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Reducing the Shortage of Railway Capacity through Introduction of Interval Regulation of Train Traffic


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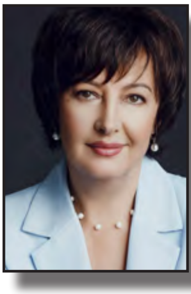
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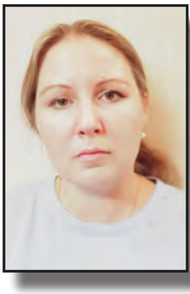
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ABSTRACT

The article presents various options for technical and technological provisions to develop the capacity of railway lines, where there is a need to master the increasing volumes of traffic caused by various factors, for example, changes in national and world cargo flows, passenger flows.

The paper considers provisions undertaken to adopt and effectively implement a new technology of virtual coupling in the interval regulation of train traffic in the conditions of limited railway capacity which makes it possible to reduce inter-train intervals, electricity costs of traction as well as of infrastructure maintenance. This type of interval control allows controlling the following locomotive considering the information that is transmitted over the radio from the locomotive of the pilot train in front. The problems that arise during the traffic process controlled through virtual coupling mode are also identified followed by the model calculations referring to a system being introduced of stimulation and bonuses awarding intended for assistant station masters and traffic dispatchers of traction divisions respective of the number of dispatched and transit trains controlled through virtual coupling mode.

Keywords: infrastructure, innovations, rail transport, region, automatic blocking systems, virtual coupling, capacity, motivation, efficiency.

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INTRODUCTION

Rail transport is among core elements of the transport system due to the significance of transportation services, processing of necessary traffic volumes, safety of goods and reliability of their delivery time, development of new industrial regions, international transport integration. The transport industry faces not prime tasks aimed at both strengthening the capacity of existing lines and developing new high-speed transport routes.

Despite the growth of main railway activity indicators in 2020–2021 (Table 1), the lack of reserves of transit and processing capacities of individual railway lines complicate movement of trains along the sections and lead to emergence of «abandoned trains» at the approaches to seaports and transshipment points. In connection with the foregoing, the railways are constantly working to increase the capacity on the main railway lines. The main activities traditionally include reconstructive, organisational and technical (technological) solutions, while the latter, taking into account insignificant investments, are preferable for the short term.

Also, JSC Russian Railways is carrying out systematic work, which consists not only in development of new regulatory documents, but also in the adoption of modern innovative long term solutions intended to enhance capacity of the now limited capacity sections. Such innovations include introduction of automatic locomotive signalling systems (ALSO) with changeable block sections, development of new systems for interval control of train traffic and virtual coupler technology (VCS) [1–4].

According to the results of a study conducted by the authors of [5], it was found that single organisational measures to ensure the required capacity of traffic-intense sections are not enough and sometimes a set of provisions is required [6]. In this regard, the authors analysed various measures to increase capacity involving the use of various train traffic systems [7; 8], an increase in the share of long and heavy trains [9; 10], changes in infrastructure parameters [11–14], choice of the type of scheduling and methods of managing the trains traffic according to the schedule [15], optimisation models, and other tools for schedule development [16–20].

So, for example, advanced technologies of virtual couplings have shown their effectiveness at the Eastern region of the Russian Railways network. The meeting of the Scientific and Technical Council of JSC Russian Railways on May 13, 2021 adopted the implementation at the Eastern region of the interval control technologies developed and tested at JSC Russian Railways, comprising changeable block sections, virtual coupling, as well as technical equipment and devices, providing interval regulation of train traffic, to increase capacity considering the feasibility study regarding specific sections.

