Integrated Management of Carriage and Train Flows along International Transport Corridor Systems

Alexander Erofeev1, Andrei Sladkevich2, Evgeniy Fedorov3 and   
Nodirjon Tursunov4, a)

1*Belarusian State University of Transport, Gomel, Belarus*2*BTLC State Enterprise, CEO, Minsk, Belarus*3*The Institute of Economics of the NASB, Minsk, Belarus*4*Tashkent State Transport University, 1 Temiryulchilar St., Tashkent 100167, Uzbekistan*

*a) Corresponding author:* [*u\_nadir@mail.ru*](mailto:u_nadir@mail.ru)

**Abstract.** New trends in the railway transport system of the Eurasian region necessitate the adoption of innovative organizational approaches to effectively manage and promote freight flows along international transport corridors. Existing inefficiencies contribute to increased transportation costs, which in turn foster conditions for unfair competition within the transport and logistics services market and exert excessive pressure on end consumers through the rising transport component in the final price of goods. To address these challenges, this paper proposes a new model for organizing carriage flows by rolling stock operators under conditions of infrastructure capacity constraints. The model incorporates the consolidation of carriage traffic and the implementation of freight train operations based on fixed through schedules along designated routes. This approach aims to optimize capacity utilization, enhance service predictability, reduce operational costs, and ensure a more balanced and competitive transport environment across international railway corridors.

**Keywords:** Railway transport, Eurasian region, freight flows, international transport corridors, logistics efficiency, rolling stock operators, infrastructure constraints, carriage flow consolidation, fixed train schedules, operational cost reduction

# INTRODUCTION

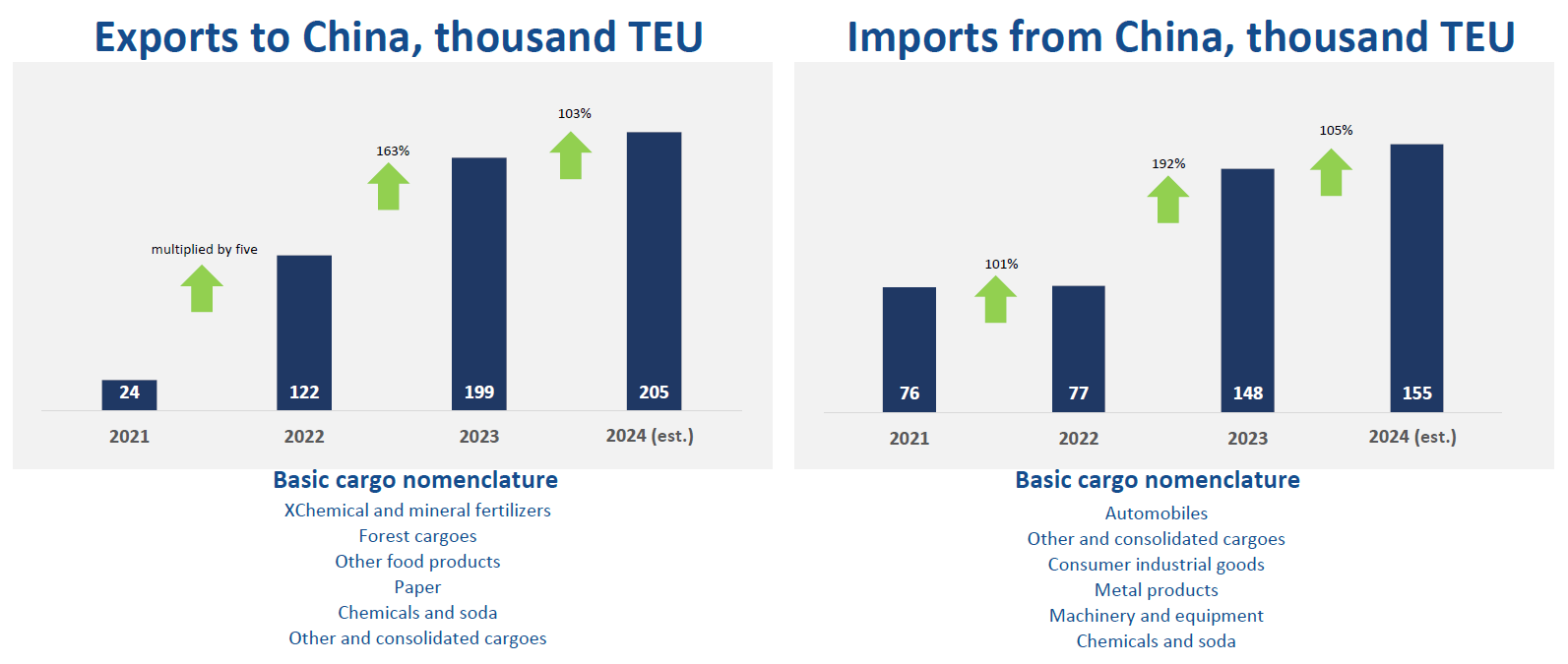
The main challenge for the transport system of the Eurasian region is the change in the vector of logistics to the East and South, which has determined a sharp increase in the load on the Eastern Polygon of the Russian Railways, and has also set a steady trend for the development of the North-South and West-East international transport corridors (ITCs) [1, 2, 3]. The development of transportation on these routes has already led to significant infrastructure, traction and other problems on the Trans-Siberian Railway, the Baikal-Amur Mainline and in the European part of Russia (approaches to the Baltic and Murmansk regions). In the near future, an increase in cargo turnover in the southern direction is predicted, which, in addition to the well-known infrastructural difficulties, will cause the need to develop a fundamentally new system for the distribution of transportation resources at the intersection points of the route network of international transport corridors [5, 7, 9].

