Запропоновано підхід для формування автоматизованої технології активного моніторингу за перевезеннями небезпечних вантажів залізничним транспортом. Представлений підхід динамічного опису поїздних станів розроблено на основі модифікації мови поїзних ситуацій у вигляді абстрактного моделювання оперативних процесів. Це дозволить забезпечити максимально швидку реалізацію алгоритмів прийняття рішень оперативним персоналом при потужній підтримці автоматизованого комплексу диспетчерського управління. Визначено, що максимальний ефект від реалізації запропонованого підходу буде отриманий при синтезі з системою активного моніторингу просування рухомих одиниць.

Моделювання довільної поїзної ситуації, яка може виникнути в реальних оперативних обставинах, надала можливість спрогнозувати порушення нормативного графіку руху поїздів та змоделювати когнітивний процес прийняття рішення поїзним диспетчером для раціонального вирішення складної поїзної ситуації в мінливих оперативних умовах при врахуванні значної кількості факторів. Модифікація мови поїзних ситуацій здатна адекватно надати просторово-часовий опис поїзних ситуацій на модельованій ділянці та є найбільш наближеною до мови диспетчерського персоналу.

Перевагами запропонованого підходу є те, що він дозволяє максимально швидко сформувати базу даних та базу знань для формування робочої моделі системи диспетчерського контролю. Дана система розроблена на основі імітації когнітивної діяльності людини оператора, тим самим надаючи можливість поглибити впровадження систем штучного інтелекту на залізниці. Ці інновації дозволять досягти максимального рівня безпеки при перевезенні небезпечних вантажів при одночасному безумовному досягненні зменшення експлуатаційних витрат та отримання підвищених прибутків

Ключові слова: небезпечні вантажі, мова поїзних ситуацій, абстрактне моделювання оперативних процесів

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FORMING AN AUTOMATED TECHNOLOGY TO ACTIVELY MONITOR THE TRANSPORTATION OF DANGEROUS CARGOES BY RAILROAD

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1. Introduction

In today's situation, issues related to improving the profitability of rail transportation are quite acute. That can be achieved both by directly receiving money and by saving the existing equipment, which may be based on strengthening the technological basis of the transportation process organization.

In this aspect, the transportation of dangerous cargoes (DCs) is of special importance. Transporting them provides railroad transport with significant financial revenues, which is a result of the constant growth of traffic volume.

However, the transportation of such cargoes is related to significant risks of the occurrence of non-standard hazardous situations, including significant material damages [1]. In addition, transporting such cargoes poses a potential danger for human life and health, as well as the environment [2].

Given this, it is expedient to solve the task of providing such transportation with technical and technological measures that would make it possible to implement the basic function of railroad transport qualitatively and efficiently.

2. Literature review and problem statement

Paper [3] established a variety of reasons based on the analysis of emergencies during the transportation of DCs. A significant proportion of such events takes place due to the technical malfunction of wagons and the catastrophic depreciation of fixed assets, as well as due to the violation of safety requirements, which lead to considerable material damage. That is why the issue of improving the technology of the transportation of dangerous cargoes at the different stages of the transportation process is extremely important; it is possible to resolve it only if all the factors of the transportation process are improved: organizational-technical, technological, information, personnel, and others.

The importance of strict compliance with the requirements of normative documents and international conventions on DC transportation is considered in [4]. It considers the transportation of radioactive materials and substances by railroad, which, under normal operation, minimizes the dangers of anthropogenic nature, both for the personnel engaged in the transportation of special-purpose cargoes and for the environment.

Work [5] built a model to estimate an accident probability involving a railroad car delivering a dangerous cargo at a sorting station by using a mathematical apparatus of Bayesian networks and fuzzy logic. A given model makes it possible to assess in detail the risk of accidents with a car transporting a dangerous cargo and to construct the time-dependent function of unreliability; it provides a possibility to apply information about events and the current status of objects at a sorting station. The work considers the estimation of the probability of the occurrence of a DC-transporting wagon accident only during its stay at the sorting station and does not pay attention to the traffic of trains with such cargoes along the railroad network when the operational staff is supported by intelligent systems.

