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Virtual Sorting: Improving Organization of Moving and Processing of Empty Car Flows

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ABSTRACT

The growth in railway cargo carriage, followed by the search for its more efficient implementation results in the need to improve the regulatory framework for interaction of all participants in the transportation process on railways and the technology of organization of moving and processing of car flows on public tracks, reducing existing costs. This explains topicality of reducing shunting operations through flexible arrangement of wagons by destination stations.

The objective of the study is to develop the technology of «virtual sorting of empty cars». The work has used methods of system analysis and the specific tools of railway traffic management and control.

The technology is based on replacing physical rearrangement of empty cars when performing shunting work by introducing changes into the documents, that accompany the car, regarding the destination station and the recipient.

It allows to reduce the planning horizon of turnover of empty cars by clarifying their destination assignments within the delivery process and, as a consequence, to obtain a significant economic effect by reducing the costs of processing transit car flows, by reducing the risks of not providing empty cars for loading, by attracting additional loading volumes, by accelerating the turnover of cars and other effects. Ultimately, the implementation of the suggested technology can increase the competitiveness of railway transport.

Keywords: *railway transport, empty car control, balance method, distribution of empty cars, application for loading, destination stations, virtual sorting, cost reduction, acceleration of movement and processing of cars.*

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Background. The main changes on the railways of the Russian Federation during the transition from the balance method of managing empty car flows to the market method referred to the procedure of directing empty cars to the loading stations. If earlier the delivery of empty cars was carried out according to the adjustment assignments using the balance method, and the loading stations were determined by the dispatching personnel at the shift-daily planning stage, then currently the empty car is directed to destination according to the complete set of transportation documents indicating the destination station and the recipient of the car [1, 2].

Under such conditions, the distribution of empty cars by loading station was performed not at the stage of shift-daily planning, but much earlier (up to 7 days before or earlier) depending on the run time of the empty run, which significantly reduced the accuracy of planning of their operation [3–6].

Due to the assignment of exact stations of destination for all empty cars [that is the destination is linked to the wagon's registration (reference) number], the volume of sorting and shunting work at technical and cargo stations increased. Empty cars of the same type and belonging to the same owner have to be processed in accordance with their destination, regardless of their location on the station tracks and within the train. At the same time, it is important for the recipient to get timely supply of cars of a certain type and design features regardless of their registration (reference) number.

On many foreign railways, empty cars are tightly tied to destination stations and senders, since this is justified by the significantly smaller distance of the empty car's journey, high rolling stock specialization and transport routing, as well as by availability of developed infrastructure and relatively low intensity of its use [7, 8]. Nevertheless, the situation described above, in the author's opinion, can also take shape on the railways of other countries, which makes the problem and the purpose of the study quite universal.

The main *hypothesis* for the study is that the amount of shunting work can be reduced when moving from rigid scheme of binding cars to destination stations to flexible model, when changes in the appointment of empty cars of the same type and design features are allowed.

The *objective* of the research is to consider virtual sorting process for empty car flows. The author uses general scientific and engineering *methods*, mathematical methods, comparative analysis, railway traffic control analytic tools.

Results.

Virtual sorting: tasks and solutions

In the virtual redistribution of empty cars by destination stations, it is necessary to consider not only the type of rolling stock, but also the design features of the cars as for their carrying capacity, body volume and others. To do this, it is necessary first to perform a decomposition of:

• fleet of cars according to all parameters, which are taken into account when distributing empty cars for loading;

• requests for loading according to permissible parameters of cars.

Regarding those cars this will allow to replace their physical rearrangement by performing shunting work with a change in the accompanying documents of the destination station and of the recipient.

Such virtual sorting of empty cars will allow to:

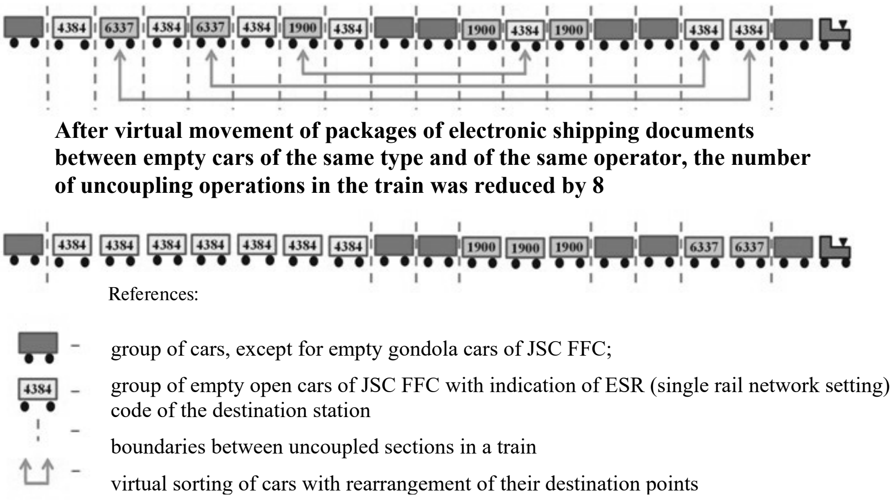
• reduce the amount of shunting work at the stations performing cargo operations thanks to a partial virtual selection of groups of cars for coupling and supply;

