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Improving the Methodology for Calculating the Average Turnover of Gondola Cars of an Iron and Steel Plant

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ABSTRACT

The average daily mileage of a wagon, its productivity and turnover determine the level of efficiency of rolling stock use. The car turnover is calculated and normalized not only for the fleet as a whole, but also for each type of rolling stock, for a particular region and road, depending on the nature of the transportation work. Accelerating car turnover increases its productivity and increases profit of an operator company. At the same time, its decrease negatively affects the capacity of the infrastructure, entails an increase in the cost of shunting and train work, which means that it will increase the cost of transportation.

In modern conditions, turnover is determined for each participant in transportation in accordance with his area of responsibility. For an iron and steel plant, the use of an optimal methodology for recording the time spent by a wagon on its tracks allows us to adequately assess this important quality indicator, as well as to monitor its change as a result of introduction of new technologies for transport maintenance of workshops, reconstruction of station layout and optimization of the transportation process.

The objective of the study is to improve the methodology for determining car turnover on access roads of a metallurgical enterprise for universal rolling stock in the context of dual operations.

The authors use general scientific methods, mathematical methods, comparative analysis.

This article presents the main provisions of the methodology, which will allow determining turnover of gondola cars subject to a single or dual operations in the form of a single indicator which is average weighted car turnover.

Keywords: *railway transport, operator company, rolling stock, metallurgical enterprise, car turnover.*

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Background. Railway transport of a metallurgical enterprise is a complex multi-factor and multi-criteria system, which is characterized by significant volumes of incoming and outgoing cargo flows, a wide range of goods transported and various types of rolling stock. In the course of analysis of the current practices in the field of metallurgical traffic management, the authors compiled a diagram of the existing car flows (Pic. 1).

From the point of view of legal regulation in Russia, provision of cars for transportation of goods by a metallurgical plant is carried out on the basis of a freight forwarding service (operation) agreement between the operator and the enterprise, which indicates the cost rate of provision of a car and normalizes time spent by rolling stock (RS) on the private access tracks [1, p. 299]. If this turnover is exceeded, the enterprise receives a fine for the excess time spent by a wagon on its tracks, and if the actual time is less than indicated, the operator can pay a premium [2, p. 265].

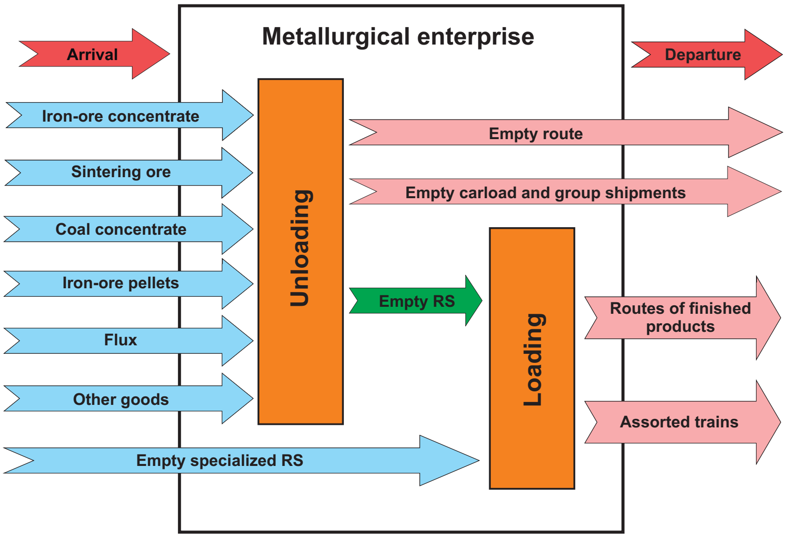
A freight wagon should spend most of the time in a loaded run, and its idle time or empty run only increase losses and represent economically lost profit [3, p. 60].

From this it follows that, firstly, a metallurgical enterprise is directly interested in reducing time spent by cars on access tracks, because lower costs for attracting rolling stock automatically reduce the share of transportation costs in the cost of metal products and increase profitability. And secondly, acceleration of car turnover will allow the operator company to carry out a similar volume of traffic with a smaller number of wagon fleet [4, p. 106].

