Set of organizational, technical and reconstructive measures aimed at improvement of section performance indicators based on the study of systemic relations and regularities of functioning of railway transport system

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Abstract. The organization of operational work should correspond to the corporate interests of the railway transport system: increasing profitability, minimizing transportation costs, increasing the interest of structural units in improving financial and economic results, focusing on high-quality transport customer service. Measures to reduce costs do not give the expected effect, resulting in the decrease in the reliability of technical means and transportation quality, may entail additional costs for the restoration of technical means and lower profitability. A constant increase in cargo turnover necessitates an increase in the throughput capacity of railway lines and sections. One of the main transport enterprises in Eastern Siberia is the East Siberian Railway. At the Bolshoi Lug - Slyudyanka railway section, the maximum ascent and descent magnitude is 18 ‰, the minimum horizontal curve radii are less than 300 meters. In this regard, the traffic operation on the mountain pass section is organized by way of pushing trains. For the estimated year 2023, the target indicators of the comprehensive project of the polygon require the throughput capacity of the section under consideration to increase to 137 pairs of trains per day. The article analyzes the factors affecting the magnitude of the section performance indicators and identifies the “bottlenecks”. It proposes the complex of organizational, technical and reconstruction activities. The value of one-time and current costs is determined. The economic effect of changing the performance indicators of structural units due to an increase in the volume of work, as well as the payback period of each event, are calculated.

1. Introduction
The organization of operational work should correspond to the corporate interests of the railway transport system: increasing transportation profitability, minimizing cargo transportation expenses, increasing the interest of all structural units in improving financial and economic results of the work, focusing on high-quality transport customer service [1-5]. The constant increase in cargo turnover necessitates the increase of the throughput of railway lines and sections in the railway transport system [6-7]. The increase, defined as the difference between the required and available throughput capacity, can be achieved by implementing organizational, technical and reconstruction measures. In order to successfully develop railway infrastructure, a set of activities is necessary [8-12]. Firstly, to eliminate the “bottlenecks” of the railway transport system by building the second, as well as third and fourth tracks in the main directions of train traffic volumes, which will increase the throughput and processing capacity of the infrastructure. Secondly, to expand the railway network through the construction of
strategic, socially significant, high-speed, cargo-forming and technological sites in the railway transport system [13, 14]. Thirdly, to regularly update obsolete infrastructure elements, reconstructing worn-out railway lines, modernizing buildings and facilities, improving the used rolling stock, increasing comfort and speed of transportation in order to ensure their competitiveness in comparison with other modes of transport, etc., and methods of randomly forming solutions [15-18].

2. Results of a study of systemic relationships and patterns of functioning of the railway transport system

Effective operational activities of the railway transport system integrates and implements the activities of elements and subsystems of railway transport, the precise organization of which ensures full satisfaction of the country's needs for transportation at the lowest cost, increases the competitiveness of railway transport, economic stability of the industry, and implements a customer focus program for the industry. The implementation of these areas is the most important criterion of the industry operation in a competitive environment with other modes of transport [19-26].

One of the main transport enterprises in Eastern Siberia, which plays a significant role in the development of regions in accordance with its geographical position, is the East Siberian Railway. The railway consists of four road station operation hubs, divided into railway sections, with their own characteristic technical and operational features.

The length of the Bolshoi Lug - Slyudyanka railway section is 83 kilometers. In the freight-hauling direction, the route profile is characterized by an excessive gradient from the Bolshoi Lug intermediate station to the Podkamennaya intermediate station. With that, the difference in elevations is 500 meters, followed by an equally long descent to Lake Baikal. The maximum ascent and descent magnitude is 18%, the minimum horizontal curve radii are less than 300 meters. In this regard, the traffic operation on the mountain pass section is organized by way of pushing trains. In the section Bolshoi Lug - I, trains are driven by pusher locomotives. Uncoupling pusher locomotives from down trains at Slyudyanka - I station, attaching to up trains (the necessity for attaching, depending on the head locomotive series and train weight) at Slyudyanka - II station. Automatic blocking with tonal rail circuits is used as a system of interval regulation of train traffic on the section. The section includes seven stations with a certain class depending on the volume and complexity of the works: Bolshoi Lug, Podkamennaya, Glubokaya, Andrianovskaya, Angasolka, Slyudyanka-I, Slyudyanka-II.

