Automation of the splitting-up processes of freight trains on the gravity sorting yards in the railway transport system

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Abstract. The basic reasons for insufficient reduction of a number of safety violations in a railway transport network are systemic and are related to the current condition of the technical and technological base of transport complexes. Aging, poor conditions of fixed assets and errors in the maintenance of the transport system are in most cases the main causes of accidents and casualties. The basis for the automation of most technological railway processes is the redistribution of material, energy and information flows in accordance with the accepted criterion of optimality. According to the analysis of the statistics, this article reveals a problem that has a direct impact on the safety of train service and shunting operations in the railway transport system - that is, the number of railcars that has been damaged on public and non-public approach lines. The dependence of the number of damaged freight cars on the speed of their collision the splitting-up of the railcars on the gravity-sorting yard of the network railway stations has been determined. Automation of the technological sorting process in a single production cycle will provide the basis for the introduction of production management systems and railway management systems as a whole, while improving the safety of the transportation process itself and the production of shunting operations. In the conditions of high-speed traffic development and the introduction of innovative technologies, these requirements need to be tightened, including the widespread use of automated processes for the splitting-up of freight trains on the gravity sorting yards. Improving the operation of the freight classification yards is a major factor in accelerating and cheapening the transportation process. In recent years much attention has been paid to the automation of station operation processes, the use of advanced labor methods, the introduction of new equipment, without which the development of the station cannot ensure the efficiency of the industry as a whole. In order to eliminate these shortcomings, it is proposed to automate the process of splitting-up freight trains on the gravity-sorting yard. For this purpose, it is necessary to equip the gravity sorting yards of railway stations with a comprehensive system of the sorting process control automation.

1. Introduction

The efficient operation of the railway transport system (RTS) is based on the available rolling stock resources, the estimated capacity of transport infrastructure, the availability of track resources of railway lines and sections. In order to ensure the smooth operation of the railway transport system, it is necessary to determine its reserves. They are often expressed in some redundancy - additional means (locomotives, railcars, railway track, rails, fuel, spare parts, etc.) or additional features (throughput capacity, etc.).
capacity, carrying capacity, estimated capacity of the railway transport system facilities) above the minimum necessary for optimal working condition and solving the goals and objectives in due course [1-3].

The goals are achieved by implementing the following basic tasks of the transportation process automation of the process of transportation:

- improving the quality of transportation regulation;
- increasing the ratio of readiness of fixed assets to the change of traffic volume;
- improving the ergonomics of the work of transportation process operators;
- ensuring the reliability of information on material components used in enterprises and in the structural units of the railway transport system, as well as related organizations;
- storing information about the process, emergency situations, and risk cases in production activities.

Automation of technological processes in the railway transport system is useful to consider as a set of methods and means designed to implement a system that makes it possible to manage the process itself without the direct involvement of the human factor, or giving a person the right to make the most responsible decisions. The basis for the automation of most technological railway processes is the redistribution of material, energy and information flows in accordance with the accepted criterion of optimality [4-7].

The solution to the problems of technological process automation in OAO "Russian Railways" (OAO "RZD") is mainly carried out with the help of the introduction of modern automation methods and the introduction of modern automation tools. Automation of the technological sorting processes in a single production cycle will provide the basis for the introduction of production management systems and railway management systems as a whole, while improving the level of safety of the transportation process itself and the production of shunting operations.

2. Analysis of the low safety factors of the rail transport process

Aging, poor conditions of fixed assets and errors in the maintenance of the transport system are in most cases the main causes of accidents and casualties. Why is that so? In the recent past, the railway transport system had been functioning clearly, smoothly, there was a regular addition of new equipment, equipment and highly skilled personnel, but over the years of market transformations, there was a set of unresolved issues. These include, first of all, the aging of vehicles, poor logistics and maintenance, the cost of training and retraining, the lack of a clear regulatory framework for human security, incompetence, negligence and irresponsibility of officials and transport system workers. The most difficult problem remains the notorious human factor - the failure to comply with prescribed instructions, regulatory documentation, and technologies. In one way or another, all these shortcomings of operation are connected with the presence of many different operators, owners of rolling stock, whose activity basis is to make a profit in the shortest possible time and with minimal costs.

Recently, OAO Russian Railways has noted a sufficiently low level of safety in the production of train service and shunting operations at the approach lines adjacent to the railway stations of public and non-public use. The main reason for this fact is the reluctance of the owners of these lines to adhere to the requirements of the Charter of Rail Transport and other regulations and documents, regulating the activities of the railway transport system [8]. This problem is quite serious and has a direct impact on the safety of train service and shunting operations in the railway transport system, as the statistics confirm. The number of freight railcars that were damaged on the approach lines reached 336 railcars in 2019. Repeated cases of unauthorized train traffic confirm the seriousness of the situation.