Study [6] constructed a model of the operational control over the process of moving wagons with dangerous cargoes in the subsystem "technical station–adjoining station" based on a fuzzy situational network. The introduction of the reported model makes it possible to reduce the risks of a potentially possible transport accident and the related losses during the execution of train or shunting operations through the intelligent maintenance of planning at the operational level. Its development and subsequent implementation within a decision support system could provide an opportunity to reduce the number of transport accidents for reasons of organizational nature. At the same time, the study paid insufficient attention to the risks that could occur when trains with DC run under conditions of passenger traffic, both along sections and cross points, which, in turn, could lead to more dire consequences as a result of an emergency.

The issues of accidents during DC transportation are relevant to all railroads in the world; the ways to resolve them are based on the large-scale application of advanced computer technologies. Their implementation and application make it possible to process the large flows of operational and normative input information with the subsequent processing and producing a specific solution.

Work [7] showed that the level of losses due to emergencies related to DCs in railroad transportation constantly increases. This, in turn, raises the need to take into consideration all kinds of dangers that may arise during the transportation of such cargoes. The work carried out simulations in the ALOHA software that makes it possible to illustrate the effects, the extent of threat, and the scale of the incident involving ammonia emissions from the tank as a result of an emergency. It is shown that the most common cause of such situations is the collision of wagons. The work reported simulation of possible scenarios when transporting DCs and gave general recommendations for preventing transport accidents. However, the work does not focus on the dynamic adjustment of a train-related case for making quick, managerial decisions by the operational staff.

Paper [8] analyzed the safety of traffic and accidents on railroads and revealed that the biggest losses and negative consequences are caused by transportation accidents during DC transportation. It is stated that losses incurred may be reduced through the comprehensive implementation of various measures to prevent emergencies. Individual actions only reduce the likelihood of a particular risk, whereas the sum of adequately selected measures would reduce risk to the accepted level. At the same time, the authors ignored the issues of technology development in the field of intelligent modeling, situational management techniques, and linguistic modeling methods in non-classical logic.

In [9], the aim is to develop the elements of an integrated security system for the risk zone of transportation events related to DC, followed by its use in international transportation, as well as by other modes of transport. The main tasks of the research were solved by using computer simulations, comparative typologies, all-round expert assessments, statistical analysis, probability theory, similarity theory, etc.

A tool for the estimation and systematization of risks in the transportation of dangerous cargoes by railroad transport was developed in paper [10]. These risks are related to the most common causes of rolling stock derailing, as well as other accidents, along the sections, registered in Canada based on the frequency of trains running over a section, traffic speed, characteristics of the railroad track, and other factors. However, references [9, 10] did not use intelligent methods, which would provide the opportunity to adjust the actions of the dispatching system on a train accident with a high level of risk of an emergency, which has already developed at the section or station. This, in turn, does not make it possible to avoid more dire consequences as its result.

Papers [11–14] describe the approaches to managing risks when DCs are transported by road, aviation, and sea transport; they revealed the growing volume of such cargoes in international traffic by different modes of transportation. However, the approaches considered in [11–14] apply standard mathematical methods of modeling without formalizing the instruction language by dispatching staff and do not take into consideration the specificity of DC transportation by railroad, which, in turn, indicates the importance of developing advanced risk-oriented technologies for the transportation of such cargoes by rail in order to increase its competitiveness against other modes of transportation and to improve the quality of multimodal, intermodal, and piggyback transportation.

The main attention is paid to identifying the causes of the occurrence of transport accidents in the transportation of DCs, a regulatory framework was devised, which does not fully cover the specificity of such transportation. Taking into consideration the changing conditions of railroad stations functioning, the development and implementation of the automated technology are needed to improve the operation of operative employees, which would make it possible to take weighted decisions through processing the large amounts of incoming information in a relatively short period of time while dynamic correcting the traffic of trains delivering DCs.

