Justification of measures aimed at increasing the capacity of a section of a railway line, taking into account its required electrical capacities

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Abstract. The annual increase in cargo turnover to the Far Eastern seaports contributes to the optimization of the railway infrastructure in order to increase the level of throughput and processing capacity of the Baikal-Amur Mainline and Trans-Siberian Railway facilities. JSC Russian Railways pays special attention to these issues. Organization and promotion of car traffic through the formation of freight trains using the connection technology, “virtual coupling”, heavy and dual trains that move on an ongoing basis is one of the innovative methods for increasing the carrying capacity for highly loaded sections and directions at a level of utilization of their throughput of 0.8 or more. Under these conditions, the organization of efficient power supply of railway sections and facilities is the main factor influencing the value of the throughput capacity of transport infrastructure facilities. The article presents a technical justification for the measure aimed at increasing the throughput and processing capacity of a section of a railway line, taking into account the stability check of the devices of the traction power supply system. The predicted parameters of the operation of the traction power supply system of the railway line section are given with a promising train schedule.

1. Introduction
The scale of the efforts invested in the operation of a complex system of railway transport has made it possible to take a leading position among other types and methods of cargo delivery. Thus, as of 2021, the freight turnover of railway transport amounted to 2,544.4 billion ton-km, which is 9.4 times more than the freight turnover of road transport, a direct competitor of the railway industry.
The leading position of railway transport in the market of transport services has been achieved by a number of individual features and advantages. These include the most important component in success from the point of view of consumers, the low cost in relation to the implementation of transportation of products in comparison with other modes of transport. The extensively developed infrastructure and the railway network as a whole, along with the logistics component, makes it possible to serve customers interested in long-distance transportation on favorable terms, and branded transport services allow us to provide various services aimed at meeting the needs of all customers. Other equally important advantages are the possibility of transporting heavy and oversized cargo, to a large extent safety and security, as well as minimal dependence on climatic and weather conditions. It is worth noting the fact of transportation of bulk cargoes of regional and national significance - these cargoes are transported only by rail [1, 2].

However, the infrastructure of railway transport is not characterized by omnidirectional development in all areas. The expansion of the railway network as a material basis in the implementation of the transportation process can be described as the result of significant phased investments, accompanied by hard hard work aimed at optimizing the operation of transport infrastructure facilities that have a direct impact on throughput and processing capacity.

2. Organization of efficient power supply of a section of railways, as a factor influencing the value of the throughput capacity of transport infrastructure facilities

The complexity of the infrastructure as a system is described by various interrelated elements: hauls, entrance and exit necks of railway stations, receiving and departure parks, power supply and power supply devices, locomotive and wagon facilities. Therefore, the need to identify and evaluate the limiting objects of railway lines is quite in demand: they have been discussed and are constantly being discussed in the scientific and industrial environment [2-4].

The throughput significantly depends on such factors as: norms of mass and length of trains, running speed, inter-train interval, type of schedule and others. Taking into account these factors has a significant impact on improving the quality of transportation, which also depends on the methods of organizing mixed train traffic, performing work on the current maintenance and repair of the track.

The possibility of fulfilling the planned indicators is affected by the capacity - an important characteristic of the railway section, showing its transportation capabilities. Without taking it into account, it is impossible to accurately plan freight transportation over the network. To determine the throughput, analytical methods based on models are used, which include a set of various parameters, such as: the interval of train traffic, the average inter-packet interval, the coefficient that takes into account the reliability of the operation of technical means, and others [3-5].

The factors affecting the value of throughput can be divided into three main groups, each of which includes its own set of its constituent elements, Figure 1.

To determine the predicted values of a possible decrease in the level of throughput and factors of influence, regression models were built on the example of the operation of section 1-2 of the East Siberian Railway, based on the initial data on failures for the period 2010–2020 [6–8].

Table 1. Summary table of station throughput values

| Directorate of Energy Supply and Energy Supply of the Eastern Railway | 2022   | 10,01 | 12,02 | 13,21 |
|---------------------------------------------------------------------|--------|-------|-------|-------|
|                                                                     | 2023   | 8,23  | 9,99  | 14,88 |
|                                                                     | 2024   | 7,01  | 10,87 | 18,33 |

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\[ y = 1.28 + 0.9x_20 + 1.15x_21 + 0.92x_22, \]

\[ (22.04) \quad (17.59) \quad (4.47) \]

\[ R = 0.993; \quad F = 212.35; \quad DW = 1.71; \quad E = 1.26 \%. \]
**Figure 1.** Factors affecting the capacity of transport infrastructure facilities.

