Method for Determining Forecast Time of Cargo Flow Occupying Transport Routes

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Abstract. At present, carriers are focused on improving profitability and efficiency of transportation, reducing freight costs, and providing high quality customer service when their operation work is planned. This is why the question of the time it takes to deliver goods to the destination stations is highly relevant. The authors introduced the concept of forecast time of cargo delivery. The progress of cargo flow along transport routes is modeled; parameters affecting the forecast time of cargo delivery are determined; a method for determining the forecast time of cargo arrival at the unloading station (transshipment) is developed. The method is based on determining the time that the flow occupies the facilities along transport routes based on their loads.

1. Problem statement

The Far Eastern Railway is the most important link in transporting export cargo to the countries of the Asia-Pacific due to its borderline and seaside geographical position. The Far Eastern Railway has:

- Access to the non-freezing seaports of Khabarovsk and Primorsky Krai (Vladivostok, Vostochny, Vanino, Nakhodka, Posyet and others);
- It has border crossings with China and North Korea.

In recent years there has been a rapid development in sea port infrastructure initiated by more export cargo shipment. Meanwhile, there is an imbalance between the capacity of sea terminals growing year after year and the capacity of the main transport routes of the Far Eastern Railway, namely the Trans-Siberian Railway and the Baikal-Amur Mainline. Comparing the higher port capacity and the capacities of the railway, one can conclude that there is a lack of the latter in the Far Eastern basin.

The implementation of plans for the development of mineral deposits in the Far East and Siberia will lead to a dramatic increase in cargo flows on the sections of the Baikal-Amur Mainline and the Trans-Siberian Railway. Thus, by 2025 the total load of the railway network in its section leading to Vanino port could reach almost 60 million tons. If we speak about Primorsky Krai, this volume will amount, according to analysts, to more than 150 million tons of all types of cargo.

Due to the constant increase in shipment, most facilities on transport routes of the Far Eastern Railway are now operating under peak loads resulting in more time that cargo flow occupies the routes and is processed.
The actual technology of the transportation process and the conditions of its operational organization differ significantly from the conditions for calculating the terms of delivery of goods. At present, the statutory time (calculated in accordance with the Transport Regulations) and the technological time (calculated in accordance with the current cargo movement regulations) are used to determine the forecast delivery times. In practice, the statutory, technological and actual time of delivery of cargo do not correspond to each other.

It is impossible to accurately predict the situation on the road for such a period. Any technical problem with all of these factors present will result in a failure to achieve consistent port delivery.

2. Purpose of the article (problem statement)

The purpose of the paper is to determine the forecast time of delivery of export and transshipment cargoes to ports on the basis of research and evaluation of technical and technological parameters affecting the time of cargo stays on the transport route.

The following theoretical and practical tasks were required to achieve the goal:

- research of scientific, methodological and practical experience of time planning of cargo traffic on transport routes;
- definition of the basic technical and technological parameters affecting the time of stay of cargo flows on transport routes;
- assessment of the influence of the allocated parameters on the time of export and transshipment traffic on transport routes;
- development of a model to calculate the time that export and transshipment cargo flows stay on transport routes.

3. Materials and results of the study

Most of the cargo flows (more than 92%) on the Far Eastern Railway are made up of export cargo consisting of mineral and raw resources. The places of loading mass cargoes going to the ports of the Far East are at a distance of 6–15 days (Eastern Siberia, Kuzbass, Sakha Yakutia). Along the transport route “Eastern Siberia (Kuzbass)—Pacific Ocean” cargo flows go through such facilities on transport routes as a loading station, sections of railways, trailing technical stations, an unloading station that have been identified in the structure of the transport route.

When simulating the movement of the export cargo flow on the transport route, the time of stay of a cargo flow is used as a characteristic for each transport facility.

The analysis of practical material on the work of transport routes of the Far Eastern Railway in 2015–2020 established that of the total number of excess-standard export cargo flow idle periods, idle periods at railway sections account for 45%, 30% happens at trailing technical stations with 12% at port stations, 8% at loading stations and 5% on private tracks.

![Figure 1. Structure of a railway transport route.]
According to the Pareto principle, better forecast of export cargo delivery to ports can be achieved by determining the value of excess idle time primarily at railway sections and trailing technical stations.

The authors introduced the concept of “forecast time of cargo delivery” determining the time of cargo delivery to the port taking into account the actual load of transport facilities.

To determine the forecast time of the cargo flow at the facilities of a transport route, the parameters influencing them were determined and ranked.

**Railway sections** The conducted research identified the main technical and technological parameters affecting the time of the flow staying on railway sections.

The parameters of the first order include parameters defining the technology of flow speed in the sections: length of the section; running speed; technical equipment of the route, such as the number of tracks in the section (single-track line/two-track line); means of signaling communication (semi-automatic blocking, automatic blocking).

The second order parameter is the filling coefficient of the throughput.

As parameters of the third order the following are identified: type of graph for single-track lines (paired non-package, paired part-package); share of passenger trains of the total number on two-track lines.

In determining the capacity of the sections and their filling factor, the following factors were also considered: track development of the reception stations park limiting these areas; trains not participating in the traffic; infrastructure outages.

The authors investigated the process of moving cargo flows along sections of transport routes at different values of the identified parameters; dependencies were found for determining the forecast time of cargo flow staying in railway sections.

**Trailing technical stations** The technological line for processing railway car flows and, accordingly, the number of phases in it determine the type of station. The service wait time in each phase of the sorting station depends on the phase load factor and the input flow variation factor.
The authors investigated the delays that occur when the flow of technological lines passes trailing technical stations.