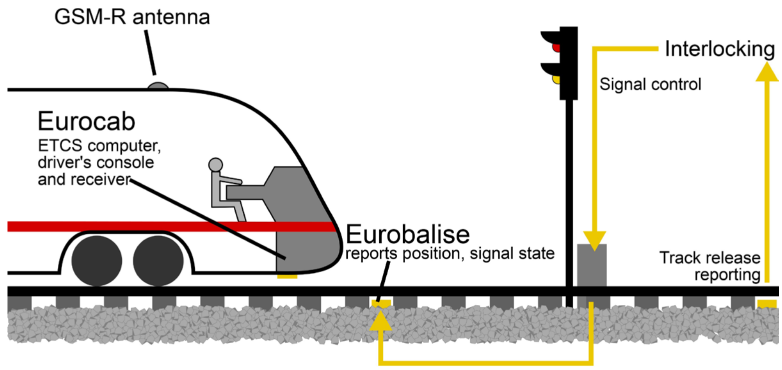

Fig. 1. ETCS level 1 scheme

3. The aim and objectives of the study

The aim of this study is to form an automated technology to actively monitor the transportation of DCs by rail.

To achieve the set aim, the following tasks have been solved:

– to develop an approach to the dynamic description of train states in a real-time mode in order to build a decision support system (DSS) for operational staff;

– to model and analyze the results obtained using arbitrary train situations arising in the operational work when managing train flows.

4. Strategic approaches to the formation of an automated technology of active monitoring of the transportation of DC by rail

In order to implement preventive measures during DC transportation, it is advisable to develop and implement an automated technology that could make it possible, in real-time, to execute control measures for managing transport units (locomotives, cars). To successfully implement any such system, it is necessary to detect the location of the wagon or locomotive in a real-time mode.

The so-called digital railroad was implemented in the EU countries, which became possible by combining automatic train protection systems (Automatic Train Protection (ATP)) and automatic control of trains (Automatic Train Control (ATC)) [15]. The basis of the developed and functioning modern technology of the automated control of train traffic ERTMS/ETCS is the idea of continuous control over the transportation process by means of a combination of various technical means, thereby the safe reduction of the passing distance is achieved, hence the increase in the capacity of railroads network. The technology of coordinate regulation provides a flexible change of intervals depending on the dynamically changing length of the brake route of a train and the location of locomotives and end wagons according to the satellite navigation data. Depending on the requirements for the particular section of a railroad, there are four main levels of ETCS: from zero to third. Fig. 1 shows the 1 level ETCS scheme.

The system also enables the level of NTC (National Train Control – the national train traffic control system), which implies additional equipment of a train with the devices to interact with the national centralization and blocking systems, not integrated with ETCS yet. The implementation of NTC, however, is associated with significant material and labor costs; for this reason, its application is not widespread.

The introduction of artificial intelligence to the transportation process management leads to global changes in the transport industry. In addition to unconditional benefits, such as the reduction of the "human factor", which plays an important role in making mistakes and taking wrong decisions thereby increasing the risk of an emergency with negative consequences, there are unresolved issues related to the reduction of human resources and to the ethical problems concerning the decisions taken by artificial intelligence, which can be attributed to the so-called "artificial intelligence factor". Therefore, it is advisable to pay attention to the DSS development, which could form rational managerial decisions while still leaving a final choice to an operator to practically execute them.

The country's railroad transport is currently engaged in experiments on the implementation of systems based on the use of GPS technologies. A given technology implies the installation of GPS sensors at each transportation unit, which provides an opportunity to detect it at any point in time, thereby detecting its location at the coordinates that are approximate to the exact position. The advantages of a given technology include the efficiency of information acquisition, a relatively low cost of sensors, the availability of ready-made technical solutions, etc. However, it should be noted that the accuracy of the identification is 1 to 5 meters. This fact restricts the use of the system on railroads as the interrail width ranges from 4,100 millimeters at a section to 5,300 millimeters at a station. That is, when trains run the two-track line, they cannot be accurately identified. The same problems arise with the identification of wagons running along the sorting tracks.

One of the possible options to overcome the specified issue is to build a rolling stock identification system. This system will be based on the logical and physical monitoring of the location of a transport unit followed by the subsequent automated-intelligent processing of information and making a rational control decision on determining the best variant for implementing the strategy for operational staff.

