Modelling the interaction of stations in the port railway junctions

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Abstract. The problem statement, qualitative analysis and main methodological approaches to the interaction of stations for the distribution of sorting and transfer work in port railway junctions with objects of railway infrastructure and rolling stock of various types are presented. The search for a solution provides for finding the optimal variant of interaction on the basis of combinatorial-optimization analysis using economic criteria, technical and technological parameters of stations and a plan of the formation of non-route gears in the area of pre-port transport hubs.

1. Introduction
Rational development of infrastructure and technology of operation of railway and sea transport hubs is the most important basis for the stable operation of the transport system of any state. The first initiative for the development of transport hubs as transport and logistics centers in Europe appeared within 60-70 years of the last century in France, Italy and Spain. But the intensive development began later in Germany, when the systematic cooperation of seaports and Railways was established [1; 2]. The main role of transport hubs with seaports is to export and import cargo.

At present, much attention is paid to the technological and well-coordinated work of transport junctions in Russia, including a port railway junction and seaport, the creation of efficient multimodal transport systems in the Baltic (Ust-Luga port), Azov-Black Sea basins (Novorossiysk and Tuapse) and the Caspian basin of the Republic of Kazakhstan (Aktau port). At the initiative of JSCo «Russian Railways», principally new technological documents – Unified Integrated Technological Processes (UITP) – were developed and approved:

- Ust-Luga transport hub [3];
- Novorossiysk transport hub and the ports of the Taman peninsula [4];
- The customs code of Aktau international sea trade port (AISTP) [5].

The UITP regulates the technology of traffic management and all railway operations, ensuring a smooth interaction of the participants in the transportation process: a dispatch center for transportation management, a shunting operator, state control bodies, operators of sea terminals, sea freight carriers, port administration, and units of a railway junction.

The customs code defines the established customs and practices of the port of Aktau, due to the technology of work, the rules regulate the procedure and conditions for the entry and exit of ships in and
out of port, the mooring of ships to berths, unloading, loading and maintenance of ships, the supply of trains, and the relationship of the port with clients.

Despite large capital investments in the development of railway-sea transport hubs, they still experience technical and technological difficulties due to the uneven loading of the main devices of port railway stations, district parks, station necks, approaches, loading and unloading and storage routes.

Of great importance for the smooth operation is the construction of a rational system of maintenance of port complexes by rail. Fluctuations of the jets and the intensity of incoming car flows to the junction determine the main reason for the non-optimal distribution of sorting, shunting and transfer work between railway stations in the junction, which leads to a failure to ensure continuity of transshipment operations, untimely supply of cars to the terminals, re-processing of cars and, consequently, increased downtime wagons and the time of their turnover in the port.

In addition, the non-rhythmic and uncoordinated supply of goods to the transshipment points arises due to the lack of a single transport conveyor, disunity of ownership and management systems of transport and other entities involved in the transport process.

2. Literature review and defining the problem

The problems of interaction and technology of operation of subdivisions of the port railway junction, which include pre-port sorting stations (PPS), port stations (PS), district parks (DP), connecting, anchorage, handling and storage routes of sea terminals (T), distribution of sorting, freight and train work are devoted to the work of many authors and researchers [8-19]. The above problems have an important theoretical and practical significance. Theoretical – because it is necessary to develop principles and models for rational mutual placement, development of basic railway devices and interconnected technology between them, as well as models for managing train and car flows in accordance with the rhythms of loading and unloading cargo fronts of sea terminals. Practical – it is essential to reduce the time of processing vehicles, apply a direct version of cargo handling, accelerate their delivery, reduce material and labor costs based on the coordinated work of the transport hub as a whole, and introduce new integrated services in ports.