As can be seen from Figure 1, the main constituent criterion for the passage of trains is the load capacity of traction power supply devices, which is present in each group of impact facts.

The constructed mathematical model of the regression type, which interconnects the particular characteristics of the influence of the organization of the work of traction power supply devices on the level of throughput and processing capacities of section 1-2 of the Higher Railway, as well as the calculations of the forecast of risk cases carried out on the basis of the software package, fully confirm the assumption that this level is related to first of all, with the main component criterion for passing trains - the load capacity of traction power supply devices [6-8].
3. Optimization of the organization of work of pushing locomotives as a way to increase the throughput of the section

The existing train schedule on the mountain pass section 1-2 provides for the passage of up to 99 pairs of freight trains. The division of traffic directions according to the condition of the need for pushing indicates the key factors for increasing the throughput of the section. For the odd direction, which does not need assistance for movement by pushing locomotives, the bottleneck in the technology of the section was the C-II station, where there were large downtimes on the receiving and departure tracks due to changes in train locomotive crews in conditions of uneven movement of this direction. This, in turn, leads to a large load on the station and the impossibility of receiving additional freight trains of odd directions. In view of the uneven movement of odd trains, a promising direction of the issue under consideration in increasing the number of missed trains in this direction will be to ensure a more uniform departure of odd trains from the C-I station, taking into account the passenger and suburban train position on the section, which will ensure a more uniform loading of the station by shifts of locomotive crews, and, as a result, a more uniform loading of the station's receiving and departing tracks. The organization of work with even-numbered trains was characterized by the constant use of pushing locomotives, the number of which was limited.

The regulated times of the day at which shifts of locomotive crews of pushing locomotives should take place, as well as the mandatory fulfillment of the requirement to comply with the duration of a 12-hour continuous work shift, were difficult tasks, the implementation of which involved a comprehensive consideration of the technology of the principles of circulation of pushing locomotives around the section and the influence of the load capacity of traction power supply devices.

The direction in increasing the number of missed trains will imply a change in the technology of circulation of pushing locomotives around the section, taking into account these factors, which will be provided jointly to achieve a better result.

When fulfilling the requirement for the timely approach of even-numbered freight trains to the pushing locomotives trailer station and reducing the inter-train interval to five minutes, in order to ensure the maximum amount of missed trains of an even direction when organizing traffic along the section, it is necessary to optimize the organization of the work of pushing locomotives. Based on the 12-hour shift of the locomotive crew, we determine the largest number of pushes that one pushing locomotive can produce. The largest number of pushes produced by one pushing locomotive per working shift of the locomotive crew, $N_{max}$, push/sm, is calculated by formula (1)

$$N_{max} = \frac{12-t_{\text{e,b}}}{t_{\text{e,h}}+t_{\text{o,h}}+t_{\text{p,h}}+t_{f}},$$

where $t_{\text{e,h}}$ – even travel time on the site, h.;
$t_{\text{o,h}}$ – odd travel time on the site, h.

$$N_{max} = \frac{12-0.78}{1.95+1.87+0.22} = 2.78 \text{ push/sm.}$$

Thus, the maximum number of pushes per shift will be no more than two. In this regard, it is necessary to provide 4 shocks per day by a pusher locomotive. For the minimum removal of odd freight trains by odd rafts, it is necessary to ensure during the day the minimum number of returning rafts at the trailer station of pushing locomotives from C-I. To this end, it is necessary to accept the maximum allowable number of pusher locomotives in a raft - according to the instructions, their number should not exceed three units.

When organizing the circulation of pushing locomotives in the section, it is necessary to be guided by the principle of ensuring the greatest downtime at the C-I station. This principle will reduce the loading of the pusher locomotive trailer station, which is characterized by a limited number of receiving
and departing tracks and the inability to “take over” the downtime of pusher locomotives in the face of increased throughput.

The organization of shift changes for each three locomotive crews returning in a raft must be carried out at approximately the same time - no more than 5 minutes one after the other. If this interval is exceeded, a delay in the departure of three even-numbered freight trains from the trailer station of the pushing locomotives will be implied, equivalent to a delay due to a passenger or commuter train. After each three successive shift changes have been completed, it is necessary to organize the pushing of even-numbered freight trains as soon as possible in order to minimize downtime at the trailer station of pushing locomotives.

