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Research paper

Principles of the Feedback Action in Local Elements of Rail Yard Interaction

Petro Yanovsky [1]*, Victoriia Yanovska [2], Sergiy Lytvynenko[3], Halyna Nesterenko[4], Larysa Lytvynenko[1]

[1] *National Aviation University,*
[2] *State University of Infrastructure and Technology,*
[3] *European University,*
[4] *Dnipropetrovsk National University of Railway Transport named after academician V. Lazaryan,*
**Corresponding author E-mail: sllitvinenko1982@gmail.com*

Abstract

Achievement of high-quality servicing level of cargo owners should be carried out under unconditionally effective use of rolling stock of railways and technical means. The real transport process should be implemented based on logistic cargo supply chains by types of connections for each shipment. The practice of railway operation shows that there is a significant shortage of train locomotives as a result of which the departure of ready trains at rail yard is often not carried out. In such cases, a feedback effect in local elements of interaction of these stations occurs. Due to delay in departure of trains, sending of already formed trains from rail yards is delayed; furthermore, because of the overflow of rail yard tracks, the sorting process on marshalling humps can be slowed down and delay of prepared trains for dismantling at arrival yard may occur. As a result of feedback action, downtimes of rail cars are increasing and movement of inventories is slowing down. In order to mitigate feedbacks effects in local elements of interaction, the principles of their operation, consideration of which will enable acceleration in passage of the rail car and cargo traffic through the railway network in practical activity, were formulated.

Keywords: *Interaction of local elements; Logistic Cargo Supply Chains; Rail Yards; Transportation Optimization.*

1. Introduction

At present railways have to solve a complex of scientific, technical, organizational, technological, economic and social tasks in a certain sequence and phasing in order to ensure high-quality servicing of cargo owners in unconditional efficient use of rolling stock, taking into account the real state of railway transport. Positive solution of the tasks will bail out the industry from a long-term crisis to the fullest extent and allow the railways to perform their functions more qualitatively, due to the implementation of logistic cargo supply chains (LCSC) by types of connections for each shipment.

In this regard, progressive reasonable standards of downtimes of railway cars should be laid in the basis of their functioning and steady reduction of the downtimes should be provided in all logistic links. The specified work is very diverse and it requires considerable financial support and long-term activities. Furthermore, it provides a stepwise solution of all tasks at each stage of the transportation process, namely: transportation planning, operational management, management of transport hubs, implementation of modern and maintenance of available technical means; efficient use of the rolling stock. Improvement of the named conditions of transportation will ensure carrying out of stated volumes of transportation on time and without obstacles, and it will also improve the quality of servicing of cargo owners.

2. Literature Review and Defining the Problem

Research of railway transport activity in market conditions was carried out by Ukrainian and foreign scientists. Particularly, the contribution of the following researchers should be noted: E. Alyoshinsky, G. Bogomazova, T. Butko, H. Kyrychenko, O. Lavrukhin, D. Lomotko, S. Panchenko, L. Parkhomenko, A. Prokhorchenko, O. Shander, O. Shapatina, G. Zambrybor, V. Zapara, Y. Zapara, as well as M. Verma and Y. Yue.

Interesting is the scientific work [1], where E. Alyoshinsky, D. Lomotko and G. Zambrybor identified the methodological aspect of the formation of logistic technologies in the processes of reforming the railways. The scientific work of H. Kyrychenko [2] is devoted to applying processes modelling to manage goods delivery. Logistic management of cargo and traffic freight car fleet was investigated in [3]. The scientific article of M. Verma [4] is devoted to the development of the tactical planning model for railroad transportation of dangerous goods. The paper of S. Panchenko, O. Lavrukhin and O. Shapatina [5] is devoted to the creating a qualimetric criterion for the generalized level of vehicle. The research paper of O. Lavrukhin, V. Zapara, Y. Zapara, O. Shapatina and G. Bogomazova [6] focuses on the study of the investigation into the bimodal transportation process by modelling rail module states.

Formation of an automated traffic capacity calculation system of rail networks for freight flows of mining and smelting enterprises were studied by S. Panchenko, T. Butko, A. Prokhorchenko and L. Parkhomenko in [7]. Scientists T. Butko and O. Shander consider formalization of the process of freight car fleet management of

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operator company in [8]. The scientific work of Y. Yue [9] is devoted to multi-route railroad blocking problem by improved model and ant colony algorithm in real world.