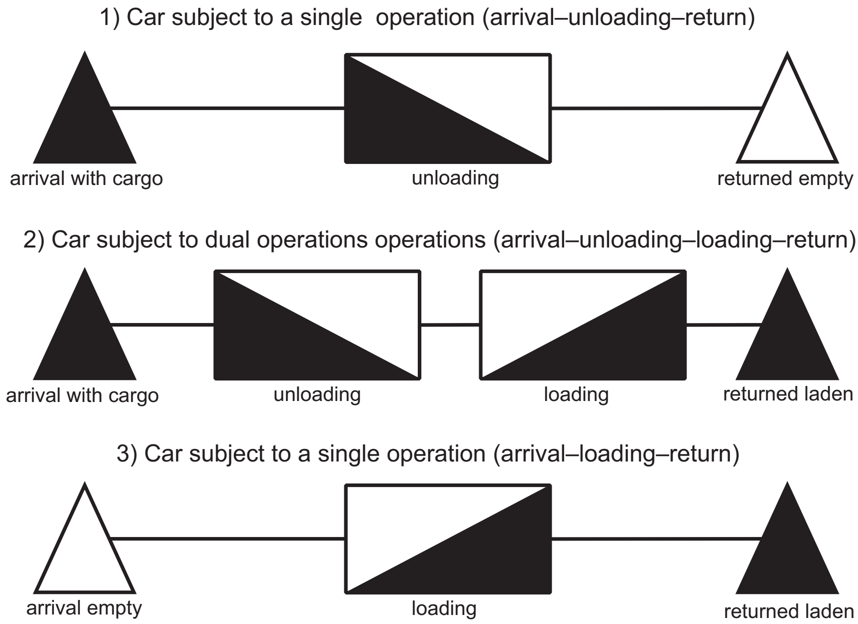
In these conditions, a special role is played by the methodology, with the help of which time spent by cars on access tracks is determined. It should be understandable, objective and give the opportunity to correctly assess the current situation in terms of turnover. To do this, it is advisable to use a single indicator, which on the one hand gives an idea of time spent by RS at the plant, and on the other, without additional labour costs makes it possible to separate turnover of cars subject to a single operation from cars subject to dual operations [5, p. 34]. The application of such a technique will help to identify unproductive idle time of rolling stock and outline a plan for further actions to eliminate bottlenecks in the process.

The planned course towards digitalization of metallurgical enterprises in particular and the Russian economy as a whole also puts forward its requirements for determining quantitative indicators of railway transport, which are among criteria that helps to evaluate the efficiency of the transportation process. It is car turnover that represents one of these indicators, which necessitates its accurate and automated calculation. Both domestic and foreign researchers continue to deal with this issue [6, p. 169; 7, p. 130].

In this regard, it is relevant to use mathematical *methods* to model traffic flows and



Pic. 1. Scheme of car flows.



Pic. 2. Arrival and delivery of a car to the network.

determine performance of the railway in order to conduct further comparative analysis and determine optimization guidelines.

Objective. The *objective* of the study is to improve the methodology for determining car turnover on access tracks of a metallurgical enterprise for universal rolling stock in the context of dual operations.

Methods. The authors use general scientific methods, mathematical methods, comparative analysis.

Results.

Determination of car turnover

The general formula for turnover has a form [8]:

$$Q = \frac{1}{24}\left(\frac{L}{V_{sec}} + k_{tech} \cdot t_{tech} + k_l \cdot t_{fr}\right), \qquad (1)$$

where L – car run, km;

V_{sec} – sectional speed of movement, km/h;

k_{tech} – number of technical stations en route;

t_{tech} – time of car stay at a technical station (average), h;

k_l – coefficient of local work, that shows the number of freight operations per time of turnover of one car;

t_{fr} – time spent by a car during a freight operation (average), h;

From the formula (1) it can be seen that car turnover consists of three main elements: direct travel time, idle time at technological stations and idle time at loading and unloading stations. In this case, it is necessary to differentiate the areas of responsibility of each of the participants in the transportation. The vast majority of metallurgical plants have their own locomotive fleet, so the cars are taken from the adjoining stations by the plant owner's locomotives, and this is stipulated by the contract for operation of the non-public railway. Thus, the area of responsibility of the enterprise for turnover starts from the moment RS is delivered (arrival at the plant) and ends with cars being put up and provided for transportation, that is delivery to the network.

Let's consider the author's scheme of arrival and delivery of a car to the network using the example of one of the largest iron and steel plants in Russia (Pic. 2).