A given technical and technological solution implies that additional equipment will be installed at a railroad station at the entry and exit points. Such equipment will count the number of axles of the locomotive and wagons that left the station for the section, and then also counts these axles when entering the next station or when passing a section point. These data, along the channels of wireless 5G communication, arrive at the automated system of traffic dispatching control of trains (ASTDCT), which determines the number of cars in a train (a complete or incomplete train). This way, the dispatcher can monitor the status of a section or a section point. However, all that will not suffice to implement the automated system of active monitoring. It is necessary, as previously noted, to accurately determine the location of each wagon. To this end, ASTDCT should include information about the number of cars in a train and the characteristics of each car and locomotive in traffic. It is assumed that the data on cars and cargo will be supplied to ASTDCT from the automated control system of cargo deliveries of Ukrzaliznytsya (united). One will also need the exact information in real time about the speed of a train, which will arrive along the channels of wireless 5G communication. Based on the combination and analysis of the information about traffic speed and a train length, for each separate unit, it becomes possible to define the exact position of rolling stock in space.

The specified data is sent along 5G channels to an automated workplace (AWP) of the operational staff at the Regional Centre for Transportation Management (RCTM). This information is basic, regarding the subsequent decision-making for the further implementation of the strategy to manga trains along a section. If the unit is equipped with the dispatcher centralization (DC), the type of CASCADE, then the dispatcher independently performs the steps to prepare a train route and monitors its traffic. In the absence of DC, the train dispatcher sends the necessary commands to the AWP of a station's personnel on duty along the 5G channels or the automated control system of cargo deliveries of Ukrzaliznytsya (united).

Given the considerable workload on a train dispatcher and on-duty station personnel, there is an issue of making an operative justified rational decision on managing the trains along a section. Operational staff must constantly solve the task of finding rational options for train operation at a station and a section. Such decisions are mainly taken on the basis of the personal experience of each employee. It should also be noted that the former USSR railroads have some technical features. This scientific work focuses on single-track traffic with a semi-automated locking.

One of the most urgent problems of train management along the network of regional branches of JSC "Ukrzaliznytsya" is the presence of single-track sections, where the simultaneous running or nonstop passing of trains from opposite directions is not possible. This condition is dictated by traffic safety terms. In this case, the procedure for receiving and nonstop passing of oncoming trains is regulated by special station intervals. In a given case, we mean the station interval of non-simultaneous arrival τ_{np}, which is a minimum time interval. This time is determined from the moment of a train's arrival to the dividing point before the arrival time or when this point is crossed by a train running in the opposite direction [16].

Fig. 2 shows the schematic representation of τ_{np} (measured in minutes) as an element of the train schedule, which represents how an odd train numbered 2101 and an even train numbered 2102 entry the dividing point *S*.

Fig. 3 shows the visual interpretation of the specified train situation.

In this case, the actions of a train dispatcher and the locomotive crew must be clearly coordinated since $\tau_{np} \in [1;3]$. Possible failures in the traffic of trains due to possible operational circumstances related to the violation of this interval can lead to significant delays in traffic and, as a consequence, the violation of meeting the entire train schedule in general. The specified situation becomes even more unsatisfactory in the case of managing freight trains with DCs. Therefore, real-time prediction and quick response to changing operational circumstances are the basis for minimizing the risks when managing trains with DCs, especially in passenger traffic conditions, both along sections and dividing points. It should be noted that along with such trains, the railroad allows trains with oversized cargoes, increased weight, increased length, trains with cargoes with an expired delivery term. Under these conditions, a train dispatcher often must almost instantly make decisions, which in the future can lead to unjustified technical and technological losses.

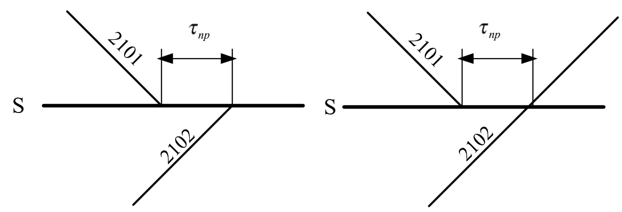

Fig. 2. Schematic representation of τ_{np} as an element of trains schedule

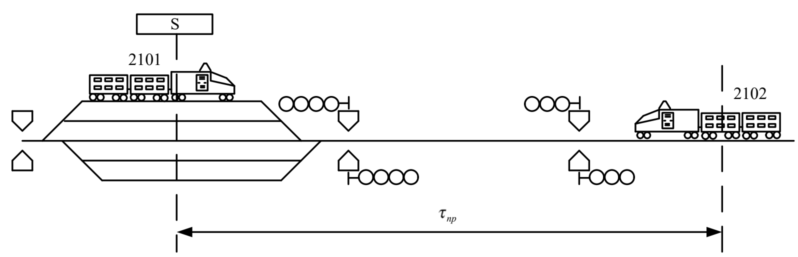

Fig. 3. Visual interpretation of the station interval τ_{np}

Given the above, it is important to form a new or improve the existing technology for forecasting the rational handling of transport events at minimal risk and lower operating costs.