RESEARCH METHODS

The Eastern region was chosen as the object of study, since it is in this direction that a significant increase in railway traffic is observed. Prior to the outbreak of the COVID-19 pandemic, a comparatively insignificant flow of container cargo along the Trans-Siberian Railway went mainly from Japan and South Korea to Europe and comprised transportation by sea to the ports of the Russian Federation, then by rail along the Trans-Siberian Railway, and then by sea from the ports of the Russian Federation and the Baltic states because of different railway gauges and insufficient development of capacity of transshipment terminals. At the moment, due to logistics problems in the Suez Canal and the increased transport demand, China is redirecting its exports to Europe through Russian railways. The necessary conditions have been gradually created: transshipment container terminals have been built on the railway connections with China, powerful logistics centres have been constructed on the western borders of Russia and Belarus, so containers are now delivered by rail. Simplification of customs and related control procedures, the presence of a «green» corridor for transit cargo has reduced the delivery time from 30 to 14 days.

Table 1

Quantitative indicators of the activity of Russian Railways Holding Company [Reference paper «Main indicators of transportation activity of the transport sector»: https://rosstat.gov.ru/storage/mediabank/Perevozka2022.xls]

Indicators of cargo transportation	2020	2021	Dynamics
Loading (mln t)	1243,5	1282,8	▲3,2 %
Tariff cargo turnover (bln tariff t•km)	2544,4	2637,7	▲3,7 %
Cargo turnover considering the empty cars run (bln tariff t•km)	3220,6	3319,6	▲3,1 %

But the question remains whether the infrastructure of the Eastern region is ready to continue to meet the growing demand in export markets and expand the capacity to process cargo originating in the region itself. These trends require a detailed study and forecasting, development of various logistics schemes for delivery of goods, conducting comprehensive studies aimed at optimising transportation processes with the interaction of various modes of transport, assessing the capacity of the most important directions of cargo flows [3].

The length of the «bottlenecks» within the Eastern railway region in 2020 amounted to more than 8,000 km. In this regard, there is an active search for various measures to reduce the number of limiting points. Under this aspect, it is important to analyse the proposed modern innovative solutions and evaluate their effectiveness.

The *tasks* of the study were to evaluate the effectiveness of the application of the virtual coupling technology at the Eastern railway region, as well as to estimate a possibility of using this technology at other railway regions to increase the infrastructure and freight-hauling capacity of the most traffic-intensive sections.

RESULTS

Features of Implementation of the Virtual Coupling Technology for Train Traffic

According to the concept of implementing the integrated technology of interval control of train traffic on the railway network, approved by the order of JSC Russian Railways dated September 28, 2020, No. 2123r, the virtual coupling technology of interval control of train traffic is one of the tools to increase capacity of railway sections with a high intensity of train traffic, as well as when the traffic on one of the main tracks is interrupted to conduct scheduled maintenance and repair works.

Let's consider the technology of virtual coupling in more detail. Prerequisites for using the virtual coupling technology comprise:

• Availability of a single system of automated train driving (USAVP), intelligent system of automated train driving of coupled trains with the help of the traction distributed along the length (ISAVP-RT-M) devices onboard of locomotives (both ahead and following ones).

• Availability of a registered order of the train dispatcher for formation and departure from the initial station (indicating the route section) of cargo trains in the virtual coupling mode.

• The minimum interval between cargo trains moving in the virtual coupling mode, supposedly being no more than eight minutes.

It is proposed to consider the virtually coupled unit consisting of two or more trains as the monitored unit of the movement of cargo trains using the virtual coupling technology along the sections served by locomotive crews, while it is deemed inappropriate to consider the virtually coupled train set in the same manner as by analogy with trains coupled via a «rigid» coupling. It is proposed to consider the moment of departure from the initial station of the leading (head) train in the virtual coupling mode as the beginning of the virtual coupling accounting. The end of accounting for the virtual coupling is the moment of arrival at the end station of the service section of locomotive crews (the station for changing locomotives or locomotive crews) of the following (second) train in the virtual coupling mode within an interval of no more than eight minutes.

In case of temporary disconnection of communication between USAVP, ISAVP-RT-M devices along the route of the virtual coupled train set and its arrival at the final service station of locomotive crews (the station for changing locomotives or locomotive crews) within an interval of up to eight minutes from the leading train, such virtual coupling is proposed to be taken into account, while in case of arrival with a longer interval it will not to be accepted.