In the conditions of growing freight traffics, going in the ports, it is necessary to find the new technical, technological, organizational decisions of nascent problems. In this context, the reliability of transport is a key concept in the technology of organization and management of train and car flows. The concept of reliability is extremely important in assessing the capacity of transport networks to provide continuity in operation. The reliability of operational work depends, among other things, on the permissible modes of traffic flows through the railway network and has a significant impact on the cost parameters [8]. The problem of effective management of railway freight traffic especially in conditions of multiple operators require rationalization of transport process. The report [9] is devoted to consideration a simple mathematical model for the calculus of capacity in two different cases: for a homogeneous utilization, meaning that all trains have the same running speeds and for heterogeneous utilization, when the passenger trains have the higher speed and hence, the higher priority over the freight trains.

In the thesis [10] for the first time the structure of zones of effective interaction of railway and sea transport in port transport hubs was set out and presented, functional tasks were set, criteria and methods of optimal flow control in each zone were proposed. A method for calculating the coordinated supply of flows to cargo terminals of the port, implemented in the simulation model, is developed. The logistics of the interaction process developed in [10] on the basis of the proposed approaches within the existing information environment and the real structure of transportation management in JSCo «Russian Railways» are used to improve the operation of the port transport junctions, and the principles and methods of optimal flow control can be used to organize coordinated cargo delivery large consumers. The technique for calculating rational technical and technological parameters of transport junctions using simulation modeling can be useful when justifying investments in the development of junctions.
The purpose of the paper [11] is investigation of interaction of two contiguous types of sea and railway transport by means of the method of factor-by-factor analysis, allowing to produce organization of carriage process by the logistic system of freight traffic management. Temporal characteristics affect the question of principal distinction of work of railway and sea transport again. The interval between vessels arrival in port is greater by several fold the interval between trains. If port processes the certain amount of cargo, the port station cannot manage with the growing freight traffic. As a result, large numbers of freight trains are accumulated on the station approaches with cargo, going in an address of port. Therefore it becomes obvious, that the production capacities of port and station must be developed in parallels. Otherwise both participants of the mixed transportations will bear losses.

The scientific article [12] is devoted to the rational development of the port railway junctions in the Far East, in which the questions of the «throwing» of trains on approaches to the port railway junctions are investigated because of the absence of settling paths in the railway subsystems of the ports. The wagons awaiting submission to the berths occupy the ways of the sorting parks. This is the reason for the inefficient use of rolling stock and increased operating costs. To determine the path development of the port stations, it is proposed to apply the current method for calculating the track development of freight stations, and the track development of the pre-port sorting stations should be determined based on the needs of each port area and a specialized berthing complex. Parks of tracks for the sagging of wagons awaiting transshipment under the direct option («warehouse on wheels»), as well as wagons long waiting for the application for the port, depending on the topographical conditions and belonging to these ways, can be placed in the composition of any element of the berthing railway complex.

Excess downtime of wagons on railway devices and berth fronts on the example of the St. Petersburg Commercial Sea Port are investigated in work [13]. The specified problem is proposed to be solved by improving the technology of operation of the railway station and loading and unloading berthing fronts. For this purpose, it is proposed to introduce the position of the second car inspector in the staff list in order to reduce the downtime of the cars from arrival to the loading for loading; rationally distribute the shunting work on the car supply and picking to the port on exhibition routes by the locomotive station, and arrange wagons for loading and unloading fronts to perform a port locomotive, which will reduce the downtime in anticipation of the supply and picking of wagons by an average of 4 hours; ensure unimpeded removal of finished trains from Avtovo and Novy Port stations; to introduce a system for centralized management of a fleet of empty wagons with the planning of destination points for empty wagons after unloading, which will reduce the downtime of empty wagons of private owners; improve interaction between railway stations and the port in terms of harmonizing the approach time of ships and wagons using contact schedules for handling ships and wagons.

The thesis [14] is devoted to the increase of the track development of the stations and the development of constantly increasing volumes of cargo flows processed in seaports. In the current situation, it may be necessary to remove the existing junction or pre-port sorting station (CSS or PPSS, respectively) outside the railway junction and urban development, which simultaneously will solve the problems of the development of these stations, and also reduce the negative impact of stations on the environment of cities and human health. The solution of this task depends mainly on the choice of the most effective mutual placement of the port facilities: the USS or the PPSS, as well as the port stations (PS) and the district parks (DP). At the same time, the railway infrastructure should ensure the development of the required train traffic in the conditions of growing cargo turnover of the seaport.