![Figure 1. Profile of the mountain pass section from Bolshoi Lug station to Slyudyanka-II station.](image-url)
One of the main problems in organizing the movement of trains at the mountain pass section under consideration is related to the need to push freight trains within the boundaries of the Bolshoi Lug - Slyudyanka-I stations. The pushing is required for the main part of down freight trains directly from the Bolshoi Lug intermediate station, as well as some up freight trains from the local station Slyudyanka-I.

The current regulatory schedule for the Bolshoi Lug - Slyudyanka-I section provides for the handling of up to 96 pairs of freight trains. The requirements for pusher locomotives make 35 units. Some pusher locomotives are delivered for up freight trains. The remaining train locomotives are returned to the station Bolshoi Lug station as a "reserve". According to established requirements, pusher locomotives are returned fastened together by three units [27-29].

The problems in organizing the pushing of trains are caused by a number of circumstances, the main of which is the insufficient development of the railway infrastructure of the Bolshoi Lug intermediate station. The existing track arrangement of this station provides for the possibility of using only one dead end track for supplying pusher locomotives for down freight trains. The minimum required time for delivery and coupling of a pusher locomotive to a freight train is 16 minutes from the “end” of the train, 24 minutes from the “head” of the train. According to the data presented, the feature of the existing amount of freight train traffic for the Bolshoi Lug station is excess downtime of freight trains and, on some days, “congestion” in the operation of the running line adjoining from the west. These station work conditions are further complicated by operations for uncoupling pusher locomotives from up freight trains. During the day, the pusher locomotives are uncoupled from 10-15 up trains. The time required for uncoupling a pusher locomotive, according to the existing technology of operation, is: 10 minutes from the “end” and 14 minutes from the “head”.

In addition the “bottleneck” in the work of the considered section is the down yard neck of the Slyudyanka-I station and the Slyudyanka-I - Slyudyanka-II running line. The existing technology for the operation of the section stipulates that a large volume of various kinds of operations takes place at the Slyudyanka-I precinct station: reception and departure of up-and-down passenger and freight trains, uncoupling pushing locomotives from even freight trains, attaching pushing locomotives to up freight trains, forming a fastenings out of pusher locomotives and their departure to the Bolshoi Lug station, departure and reception of motor vehicles during the track possessions, etc. [1, 5, 30].

The main operations are performed at the station due to the need of train or shunting movements in its down yard neck. Due to the existing down yard neck construction, many of the routes envisaged by technological operations are mutually antagonistic. This imposes significant restrictions not only on the operation of the station itself, but also on the possibility of handling trains along the Slyudyanka-I - Slyudyanka-II running line adjacent to its down yard neck.

Analyzing the existing technology of the site and its constituent stations, the designed and constructed schedules for the passage of trains, their performance should also be noted the presence of “reverse removal” of freight trains by suburban ones (where removal means the inability to handle the lines of freight trains along the running line due to the passage of passenger trains). In relation to the section under consideration, the need to remove the paths of the freight train schedule due to the suburban trains is implied due to the fact that the station-to-station travel time of the latter ones is longer than that for freight trains. The fact that commuter trains need more time to overcome the running lines is due to the presence of stops along the route with almost identical restrictions on the maximum speeds of freight and suburban trains.

It is important to note that the issue of lack of throughput capacity is complex, while its causes and solutions must be sought not only within the boundaries of the Bolshoi Lug - Slyudyanka-II section, but also beyond them. Due to the high traffic density and lack of reserves for train handling, any malfunctions that occurred in one place automatically lead to the emergence and growth of unproductive downtime of trains throughout the entire mainline.

