Computational procedure for preparing the technical conditions for stowage and securing cargo in rail cars and containers

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Abstract. The transition of the railway industry from information management systems to systems with full management can be achieved by combining automated information systems integrated into production processes in the railway network. Russian Railways OAO acts as a driver for the development of modern technologies in the transport sector, aiming to increase efficiency in organizing the transportation process. Monitoring changes in customer needs, as well as focusing on increasing the value of services and products for consumers, including service quality improvement by digitalizing individual operations related to the cargo handling during loading, is becoming increasingly important. The introduction of the developed automated system for the preparation of technical specifications for the stowage and securing of cargo in rail cars and containers will increase production system organization quality in railway transport, as it will eliminate the incompetence, negligence and irresponsibility of workers associated with the handling, stowage and securing, reduce the time for preparing technical documentation, and improve the transport system operation quality. To achieve the stated goal, based on the studies, the author developed a computational decision-making procedure for the stowage and securing of cargo in the rail car, taking into account a possible two-coordinate shift. The procedure allows employees responsible for accepting cargo for transportation to assess the quality of the cargo securing according to the criterion of permissible shift at the initial stage of the transportation process. The developed automated system has many positive aspects. The security of the system significantly increases, the risk of errors is reduced, and the influence of the human factor is minimized. The complexity of the process of compiling a sketch of the stowage and securing of the cargo in the rail car loaded in accordance with the Technical Specifications is reduced. Most of the work is done by automated software, the cargo shipper has more time to control the loading process; time limits of various works and projects generally decrease.

1. Introduction

Railway transport system (RTS), representing one of the leading sectors of the transport complex of the Russian Federation during all periods of its activity, has been one of the leaders in the development of digital technologies and systems. Today, to ignore new approaches in the information environment means to miss opportunities for optimizing the resource base, developing fixed assets and technologies, capital investments, operating expenses, generating additional income and profit [1]. It is advisable to highlight the main trends in the railway digitalization of railway transport system: multimodal transportation; customer focus; new business models and participation in business
networks; work with data. More and more projects are based on the collection and analysis of data. The implementation of these directions will optimize freight and passenger flows, build smart traction rolling stock, minimize the time components of the transportation process and improve financial and economic indicators. In connection with these factors, the need for digitalization of the transportation process is obvious. But it should be borne in mind that it is simply impossible to implement these projects without digitalization of the basic level of infrastructure. The digital presentation of information allows optimizing the process of its accumulation, storing and transferring, as well as applying unified methods of its mathematical processing in automatic mode, which reduces the human factor influence. This, in turn, increases the reliability of the operation of all structural divisions of railway transport system responsible for the implementation of the train schedule [2, 3].

Maximum integration and comprehensive one-time development of all structural divisions of the railway system will make it possible to get a reinforcing effect with seamless interaction of all objects included in the system. The goal of creating a unified digital platform for the transport complex of Russia is to reduce transportation costs and unify transport and logistics solutions. This will improve the safety, quality and availability of transportation; reduce costs; provide maximum load of infrastructure; expand export and transit capabilities of the country; open up new growth opportunities for the transport industry [4-7].

2. Digitalization of technological processes in railway transport systems

The transition of the railway industry from information management systems to systems with full management can be achieved by combining automated information systems integrated into production processes in the railway network. Russian Railways OAO acts as a driver for the development of modern technologies in the transport sector, aiming to increase efficiency in organizing the transportation process [8]. Digitalization and automation of technological processes within the framework of a single production process allows organizing the basis for the optimization of process control systems and work of organization systems of railway structural divisions. Alongside with that, the level of safety of the transportation process itself and shunting work increases.

Failure analysis [9] showed that the violation of the safety of the railway transport system and its subsystems is associated with the handling and securing of cargo at the loading terminal, since the uninterrupted transportation process depends on the correct stowage and securing of a cargo on a rolling stock [10-12]. Monitoring changes in customer needs, as well as focusing on increasing the value of services and products for consumers, including service quality improvement by digitalizing individual operations related to the cargo handling during loading, is becoming increasingly important [13, 14]. The cargo presented for carriage must be prepared in such a way that the safety of train traffic, cargo and the entire infrastructure are ensured during the transportation process. The onset of risk cases associated with improper loading and securing of cargo at the point of departure will lead to the following subsystem malfunctions: damage to fixed assets in the infrastructure subsystem; additional shunting operations on the decoupling and attaching of a rail car with defects in the shunting subsystem; non-scheduled stop or train delay in excess of established standards in the train subsystem; additional operations of cargo securing or its transshipment in the cargo subsystem.