Another significant trend is that the logistics market has formed a stable perception of container rail transportation as a separate type of transport and logistics service with a high speed of delivery and the possibility of high-quality integration into multimodal logistics services [4, 6, 8]. As a consequence of this perception of container traffic on the railway transport network of the Eurasian region, a new category of flow has appeared in the system of organizing carriage and train flows with increased requirements for passage along the routes [10-12].

# CHARACTERISTICS OF THE PROBLEM

The growth dynamics of container traffic characteristic of the region can be assessed on the example of the Republic of Belarus. The main destination country for Belarusian export products in containers is China. China is also the main country from which containers with consumer goods, industrial goods, cars and other products arrive in Belarus.

The volume of shipped containers with Belarusian export products in 2022 increased by 5 times compared to 2021. In 2023, the growth continued, and amounted to 163% by 2022. According to the forecasts of logistics industry experts, it is expected that by the end of 2024, the growth rate will be at least 10% by 2023. If in 2022 the growth rate compared to 2021 was 1%, then by the end of 2023, the volume of import traffic increased almost 2 times (193%). It is expected that by the end of 2024, the positive growth trend in import container traffic will continue and will amount to about 10% compared to 2023 (Figure 1) [13, 17, 20].



**FIGURE 1.** Export-import transportation of containers (using the example of the BTLC company)

As a result of the influence of the described trends in the Eurasian region, there was a shortage of throughput, transportation and processing capacity of railway sections, stations, international border crossings, sea terminals, which, in turn, led to an increase in the turnover of wagons and containers, an increase in the downtime of wagons and containers waiting for loading, and after loading - their departure, a decrease in the section and route speeds of trains, an increase in the number of "abandoned" trains. Overcrowding of terminals. In addition, infrastructure constraints lead to disruptions in supply chains, lower export revenues, higher logistics costs and, ultimately, higher costs for consumers and lower competitiveness of export products in foreign markets and transit competitive advantages of trans-Eurasian routes [14].