According to statistics, 4,105 violations of the requirements of the legislation of the Russian Federation have been identified on the largest railways for the two quarters of this year, of which 3,713 cases have been eliminated and 1,335 are related to the threat to traffic safety in the railway transport system and require the application of prohibitive measures [9]. In the total volume of freight
railcars with commercial faults, requiring an uncoupling to eliminate this type of defects, on average, 25% accounts for railcars loaded in violation of the requirements of technical conditions for the placement and fastening of cargo in railcars and containers (TU). 48.5% is the disorder of the established scheme of loading cargo on the railcar on the cargo travel route from the loading point to the destination point. 28.7% are other types of commercial faults. Specifically, the violation of loading and fastening conditions in the railcar are accounted for by more than 75% of all types of commercial faults [10]. Other reasons include:

- violation and breakage of the existing locking devices;
- leakage flow from tanks;
- spontaneous opening of gondola car hatches;
- broken loops of the railcar hatches;
- malfunctions of the floor of the railcar, etc.

Statistics show that a large percentage of the causes of violations are accounted for by the excess of the collision speed of the railcars during the splitting-up from the gravity sorting yards of railway stations. This is what, largely, leads to a violation of the Technical conditions for the placement and fastening of goods during transportation.

During the period under review, there has been an increase in the volume of damaged freight railcars at railway stations by an average of 8.5%. At the same time, up to 300 railcars out of the total volume on the station gravity sorting yards are damaged, which is on average 60% of the total number of sorted railcars. This volume includes:

- violation of the regime of splitting-up and braking of railcar cuts;
- non-observance of the requirements of the instructions for the maintenance of inclined railroad tracks and classification railroad tracks;
- malfunction of gravity sorting yard devices;
- human factor.

Taking into account the existing methodology [11-12], the number of freight railcars damaged on gravity sorting yards, on average per 1000 recycled ones, due to malfunctions of gravity sorting devices, is determined by the formula (1):

$$n_{\text{overtaking}} = 0.00143V_{\text{coll}}$$

where $V_{\text{coll}}$ is the average speed of collision of freight railcars during the splitting-up, m/s;

$$n_{\text{overtaking}} = 0.00143 \cdot 2.93 = 0.00417 \text{ railcars}.$$  

The volume of damaged freight railcars when splitting-up at the gravity sorting yard of a railway station with daily rehandling of 2485 railcars per year can be calculated using the formula (2):

$$N_{\text{damage}} = \frac{N \cdot 365}{1000} \cdot n_{\text{damage}}$$

where $N$ is the average daily number of freight railcars rehandled on the downhill section of the gravity sorting yard.

$$N_{\text{overtaking}} = \frac{2485 \cdot 365}{1000} \cdot 0.00417 = 3.782 \text{ railcars}.$$  

If the permissible speed of unification of cuts is exceeded, various degrees of damage to freight cars occur, requiring one or another type of repair. According to statistical data, the average cost of repairing one such railcar is about 10-15% of the market value of a new freight railcar [5]. Taking into account the average cost of a freight railcar, the approximate average statistical cost of repairing a traction vehicle unit will be 967 thousand rubles, while the total cost of repairing the total amount of damaged railcars that were damaged when being split-up from a sorting gravity yard will amount to 3.15 million rubles per year.
In order to determine the dependence of the number of damaged freight railcars ($N_{\text{damage}}$) on the speed of their collision ($V_{\text{coll}}$) during the splitting-up, we calculate the data according to Table 1 with a collision speed interval of 0.5 m/s and taking into account the data calculated according to formulas 1 and 2.

