the safety of the transport of dangerous goods by multimodal transport in Ukraine." Available: http://mtu.gov.ua/news/27655.html. [Accessed July 01, 2018].

[4] Studer, L., F. Borghetti, P. Gandini, R. Maja, and V. Todeschini. (2012) "Improving Knowledge of Risk in Dangerous Goods Transport", in *Proceedings of Smarter on the way: 19th ITS World congress (Vienna, Austria 22-26 Oct. 2012)*. 1-9.

[5] Nowacki, G, C. Krysiuk, and R. Kopczewski. (2016) "Dangerous Goods Transport Problems in the European Union and Poland". *The International Journal on Marine Navigation and Safety of Sea Transportation* ***10*** (1): 143-150.

[6] Solc, M., M. Hovanec. (2015) "The Importance of Dangerous Goods Transport by Rail. Our sea." *Dubrovnik* **62** (4): 181-186.

[7] Conca, A.., C. Ridella, and E. Sapori. (2016) "A risk assessment for road transportation of dangerous goods: a routing solution", in *Proceedings of Transport research arena: 6th European transport research conference (Warsaw, Poland 18-21Apr)*. 2890-2899.

[8] Macciotta, R., S. Robitailleb, M. Hendryc, and Derek Martin C. (2018) "Hazard ranking for railway transport of dangerous goods in Canada." *Case studies on transport policy* **6** (6) 43-50.

[9] Luan, T., Z. Guo, and L. Pang. (2017) "Early Warning Model for Risks in Railway Transportation of Dangerous Goods Based on Combination Weight". *Tiedao Xuebao journal of the China Railway Society* **39** (12): 1-7.

[10] *Statistical data for the Ukrainian railways.* Available: https://mtu.gov.ua/content/statistichni-dani-pro-ukrainski-zaliznici.html. (access date July 3, 2018).

[11] The current issue of the press center of Ukrzaliznytsya. URL: https://www.uz.gov.ua/press_center/up_to_date_topic/468292/. [Accessed July 01, 2018].

[12] *Analysis of the status of traffic safety in the structure of PJSC Ukrzaliznytsya in 2017*. Department of Transport Security of the Ministry of Infrastructure of Ukraine. Kyiv: 2017, 158 .

[13] Butko, T.V., A. V. Prokhorchenko, and S. I. Muzykina. (2012) "Formation of a model for the operational management of the process of moving cars with dangerous goods in the subsystem "technical station - adjacent area" on the basis of a fuzzy situation network". *Information-control systems on railway transport* **5**: 13-16.

[14] Muzykina, S.I. (2015) "Forming a model for forecasting the consequences of emergencies in railway transport during the transportation of dangerous goods". *Collection of scientific works of the Ukrainian State University of Railway Transport* **156**: 109-116.

[15] Chekhunov, D.M. (2018) "Formation of a risk assessment model at the sorting yard when operating cars with dangerous goods using mathematical devices of fuzzy logic and Bayesian networks". *Information-control systems on railway transport* **1**: 35-41.

[16] *DSTU 4500-3. Dangerous goods. Classification. [Introductions 2010-04-01]. Official revision*. Kyiv: Gospotrebstandart of Ukraine, 37.

[17] Annex 2 to the Agreement on International Goods Transport by Rail (IGbR). Rules for transportation of dangerous goods: Organization of the cooperation of railways (OCRW). 2017. 119.

[18] Gladkov, L. A., V. V. Kureichik, and V. M. Kureichik. (2006) "Genetic Algorithms: Textbook". Astrakhan, 320.