• reduce the volume and speed up the performance of sorting work at technical stations, thanks to the reduced number of cuts within the trains;

• reduce the time of accumulation of trains thanks to the virtual formation of closing groups and/or to virtual thickening of the supply of cars cumulated for a destination;

• increase the distance range of technical routes thanks to formation of trains for more distant destinations with a virtual condensation of the supply of empty car flows assigned to a specific destination.

Transition to this technology will also be beneficial for large car operators, since it will be possible to replace irrelevant stations of destination of empty cars with current



Pic. 1. Decrease in number of uncoupling operations at the example of a particular train.

ones, to quickly compensate for the loss of loading resources within the limitations set by the train formation plan and other regulatory documents that determine the conditions for organizing local work and stations' work.

It will also reduce the risks associated with uneven transit of empty car flows and possible changes in loading plans due to planning of the supply of empty cars for loading for many days [9]. Considering the tendency to consolidation of carrier companies, the efficiency of using this technology will increase, since the share of cars of individual operators in the total car flow will increase.

Analysis of marked wagon lists of freight trains containing empty open cars of JSC First Freight Company (JSC FFC) showed the feasibility of performing virtual sorting of appointments for them even within one train. So, in some cases (Pic. 1), it is possible to reduce the number of uncoupling operations in the train by 6–7 operations, which will accelerate the speed of the sorting of a train's cars at a sorting station. Also, the technology of virtual sorting will reduce the volume of shunting work at stations, when the selection of groups of empty cars for moving them to the cargo loading facilities, for coupling to trains and other operations will be performed by virtual rearrangement of appointment of cars' destination in electronic documents, rather than by physical moving of the cars.

Target function

The target function of efficient virtual sorting of empty cars should ensure minimization of the number of groups of cars of one and the same destination in trains and on station tracks:

$$\sum\left(k_{uncoup}^{sort} n_{uncoup}^{sort} + k_{coup}^{loc} n_{coup}^{loc} + k_{uncoup}^{loc} n_{uncoup}^{loc} + k_{\mathrm{sup}}^{\mathrm{cargo}} n_{\mathrm{sup}}^{\mathrm{cargo}}\right) \to min,$$

where k_{uncoup}^{sort}, n_{uncoup}^{sort} are, respectively, the weighting coefficient and the number of uncoupling operations in the train or on station tracks (during accumulation);

k_{coup}^{loc}, n_{coup}^{loc} – respectively, the weighting coefficient and the number of groups of cars on station tracks prepared for coupling operations in accordance with the formation plan;

k_{uncoup}^{loc}, n_{uncoup}^{loc} – respectively, the weighting coefficient and the number of groups of cars in the train or cumulated for further uncoupling operations at the destination station or at core station;

$k_{\mathrm{sup}}^{\mathrm{cargo}}$, $n_{\mathrm{sup}}^{\mathrm{cargo}}$ – respectively, the weighting coefficient and the number of groups of cars in the train or on station tracks prepared to be supplied to the cargo loading facilities;

Constrains to be met:

• ensuring timely supply of empty cars at the destination station:

$$t_{arr}^{est} \ge t_{calc} + t_{run}^{empty};$$

• new car's destination station must meet the requirements of the freight train formation plan and other regulatory documents defining the conditions for organizing local work and station operation:

$e_j^{'} \in E_{ij}$;

• supply of the required number of cars in accordance with the applications of the senders for planning periods *t*:

$$\sum_{j=1}^{n} x(t)_{ij}^{'} = q_j(t);$$

• non-exceedance of the available throughput and processing capacity of the used infrastructure facilities and of non-public tracks during planning periods *t*:

$$\sum_{j=1}^{m}\sum_{i=1}^{n} x(t)_{ij}^{'} \le N_k(t);$$

• compliance of the car's design features (type, model, model characteristics) with the additional requirements of the application for loading:

$h_j^{'} \in H_j$;

• sufficiency of the residual run of the car until the scheduled repair/maintenance to perform the planned transportation:

$$l_{res}^{car} \ge \left(l_{empty}^{res} + l_{cargo}^{pl}\right),$$

where t_{arr}^{est} is estimated date of loading or planned time of arrival of the car for loading, hours;

t_{calc} – time of calculation, hours;

t_{run}^{empty} – estimated time of delivery of the car from the current position to the destination station, hours;

e_j – code of the destination station *j* of the empty car after the «virtual sorting» operation;