The tasks associated with increasing the capacity of the ferry crossing by replacing old ferries with more powerful and capacious ones, with the establishment of effective interaction between the ports of the Azov-Black Sea basin for increasing passenger and cargo transportation are explored in the article [15] «On the rational distribution of rail freight traffic between the Azov-Black Sea basin in the foreseeable future».

In work [16] proposals are formulated to improve the indicators of the use of rolling stock (laden and empty trip) of the operator company for the carriage of goods in international corridors in the port transportation and technological system. Using the methods of geometric and economic-geographic modeling and their modifications to differentiate the spheres of influence of the station of wagons owned
by the operator, an algorithm and method for distributing the rolling stock from loading stations to the port stations have been developed with the aim of reducing the duration of the car turnover. A decrease in operating costs for the transportation of laden wagons at port stations was obtained, depending on the length of the route, which gave an economic effect for the aggregate of regional distribution stations from the presence of wagons owned by the operator companies on them.

The delivery time of goods and empty wagons is of great importance for operators and cargo owners in terms of capital invested in goods and subsequently affects its turnover rate [17]. This approach provides probabilistic estimates of the rolling stock use efficiency for different approaches to the organization of car traffic volumes, as well as establishes the effect for each of the participants in the transportation process.

Significant contribution to the study of issues of interaction between rail and sea transport, underlying the modern theory of designing railroad and transport junctions, technologies for their effective work were also made by foreign scientists: G. Biddle, A. Jackson, J.E. Connor, I. Pachil, L. Frendrish, K.J. Holland, K. Hol and others.

The greatest interaction of maritime and rail transport in transport hubs is in container shipping. Therefore, at present, the task of the key operators of the European container business is to invest in the development of railway services and infrastructure on the approaches to the ports. More than half of the total investments of Hamburger Hafen und Logistik AG (HHLA), the largest terminal operator in the port of Hamburg, are in the development projects of railway operations and domestic terminals.

Foreign investors consider the European rail freight market to be promising. However, the uneven loading of terminals when entering mega-container ships remains a painful problem for ports. Large ships create a huge load on the entire port complex of Hamburg, where almost half of the containers are imported and shipped by rail. According to the executive board of the HHLA, an average of 53 trains are in the port waiting for cargo when entering a mega-container ship at the port.

The quality, reliability and profitability of the transportation process in the transport hubs are directly dependent on the technological stability of the port railroad junctions, the main elements of which are passenger, sorting, freight stations, facilities and devices serving the port’s sea terminals [18]. Depending on the conditions for the development of the port railway junction, two or more sorting stations, a freight station, may be included in it, and in small junctions – one integrated station that performs all operations. The interaction of marshalling yards at the railway junction, as regards the distribution of sorting work between them, was investigated in [20-23].

The railway station is a complex system consisting of a number of different elements, which interact closely one to another in the process of operation providing mutual influence. The determination of rational parameters of railway stations is a complex multi-variant and multi-criteria problem. Currently, the simulation method is the most effective for modeling the technological processes of the station and evaluating its quality. In addition, the efficiency of functioning a station is largely dependent on the level of operational management by dispatch personnel. Simulation models can serve as an effective tool for analysis and assessment of functioning of the stations, their technical-technological and economic parameters that would allow making rational decisions to increase the profits of transportation by rail [24]. In paper [25] the area of rational use of trains’ breaking-up order model, formalized in the form of stochastic programming problem is determined. This model depends primarily by two factors – accuracy of traffic forecasting and size of car processing.

As the analysis showed, in the previous studies, various options for port servicing are proposed without taking into account the reciprocal links between the pre-port sorting stations (PPS), port stations (PS) and district parks (DP). The costs associated with the incoming car traffic flow are taken into account, the cost of transferring traffic, delays of trains for non-acceptance of the PPS and the PS, as well as additional costs for increasing the capacity of the latter are not taken into account. The existing methods of rational servicing of port complexes by railway transport do not make it possible to plan and
consider all distribution options for sorting cars and forming gears and trains, depending on the power of the incoming traffic of cars of various accessories.