**Table 1. Number of damaged railcars during the splitting-up on the gravity-sorting yard.**

| Railcar collision speed, m/s | The number of damaged railcars per 1000 rehandled ones during the splitting-up of the cuts, raile. | The number of damaged railcars per year during the daily rehandling of 2.485 railcars, raile. |
|-----------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| 0.5                         | 0.00072                                                                         | 0.649                                                                           |
| 1                           | 0.00143                                                                         | 1.297                                                                           |
| 1.5                         | 0.00215                                                                         | 1.946                                                                           |
| 2                           | 0.00286                                                                         | 2.594                                                                           |
| 2.5                         | 0.00358                                                                         | 3.243                                                                           |
| 2.93                        | 0.00418                                                                         | 3.787                                                                           |
| 3                           | 0.00429                                                                         | 3.891                                                                           |
| 3.5                         | 0.00501                                                                         | 4.540                                                                           |
| 4                           | 0.00572                                                                         | 5.188                                                                           |
| 4.5                         | 0.00644                                                                         | 5.837                                                                           |
| 5                           | 0.00715                                                                         | 6.485                                                                           |
| 5.5                         | 0.00787                                                                         | 7.134                                                                           |
| 6                           | 0.00858                                                                         | 7.782                                                                           |
| 6.5                         | 0.00930                                                                         | 8.431                                                                           |
| 7                           | 0.01001                                                                         | 9.079                                                                           |
| 7.5                         | 0.01073                                                                         | 9.728                                                                           |
| 8                           | 0.01144                                                                         | 10.376                                                                          |
| 8.5                         | 0.01216                                                                         | 11.025                                                                          |
| 9                           | 0.01287                                                                         | 11.673                                                                          |
| 9.09                        | 0.01311                                                                         | 11.790                                                                          |
| 9.5                         | 0.01359                                                                         | 12.322                                                                          |
| 10                          | 0.01430                                                                         | 12.970                                                                          |

Based on the calculation data of table 1, we will build a histogram of the number of damaged railcars per year depending on the collision rate of the cuts (Figure 1).

The submitted dependency determines that the values of the collision rate of the cuts during the splitting-up on the railway station gravity-sorting yard and the number of damaged freight cars are linearly dependent. That is, the greater the collision rate of the cuts, the more railcars will be damaged in the period under review, and accordingly there will be more costs for the restoration and repair of rolling stock.

An analysis of the statistics [5] of failures shows that most of them are related to technical equipment. Technical equipment failures, as the main causes of operational security breaches, dominate in the main technical complexes of railway transport systems. Figure 2 presents the diagram of the distribution of failures related to the complexes that are part of the railway transport system in 2019.
Analysis of the results of the studies allows one to identify bottlenecks and to outline reserves in the use of sorting devices at railway stations, as well as to develop timely organizational and technical measures to phase out the limiting elements of their throughput and estimated capacities of the railway-transport system facilities.

To date, according to the data [8], the main reason for the lack of throughput and estimated capacity of the most freight classification yards of the OAO Russian Railways is the inconsistency of the level of development of the federal railway network, the legislative framework for the transportation process and the railcar fleets moving along the network. The situation is aggravated by the lack of an effective system of centralized transportation planning, which leads to errors in the management of railcar fleets.
3. Automation of the splitting-up processes of freight trains on the railway transport system
gravity sorting yards

An analysis of the statistics [5, 6] in recent years has shown that the reasons for the insufficient
reduction in the number of security violations are systemic and related to the current state of the
technical and technological base of the complexes. In these circumstances, the formation of
requirements for the railway equipment and processes developed, including reliability, safety and
overall quality indicators, plays a major role in reducing safety violations. In the conditions of high-
speed traffic development and the introduction of innovative technologies, these requirements need to
be tightened, as well as the widespread use of automated processes of control of their execution [13-
15].

In order to eliminate these shortcomings, it is proposed to automate the process of splitting-up
freight trains on the gravity sorting yards of the whole railway transport system [14-18]. For this
purpose, it is necessary to equip the railway station gravity sorting yards with a comprehensive system
of the sorting process control automation. For the efficient and uninterrupted operation of the railway
stations of the railway transport system, the implementation of the specified amount of work of the
sorting system should include the following subsystems of the gravity sorting yard complex:

- automatic switching with the introduction of the accumulation of railcars in the marshaling
  yard (AS-MA), which will allow one to ensure the automatic formation of the rolling-down
  routes of cuts in automatic and manual modes, automatic tracking of movement on the gravity
  sorting yard;
- subsystem of automated control of the speed of the rolling-down and control of target braking
  (ACS-CTB), which will provide automated control of the speed of the rolling-down of the cuts
  through interval-target braking on the gravity and yard braking positions.

To achieve the optimal level of automation of the studied processes of the sorting slide, as well as
to improve the safety level, it will be necessary to install radar indicators of the speed of rolling-down
of the cuts "RISVZ-M" on the braking positions of the descent part of the gravity sorting yard and the
first yard braking position. The AS-MA measuring section should be equipped with devices that
control the track occupancy along the entire tracks of the station's marshalling yard in order to form a cut describer that includes:

- four axle count devices of a CPRD-21-type to count railcars in the cuts;
- radiotechnical switching sensors to record the splitting-up of the train into cuts;
- weight meter to determine the load on each wheel set of the railcar;
- axles count sensors on the switches and hump braking positions – for precise control of the cut position in these sections and for organizing track sections on the axle count devices without track circuits.