The latter model shown in Pic. 2 is typical of platforms, tanks and other types of specialized RS, which will not be considered in this article.

1) Car subject to a single operation (arrival–unloading–return)

Calculation of time spent by the car on non-public access tracks starts from the moment the car is recorded as delivered one. After the train is disbanded, delivered to the freight front and unloaded, empty cars are removed, the transfer train is formed to be returned to the network and the train is put up at the adjoining station.

In this case, time spent by the gondola car on non-public tracks is determined by the formula [9, p. 85]:

$t_1 = t_{id.i.} + t_{disb.} + t_{d.a.} + t_{del} + t_{set} + t_{unload} +$
$+ t_{rem} + t_{sort} + t_{id.a.} + t_{form} + t_{id.dep.} + t_{set}$, (2)
where $t_{id.i.}$ – idle time of cars at the internal station;

$t_{disb.}$ – time to disband the train, h;

$t_{d.a.}$ – delivery accumulation time, h;

t_{del} – time for delivery of cars to the freight front, h;

t_{set} – time for setting cars to the unloading front, h;

t_{unload} – unloading time, h;

t_{rem} – time for removal of cars, h;

t_{sort} – time for cars sorting, h;

$t_{id.a.}$ – idle time of cars under accumulation, h;

t_{form} – time of train formation, h;

$t_{id.dep.}$ – idle time in departure zone, h;

t_{set} – time for setting cars to the adjoining station, h.

To simplify the formula (2), time spent by the car subject to a single operation on the enterprise's tracks can be represented as:

$t_1 = t_{a\text{-}unload} + t_{unload\text{-}r}$, (3)

where $t_{a\text{-}unload}$ – time from arrival of the car until the end of unloading, h;

$t_{a\text{-}unload} = t_{id.i.} + t_{disb} + t_{d.a.} + t_{del} + t_{set} + t_{unload}$, (4)

$t_{unload\text{-}r}$ – time from the moment unloading is completed until the empty car is delivered to the network, h;

$t_{unload\text{-}r} = t_{rem} + t_{sort} + t_{id.a.} + t_{form} + t_{id.dep.} + t_{set}$. (5)

2) Car subject to dual (two) operations (arrival–unloading–loading–return)

If the car after unloading is delivered to another freight front for subsequent loading, then in this case its turnover is calculated as follows [9, p. 85]:

$t_2 = t_{id.i.} + t_{disb} + t_{d.a.} + t_{del} + t_{set} + t_{unload} +$
$+ t_{rem} + t_{sort} + t_{mov} + t_{del.l.} + t_{load} + t_{rem.lad.} +$
$+ t_{id.a.} + t_{form} + t_{пр.\ отп} + t_{set}$, (6)

where t_{mov} – time for moving cars to the front of loading, h;

$t_{del.l.}$ – time for delivery for loading, h;

t_{load} – loading time, h;

$t_{rem.lad.}$ – time for removal of laden cars, h.

By analogy with turnover of a car subject to a single operation, we write the formula (4) in the form:

$t_2 = t_{a\text{-}unload} + t_{unload\text{-}load} + t_{load\text{-}r}$, (7)

where $t_{unload\text{-}load}$ – time from the end of unloading to the end of loading, h;

$t_{unload\text{-}load} = t_{rem} + t_{sort} + t_{mov} + t_{del.l.} + t_{load}$, (8)

where $t_{load\text{-}r}$ – time from the end of loading to the moment of return of a laden wagon to the network, h.

$t_{load\text{-}r} = t_{rem.lad.} + t_{id.a.} + t_{form} + t_{id.dep.} + t_{set}$. (9)

Weighted average car turnover

For commercial settlements with the operator, separate accounting of cars subject to a single or dual operations is carried out. Maintaining such records is technically not very convenient for the following reasons:

- difficulty of tracking time at each stage: «arrival–unloading», «unloading–loading», «unloading–return», «loading–return»;
- absence of a single value reflecting the situation as a whole in terms of turnover while differentiating cars subject to a single or dual operations.