Figure 1 shows statistics on the total number of uncoupled rail cars with malfunctions. This type of graphs allows one not to reject the consistency of the considered values with the exponential distribution law. To confirm this, the consistency of statistical and theoretical distributions was checked using the Pearson chi-squared test [15-17]. With a large number of observations $n$, the distribution law of the quantity $U$ approaches the chi-squared distribution ($\chi^2$):

$$U = x^2 = \sum_{i=1}^{k} \frac{(m_i - nP_i)^2}{nP_i},$$

where $m_i = n \cdot P_i^*$ is the number of values of a random quantity in the place.
To date, the railway transport system uses various automation programs and systems to prepare the technical specifications for the stowage and securing of cargo in rail cars and containers, but all of them still have a fairly low degree of automation and limited functionality.

3. Computational procedure for preparing the technical conditions for the stowage and securing of cargo in rail cars and containers

Based on the results of the studies, the author developed a computational decision-making procedure for the stowage and securing of cargo in the rail car, taking into account a possible two-coordinate shift. The procedure allows employees responsible for accepting cargo for transportation to assess the quality of the cargo securing according to the criterion of permissible shift at the initial stage of the transportation process. The presented version of the software package to prepare technical conditions for the stowage and securing of cargo in rail cars and containers allows providing the user with a base of reference and regulatory information on rail cars, permissible loads on elements of rail car bodies, cargo securing elements and materials used for securing cargo. It is designed taking into account regulatory documents that are effective in the network of Russian Railways [4, 5, 18-20].

One can use this program in two directions:
- the selection of the type of a rolling stock and the optimal location of the unit or quantity of cargo in the body of a rail car or container;
- the selection of a method of securing cargo on a rolling stock.

For the program to work, the overall dimensions of the goods and the overall dimensions of the rolling stock are required: length, width, height (m). The following are also indicated:
- cargo weight, t;
- parameters for calculating the center of gravity;
- the presence of cargo loops;
- the quality of the rail car floor (wooden or wood);
- physical and geometric parameters of flexible fasteners.

The calculation takes into account various additional restrictions, such as load capacity, maximum pressure on the box (if the cargo is packaged), pressure balance on the axis of the rail car bogie, stacking, etc. In addition, we can choose one of three loading options: through the back door (like into a container), through the side door (like into a rail car), or from top to bottom (like onto a platform).

To develop a computational procedure, it was required:
- to obtain an analytical solution to the problem by the criterion of the permissible value of the tension in the fastenings of the transported cargo from the influence of the spatial system of forces by constructing a physical model of securing the cargo in the rail car, and a mathematical model on its basis;
- based on the constructed model, to carry out calculations of fastenings in a plane system of forces;
- to derive analytical formulas for determining the shift of the cargo in the direction of the spatial system of forces, as well as the tension in the cargo fastenings [21, 22].
The author obtained graphical dependences of the cargo shift $\Delta s$ in the direction of the force $\Delta F$, as well as the shifts along the $\Delta x$ and across the $\Delta y$ of the rail car depending on the angle of inclination $\lambda$ of the force $\Delta F$ relative to the longitudinal axis $x$ (figure 2).

![Figure 2](image-url)

**Figure 2.** Graphical dependences of the cargo shift $\Delta s = f(\lambda)$, $\Delta x = f(\lambda)$ and $\Delta y = f(\lambda)$.

Summarizing the results of the computational experiments, we note that for given initial data and the technology of securing the cargo in the rail car according to technical specifications, if the length of the fasteners $l_i$ exceeds 2.284 m at $kd_x = 1.2$ kN and 2.397 m at $kd_x = 1.1$ kN, then there is a risk of rupture of such fasteners. In this regard, there is a need to make changes to the geometry of the load securing.