Evaluation of Effectiveness of Application of the Virtual Coupling Technology

The relevance of this topic was also confirmed by the Scientific and Technical Council of JSC Russian Railways on May 13, 2021, held on the topic «On development and implementation of technologies for interval regulation of train traffic to increase capacity of the Eastern railway region». At the meeting, the main guidelines and decisions announced were aimed at further development of technology. They concerned: the permanent use of virtual coupling technology for organising train traffic on Karymskaya–Khabarovsk–Smolyaninovo section of Zabaikalskaya and Far Eastern railways; expansion of the area for introduction of the virtual coupling technology, taking into account availability of the necessary locomotive fleet, locomotive crews and dispatchers on duty in Karymskaya–Taishet section, as well as the adoption of the technology in areas of predominantly passenger traffic in the direction of the Black Sea coast; refinement of the algorithms for operation of ISAVP-RT-M in the virtual coupling mode; preparing proposals for organising the accounting of indicators of statistical reporting and motivation of personnel regarding train traffic using the virtual coupling technology, and others.

Operational tests are being carried out on driving trains in the virtual coupling mode, the commissioning of KLUB-U on-board safety equipment with modified software, digital radio modems and the ISAVP-RT-M system that supports this technology on locomotives of the 3ES5K series is being accomplished at Karymskaya–Khabarovsk II–Smolyaninovo section.

To assess the effectiveness of implementation of the technology of interval control, it is proposed to take into account cargo trains following in a virtual coupling mode according to the following parameters:

• Number of virtually coupled train sets travelled during the reporting period.

• Gross (net) ton-kilometres transported in virtual coupling mode.

• Car-kilometres travelled in virtual coupling mode.

• Average sectional speed of movement of each cargo train in virtual coupling mode.

• Consumption of fuel and energy resources for train traction for each cargo train in virtual coupling mode.

• Average traffic interval between cargo trains in virtual coupling mode.

• The percentage of trains running in the virtual coupling mode, taking into account the duration of the temporary disconnection between the USAVP, ISAVP-RT-M devices of the leading and following locomotives.

To date, there are several difficulties in analysing the application of this technology, that will be further considered. First, there is the need for automated traffic control of trains in the virtual coupling mode followed by an analysis of the performance of the technology. Currently, these trains are monitored in the «manual» mode. This approach does not allow obtaining complete information about the results of journeys, identifying deviations from the traffic schedule, assessing the state and readiness of traction resources.

To generate factual data and analyse the effectiveness of application of this technology, the departments and branches involved have developed a list of the indicators to be included in the statistical reporting forms (Table 2).

To implement the task, it is necessary to develop a few regulatory documents and organise automatic generation of reference and analytical forms by the Central Directorate of Traffic Control. For this purpose, an order was prepared, based on which it is planned to approve and put into effect from June 1, 2024, the form of internal statistical reporting called DO-44 VCS «Report on cargo trains running along the infrastructure of JSC Russian Railways using the virtual coupling technology».

The main blocks of data for evaluating the effectiveness of application of the virtual coupling» technology are presented in Pic. 1.

After the necessary documents have been developed in accordance with the established procedure, these proposals will be implemented in automated systems ASOUP (Automated system for operational management of transportation), GID «Ural-VNIIZhT» (Automated system for maintaining and analysing the schedule of completed traffic), AWP OND (Automated workplace «Reporting and number data») as part of the program of digitalisation of the transport industry. This will ensure development of a single database of locomotives equipped to work using the virtual coupling technology; automated generation of data on trains running in VC mode; the use of data for an objective assessment of the work of employees and their motivation. The second stage will be automation of the generation of information necessary to assess the effectiveness of the technology application.