At present, with the widespread introduction of automated information and logistics systems, the creation of the Automated Control System-Port (ACS-Port), and the organization of a common information space for participants in multimodal transport, it is necessary to develop an integrated method for distributing work in the port railway junction, which, in conditions of irregularity and fluctuations of incoming traffic flows, with disproportionate capacity and loading of railway devices, would provide for the establishment of a rational interaction between the railway transport and seaport in view of technical equipment and adopted technology work, as well as the implementation of various operational adjustment measures in the rail unit complex.

3. Research of the parameters of the solution

If the port junction has a significant cargo turnover and a sorting station at a sufficiently large distance from it, then various options for servicing the port [19] by railways arise (Figure 1).

![Figure 1. Schemes of relative location of railway equipment serving the port: a) servicing of sea terminals (T) by a pre-port sorting station (PSS); b) servicing of sea terminals for PSS and district parks (DP); c) servicing of sea terminals of the PSS and the port station (PS); d) service of sea terminals by all three railway devices](image)

When deciding on the application of a scheme of the port service by rail transport, the condition of continuity of loading and unloading operations in the port and the arrival of wagons to each port area with goods of the corresponding categories should be taken into account first of all. The article [26] is devoted to the study of major port systems in Europe, in which a model of port classification was developed according to their actual position and regional role.

The operations for sorting wagons, their selection by separate areas and loading and unloading terminals of the port are performed at the pre-port sorting station. More detailed sorting — not only by cargo areas and berths of sea terminals, but also by ship holds at the port station, in special regional parks or directly on loading and unloading routes of sea terminals.

To solve this problem, the methods of analysis, applied combinatorics, simulation modeling of port stations and junctions are used. The original data of the problem: the operating car traffic volume having a discrete character on the approach to the port hub (the plan for the formation in the area of the pre-port railway hub on the basis of the reporting form DO-17), the layout of the main devices in the junction and their throughput, cost parameters.

4. Problem statement

The task is combinatorial-optimization, the nature of which is determined by the search of all possible options for the distribution of work, their technical and economic comparison and choosing the best option in the pre-port railway hub.
All operations carried out in the unit with wagons following to the port can be divided into three enlarged groups, then the operation of the port junction based on the UITP necessitates a significant modernization of the calculation dependences [6] in order to take into account modern features of the operation of the port units with the wagon flows of different cost estimates related to:

1) with the train flows entering the junction and leaving the junction – processing at the stations: \( E_{\text{pro}} \) – the costs of the owner of the public infrastructure and the railway carrier, as well as the owner of the non-public use path serving the terminal, and the shunting operator; accumulation at stations: \( E_{\text{accu}} \) – expenses of the operator of rolling stock; the formation of train trains and shunting transmissions at the stations: \( E_{\text{shun}} \) – the costs of the owner of the non-public way operating the terminal, and the shunting operator; train runs on sections, in-junction moves and connecting branches: \( E_{\text{run}} \) – expenses of the owner of the general infrastructure and railway carrier; runs of single train locomotives due to traffic disparity in the sectors: \( E_{\text{in,loco}} \) – expenses of the owner of the public infrastructure and railway carrier; downtime of wagons and train locomotives at stations: \( E_{\text{run,loco}} \) – the costs of the operator of rolling stock, \( E_{\text{run,wag}} \) – the costs of the owner of the general infrastructure and the railway carrier; delays of trains on unacceptable stations: \( E_{d} \) – expenses of the owner of an infrastructure of the general using and a railway carrier.

2) with the processing of intra-junction wagons – the organization of the transfer between the stations: \( E_{\text{trans}} \) – the cost of the owner of the public infrastructure and the railway carrier and shunting of the sea terminals: \( E_{\text{shun}} \) – loading and unloading operations in the port with the cars of the transfer train – the costs of the owner of the non-public way, and the shunting operator.