5. Construction of an abstract model of operational processes in a general form and modeling the dynamic correction of an arbitrary train situation

Solving the modeled actual case, shown in Fig. 3, 2, based on the automated (subsequently, automatic) prediction mode, is a complex scientific and applied task.

In order to quickly respond to a change in the transportation events, this scientific work, as noted earlier, will apply the modification of the language of train situations (LTS) in the form of abstract modeling of operational processes (AMOP). This very approach could ensure the fastest implementation of decision-making algorithms by operational staff given the powerful support from an automated complex of dispatching control.

Hereafter τ_{np} shall be described in the terms of AMOP. Accordingly, τ_{np} is to be represented in the form of a predicate of the collision of a non-simultaneous arrival similar to the predicate of the collision of gone LTS. Unlike the latter, it will give an unconditional priority to one train compared to another as regards the priority of receiving or passing through a dividing point in counter traffic. Thus, a predicate of the non-simultaneous arrival collision β_{np} can be represented as follows:

$$\beta_{np}\left(p_i^{`}, p_j^{``}, t_n\right), \qquad (1)$$

where $p_i^{`}$ is the conditional designation of a train that moves towards the dividing point from the odd direction; $p_j^{``}$ is the conditional designation of a train moving towards the dividing point from the even direction; t_n is the event execution time (the arrival of a train to the station), hours.

In a general form, the abstract model of the operational process of the arrival of trains from opposite directions at the dividing point can be represented as follows:

$$\beta_{np}\left(p_i^{`}, p_j^{``}, t_n\right) \Rightarrow \left(p_i^{`}\chi_{\in} s\right)\tau_{(\bullet)}\left(t_n\right) \& \left(p_j^{``}\chi_{\in} s\right)\tau_{(\bullet)}\left(t_n\right), \qquad (2)$$

where $\chi_{\in}$ is the relative value, which characterizes the event of a certain object being at the defined infrastructure component (station, track, section); s is the designation of a model's physical component as an infrastructure component of a railroad unit (railroad station); $\tau_{(\bullet)}\left(t_n\right)$ is the time-dependent relative value, which characterizes the implementation of the event at time t_n.

However, such notation does not satisfy the specified conditions of the non-simultaneous arrival and the very sense of the predicate collision β_{np}, therefore, according to the set requirements, an abstract model of the operational process of the non-simultaneous arrival of trains from opposite directions at the dividing point will be represented as follows:

$$\beta_{np}\left(p_i^{`}, p_j^{``}, t_n\right) \Rightarrow \left(p_i^{`}\chi_{\in} s\right)\tau_{(\bullet)}\left(t_{n-1}\right) \& \left(p_j^{``}\chi_{\in} s\right)\tau_{(\bullet)}\left(t_{n+1}\right). \qquad (3)$$

In accordance with expression 3, the following expression will hold:

$$\tau_{np} = \left(t_{n+1}\right) - \left(t_{n-1}\right). \qquad (4)$$

Therefore, the complex linguistic structure, reported in work [16], can be represented in the form of the AMOP predicate and a derivative from the basic LTS structure [18].

This approach greatly simplifies the modeling of any transportation processes, which are based on the elements of artificial intelligence, to further automate the specified processes.

As an example, we shall simulate a train situation, which can occur in real operational circumstances when violating the normative schedule of trains.

Fig. 4 shows an example of the normative train schedule (NTS). According to this fragment, we modeled a variant of its implementation, which implies passing a through train 2101 calling at station S to cross with train 2102.

For the predefined time, at station S, we modeled an operational situation (Fig. 5), which conditionally reflects the compliance with the developed NTS from Fig. 4.

When describing the case from Fig. 5, it is important to note the following: an odd train should run along main track I; however, according to NTS, this track is for a stop-free pass of the through cargo train 2102. Under these conditions, 2101 can run along track 3 or 5.