E_{ij} – allowable range of codes of destination station of the car, depending on the current location *i*, technological condition, plan for formation of freight trains, technology for organizing local work;

$x(t)_{ij}$ – number of cars moving from station *i* to station *j* after virtual sorting according to planning periods *t*;

$q_j(t)$ – function of demand for empty cars at station *j* for planning periods *t*;

$N_k(t)$ – capacity to allow passing or to process empty car flows of infrastructure facilities for planning periods *t;*

h_j – parameters of the car, sent to station *j* after virtual sorting;

H_j – set of permissible parameters of the car for the application for loading at station *j;*

l_{res}^{car} – residual car mileage before scheduled maintenance, km;

l_{empty}^{res} – distance from the current location of the car to the loading station, km;

l_{cargo}^{pl} – planned travel distance of the loaded car in accordance with the application for loading, km.

The rearrangement of appointments should be made in an array of empty cars of one and the same operator (or regarding a consolidated fleet of several operators) accepted for transportation and not supplied to the track of non-public use. Essentially, this is a refinement of distribution of cars by loading stations, taking into account their current state in order to reduce the costs of the company responsible for this (in our case, JSC Russian Railways) to carry out transportation during sorting and shunting work and to reduce unproductive operations with empty cars due to adjustment of the cargo handling plan and the uneven movement of the car flows.

The calculation of the cost of an empty car's travel when implementing a virtual sorting technology should be performed regarding the actual distance that the empty car has traveled.

Stages of implementation

Given the complexity of the technology of virtual sorting of empty cars, it is advisable to organize its implementation through several stages.

1st stage: performing virtual sorting in manual mode and regarding a single train. At this stage, the following is fulfilled:

• interaction of automated control systems (ACS) of the car operator with information management systems of JSC Russian Railways in terms of development of restrictions on rearrangement of appointments of empty cars (Pic. 1), taking into account the type and design features of the cars;

• information support of the virtual sorting technology operation in the automated control system of JSC Russian Railways.

2nd stage: implementation of virtual sorting within the array of trains, which are to be sorted at one and the same sorting station. At this stage, rearrangement of appointments between empty cars in different trains will be made.

3rd stage: implementation of virtual sorting for empty cars moving within local traffic. At this stage, virtual sorting of cars operated locally with a partial selection of groups of cars for uncoupling/coupling and for supplying to cargo loading facilities will be made.

4th stage: implementation of virtual sorting for empty cars at the network level with redistribution of empty cars along the network in accordance with the specified constraints. At this stage, interaction with rolling stock operators is being organized in terms of replacing part of irrelevant appointments of empty cars with currently required destinations, supplying empty cars to meet urgent requests and replenishing the «loss of loading resource» due to redistribution of their assignments during the transit process, accelerated formation of trains thanks to virtual thickening of the cars' supply of assigned destinations to the sorting station.

5th stage: implementation of virtual sorting for empty cars of different owners. Redistribution of appointments of empty cars of different owners is made in order to achieve the minimum of the target function.

Conclusions. The main conclusion that follows from the conducted research is the proved possibility of obtaining a positive effect, first of all, an economic one, when introducing the technology of virtual sorting for all participants in the transportation process.

The economic effect for the company responsible for the sorting process of empty cars (in our case, JSC Russian Railways) when implementing the technology of virtual sorting of empty cars is achieved thanks to the results that follow:

- reduction of costs of processing of transit car flows;
- reducing the risks of not providing empty cars for loading and attracting additional loading volumes;
- acceleration of car turnover, increasing thus the competitiveness of railway transport;
- reduction of costs and time for sorting trains, thanks to diminished number of uncoupling operations;
- acceleration of accumulation of trains thanks to the virtual formation of closure groups of cars for accumulated trains and virtual thickening of supply of cars in certain periods;
- reduction of shunting work at the stations of cargo operations during selection of groups of cars to be supplied to the cargo loading facilities and coupling / uncoupling of cars from trains and other operations.

The economic effect for carrier companies is achieved through the following:

- reduction of repeated empty voyages of cars, of downtime during waiting for loading, of cases of late arrival of cars to the station of demand;
- replacement of irrelevant appointments of empty cars with actual ones and replenishment of the loss of the loading resource in the process of delivery;
- redistribution of appointments of empty cars, taking into account the unevenness of the empty car flow;
- tariffing of an empty voyage of cars according to the actual distance traveled from the unloading station to the loading station without taking into account the change in the car assignments during the operation of virtual sorting of empty cars.

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