The computational procedure includes:
- selection of a physical model of cargo fastenings (figure 3);
- input data entering (figure 4);
- calculation of the spatial system of forces perceived by means of fastenings and their components both along and across the rail car;
- calculation of equivalent stiffness of guy-ropes from the influence of the spatial system of forces and their components. Performing processing of the received data and their analysis;
- prediction of the magnitude of the shift of the cargo in the direction of the spatial system of forces and its components, taking into account the guide angle. Performing processing of the received data and their analysis;
- calculation of tension in fastenings from the influence of the spatial system of forces and from their components both along and across the rail car;
- registration of calculation results in the form of tabular data, their processing, analysis of the obtained results and issuing practical recommendations on the development of a rational technology for securing cargo (figure 5), taking into account the exclusion of risk cases and ensuring the safety of the railway transport system operation. The substantiation of the technology of cargo securing in the rail car by the results of computational experiments.

The introduction of the developed automated system for the preparation of technical conditions for the stowage and securing of cargo in rail cars and containers will increase the railway transport system safety, as it will eliminate the incompetence, negligence and irresponsibility of workers associated with the handling, stowage and securing, reduce the time for preparing technical documentation, and improve the transport system operation quality [2, 3, 23].
Figure 3. The window of selecting the type of a cargo with a flat support (a, b).
Figure 4. The window of the configuration of a cargo with a flat support (a, b).
The analysis using results from figure 2 shows that for given initial data, the values of the tension in all the fasteners (figure 6) turned out to be less than the standard tension in the fasteners that meet the technical specifications (in figure 6, for example, even in the most low-sloped lengthwise guy-rope $l_5$ the tension $R_5$ is equal 32.2 kN), which confirms the rationality of the recommended technology for securing cargo (figure 5) in comparison with the existing one (figure 3).

The results of computational experiments conducted to find the tension in the fasteners when varying the coefficient of the longitudinal dynamics of the rail car, made it possible to note that, according to the recommended technology for securing the cargo, the guy-ropes can withstand a load exceeding...
18% of the cargo weight, which is more than the recommended value depending on the weight according to technical specifications.

The implementation of the computational procedure to support decision making on the stowage and securing of cargo in the rail car, taking into account a possible two-coordinate shift, will improve the railway transport safety, since it will make it possible to forecast the occurrence of risk when accepting cargo for transportation. Thereby, it will eliminate the incompetence, negligence and irresponsibility of employees associated with the handling, stowage and securing of cargo will increase the quality of the transport system and its operation safety. This, in turn, will reduce the unproductive expenditures of the railway transport system associated with the elimination of the consequences of accidents, crashes and defects in work [4-7, 24].

The amount of unproductive expenditures associated with the elimination of the consequences of commercial rejects caused by violation of technical specifications includes:

- the expenditures associated with stopping the train, excluding the dwell time;
- the value of operating costs associated with the downtime of the train at the station waiting for a commercial inspection and uncoupling of wagons in violation of technical specifications;
- the cost of additional shunting operations for uncoupling and attaching rail cars in violation of technical specifications;
- additional costs for car hours of downtime at the station while the commercial malfunctions are eliminated;
- labor expenses of working crews at commercial inspection station engaged in the reoperation; additional costs for the necessary materials for restoration according to technical specifications.

At the same time, depending on the location of elimination and the conditions for detecting a commercial malfunction, unproductive expenses associated with the malfunction elimination will include various elements. According to the calculations, the total costs associated with the elimination of one commercial malfunction caused by the violation of technical specifications are 16397.76 rubles per car. According to the reported data, in 2019 (figure 1), 4264 of rail cars were uncoupled to eliminate commercial malfunctions related to violation of technical specifications. The total savings will be 69.92 million rubles/year.

4. Conclusion
The main advantages of the developed computational procedure are:

1. Improving the security of the system, reducing the risk of errors, minimizing the human factor;
2. Reducing the complexity of the process of compiling a sketch of the stowage and securing of the cargo in the rail car loaded in accordance with the Technical Specifications. Most of the work is done by software; the cargo shipper has more time to control the loading process;
3. Decrease of time limits of various works and projects in general;
4. Increased efficiency, for example, the effective use of all the capabilities of fastening devices, etc. Therefore, the developed model makes it possible to reduce the required number of guy-ropes in comparison with the calculations according to the current Technical Specifications in compliance with the conditions of reliability of cargo securing;
5. It allows calculating the required number of guy-ropes while complicating the conditions of cargo transportation (increasing the possible risks of commercial rejects). In each case, the decision remains with the cargo shipper;
6. Systematization of all enterprise information, the buildup of databases;
7. Increased competitiveness and profit of transport enterprises [5].

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