3. Purpose and Objectives of the Research

The purpose of the research is to develop the principles of the feedback action in the local elements of interaction (LEI) of the rail yard.

To achieve the aim, the following objectives were identified:

- to determine the value of the feedback under different initial conditions;
- to identify regularities and mathematical expectation of train delays at the departure yard because of the impossibility of their departure for a certain period of time.

4. Overview Key Findings

All participants of the transportation, their degree of participation and hence responsibility should be defined in the work plan of each LCSC. In such an integrated planning, all cargo owners (private companies), modes of transport, railway car owners, intermediaries, ports and border crossings should be considered as participants (equal partners) with a clear definition of their functions and level of responsibility. Optimization of transportations can be ensured only taking into account all the realities of their performance, which is possible if compatible analyses are carried out by each shift and daily, on the basis as a result of which the existing reserves are determined and operational measures to eliminate various difficulties in the work are taken. A detailed elaboration of the interaction between all participants of the LCSC should be reflected in the relevant operational (current) plan of transportation. But each LCSC has its own features and its participants in the process, including its own stations, and therefore they will have some differences in the servicing of specific transportation.

For the purpose of qualitative organization of transportation with the participation of different transport modes, it is necessary to develop and implement continuous schedule plans for the trans-shipment points. Such rational schedules are required for servicing access roads of industrial enterprises. In addition, as evidenced by the previous experience of the railways with the participation of different enterprises in various conditions, an essential prerequisite for timely resolution of interaction problems is the introduction of a clear and understandable stimulation system for all participants of the transportation process for obtaining success and expected results.

The influence of the main factors on the operation of rail yards was detailed enough studied in the 1960-1970s. It was proved that their work is useful to represent as a complex multiphase system, each phase of which is represented as one or more parallel operating technological lines (service channels). In determining the parameters and indicators close to the optimal values of each line the following aspects are taken into account: direct links that are caused by the influence of the previous lines to the next ones; feedback connections that are caused by the influence of the next lines on the previous ones.

Detailed researches have previously established the following: probabilistic regularities of fluctuations of the values of train traffic, the length of processing trains in rail yard (taking into account expectations) and the determination of optimal technical and technological parameters were investigated; complex interconnections between the elements that essentially influence the downtimes of railway cars were identified. For the comprehensive solution of the problem of justifying progressive norms of downtimes of railway cars in the elements of the station, analytical dependencies of performing technological operations and their expectations were obtained.

It has been established that time in waiting for servicing depends on the loading of the service facility ψ, the intensity of servicing t_{ser} and coefficients of variation the traffic arriving at the station v_1 and duration of servicing v_2:

$$t_w = f(\psi, t_{ser}, v_1, v_2). \quad (1)$$

Taking into account the length of performing technological operations and interoperational downtimes, the total time spent by railway cars at a technical station can be represented as follows:

$$t_{\max} = \sum_{i=1}^{n} t_{\max} + \sum_{i=1}^{n} t_w + t_{ac}, \quad (2)$$

where i = 1, 2, 3, … , n – number of servicing facilities at the station; $\sum_{i=1}^{n} t_{\max}$ – duration of technological operations; $\sum_{i=1}^{n} t_w$ – the sum of interoperational downtimes of railway cars; t_{ac} – downtime of a railway car under accumulation.

The duration of expectations is significantly influenced by the degree of loading servicing facilities, which is taken into account by its quantitative expression in calculations – load factor, coefficients of variation of the incoming traffic and duration of servicing. Each station, with constant technical equipment and technological support, has a marginal (optimal) value of the processing volume at which downtimes will be minimal.

The further increase in the volumes of processing causes a different growth in downtimes of railway cars. In addition to calculating the parameters of all elements of technical stations based on analytical dependencies, a method of modelling station processes on a computer may be recommended.

In the conditions of constant fluctuations of railway car traffic at the rail yards, particular attention was paid to the issues of determining the correct ratio of capacities of the elements of the rail yard complex and ensuring their stable interaction. Daily fluctuations in the time of arrival of trains are caused by unevenness in hours and days of loading, specialization of trains, conditions of stockpiling, passage of different categories of trains, etc. Terms of stockpiling, periodicity of loading and laying of trains in the schedule should be aimed at increasing the regularity of train movement.