3) with the change of technical and technological parameters of stations, district parks and sea terminals of the junction in the redistribution of the traffic volume and transformation of their parameters: \( E_{\text{tex}} \) – the costs of the owner of the public infrastructure and the railway carrier and the costs of the owner of the non-use route serving the terminal and the shunting operator.

Limitations of the task are determined by the stationary resources of the transport hub (approaches, in-junction hauls and connections, track development of stations, district parks, non-public routes, technical equipment of technological lines, the presence of a contact network and the type of current, fixed reloading and traction devices of terminals) and mobile resources and shunting locomotives, operational staff, mobile reloading and traction devices of terminals).

The task of justifying the technological parameters of the port railway junctions is combinatorial-optimization, the nature of which is determined by the nonlinearity and integer of a number of components of the objective function. In this case, the target function itself cannot be written down as a simple sum of the component costs associated with different train flows and with the technical and technological parameters of the components of the junction. As indicated above, the costs are borne by different participants in the transportation process, which requires decomposition into a series of single-objective tasks with subsequent coordination of the results.

The formal formulation of the problem is formulated as follows: it is necessary to choose such an option for organization of sorting in the conditions of current operation and for the future, in which the functioning of the railway port junction is ensured with minimal costs.

There is a managed system – a set of stations: pre-port sorting (PSS), port stations (PS) or district parks (DP), sea terminals with access roads of industrial stations (T) performing sorting work in the port junction. As control actions are variables: \( K_r \) – the number of assignments of the trains being formed on the interacting stations \( r \); \( N_{\text{distr},r} \) – car traffic volume between stations, involved in the distribution of sorting work; \( n_{\text{fre},x} \) – number of freight trains between stations by section (in-unit connecting line) \( x \). The state of the system is understood as the distribution of sorting work. Then the set of controls is represented as follows:

\[
S_i = \{ K_r, N_{\text{distr},r}, n_{\text{fre},x} \}
\]

(1)

The choice of the optimal variant of the distribution of sorting work is connected with the choice of such control, in which the objective function reaches the minimum value,

\[
E_{\text{min}} = \min \{ E(S_i) \}
\]

(2)
Target function – total average daily costs – includes components associated with various train flows and with technical and technological parameters of the stations. Finding a rational variant of the distribution of sorting work in the port junction reduces to solving the objective function:

\[
S = \sum_{r} E_{\text{pro}} + \sum_{r} E_{\text{acc}} + \sum_{r} E_{\text{shun}} + \sum_{r} E_{\text{runs}} + \sum_{r} E_{\text{runsmov}} + \sum_{r} E_{\text{runswag}} + \sum_{r} E_{\text{loco}} + \sum_{r} E_{\text{trans}} + \sum_{r} E'_{\text{shun}} \rightarrow \min
\]

under the following restrictions:

\[
k_r \leq k_{\text{max},r}
\]

\[
N_{\text{obl},r} + N_{\text{distr},r} \leq N_{t,r}
\]

\[
N_{\text{frei},x} \leq \gamma_{\text{sec},x} n_{\text{cap},x}
\]

\[
M_{\text{need},g} \leq M_{\text{max},g}
\]

\[
N_{i} \geq N_{\text{min},i}
\]

where \(K_r\) is the number of train assignments generated in the sorting system \(r\); \(k_{\text{max},r}\) – the same as the maximum allowable for given processing sizes in the sorting system \(r\); \(N_{\text{obl},r}, N_{\text{distr},r}, N_{t,r}\) – car traffic volume processed in the sorting system \(r\) – mandatory, distributed and technically acceptable for a given number of appointments, wagons / days; \(n_{\text{cap},x}\) – the capacity of the section (in-house course, connecting line) \(x\) for freight traffic, trains / days; \(\gamma_{\text{sec},x}\) – permissible level of use of a throughput of a site (in-house course, connecting line) \(x\); \(M_{\text{need},g}, M_{\text{max},g}\) – the required and maximum permissible fleet of train locomotives of the \(g\)-ing specialization (the treatment area); \(N_{i}, N_{\text{min},i}\) – destination power \(i\) – respectively calculated and minimally permissible due to timely delivery of goods, wagons / days.