# ONGOING ACTIVITIES

In order to increase the throughput and carrying capacity of railways in freight-intensive areas, large-scale infrastructure projects are being implemented, which will allow, upon their completion, to significantly increase the volume of traffic [5, 15]. However, their implementation will be completed in the medium and long term, and the forecasts of the required volumes of transportation and their structure of such depth are quite uncertain. At the same time, the existing railway infrastructure is already operating at the limit of its capacity and carrying capacity.

Also, a number of organizational projects are already being implemented at the Eurasian polygon aimed at increasing the throughput and carrying capacity of railways. Among them are the organization of the departure of container trains with a length of 100 conventional wagons or more, loading loaded containers with imported products into gondola carriages, optimizing the train schedule and other activities. The Belarusian Railway, Kazakhstan Railways, Chinese Railways, Russian Railways, Ulaanbaatar Railway, as well as the railways of the EU countries are actively involved in the development of the organization of train traffic according to agreed schedules in the container transportation segment. A number of initiatives are being implemented to create container services based on constantly circulating trains, such as the creation of its own European railway carrier (Eurasian Railway Carrier Sp. z.o.o., operating on the 1435 mm gauge) by the Belarusian company BTLC, projects of UTLC ERA and a number of others.

At the same time, it is obvious that the use of traditional methods of organizing carriage and train flows on the railway network in the current conditions often does not allow building an optimal system due to the lack of the necessary methodological approaches to solving transport problems in the new formulation.

# SUGGESTED SOLUTIONS

For the effective development of the market of transport and logistics railway services, it is necessary to create and develop innovative organizational solutions aimed at a comprehensive solution to the problems of promoting flows in the context of a dynamically changing load of a complex branched polygon of the network of international transport corridors.

Such solutions, according to the authors of the article, include the development of models for organizing carriage flows of rolling stock operators in conditions of capacity shortages, including the consolidation of carriage traffic and the organization of freight train traffic according to permanent through schedules on the routes.

Given the train situation on the Russian Railways network, as well as the periodic shortage of locomotives at intermediate stations, logistics operators are faced with the problem of significant delays of carriages at route. As a result of the analysis of the turnover of wagons of large logistics operators of the Republic of Belarus, it was found that for polygons with a range of up to 700 km, monthly fluctuations in the average daily mileage of wagons reach a value of more than ±40% of the average values, and the route speed in the forward and reverse directions on the same route can differ by more than 2 times. At the ranges with a range of up to 1200 km, monthly fluctuations in the analyzed sample reached ±69%, while the difference in route speed in the forward and reverse directions on the same route was 25-30%.

The current situation forces transport and logistics companies to include in the price of the services provided additional costs associated with a decrease in the efficiency of the use of rolling stock and possible penalties for exceeding delivery times. The lack of effective mechanisms for organizing carriage flows on the railway network, ensuring guaranteed compliance with the delivery time of goods and methods for reliably assessing the risks of violation of delivery times, creates the prerequisites for unfair competition in the market of transport and logistics services, as well as excessive pressure on the consumer sector due to a significant increase in the transport component in the final price of transported products.

The systems of carriage flow management currently used in the 1520 gauge space assume that for each declared correspondence of the carriage flow (), the carrier establishes a group of destinations of the PF (), which will include the movement of the flow, from a variety of options available to it. The choice of train destinations is carried out according to the efficiency criteria used by the carrier when organizing carriage flows to trains:

|  |  |
| --- | --- |
|  | (1) |

As a rule, carriers integrate the correspondence of carriage flows into train destinations depending on the capacity of the carriage flows, without taking into account the parameters of the flow time that are critical for freight forwarders and rolling stock operators. At the same time, the scientific community of railway workers recognizes that such an approach in some cases can lead to an overload of the railway infrastructure and requires the adoption of systemic measures to manage flows in the operational perspective. For these purposes, the EAEU railway companies are developing automated systems for monitoring the load of infrastructure, such as the "Dynamic Map" of the Belarusian Railway [6], the Dynamic Model of Infrastructure Loading of Russian Railways [7].