The high loading level of sorting devices in combination with unevenness lead to the growing influence of both direct and reverse relationships. Unevenness significantly affects all aspects of the technology of the station operation and adds additional conditions to the ratio between the volume of processing and the capacity of the sorting device.

In conditions of unevenness, to maintain a stable operating mode the technical station, in addition to the minimum-required capacity of technical means $N_{\min}$, calculated in the absence of unevenness, should also have their additional capacity ΔN_{res}:

$$N_{un} = f(N_{\min}, \Delta N_{res}). \quad (3)$$

As revealed by L. Elnikova in [10], there are significant shortcomings in the functioning of the system of supporting trains with locomotives, furthermore, the share of the waiting time of locomotive trains is very significant in the total value of downtimes of railway cars at the rail yards and ranges from 10% to 60% depending on the category of railway cars.

Such lasting downtimes of railway cars due to the effect of feedbacks in the LEI negatively affect the state of the previous elements of the rail yards, which significantly worsens their functioning. Subject to catastrophic depreciation of a locomotive fleet, a deep study of the influence of feedbacks in the LEI on the passage

of railway car traffic through the rail yards becomes of particular relevance.

The most noticeable reverse effect is manifested at the high loading level of the elements of the rail yard complex and at significant disproportions between the necessary and available capacities of the elements of the rail yard complex and the violation of its interaction with adjacent sections. Any delay of ready trains at the departure yard causes its overflow (during the congested train formation), the delay of accumulated trains in the rail yard and, as a consequence, the termination of the disbandment of trains on the marshalling hump and over downtimes of arrived trains at the arrival yard.

This leads to a slowdown in the turnover of railway cars, which makes it difficult to use them. Fig. 1 shows the formation of delays (additional downtimes) of trains (its formation and transit trains) at the departure yard due to the impossibility of their departure for a certain period of time t_{nd}^{d}.

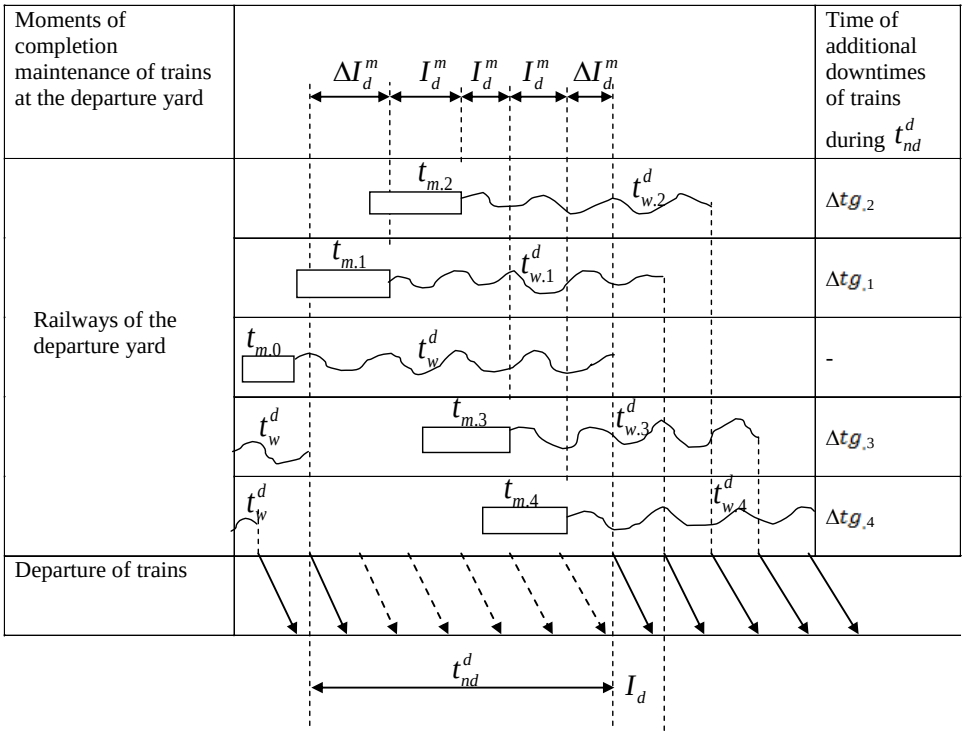


Fig. 1: A fragment of forming delays of trains at the departure yard due to the impossibility of their departure for a certain period of time