Restrictions (4) and (5) are interdependent. There is an overflow of sorting tracks under continuing condition of railway infrastructure and the growth of the incoming car traffic flow to the processing. As a result, it is necessary to allocate additional rail tracks, which reduces the possible number of generated appointments of the plan of formation. Figure 2 shows an example of this dependency, which demonstrates the dynamics of the power of the number of destinations from the allowable value of processing of the incoming car flow. At the same time, calculation of the operational performance is made on simulation models of port junctions and stations.

![Figure 2. The graph of dependence of permissible processing of the car traffic flow on the number of generated appointments](image-url)
line of uncommon use, the shunting operator and the operator of rolling stock) has its components of the cost in the objective function (3). The choice of a solution within the limits of constraints (4 - 8) is made by finding a compromise management according to the principles [28]. The components of the objective function and the constraints of the problem (3) - (8) are nonlinear and integer. This determines the choice of solution methods.

5. Operational issues by transfer traffic
Among the many aspects of port-station cooperation, the basis is the train schedule. There is a method of volumetric-calendar planning and production schedule drafting – network planning, which is related to serial or serial-parallel execution of certain works and operations in order to shorten the total delivery cycle of intermodal freight in containers [27]. One of the main instruments for organizing and technological basis for the work of all railway departments is the schedule of trains, which on the landfill of interaction with cargo-handling complexes should provide for docking:

- traffic schedule with allocation of firm schedules of freight trains on sites;
- «Christmas» schedule of the movement of transfer trains in a transport hub linking the pre-port sorting station of the junction, individual port stations and their district parks;
- contact schedule for handling vehicles.

At the same time, the «Christmas tree» schedule should provide for:

1) the correspondence of the linked threads of the core of the trains on the sections and in the junction;
2) intervals of arrival and departure of trains from the line to the junction and from the junction to the line, ensuring the possibility of following the same strings as transit for the pre-port sorting station, and processed (formed) trains with minimal delays;
3) the possibility of moving transfer locomotives between port stations (district parks, terminals) and skipping group transfers with a detachment at port stations.

There are the following types of transfer trains in the port junctions (see Figure 1):

- between the pre-port sorting station and the industrial stations (loading and unloading fronts) serving the port terminals;
- between the pre-port sorting station and the district parks;
- between the pre-port sorting station and the port stations of the junction;
- between the pre-port sorting station, port stations and district parks.

The establishment of optimal parameters for the transfer movement, namely the number of trains and the size of their trains, is based on the following recommendations. For the selected sorting distribution option in the junction, it is necessary to determine the number of wagons transferred when distributing flows from one unit of the junction to another, and for these trains to establish the optimal dimensions of the movement of the transfer trains, as well as the required number of locomotives for servicing them.

The optimal dimensions of the transfer motion are determined by the number of transfer trains, in which the total average daily costs will be minimal for the junction as a whole.

The considered order of justification of the technology of the transfer movement in the junction includes:

- determination of average daily expenses for the transfer movement for each intermodal assignment;
- determination of the required fleet of transfer locomotives;
- comprehensive selection of rational sizes of transmission motion for the junction as a whole;
- drawing up the junction train schedule.

Possible options for the size of the movement of transfer trains for each destination are limited to the minimum number of trains:

$$n_{\text{min pow}} = \frac{N_{\text{pow}}}{m_{\text{trans min}}} \quad (9)$$

where $N_{\text{pow}}$ is the power of the assignment of the transfer trains, taking into account the wagon flows, distributed with the PSS at the PS or DP, wagons / day;
$m_{\text{tra,max}}$ – the maximum composition of the transfer train, wagons.