In the context of the availability of reliable operational information on the situation at the Eurasian railway range, it is advisable to provide logistics operators with the necessary data on the expected travel time of trains to the destinations, the current plan for the formation of freight trains and the duration of the stay of wagons at technical stations for planning logistics routes. In this case, a service of prompt readdressing of wagons can be implemented (Figure 2) with the replacement of the criterion of the shortest distance with the minimum time of the wagon's travel along the network range, providing the logistics operator with a cost-effective level of transportation costs at a competitive level by optimizing the risk component:

(2)



**FIGURE 2.** Schematic diagram of the functioning of the wagon readdressing service by the wagon operator

The implementation of such a mechanism through the organized redirection of carriage traffic to routes within the purposes of the current PF, ensuring the required travel time taking into account the current train situation obtained from the automated monitoring systems operating at the test site, or on the basis of their own models for analyzing the operational reporting of railway administrations, will provide a synergistic effect by improving the quality of service and reducing the transport component of costs for railway transport customers, accelerating the turnover of wagons of operating companies, reducing the load on technical stations and railway sections that are experiencing significant difficulties in the short term and, accordingly, improving their quality indicators.

Another effective mechanism is the organization of train flows of logistics operators according to permanent agreed schedules. At the same time, the logistics operator is responsible for consolidating the necessary carriage traffic, and the infrastructure operator streamlines the use of transportation resources through efficient and predictable distribution.

The regulated goals of organizing the movement of container trains according to through schedules are:

­- ensuring the quality of organization and efficiency of transportation by container trains along the entire route;

- proper use of the carrying capacity of railways on the sections of China, broad gauge and Europe, control of the time for the performance of operations at all links of the transportation process, as well as increasing the competitiveness of container trains in the China-Europe-China traffic;

- optimization of the schedules of container trains in the China-Europe-China traffic along the entire route and the implementation of uninterrupted transmission between the sections of China, broad gauge and Europe;

- elimination of inefficient downtime at border stations on sections of China, broad gauge and Europe when transferring trains from one gauge to another;

- optimization of available resources by monitoring the movement of container trains in the China-Europe-China traffic along the entire route.

Promising areas for the development of the system for organizing the movement of freight trains according to a permanent through schedule on the network of international transport corridors are potential popular railway route routes, on which stable carriage flows in international traffic are formed: the Chinese initiative "One Belt, One Road"; train services in the Asia-Pacific region through the ports of the Far East; train services in the direction of the Baltic region to the ports of the St. Petersburg hub and Murmansk, in the southern direction through the ports of the Black and Caspian Seas, through land railway crossings to the southern region of Asia [8].

However, it is obvious that in order to form a new service, it is necessary to change the approach to the organization of train flows on the network, primarily in the key directions, which are ITCs. Taking into account the structural changes in the PF of carriers' trains and the principles of organizing train flows on polygons of considerable length, it is necessary to establish new links between the backbone documents: the PF and the schedule of train traffic (GDP). To do this, it is necessary to establish the priorities of flows and develop key provisions on the order of their organization at the ITC network polygon.

The correspondence of GDP to the structure of PF assignments can be characterized by the average number of lines of the standard GDP used to organize the movement of trains according to the PF destinations. Studies [9] have established that the GDPs are characterized by a weak relationship, there is a significant excess of the number of lines installed in the GDPs over the required number of trains for through destinations provided for by the PF. Thus, when organizing the passage of one train for the transportation of coal, ore, fertilizers, 3.15 lines are used in the GDP, trains with liquid cargo - 2.09, through trains, not specialized by the type of cargo - 1.46. At the same time, there is a positive experience in organizing the movement of container trains on a permanent schedule.