Additional expenses of train-hours at the departure yard due to impossibility of the departure for a certain period of time t_{nd}^{d} (absence of train locomotives, occupation of the adjacent section, etc.) consist of simple trains prepared for departure, but not sent at the beginning of the nondeparture period ΔC_1 and those prepared for departure on the railways of the departure yard during the nondeparture period ΔC_2:

$$C_{\text{nd}}^{\text{d}} = \Delta C_1 + \Delta C_2 \tag{4}$$

The value of additional train-hours of trains $n_{rem.i}$, nondeparture and detained till the onset of the departure period of trains is determined by the formula:

$$\Delta C_1 = n_{rem.i} \cdot t_{nd.i}^{d}, \tag{5}$$

where $n_{rem.i}$ – remainder of not sent trains at the departure yard at the beginning of the period $t_{nd.i}^{d}$; $t_{nd.i}^{d}$ – the duration of the period during which trains are not sent from the departure yard to the section.

The values $n_{rem.i}$ and $t_{nd.i}^{d}$ are random and can take any value from zero to the maximum possible value. Therefore, the mathematical expectation will be:

$$M\left[\Delta C_1\right] = M\left[n_{rem.i} \cdot t_{nd.i}^{d}\right] = M\left[n_{rem.i}\right] \cdot M\left[t_{nd.i}^{d}\right] \tag{6}$$

Mathematical expectation in the formula (6) according to [11; 12] with a sufficient degree of accuracy can be estimated by the average values of random variables. Then the average train-hours $\overline{\Delta C_1}$ can be determined by the dependency:

$$\overline{\Delta C_1} = \overline{n_{rem}} \cdot \overline{t_{nd}^{d}}, \tag{7}$$

where $\overline{n_{rem}}$ – the average remainder of trains not sent at the beginning of the period of nondeparture of trains to the section; $\overline{t_{nd}^{d}}$ – average duration of the period of nondeparture of trains to the section.

Taking into account that during interval $\overline{t_{nd}^{d}}$ the maintenance of *k*-trains will be completed, additional train-hours ΔC_2 (according to Fig. 1) over time t_{nd}^{d} are determined in a such way:

$$\Delta C_2 = \Delta t_{g.1} + \Delta t_{g.2} + \Delta t_{g.3} + ... + \Delta t_{g.k};$$

$$t_{g.1} = \sum_{i=1}^{k-1} I_{bi}^{m} + \Delta I_{bi}^{m};\ t_{g.2} = \sum_{i=2}^{k-1} I_{bi}^{m} + \Delta I_{bi}^{m};$$

$$t_{g.3} = \sum_{i=3}^{k-1} I_{bi}^{m} + \Delta I_{bi}^{m}; \ldots; \Delta t_{g.(k-1)} = I_{bi}^{m} + \Delta I_{bi}^{m}; \Delta t_{g.k} = \Delta I_{bi}^{m},$$

where $\Delta t_{g.1}, \Delta t_{g.2}, \Delta t_{g.3}, ..., \Delta t_{g.k}$ – downtime during time $t^d_{nd.i}$ respectively 1,2,3,.., *k*-train.

$$\Delta C_2 = \sum_{i=1}^{k-1} I^m_{bi} + \sum_{i=2}^{k-1} I^m_{bi} + \sum_{i=3}^{k-1} I^m_{bi} + \dots + I^m_{bi} + k \cdot \Delta I^m_{bi}$$

Values I^m_{bi} and k are random and do not depend on each other. Then the mathematical expectations of the value ΔC_2 are determined by the formula:

$$M[\Delta C_2] = M\left[\sum_{i=1}^{k-1} I^m_{bi}\right] + \left[\sum_{i=2}^{k-1} I^m_{bi}\right] + \left[\sum_{i=3}^{k-1} I^m_{bi}\right] + \dots + M\left[I^m_{bi}\right] + \left[Mk \cdot \Delta I^m_{bi}\right] \quad (8)$$

Random values I^m_{bi} and ΔI^m_{bi} [11; 12] with a sufficient degree of accuracy can be estimated by their average values:

$$M\left[I^m_{bi}\right] = \overline{I^m_{bi}} = \frac{t^{\text{в}}_{\text{н}}}{k}; M\left[\Delta I^m_{bi}\right] = \frac{1}{2} I^m_b$$