Comparable in different variants, the average daily cost for the transfer movement in the port railway junction is determined for each destination of the transfer trains according to the formula:

$$E_{\text{tran}} = E_{\text{accu}} + E_{\text{form}} + E_{\text{wait,dep}} + E_{\text{move}} + E_{\text{wait, arr}} + E_{\text{dish}} + E_{\text{maint loco}} + E_{\text{back}}$$  \hspace{1cm} (10)

where $E_{\text{accu}}$ – the costs associated with the accumulation of transfer trains, rubles / day;
$E_{\text{form}}$ – expenses for the formation of transfer trains, rubles / day;
$E_{\text{wait,dep}}$ – costs associated with the expectation of operations with the transfer train at the departure station (the end of formation, processing and departure), rubles / day;
$E_{\text{move}}$ – expenses for movement of transfer trains on the intra-junction line, rubles / day;
$E_{\text{wait, arr}}$ – costs associated with the expectation of operations at the station of arrival of transfer trains (technological processing upon arrival and disbandment), rubles / day;
$E_{\text{dish}}$ – expenses for the disbandment of transfer trains, rubles / day;
$E_{\text{maint loco}}$ – expenses for the maintenance of the fleet of transfer locomotives, rubles / day;
$E_{\text{back}}$ – costs for reserve run of transfer locomotives due to traffic disparity, rubles / day.

To determine the optimal dimensions of the motion, you must determine each of the cost elements that is included in (10), and select the value of the $E_{\text{gross}}$ corresponding to the minimum value.

With the increase in the number of transfer trains, the loading of the shunting locomotives of the formation increases, the loading of the brigades of the technical service of cars at departure, the loading of the output section, the loading of the brigades of the technical service of cars for receiving, and the loading of the sorting device of the destination system. This generally affects the wagons' downtime of transfer trains at gantry stations. Therefore, these issues should be resolved in conjunction with the issues of technology and the structure of the dispatching management in the port railway junction with the concentration of work management in the hands of one replacement manager.

The behavior of the above cost elements (10) can vary considerably depending on the weight and length of transfer trains (Figure 3).

![Figure 3. Dependence of the components of function (10) on the mass of the transfer train](image)

The increase in train accumulation costs is due to increased downtime of wagons on sorting tracks, while traffic costs are reduced as a result of costs reduction associated with the mileage of the rolling stock, as well as savings on fuel or electricity costs.

6. Conclusions
1. Developed and scientifically substantiated the theoretical basis of the method of distribution of sorting and transfer work in the interaction of stations in the pre-port railway hubs.
2. The proposed classification of constraints and controlled variables in solving the problem takes into account the fluctuations of the jets and the unevenness of incoming traffic flows to the port area and the technically permissible load level of railway infrastructures.
3. The search for a solution to the problem involves directional sweeping of the wagon traffic flows into the junction, checking for constraints in accordance with the device interaction scheme (Figure 1)
and then finding the optimal variant of the distribution of sorting and transfer work among the stations at the pre-port junction.

4. The software created on the basis of the methodology will make it possible to calculate options for servicing seaports by railway transport, both with the existing capacity of permanent devices of railway facilities, and when the technical equipment of the port infrastructure is changed with the least amount of time.

5. The numerical implementation of the developed methodology made it possible to determine the best option for servicing the sea terminals of the Aktau port by rail. The evaluation of service options by the formulas (3) and (10). It was found that in the implementation of the optimal variant, a simple carriage to the port at the railway stations Aktau-port, Mangyshlak, Stroitelnaya, in the «Khimichesky» and «Port» shunting parks - decreased by an average of 8%.

6. The presence of such a technique allows: to establish a rational distribution of rolling stock, shunting means, rational implementation of sorting and transfer work; to adjust the plan for the formation of trains in the area of the pre-port railway junction, both on-line and during planning; establish performance indicators of railway stations and district (shunting) parks at junctions; evaluate the performance of the rolling stock and technical means of railway devices.

7. On the basis of the research results reviewed in this article, changes and additions have been made to the Instructive Instructions [7] regarding the calculation methodology for the distribution of sorting work and the organization of transfer traffic in the pre-port railway hubs.

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