For the estimated year 2023, the target indicators of the comprehensive project of the Eastern polygon provide for the need to increase the throughput of the section under consideration to 137 pairs of trains per day, including 107 pairs of freight trains per day and 19 fastenings of down pusher locomotives. The track turnover of the section is going to increase to 116.7 million / ton per year. With the specified
parameters of the prospective amount of transportation, the available throughput capacity shortfall of the Irkutsk - Slyudyanka section should be 14 pairs of trains by 2023. In freight traffic, subject to the use of all reserved paths provided for in the regulatory schedule, the throughput capacity shortfall will be 11 pairs of trains of various categories.

3. Reconstructive measures aimed at improving the performance of the section, through the construction of additional reception and departure tracks of the station

The measures taken in recent years to reconstruct the railway transport, especially to introduce new types and methods of traction, present new requirements for the operation of these structural units. When solving issues of technical equipment and improving the technology of work, it is necessary to ensure such a relationship between the volume of work performed and the existing fixed assets of the station and its technical means, that the total operating costs are minimal. The optimal solution to this problem can only be achieved by taking into account the real operating conditions of the railway station, i.e. during the non-uniform loading of station devices.

The analysis of the technology of operation of the Bolshoi Lug intermediate station and analysis of the developed daily schedule of work and its indicators made it possible to determine the need for the construction of additional receiving and departure tracks at the station – to restore for operation receiving and departure tracks No. 4 and 15 of the intermediate Bolshoi Lug station.

Table 1. Performance indicators of the intermediate station Bolshoi Lug taking into account the reconstruction activities.

| Indicator                        | Unit of measurement | Indicator value with existing work technology | Indicator value taking into account the reconstruction activities |
|----------------------------------|---------------------|----------------------------------------------|---------------------------------------------------------------|
| Train-hours of detention         | t/h                 | 1212.8                                       | 1136                                                          |
| Locomotive-hours of detention    | l/h                 | 3154.8                                       | 3936                                                          |
| The number of handled down trains | trains              | 98                                            | 119                                                           |
| The number of handled up trains  | trains              | 95                                            | 106                                                           |
| Number of pusher locomotives    | locomotive          | 28                                            | 30                                                            |

The implementation of the proposed reconstruction activities will improve the technical work of the station by reducing the detention time of trains, and will increase the throughput and operating capacity. Train-hours of detention at the Bolshoi Lug station will be reduced by 1.13 hours, and the throughput capacity will increase by 21 down trains and by 11 up trains.

Carrying out this reconstruction at the Bolshoi Lug station will require a one-time investment of 114,693.83 thousand rubles. In connection with the restoration of additional receiving and departure tracks for the station, the annual operating costs for the maintenance of new fixed assets will change by 19004.27 thousand rubles per year. The introduction of this event gives an economic effect in the amount of 262,764.64 thousand rubles per year. The payback period is 1 year.
4. Set of measures to increase the throughput and operating capabilities of railway stations and adjacent running lines

According to the existing work technology, the pusher locomotives are returned from the Slyudyanka station to the Bolshoi Lug station fastened together by three units each. The authors examined the work of the station Slyudyanka-II and Slyudyanka-I during the commissioning of the third main track between the stations and a change in the operation technology of pushing locomotives. This, in turn, will increase the throughput and operating capacity of the railway station itself and increase the performance of adjacent running lines. The construction of the third main track between the stations will allow accumulating and returning locomotives fastened together by five units each.