Then the formula (8) takes the following form:

$$M[\Delta C_2] = (k-1)\overline{I^m_b} + (k-2)\overline{I^m_b} + (k-3)\overline{I^m_b} + \dots + \overline{k \cdot \Delta I^m_b};$$

$$M[\Delta C_2] = \frac{1}{2} k(k-1) \cdot \overline{I^m_b} + \frac{1}{2} k \cdot \overline{I^m_b} = \frac{1}{2} k^2 \cdot \overline{I^m_b}$$

However, the number of trains *k* which have completed the maintenance during the period t^d_{nd} is random. Therefore, their average train-hours will be determined in the following way:

$$\overline{\Delta C_2} = \frac{1}{2} I^m_b \sum_{k=1}^{n} k^2 \cdot P_k \quad (9)$$

where P_k – the probability of that during time t^d_{nd} the number of *k* trains will be prepared for departure; $\sum_{k=1}^{n} k^2 \cdot P_k$ – second starting point of the number of trains prepared for departure during time t^d_{nd}.

According to [11; 12] the second starting point of a random variable can be determined from the dependency:

$$\sum_{k=1}^{n} k^2 \cdot P_k = D_{p.d} + \overline{k^2} \cdot v^2_{p.d} + \overline{k^2} = \overline{k^2}(1 + v^2_{p.d}), \quad (10)$$

where $D_{p.d}$ – dispersion of the number of trains prepared for departure in time t^d_{nd}; $v_{p.d}$ – coefficient of variation of the number of trains prepared for departure during time t^d_{nd}.

Substituting the value (10) into expression (9) the following is obtained:

$$\overline{\Delta C_2} = \frac{1}{2} I^m_b \overline{k^2} \cdot (1 + v^2_{p.d})$$

Using values of $\overline{I^m_b}$ we get that:

$$\overline{\Delta C_2} = \frac{1}{2} \cdot \frac{t^d_{nd}}{k} \cdot \overline{k^2} \cdot (1 + v^2_{p.d}) = 0{,}5\, t^d_{nd} \cdot \overline{k} \cdot (1 + v^2_{p.d}) \quad (11)$$

Total costs of train-hours during time t^d_{nd} according to (4) are:

$$\overline{\Delta C^d_{nd}} = \overline{n_{rem}} \cdot \overline{t^d_{nd}} + 0{,}5\, t^d_{nd} \overline{k} \cdot (1 + v^2_{p.d}) = \overline{t^d_{nd}}\left[\overline{n_{rem}} + 0{,}5 \cdot \overline{k}(1 + v^2_{p.d})\right] \quad (12)$$

Additional downtime of trains at the departure yard in train-hours per day is determined by the formula:

$$\overline{\Delta C^d_{nd.day}} = \overline{p} \cdot \overline{t^d_{nd}}\left[\overline{n_{rem}} + 0{,}5 \cdot \overline{k}(1 + v^2_{p.d})\right], \quad (13)$$

where $\overline{p}$ – the average number of violations in interaction of the departure yard with adjacent sections per day.

The average additional downtime of any train at the departure yard per day due to the violation of the conditions of interaction of the departure yard with the adjacent sections (in hours per train) are determined by the formula:

$$\Delta t^d_{nd} = \overline{p} \cdot \frac{\overline{t^d_{nd}}}{\overline{N_{day}}}\left[\overline{n_{rem}} + 0{,}5 \cdot \overline{k}(1 + v^2_{p.d})\right], \quad (14)$$

where $\overline{N_{day}}$ – the average number of trains sent to sections from the departure yard per day.

Based on formula (14), it can be concluded that there is the dependency of the amount of additional downtimes of trains at the departure yard due to the violation of the interaction of its operation with the schedule of train movement in the adjacent sections on the main factors. The amount of train delays is directly proportional to the number and duration of violations per day, as well as to the remainder of trains that are prepared for departure, but not sent to the section due to the violation of the interaction conditions. The quantity of trains with completing maintenance at the departure yard has different effect on the value of additional downtime Δt^d_{nd} in case of violation of the interaction condition.