The time most suitable for the successive change of all locomotive crews must be chosen at the end of the day due to the lack of passenger and commuter trains. This event will make it possible to systematize the departure of packages consisting of three even-numbered freight trains, separated from each other by an inter-train interval of five minutes, and, further, to return the rafts evenly, without causing their shortage at the trailer station of pushing locomotives due to the unevenness of their arrival.

Further organization of the second nudge will adopt a repetitive algorithm. Thus, the first two pushes, carried out according to the principle of the most rhythmic work of locomotive crews, will provide a margin in the form of the observed final long idle time of locomotives at station C-I, which ensures the timely arrival of rafts at the trailer station of pushing locomotives for further shift change without disturbing the continuous duration of work locomotive crews.

4. Effect of intertrain interval reduction on the required electric power of transport infrastructure facilities of a railway line section

Based on the results of traction calculations, using the LVI table of the CORTES software package, we plot the dependence of the change in the total current on the train coordinate for all types of trains in the even and odd direction [9-14]. The resulting graphs are shown in Figures 2 and 3.

![Figure 2](image_url)

**Figure 2.** Graphs of dependences of the total current on the coordinates of the movement of a freight train of an odd direction of various masses in section 1-2.
Figure 3. Graphs of dependences of the total current on the coordinates of the movement of a freight train of an even direction of various masses in section 1-2.

Figure 4. Freight train schedule in odd and even directions on section 1-2 with new skip technology.

According to the construction of a variant train schedule, it is possible to pass 134 freight trains in an even direction and 136 freight trains in an odd direction with 22 passenger fast trains and 14 units of electric rolling stock. The schedule assumes the organization of traffic with pushing locomotives-pushers 132 even freight trains, and 12 odd freight trains - heavy, as well as container. The need for pushing locomotives is 34 units.
When organizing the work of thirty pushing locomotives, which implies performing two pushes per shift and reversing them between stations 1 and 2, as well as when organizing the work of three pushing locomotives, which implies performing four pushes per shift with the circulation of the latter from station 1 to station 2, we determine the average number shocks per one pushing locomotive per shift.

The average number of pushes per one pushing locomotive per shift is determined by formula (1) and is

\[ N_{\text{podt.mid}}^{33} = \frac{30 \times 2 + 3 \times 4}{33} = 2.18 \text{ push/sm}. \]

The variant train schedule, which provides for the most unfavorable conditions for the passage of freight trains through the section due to the consideration of the maximum possible number of passenger, suburban trains, single-use trains per day, provides an increase in the percentage of throughput by 37.9%, which corresponds to additionally missed even trains in the amount of 35 units, and odd - in the amount of 38 units. The increase in throughput requires the purchase of three additional pusher locomotives [15].

The new technology of the section operation will increase the throughput capacity in both directions by 73 trains in total, which will lead to an increase in freight turnover in the section by 9186.13 million t-km / year. The increase in freight turnover will increase operating costs by 1,959,426.69 thousand rubles/year, while reducing the cost of work by 0.02 rubles/10 t-km from 2.207 rubles/10 t-km to 2.187 rubles/10 t-km. On the other hand, the growth in freight turnover will increase the income of Russian Railways by 12,952,433.3 thousand rubles per year. The total economic efficiency will be positive and amount to 10993016.61 thousand rubles/year [16-18].

5. Conclusion

From the main characteristics of the operating mode of section 1-2, it can be seen that the limiting load factor for the two types of trains does not go beyond the allowable value of 2.0. Transformer oil temperature is 65°C, which does not exceed the permissible 95°C. The voltage is within the allowable value. The temperature in the contact network and the suction line is low and does not exceed the maximum allowable value of 90°C.

Analyzing the results obtained, it can be seen that when the trains move according to the proposed technology for the movement of pushing locomotives, the energy consumption, losses in the traction network, the limiting load factor and the temperature in the contact network and the suction line are lower than when the train moves with the existing one. The minimum and average 3-minute stress is much higher.

Thus, it can be concluded that the use of the presented technology in section 1-2 of the Eastern Railway is preferable, since its application reduces losses in the traction network, power consumption and other parameters of the traction network, and the voltage on the locomotive pantographs is significantly higher than when using the existing train passing technologies.

The measures considered in this scientific article provide an increase in sectional speed by 13.4% in the odd direction of movement, and a decrease in it by 4.5% in the even direction. The average sectional speed has a positive growth trend and is characterized by an increase of 8%. Along with this, there is an increase in the productivity of pushing locomotives by 20.7%.

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