The calculations and predicted values showed that the proposed solutions will lead to an increase in the labor productivity of workers of freight classification yards by an average of 11%, ensure an increase in the safety level of the splitting-up of freight trains on gravity sorting yards by 12%. They will also increase the safety of the car fleet and the volume of transported goods of the railway system by 7%, allow bringing the processing capacity of the gravity sorting yard of the railway station to the permissible design level, increasing the throughput and estimated capacity of the station as a whole by 22%.

The effectiveness of the implementation of the technology of automated control of technological processes for splitting-up trains on gravity sorting yards is achieved by reducing the hump interval, eliminating additional shunting operations, increasing the operating resources of floor equipment and shunting locomotives, reducing operating costs associated with repairing damaged railcars after collisions. It is also reached by eliminating cases of damage to goods, repair, with a decrease in the shunting work of pushing railcars back in the marshalling centre and rearrangement of "outsiders" (a railcar cut deviated from the splitting-up program), with a decrease in the time for rehandling railcars, a reduction in fuel consumption for shunting movements.

The main items of savings in operating costs when introducing automated systems in the new operating conditions of railway transport systems are:

- reduction in the volume of expenses associated with the presence of railcars at the railway station in the process of breaking-up;
- reduction in the number of required operating personnel and the associated reduction in the payroll;
- reduction of cases of damage to goods, rolling stock and related costs for repairs, detention of railcars and compensation for losses to the consumer of transport products;
- reduction in the required number of locomotives employed in shunting operations and, as a consequence, in locomotive crews and shunting masters.

When introducing an automation system, damage cases are foreseen in the amount of 15% of the base case due to failures of automation devices. The savings from reducing the time spent by railcars at the railway station in the process of breaking-up will amount to 6.109.06 thousand rubles. The annual savings on wages for maintenance personnel, taking into account mandatory contributions, will amount to 4018.62 thousand rubles. The amount of fuel saved for the year is 1722.8 thousand rubles. The total costs associated with the elimination of one commercial malfunction are 16397.76 rubles / railcar (Table 2).

The annual savings due to a reduction in the number of damaged railcars and damage to cargo during the introduction of the hump complex will amount to 2.2 million rubles. The total savings in operating costs per year will amount to 7.3 million rubles. The payback period of the proposal is 3.14 years. Annual economic effect is 722.213 thousand rubles.
Table 2. Summary table for calculating unproductive operating costs of the industry.

| Type of charges                                                                 | Amount of costs, rub/railcar |
|---------------------------------------------------------------------------------|-----------------------------|
| Expenses associated with train detention while waiting for uncoupling of railcars with malfunctions | 998                         |
| Costs of additional shunting operations for uncoupling and attaching railcars in violation of technical specifications; | 938.4                       |
| Costs for railcar-hours of detention time of railcars under elimination of violations | 370.8                       |
| Remuneration for the work of commercial inspection stations engaged in correcting violations | 91133.56                   |
| Operating costs of loading and unloading machines                               | 2457                        |
| The cost of materials for the restoration of the technical conditions for the placement and securing of cargo | 2500                        |
| The total costs associated with the elimination of a risk event                 | 16397.76                    |

4. Conclusion

However, in modern practice, interruptions in the regularity of operation pace of railway-freight classification yards of OAO RZD often lead to stops in train traffic volumes. This leads to a decrease in local speed and locomotive productivity, while the fleet of locomotives sharply increases and, coincidently, there is a shortage of them at the locomotive shift points. The transition to the operation of the locomotive fleet in long circulation journeys seriously increases the price of errors in adjusting the locomotive fleet. The use of technology for handling empty trains with a length of 100 conditional railcars leads to the emergence of oddness.

As a result, on the Trans-Siberian Railway there is traditionally an excess of circulation on the eastern borders and, vice versa, a lack of circulation on the western ones. All these factors mean that at present, and even more so in the near future, many directions and objects of the railway network will operate in load modes that are close to the limit, and sometimes in overload modes, which requires timely technical decisions of varying complexity. Improving the operation of the freight classification yards is a major factor in accelerating and cheapening the transportation process. In recent years, much attention has been paid to the automation of station operation processes, the use of advanced labor methods, the introduction of new equipment, without which the development of the station cannot ensure their operation efficiency.

Automation devices are the most important elements of the technical equipment of railway transport and make it possible to effectively solve the problems of the transportation process, contributing to an increase in the throughput capacity of railway facilities, ensuring the safety of train traffic and uninterrupted communication between all divisions of railway transport.

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