The real operation of the rail yards shows that while optimizing their parameters, it is necessary to study the degree of coordination of local interaction elements of the station (entrance sections, railways of the departure yard, marshalling hump, tracks of the marshalling bay, stretches of formation, tracks of the departure yard and adjacent sections). The effectiveness of the functioning of any rail yard depends not only on the technical equipment and technology of the subsystem of dismantling (the arrival yard and marshalling hump), but also on the capacity of other yards (rail, departure). Therefore, the technological process of the station operation should be developed taking into account the interaction of all its elements with each other and with the schedule of train movements at the adjacent sections. Violation of the interaction conditions leads to complications in the operation of the rail yard as a whole. In order to detect and eliminate various inconsistencies between the elements of the yard, it is necessary to investigate the mutual relationships of the parameters of individual internal station processes, starting with the departure yard, taking into account the effect of feedback in the LEI at the rail yards.

5. Conclusions

The basis of the formulation of conceptual principles for reducing time spent by cargo railway cars in all parts of transport and logistics system is created by their interaction during the transport process. Practical ensuring of optimal processing of car traffic at stations is possible due to the timeliness and reasonableness of operational planning in the performance organization for next day and shift.

In conditions of rather long duration of the car turn there is a need to reach the high-quality level of current plans. In addition, it is necessary to develop schedule for binding a railway car with specific shipment for the successful planning of operation of each car, that is, to carry out binding of cars to each shipment by numbers.

This can be done on the basis of reliable and timely information on the actual condition of a specific car and on cargoes for each scheduled period.

Delays of trains in departure yards lead to overcrowding of tracks of the marshalling bay, due to an untimely composition of accumulated and formed trains in the departure yard. In turn, this leads to termination of dismantling of trains on the marshalling hump and as a result there is a delay of trains prepared for dismantling in the departure yard. This is how feedback actions are manifested in local elements of rail yard interaction.

Therefore, using the above-given methodology, an increase in downtimes of trains in marshalling bay and arrival yard is being studied. The final assessment of non-compliance with conditions of interaction between elements of station technology and costs of loading resources is carried out on the basis of the amount of additional downtimes in departure yard, determined by the formula (14), as well as additional downtimes in marshalling bay and departure yard determined analytically.

There are other factors other than those already mentioned that influence on downtimes of local trains for loading, unloading and transhipment stations. Therefore, in real conditions, when studying the process of processing local railway cars, it is necessary to consider many additional factors of internal nature. Of course, in the process of processing local railway cars the determinative place is occupied by interoperational downtimes, which reach significant values in modern conditions. To reduce them, it is urgently necessary to implement a complex of legal, organizational and technological measures.

In order to detect the existence of interconnection between station processes, movement systems and processing of railway cars, it is important to determine the degree of influence of external factors on downtimes of cars: planning of the organization and regulation of transportations. It is known that planning of transportation is the basis of organization of railway performance. The transportation plan should provide full and timely satisfaction of needs of all cargo owners with minimal transport costs. Monthly comprehensive transportation plans create favourable conditions for a rational organization of the transport process.

Simultaneously, routing the traffic from the loading places is important to reduce downtimes of cars along with qualitative planning of transportation.

At present cargo owners are uninterested in the organization of departure routes because the existing legal framework (Statute of Ukrainian railways) does not oblige them to be engaged in the formation of routes. Taking into account their economic efficiency for national economy as a whole, this issue should be corrected.

The external factors affecting downtimes of cars at technical stations should include the system of railway car traffic organization. It establishes rational ways of railway car traffic transit by directions of the network and the order for the inclusion of cars of various destinations in trains. Improving the efficiency of the system of railway car traffic organization is directly related to the optimization of the formation of trains at stations. Increase in the transit of car traffic and reduction of the number of its alterations at stations en route is an important factor for acceleration of freight traffic.

Special influence on the increase of performance of cars intensity and the reduction of their downtimes at stations is made by the performance management system, which includes operative decision-making with current measures that ensure the efficient use of cars. Also, the system of continuous control of availability and movement of loaded and empty freight cars and analysis of the placement of cars, on the quality of which the effect of regulatory measures greatly depend, is important. In order to improve the use of cars, it is necessary to ensure high quality in analysis (current and periodic) of loading and unloading plan fulfilment, adjusting tasks, implementation of the rules for transfer of cars and movement of trains, execution of schedule and train formation plan, use of cars and locomotives, their placement.

Among the important factors that have a negative effect on the movement rate of cars is also the violation of the supply of cars, containers and locomotives to railways, insufficient strengthening of the repair base of rolling stock, which is now observed in rail transport.

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