However, since track 3 is taken by freight wagons (possibly local, under loading or under unloading), 2101 may take vacant track 5. The track can be used, according to the Technical and Administrative Act of the Station (TAA), to serve passenger traffic. This track, as seen in Fig. 5, is located near a passenger building, located at the side of the city.

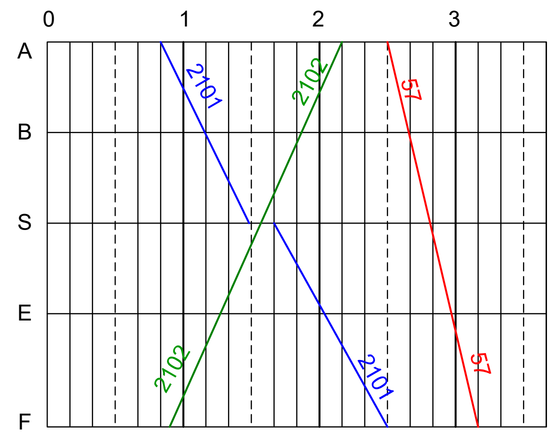

Fig. 4. Fragment of the valid normative train schedule

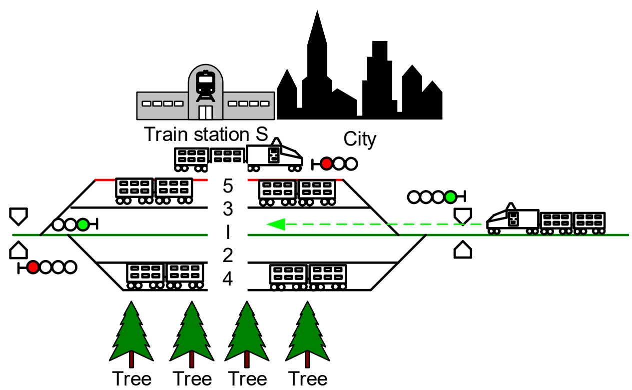

Fig. 5. Visual model of the train operational status at station S under the current NTS

It should be added that Fig. 5 shows the modeled state that corresponds to NTS in terms of strict observance of the schedule of all categories of trains. It meets the condition of equivalence of trains 2101 and 2102 (trains without any special signs that were considered earlier).

The specified situation at a station can be described by the predicate of collision β_{np} that corresponds to expression (3). In this case, the corresponding modifications of basic products will be applied to each of these trains [17].

To predict the approach implying receiving train 2101 at a station for crossing with a stop, the products of (5) and (6) shall be used:

$$\left(p_i^{`}\chi_{\in} d\right)\tau_n\left(t^{\mu}\right) \& \left(p_i^{`}\chi_{\in} d\right)\tau_{\Delta}(l) \Rightarrow \left(p_i^{`}\chi_{\in} d\right)\tau_k\left(t^{\mu}+l\right), \qquad (5)$$

where $\tau_n\left(t^{\mu}\right)$ is the time when the event started; $\tau_{\Delta}(l)$ is the time interval over which the specified event is performed;

$$\left(p_i^{`}\chi_{\in} d\right)\tau_k\left(t^{\mu}\right) \& P_{vp}\left(d, t^{\mu}\right) \Rightarrow \left(p_i^{`}\chi_{\in} s\right)\tau_n\left(t^{\mu}\right), \qquad (6)$$

where $\tau_k\left(t^{\mu}\right)$ is the time of completion of the event; $P_{vp}\left(d, t^{\mu}\right)$ is the predicate of section idling at time t^{μ}.

To predict the approach implying the subsequent stop-free pass of train 2102 at station S, the modifications of products (7) and (8) will be used:

$$\left(p_j^{``}\chi_{\in} d\right)\tau_n\left(t^{\mu}\right) \& \left(p_j^{``}\chi_{\in} d\right)\tau_{\Delta}(l) \Rightarrow \left(p_j^{``}\chi_{\in} d\right)\tau_k\left(t^{\mu}+l\right), \qquad (7)$$

$$\left(p_j^{``}\chi_{\in}s\right)\tau_k\left(t^{\mu}\right)\&P_{vp}\left(d,t^{\mu}\right)\Rightarrow\left(p_j^{``}\chi_{\in}d\right)\tau_n\left(t^{\mu}\right). \quad (8)$$

Thus, when using the symbol-type variables in a proper form, we recorded the interpretation of the cognitive activity of the human operator as regards resolving train operational circumstances.