Table 2. Indicators of the daily schedule of work of the station Slyudyanka-II with the existing and modified technology of work.

| Indicator | Unit of measurement | Indicator value with existing work technology | according to the proposed technology of the section Slyudyanka-II and Slyudyanka-I |
|-----------|---------------------|-----------------------------------------------|----------------------------------------------------------------------------------|
| Transit car detention without yard operation | hr | $t_{tr}^{w/y} = 0.89$ | $t_{tr}^{w/y} = 0.58$ |
| Medium detention of the local car | hr | $t_l = 13.2$ | $t_l = 12.4$ |
| The ratio of dual operations | - | $K_{dua} = 1.4$ | $K_{dua} = 1.4$ |
| Average detention of the local car under one freight operation | hr | $t_{fr} = 9.43$ | $t_{fr} = 8.72$ |
| The working fleet of cars | cars | $n_w = 132$ | $n_w = 132$ |
| Station car turnover | Cars | $n_{tu} = 5746$ | $n_{tu} = 5993$ |
| The ratio of using check station crews | - | $\varphi_1 = 0.39$ | $\varphi_1 = 0.57$ |
| | | $\varphi_2 = 0.48$ | $\varphi_2 = 0.43$ |

Thus, it is obvious that a set of measures to increase the effective values of the throughput and operating capabilities of the Slyudyanka-II station makes it possible to reduce the car detention time and improve overall performance. The transit car detention without yard operation was reduced by 0.29 hours, and the transit car detention with yard operation was reduced by 0.2 hours. The value of car turnover will improve by 3834 cars due to the reduction in the car detention time. This, in turn, will lead to an increase in the volume of departed cars per day and, as a result, an increase in throughput and processing capacities.

A set of measures to increase the effective values of the throughput and operating capabilities of the Slyudyanka-II station makes it possible to reduce the car detention time and improve overall performance. The transit car detention without yard operation was reduced by 0.31 hours, the average detention of the local car was reduced by 0.8 hours, and the average detention of a local car under one freight operation was reduced by 0.72 hours. The value of car turnover will improve by 247 cars due to the reduction in the car detention time. This, in turn, will lead to an increase in the volume of departed cars per day and, as a result, an increase in throughput and processing capacities.

A set of measures on the Slyudyanka-II and Slyudyanka-I sections will require capital investments in the amount of 883740.249 thousand rubles. Due to the reconstruction, the value of the annual operating costs will change. The increase will amount to 286301.499 thousand rubles per year.
The economic effect, caused by the increase in the throughput capacity of the stations and the improvement of the section performance, will amount to 348,908.391 thousand rubles. The payback period of the project is 15 years.

### Table 3. Indicators of the daily schedule of work of the station Slyudyanka-II with the existing and modified technology of work.

| Indicator                                      | Unit of measurement | with existing work technology | according to the proposed technology of the section Slyudyanka-II and Slyudyanka-I |
|------------------------------------------------|---------------------|-------------------------------|---------------------------------------------------------------------------------|
| Transit car detention without yard operation   | hr                  | $t_{tr}^{w/y} = 0.98$        | $t_{tr}^{w/y} = 0.69$                                                         |
| Transit car detention without yard operation   | hr                  | $t_{tr}^{w/y} = 1.9$         | $t_{tr}^{w/y} = 1.7$                                                          |
| The working fleet of cars                      | cars                | $n_w = 168$                  | $n_w = 226$                                                                     |
| Station car turnover                           | cars                | $n_{tu} = 8120$              | $n_{tu} = 11954$                                                                |
| The ratio of using check station crews         |                     | $\phi_1 = 0.57$             | $\phi_1 = 0.64$                                                                 |
|                                                |                     | $\phi_1 = 0.54$             | $\phi_1 = 0.6$                                                                 |

5. Evaluation of measures to increase the voltage level at the limiting running lines of the section

The main purpose of all calculations of the energy supply system is to establish such parameters of this system that would ensure reliable and cost-effective working conditions of the electric railway. The considered section is serviced by five traction substations. The results of traction calculations for the up-and-down train traffic in the section under consideration at different weight standards showed that, according to the existing scheme with a given inter-train interval of 8 minutes, in the section Bolshoy Lug – Slyudyanka-I there are four limiting running lines: Bolshoi Lug – Podkamennaya, Glubokaya – Andrianovskaya, Andrianovskaya – Angasolka, Angasolka – Slyudyanka-II. The inter-train interval was 12, 14, 16, 13 minutes, respectively. Considering the obtained calculation results, we can conclude that to ensure the passage of trains of a given amount of traffic with a given inter-train interval of 8 minutes, measures are required to increase the voltage level at the limiting running lines.