In this case, it is advisable to introduce a new indicator which is weighted average car turnover, consisting of four elements: $t_{a\text{-}unload}$, $t_{unload\text{-}r}$, $t_{unload\text{-}load}$, $t_{load\text{-}r}$. In order for the indicator to most fully and adequately reflect the current situation, it is necessary to determine time for each of the situations (winter and summer periods should be taken into account separately) and for further calculations take the average value for each:

$$t^{cal}_{a-unload} = \frac{\sum_{n=1}^{N} t_{(a-unload)n}}{N}, \qquad (10)$$

where N – number of cars at the stage «arrival–unloading».

$$t^{cal}_{unload-r} = \frac{\sum_{m=1}^{M} t_{(unload-r)m}}{M}, \qquad (11)$$

where M – number of cars at the stage «unloading–return».

$$t^{cal}_{unload-load} = \frac{\sum_{l=1}^{L} t_{(unload-load)l}}{L}, \qquad (12)$$

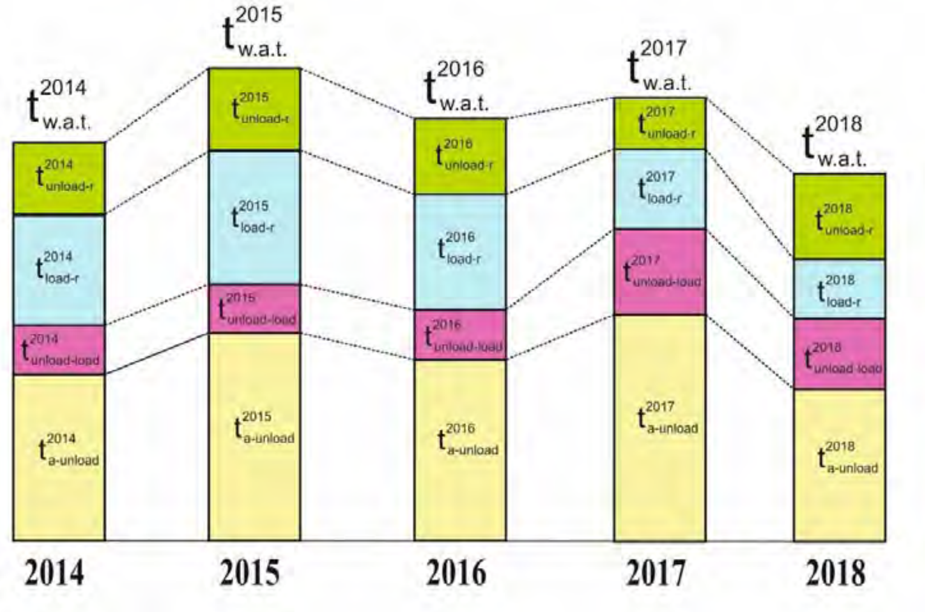
where L –number of cars at the stage «unloading–loading».

$$t^{cal}_{load-r} = \frac{\sum_{i=1}^{I} t_{(load-r)i}}{I}, \qquad (13)$$

where I – number of cars at the stage «loading–return».

After that, the share of rolling stock returned empty after unloading to the network and cars sent for loading is determined. The final calculation of weighted average turnover is carried out according to the formula:

$$t_{w.a.t.} = t^{cal}_{a-unload} + \frac{t^{cal}_{unload-r} \cdot X}{100} + \frac{t^{cal}_{unload-load} \cdot Y}{100} + \frac{t^{cal}_{load-r} \cdot Y}{100}, \qquad (14)$$



Pic. 3. Example of dynamics of weighted average turnover.

where X – share of cars subject to a single operation, %;

Y – share of cars subject to two operations, %.

If the enterprise has an information system for monitoring cars, this calculation should be automated in order to reduce time spent on it, as well as to ensure accumulation of data of the past periods and visualize the obtained values to clearly demonstrate time spent by rolling stock on the access tracks. As a result of determining time spent by a car on the access tracks of a large metallurgical enterprise, the authors constructed the following graph showing the dynamics of the change in weighted average car turnover over the past five years (Pic. 3).

Conclusions. In modern market conditions, the effective operation of both own and third parties' cars includes improvement in the operation of rolling stock and decrease in transportation costs. At the same time, an insufficient level of development of fleet management reduces productivity and increases load on the infrastructure [10, p. 72].

The application of the methodology for determining weighted average car turnover on the access tracks of a metallurgical enterprise will increase accuracy and reliability of calculating time spent by rolling stock inside the plant, and transport logistics specialists will be able to control time spent by a gondola car at each of four stages (arrival, unloading, loading, departure) to respond quickly to exceed standard values. This, in turn, will improve the efficiency of the entire industrial railway transport system and will have a beneficial effect on transport infrastructure. A further development of the methodology will be transition to operational technological and economic assessment of the results of work, based on a natural value meter, which will clearly reflect the relationship between the work of transport workers and payment of the results [11, p. 39]. Material incentives in this case will increase the level of competitive relations within the team, increase labour productivity and reduce transportation costs [12, p. 75].