It should be noted that operational circumstances at line railroad units and sections are constantly dynamically changing and can differ significantly from plans compiled for a shift or a day, especially for a year. In these circumstances, an operative worker, in this case, a train dispatcher, must predict such changes, and, in some cases, instantly take informed decisions on the operative adjustment of NTS.

Fig. 6 shows the modeled fragment of the fulfilled schedule of trains, which differs from the above NTS fragment. It is evident that train 2101 deviated from the normative schedule for 10 minutes while it includes cars with DCs, as evidenced by the corresponding mark (2101dc).

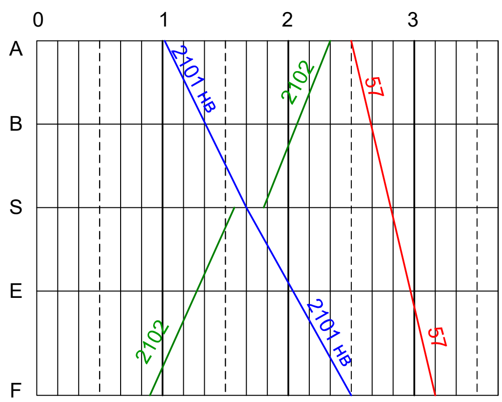

Fig. 6. Fragment of the fulfilled schedule of trains

The situation is complicated by the fact that, according to the TAA for station S, trains with DCs are banned to pass track 5, since this track is used to serve passenger traffic and is located near a passenger building (a station), which is in close proximity to the city.

A train dispatcher should adjust the GRP in such a way as to ensure the safety of passengers and the population. At the same time, one should (should?) minimally affect the overall strategy of train traffic along a direction as this can lead to a chain reaction and cause significant damage.

Fig. 7 shows the graphical interpretation of a train status at station S, which corresponds to the fulfilled schedule of trains (Fig. 6).

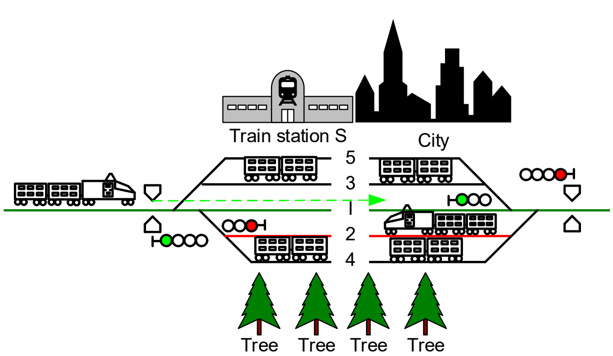

Fig. 7. Graphic interpretation of train status at station S according to the fulfilled NTS

In the above situation of the fulfilled NTs, the predicate of collision β_{np} can be represented as follows:

$$\beta_{np}\left(p_j^{``},p_i^{`},t_m\right)\Rightarrow\left(p_j^{``}\chi_{\in}s\right)\tau_{(\bullet)}\left(t_{n-1}\right)\&\left(p^{`}\chi_{\in}s\right)\tau_{(\bullet)}\left(t_{\ +1}\right). \quad (9)$$

According to the changes in NTS in the form of the fulfilled NTS and the predicate of collision β_{np} given in expression (9), the modifications of basic products for trains 2101dc and 2102 will be interpreted in the following way:

– for 2101dc $\left(p_{\bullet}^{`}\right)$, the product that is responsible for the end of the traffic along a section will be identical to product (5), while the product that describes the beginning of the traffic from the station will take the following form:

$$\left(p_i^{`}\chi_{\in}s\right)\tau_k\left(t^{\mu}\right)\&P_{vp}\left(d,t^{\mu}\right)\Rightarrow\left(p_i^{`}\chi_{\in}d\right)\tau_n\left(t^{\mu}\right), \quad (10)$$

– for 2102 $\left(p_j^{``}\right)$, the product, which is responsible for the end of the traffic along a section, will be identical to product (7), while the product that describes the beginning of idling for performing the procedure of crossing with 2101dc at station *S* will take the following form:

$$\left(p_j^{``}\chi_{\in}d\right)\tau_k\left(t^{\mu}\right)\&P_{vp}\left(d,t^{\mu}\right)\Rightarrow\left(p_j^{``}\chi_{\in}s\right)\tau_n\left(t^{\mu}\right). \quad (11)$$

Thus, as a result of the transformation, we formed the basic, modified abstract products that correspond to the procedure of the beginning of traffic and the crossing of trains at a station.