The event will require capital investments in the amount of 65,660,200 thousand rubles. The increase in annual costs will amount to 107,315.738 thousand rubles. The payback period of this proposal is 4 years.

The results of the study of systemic relationships and work patterns of the Bolshoi Lug – Slyudyanka-I section based on a set of organizational, technical and reconstruction measures are listed in Table 4.
Table 4. Performance indicators of the section Bolshoi Lug - Slyudyanka-1.

| A section performance indicator | Units of measurement | Section performance indicators during the construction of an additional main track and a change in the operation technology of pusher locomotives | while strengthening the power supply system |
|--------------------------------|----------------------|--------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|
|                                 |                      | while strengthening the track arrangement of the Bolshoi Lug station and a change in the operation technology of pusher locomotives |                                               |
| Train-hours                    | t-hour train         | 514.55 677.88 647.91 725.5                                                                                                    |                                               |
| The number of trains of even direction |                      | 79 100 105 114                                                                                                                  |                                               |
| - freight                       |                      | 10 10 10 10                                                                                                                     |                                               |
| - passenger                     |                      | 8 8 8 8                                                                                                                          |                                               |
| - suburban                      |                      | 1 1 1 1                                                                                                                          |                                               |
| - goods collecting              |                      | 79 10 105 114                                                                                                                   |                                               |
| Number of trains of odd direction |                      | 91 95 102 113                                                                                                                   |                                               |
| - freight                       |                      | 9 9 9 9                                                                                                                          |                                               |
| - passenger                     |                      | 8 8 8 8                                                                                                                          |                                               |
| - suburban                      |                      | 1 1 1 1                                                                                                                          |                                               |
| - goods collecting              |                      | 91 9 102 113                                                                                                                   |                                               |
| The number of pusher locomotives | loc.                | 28 30 21 37                                                                                                                     |                                               |
| Civil speed                     | km/h                 | 45.8 46 47.6 39.3                                                                                                                |                                               |
| Service speed                   | km/h                 | 34.8 33.7 37.1 36.7                                                                                                             |                                               |
| Service speed ratio             | -                    | 0.76 0.73 0.78 0.93                                                                                                             |                                               |
| Weight of train                 | t                    | 4163 4163 4163 4163                                                                                                              |                                               |
| The average train formation     | car                  | 65 65 65 65                                                                                                                     |                                               |
| Locomotive journey              | hr                   | 6.52 7.7 6.52 6.88                                                                                                              |                                               |
| The required number of train locomotives | loc. | 23 33 29 31 |                                               |
| The average daily mileage of a locomotive | km      | 728 681 767 718                                                                                                                |                                               |
| Locomotive performance          | ton-km gross         | 2497 2835 3193 2990                                                                                                             |                                               |

6. Conclusion
A significant drawback in the operation of the railway transport system, compared to other modes of transport while implementing the customer focus policy, is a rather high level of tariffs for both freight and passenger transportation. In connection with these factors, much attention has always been paid and is being paid to the search for areas of activity to attract additional traffic volumes. A special emphasis in this matter has been placed to directions for reducing tariff levels, but in most cases a solution is possible only in case of the reduction of the operational costs of the railway transport system associated
with transportation. The accumulated experience in this field shows that measures to reduce the level of expenses in most cases do not give the expected result and more often lead to a decrease in the reliability of technical means and quality of transportation. In the future, this may entail not only additional costs for restoration of technical means, but also a decrease in profitability due to the loss of traffic. Thus, the main areas of activity in the fight for the client between carriers are: the use of modern digital technologies, customer focus, increasing the throughput and operating capabilities of the infrastructure of the railway transport system that can determine the needs of the client, reduce its transportation costs, simplify access to the railway service, thereby increasing the attractiveness of the industry.

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