The analysis confirms the insufficiency of the applied specialization of freight train schedules to take into account the regional features of their passage through the infrastructure range, as well as the lack of systematic coordination of transit freight train schedules at technical stations. It has been established that the practical methods of developing the GDPs do not meet the modern requirements for the organization of freight train traffic for a number of reasons: the lines of the GDPs are not tied to the actual traffic flows of carriers and shippers; the volume of traffic in the GDP on infrastructure sections is determined on the basis of a comparative analysis of changes in the flow of applications for the transportation of goods; the linking of the end-to-end lines provided by the Pension Fund for technical stations is carried out after the development of the GDP on the infrastructure sections in a simplified way by the method of selecting schedules and does not provide for a systematic assessment of the corrected version of the GDP; the principles of priority in the laying of freight train lines are taken into account when agreeing on the options of the GDP, developed for individual sections of the infrastructure polygon [9].

In order to implement the systematic organization of through passage of freight trains, it is necessary to apply methods and criteria for the comprehensive development and assessment of the GDP at the infrastructure range, which will make it possible to choose the most effective option for organizing train traffic [10].

The role of the GDP, as the main regulator of relations between participants in the transport services market in the organization of train traffic, makes it possible to determine the target indicator of the model's efficiency through a set of indicators of the efficiency of transport activities of all participants in the transport services market:

|  |  |
| --- | --- |
|  | (3) |

where is the transport effect of the infrastructure operator from the organization of train traffic, the *i*-th carrier from the organization of transportation of the declared carriage flows of customers, the *j*-th operator of the wagon fleet from the movement of the commodity mass of customers.

The maximum efficiency of the organization of freight train traffic is achieved provided that the schedules of their passage along the routes are fully consistent with the established standards (standards) of service time at the infrastructure facilities. In this case, the target indicator for assessing compliance with the conditions for the passage of the declared freight trains along the routes for the GDP at the infrastructure range can be determined as:

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

where are the train-hours of exceeding the travel time of the j-th freight train declared by the carrier along the route on the i-th destination of the PF from the station of formation of the train to the station of destination from the established reference values; – respectively, the maximum permissible period of travel of the j-th freight train declared by the carrier along the route , modeled in the GDP; – a lot of freight trains declared by carriers that are subject to passage at the infrastructure range along the lines of the GDP.

One of the possible methods for solving the problem of optimal modeling is the adaptation of the GDPs on infrastructure sections to the schedules for the passage of freight trains along the routes on the public railway transport infrastructure network [11]. The following elements are identified in the structure of the proposed method:

1. Identification of the processes of train operation on the railway range as a set of events ordered in time and space related to the movement of each declared freight train on the route along the PF;

2. Clustering of schedules of freight trains subject to passage according to the permanent schedule, according to the degree of homogeneity of requirements for the conditions of their passage at the infrastructure range;

3. Methodology for modeling the processes of train operation, taking into account the mutual impact of the flow of freight trains and restrictions in the use of the throughput capacity of the infrastructure facilities of the railway polygon.

The implementation of the proposed method involves a change in the organizational procedure for the development of the GDP (Figure 3), developed on the basis of train clusters systematized according to the parameters of train requests, determines the schedules for the passage of freight trains along the routes for the infrastructure facilities of the infrastructure polygon and is process-object (PDP). It has the properties necessary for all participants to meet the requirements for the organization of the passage of freight trains according to permanent schedules due to the distribution of the capacity of the infrastructure facilities, taking into account the system of priorities of the processes of passing trains and their interconnection in time [16, 19].



**FIGURE 3.** Change in the organizational procedure for the development of the GDP

# CONCLUSION

Thus, the authors have developed the necessary tools to bring the system of organizing carriage flows and train flows on a complex branched polygon of the railway network in line with the current customer requests for the quality of transport and logistics services. The development of the system in this direction will ensure, on the one hand, timely delivery of goods to recipients, reduce the cost of logistics, increase the attractiveness and competitiveness of trans-Eurasian routes for shippers and consignees, on the other hand, this will significantly improve the operational performance of railways, owners of rolling stock and containers, terminals.

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