Proposals to Motivate Assistant Station Masters and Train Dispatchers to Implement New Technology

An important role in implementation of the new technology is played by employees who ensure the movement of trains with reduced inter-train control intervals throughout the route. A single position has been developed on the need to motivate the assistant station masters and train dispatchers of the traffic control directorates and employees of the traction directorates by paying a fixed monetary remuneration for each train dispatched and proceeded from/through the section in the interval regulation mode.

As part of the work on proposals for staff motivation, a list of indicators of statistical observation was formed, reflecting the implementation of this technology:

• Total number of trains dispatched in the virtual coupling mode.

• Number of trains that have passed through the entire section in the virtual coupling mode, while calculating their share in the total number of dispatched trains.

Table 2

Indicators for analysing the effectiveness of the application of the virtual coupling technology [compiled by the authors]

Technology implementation	• The number of trains departed from the railway region's stations in the virtual coupling mode. • The number of trains travelled in the virtual coupling mode. • The average traffic interval between cargo trains in the virtual coupling mode. • The percentage of trains running in the virtual coupling mode, taking into account the duration of the temporary disconnection between the leading and following locomotives.	Assessment of the scale of technology implementation and fulfilment of technological requirements
Processing of cargo	• Gross ton-kilometres (net) transported by trains in the virtual coupling mode, identifying the leading and following locomotive. • Car-kilometres travelled by trains in the virtual coupling mode, identifying the leading and following locomotive.	Assessment of the increase in the capacity of sections
Quality of traction use	• Average sectional and technical speed of cargo trains in the virtual coupling mode. • Average mass of a train (gross) in the virtual coupling mode, calculated as the average mass of each of the trains travelling in the virtual coupling mode.	Assessment of the effectiveness of organisation of operations of locomotives and locomotive crews
Need for resources	• Specific consumption of fuel and energy resources for train traction. • Absolute and specific recuperation values for trains operated in the virtual coupling mode.	Estimating resource consumption when implementing the technology

• Number of trains that moved through a part of the section in the virtual coupling mode, while calculating their share in the total number of dispatched trains.

To do this, in accordance with the bonus system adopted by the company (approved by order of JSC Russian Railways dated July 20, 2010, No. 1573r), when providing additional awards, it is necessary to ensure the following basic conditions:

1. Define bonus indicators.

As indicators for the period of trial operation of the virtual coupling technology, it is proposed to apply the following indicators:

• Number of trains dispatched from the stations in the virtual coupling mode.

• Number of trains travelled through the railway region in the virtual coupling mode, provided that they travelled along at least 85 % of the dispatching sections length in this mode.

2. Establish a range of employees who directly affect implementation of these indicators and are thus subject to bonus awarding.

3. Bonuses are planned to be awarded on a monthly basis, depending on the results of each employee involved in this motivation system.

4. One of the most important mandatory conditions is availability of reliable statistics on achievement of bonus indicators.

It is planned that the bonus system will be extended to assistant station masters at the railway stations of train departure and to train dispatchers of the sections through which these trains pass.

Let us consider an approximate calculation (if a decision is made to change the amount) of the average payment of bonus remuneration and the bonus fund for train dispatchers (TD) and assistant station masters (ASM).

Let's make a calculation for ASM:

$$F_{bonus}^{ASM} = \frac{n_{dep} \cdot P}{k_{people} \cdot DC}, rub . \quad (1)$$

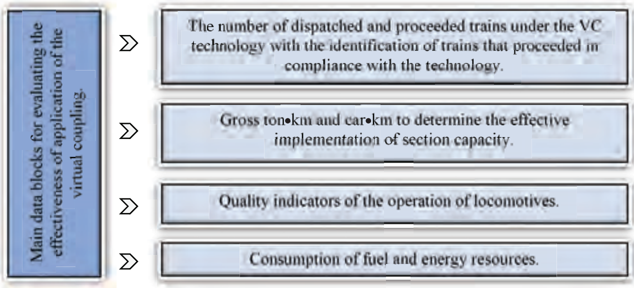
where n_{dep} – number of train departures in the virtual coupling mode;

P – amount paid per each pair of trains;

k_{people} – number of ASM employees using interval control technology;

DC – district coefficients.