Model for better forecast of export cargo delivery to ports.

If the technological time of export cargo traffic on a transport route is taken for \( T_\tau \); the forecast time is \( T_{pr} \), then the task of improving the forecast of export cargo delivery to ports in general form can be presented as:

\[
T_{pr} = T_\tau \pm \Delta T;
\]

\[
\Delta T = f(\Delta t_{a_i}; \Delta t_{a_j}; \Delta t_{v_{k+1}}; U);
\]

(1)

if the following constraints are met:

1. For each transport object other than input and output, the amount of the incoming flow is equal to the amount of the outgoing flow:

\[
U_{v_j}^+ - U_{v_j}^- = 0; v_j \neq v_1; v_j \neq v_k + 1;
\]

\[
U_{a_i}^+ - U_{a_i}^- = 0;
\]

(2)

2. The flow going through the transport network cannot exceed the capacity of transport facilities:

\[
0 \leq U(V; A) \leq G(V; A); (V; A) \in D \text{ or}
\]

\[
0 \leq \lambda + \delta \leq G(V; A); (V; A) \in D,
\]

(3)

3. The throughput of a route equals the lowest throughput of any transport facility that is part of it:

\[
G(V; A) = f(g_{a_1}, g_{a_2}, g_{v_1}, g_{v_2}, g_{v_{k+1}}, K, g_{v_1}, g_{v_2}, K, g_{v_{k+1}}) \rightarrow \min,
\]

(4)

where \( \Delta t_{v_1} \) is a difference between technological and forecast time of flow at a loading station (from the moment when loading starts to departure), hour; \( \Delta t_{a_i} \) is a difference between technological and forecast time of flow in sections, hour; \( \Delta t_{v_k} \) is a difference between technological and forecast time of flow at trailing technical stations, hour; \( \Delta t_{v_{k+1}} \) is a difference between technological and forecast time of the flow at the unloading station (from the moment of arrival to the moment of unloading), hour; \( U \) is the capacity of the cargo flow, car/day; \( U_{v_j}^+ \) is the flow entering a transport facility, a station and a section, respectively, car/day; \( U_{v_j}^- \) is the flow leaving a transport facility, a station and a section, respectively, car/day; \( D \) is a set of transport facilities included in a transport route; \( A \) is a set of sections included in a transport route; \( U(V; A) \) is a flow passing through a transport network, car/day; \( G(V; A) \) is the capacity of a transport route, trains; \( g_{a_2}, g_{v_{k+1}} \) is the capacity of sections and stations, trains, respectively, trains.

The forecast and technological time of delivery of cargoes is determined, respectively, hour:

\[
T_{pr} = t_{pr}^i + \sum_{i=1}^{n} t_{pr}^{s_i} + \sum_{j=2}^{k} t_{pr}^{v_j} + t_{pr}^{v_{k+1}};
\]

(7)
\[ T_n = t_y + \sum_{i=1}^{n} t_{i,y} + t_{k,y}; \]
\[ \sum \Delta T = \Delta t_{v_{j}} + \Delta t_{v_{i}} + \Delta t_{v_{k+1}} \rightarrow \min. \]

The calculation of the difference between the technological and forecast time of the flow on a transport route will minimize the costs associated with unsatisfactory use of the transport and port infrastructure, transshipment facilities and rolling stock, warehouses and increased costs run by cargo owners due to changes in the loading and unloading plans, rubles:

\[ C = \sum B_{pr} \cdot e_{vag,ch} + \sum P_{gr} \cdot e_{mex} + \sum K_{ck} \cdot e_{c,v} + \sum F_{ck} \cdot e_{c,ck} + W_{z} \cdot e_{z} + \sum E \rightarrow \min, \]

where \( e_{vag,ch} \) is the cost of the idle time for one car-hour; \( e_{mex} \) is the cost of the idle time of one hour for loading and unloading mechanisms; \( e_{c,v} \) is the cost of a vessel’s idle time during an hour; \( e_{c,ck} \) is the cost of using the railway infrastructure for an hour by temporarily delayed trains, taking into account the costs of their maintenance depending on the class of cargo transported; \( e_{c,ck} \) is the cost of using storage facilities for cargo storage in anticipation of the ship; \( S_{ck} \) is the area of used storage facilities, \( m^2 \); \( B_{pr}, P_{gr}, K_{c}, W_{z}, F_{ck} \) is respectively, the minimum total cost of idle time of cars, loading and unloading mechanisms, ships, trains left behind from traffic, storage facilities; \( \sum E \) is increase of cargo owners’ costs due to late delivery of cargo.

4. Conclusions

The development of the infrastructure of the Far East is closely connected to the development of transport routes. Currently, the load of facilities on transport routes reaches 92-97%, which indicates a shortage of throughput and transportation capacities. Due to such loading, cargo flow stays on transport route facilities for a longer time. All this together makes it difficult to predict the time of arrival of cargo flows to the port and to harmonize the interaction between sea and rail transport.

The authors developed a method for determining the forecast time of cargo delivery to the unloading station (transshipment). The method is based on determining the time that the flow occupies the facilities along transport routes based on their loads. The method was tested and proved its adequacy in fulfilling the set tasks as well as its effectiveness in calculating the forecast time of the export coal cargo flows staying on transport routes.

The calculation of the difference between the technological and forecast time of the flow on a transport route will minimize costs associated with unsatisfactory use of the transport and port infrastructure, transshipment facilities and rolling stock, warehouses and increased costs run by cargo owners due to changes in the loading and unloading plans.

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