7. Discussion of results of developing the approaches to describe train situations

The result of our study is a breakthrough approach (3), (4), (6), (7), Fig. 3, 4, 6, 7, regarding the description and identification of train situations, rendering the decision-making by operational staff quicker and safer compared to existing approaches. This is because instead of cumbersome linguistic constructs that describe the train status, we apply short symbolic structures understandable to humans. This makes it possible to simplify the programming code when implementing a given technology in an automated form.

For a given integrated technology of dispatching management, we developed controlling producing rules (5), (6), and their modifications (7), (8), (10), (11), which ensure control over the technological correctness of train situations. The developed rules perform the function of forecasting possible failures and deviations, which can occur in a technological process. In a given case, operational staff, namely the dispatching staff, is provided with a possibility to analyze and optimize the taken decisions in the interactive mode by using the production rules and an expert knowledge base underlying this system.

However, it should be noted that this approach has some limitations since the human operator will have to memorize certain abstract structures in the beginning, which were developed from linguistic interpretations. It means that the description of train situations, which was previously recorded with a whole sentence, will need to be replaced with a certain symbolic notation. As an example, one can give the product $\left(p_i^{`}\chi_{\in}d\right)\tau_n\left(t^{\mu}\right)$, which is linguistically interpreted as follows "train No, which is at the station, must be sent to an odd section at a certain time".

This study is to advance towards the final formation of an automated technology of active monitoring, implying the industrial implementation. We plan to develop a unique, independent technical and technological complex, which could fully implement the described approach.

The proposed approach can be adapted and integrated into existing automated train traffic control systems, such as the automated control system for cargo or passenger transportation (the automated control system of passenger deliveries of Ukrzaliznytsya and the automated control system of cargo deliveries of Ukrzaliznytsya (combined)), or a system of dispatching control, the type of CASCADE.

8. Conclusions

1. We have developed an approach for the dynamic description of train states under a real-time mode, based on the modification of the language of train situations in the form of abstract modeling of operational processes. The maximum effect of implementing the proposed approach could be obtained when synthesizing it with an active monitoring system of movable units (AMMS). Information about an actual train status, which is dynamic in nature, comes from different communication channels: telephone communication from station on-duty personnel; the automated control system of cargo deliveries of Ukrzaliznytsya, CASCADE; in the form of a document package on paper and electronic media. The perception, processing of input information, and subsequent adoption of an effective managerial decision by operational staff take a lot of time, which is decisive and critical in the constantly changing conditions of acquiring new operational information that changes the current train situation. In order to generalize and systematize the input flow of information and those additional factors that influence a train status, the process of computerization is necessary, namely the development of a semantic-type situational management language. The product rules reported in this work are the base for the module of interpretation and consultation of the system of dispatching control, which will make it possible for the dispatcher to not only make a decision based on the processed information but would give the ready managerial decision for the immediate transformation into an actual state.

2. We have modeled an arbitrary situation that could occur in real operational circumstances when violating a normative schedule of trains. The specified procedure provided an opportunity to predict the violation of normative NTS, to simulate a cognitive process of decision-making by a train dispatcher in order to rationally solve a complicated train situation under changing operational conditions while accounting for a significant number of factors.

The proposed approach to the modification of the language of train situations in the form of abstract modeling of operative processes makes it possible to improve the qualitative indexes of railroad operation, which include a delay time of trains near incoming traffic lights, the downtime of transit wagons and cars processed at a station. Particular attention should be paid to an integrated qualitative indicator, a wagon turnover, which is measured in hours and days. This indicator is strategically important, both in terms of the economy and operational quality of the railroad industry of transportation at the global level. The implementation of a given intelligent technology of active monitoring into the automated complexes of operative dispatching staff would reduce the turnover time of freight cars by 15 %; such an amount of time accounts for the downtime of cars at a station.

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