Let us show an example pf calculations, if the amount of the bonuses for ASM will be fixed, e.g., at the rate of 700 rubles per each pair of trains dispatched from the station in the virtual coupling mode. For example, the number of ASM involved in bonus system is 52 people at eight train departure stations using the technology of interval regulation, including Karymskaya (12 people), Chernyshevsk-Zabaikalsky (5 people), Mogocha (10 people), Urusha (5 people), Smolyaninovo (5 people), Ruzheno (5 people), Khabarovsk-2 (5 people), Obluchye (5 people). Based on the average monthly data used for model calculating on the number of train departures in the virtual coupling mode during nine months (180 pairs of trains per month), the average amount of bonuses for ASM, taking into account district wage regulations



Pic. 1. Main data blocks for evaluating the effectiveness of application of the virtual coupling technology [performed by the authors].

[*additional payment for work in remote areas*], will be per month:

$$F^{ASM}_{bonus} = \frac{180 \bullet 700}{52 \bullet 0,6245} = 3880\, rub./\, month$$

Let's make a calculation for TD:

$$F^{TD}_{bonus} = \frac{n_{dep} \bullet b_{sec}}{k_{people} \bullet DC}, \qquad (2)$$

where $b_{\sec}$ is the number of dispatching sections where this technology is applied.

For train dispatchers, let us assume the amount of the bonus to be 300 rubles per each pair of trains that passed through the railway region in the virtual coupling mode, provided that they travelled through at least 85 % of the dispatching sections along the route in this mode. The bonuses cover 78 train dispatchers of 13 dispatching sections, including eight dispatching sections of Zabaikalskaya Railway (48 people) and five dispatching sections of Far Eastern Railway (30 people).

Based on the condition that each of the 180 dispatched trains will pass on average in the virtual coupling mode through 11 dispatching sections (85 % of the total length of the train route), the bonus amount for the month will be:

$$F^{TD}_{bonus} = \frac{180 \bullet 11 \bullet 300}{78 \bullet 0,62498} = 12185\, rub./\, month\,.$$

Let's calculate the need for the wage fund for payment of additional bonuses for ASM and TD on an annualised basis:

$$\sum F^{ASM,TD}_{bonus} = (3880 \bullet 52 + 12185 \bullet 78) \bullet 12 =$$
$$= 13826280\ rub./\, year.$$

This technique may be applied when making future calculations according to the real awarding conditions that will be determined.

CONCLUSION

New technological and innovative solutions that are being adopted for implementation to increase the capacity of railway lines, of course, require technical and economic calculations, pilot operations to correct errors and shortcomings identified during testing. It should be noted that the main risk of this technology is the loss of communication between locomotives via radio channels, which might lead to a break of the virtual coupling, and thus to the transition to «manual» control of the following train and an increase in the interval between trains.

As part of modernisation of organisation of train traffic on the sections of the Eastern railway region for the period up to 2025, considering the updated estimated cargo flows, it is necessary to develop options for train traffic that use innovative technologies for interval control based on mathematical modelling, to perform traction and electrical calculations to determine the allowable inter-train intervals for the virtual coupling mode. At the same time, adoption of the virtual coupling system will require solutions to the following issues:

• Reequipment the locomotives with modern safety devices, automatic driving systems and data transmission devices.

• Updating the train traffic control technology considering the reduction in inter-train intervals, as well as the need to increase the length of the receiving and departure tracks and the use of flat turnouts.

It is also necessary to consider the adoption of this technology when developing Instructions for calculating the capacity of the railways of JSC Russian Railways, to develop proposals for increasing the degree of automation of the transportation process at sections and most important stations of railway regions to ensure the maximum transition from information to control systems when implementing technologies of interval regulation of train traffic.

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