The next step in improving the methodology for calculating the weighted average turnover is its automation and application to specialized rolling stock with differentiation of time spent inside the metallurgical plant at the appropriate stages.

The proposed methodology for determining turnover of gondola cars on the access road of a metallurgical enterprise can, in our opinion, find application both at industrial sites in various sectors of the economy of Russia and foreign countries [13, p. 38; 14, p. 435].

REFERENCES

1. Khmelev, A. S., Popov, A. T. Railway freight transportation market review [*Obzor rynka zheleznodorozhnykh gruzoperevozok*]. *School of Young Scientists on the Problems of Technical Sciences: Proceedings of the regional specialized seminar*. Lipetsk, LSTU, 2018, pp. 298–302.

2. Khmelev, A. S., Popov, A. T. Optimization of interaction of an industrial enterprise and operator companies [*Optimizatsiya vzaimodeistviya promyshlennogo predpriyatiya i operatorskikh kompanii*]. *Infocommunication and Intelligent Technologies in Transport IITT 2018: Proceedings of I international scientific and practical conference*. Lipetsk, LSTU, 2018, pp. 262–269.

3. Eliseev, S. Yu., Shatokhin, A. A. Effective use of own cars of transport companies following logistic principles [*Effektivnoe ispolzovanie sobstvennykh vagonov transportnykh kompanii na logisticheskikh printsipakh*]. *Ekonomika zheleznykh dorog*, 2014, Iss. 6, pp. 60–67.

4. Zubkov, V. V., Sirina, N. F. Methods for determining the criteria for effectiveness of the transport-production process [*Metody opredeleniya kriteriev effektivnosti transportno-proizvodstvennogo protsessa*]. *Bulletin of Rostov State Transport University*, 2019, Iss. 3 (75), pp. 100–108.

5. Portnova, O. Yu. On some problems and constraints of development of the regional railway transportation market [*O nekotorykh problemakh i sderzhivayushchikh faktorakh razvitiya regionalnogo rynka zheleznodorozhnykh perevozok*]. *Transport Urala*, 2013, Iss. 2 (37), pp. 32–37.

6. Goosens, J. H. M. Models and algorithms for railway line planning problems. Ph.D. thesis. University of Maastricht, Netherlands, 2004, 182 p. [Electronic resource]: https://mafiadoc.com/models-and-algorithms-for-railway-line-planning_5c347b30097c4766178b4594.html. Last accessed 03.08.2019.

7. Baublys, A. Introduction to the theory of transport systems (Transporto sistemas teorijos ivadas). Vilnius, Technika, 1997, 298 p. (in Lithuanian).

8. On approval of the monitoring procedure for provision of railway rolling stock for cargo owners and the use of railway rolling stock by participants in the transportation process and the methodology for assessing the effectiveness of the use of railway rolling stock. Order of the Ministry of Transport of the Russian Federation of May 5, 2012, No. 136 [*Ob utverzhdenii poryadka monitoringa obespecheniya zheleznodorozhnym podvizhnym sostavom gruzovladeltsev i ispolzovaniya zhelezno-dorozhnogo podvizhnogo sostava uchastnikami perevozochnogo protsessa i metodiki otsenki effektivnosti ispolzovaniya zheleznodorozhnogo podvizhnogo sostava: prikaz Mintransa RF ot 5 maya 2012, № 136*]. [Electronic resource]: http://www.consultant.ru/document/cons_doc_LAW_134024/9e132d50f2de3667a6740624cedc9d5c6e5b4616. Last accessed 03.08.2019.

9. Erofeeva, E. A., Zubkov, V. N. Improvement of the technique of technical standardization of the indicator «car turnover» under conditions of multiplicity of rolling stock operators [*Sovershenstvovanie metodiki tekhnicheskogo normirovaniya pokazatelya «oborot vagona» v usloviyakh mnozhestvennosti operatorov podvizhnogo sostava*]. *Electronic Scientific Journal*, 2016, Iss. 6, pp. 80–89.

10. Zharkova, A. A. Research on efficiency of using rolling stock in interaction of operator companies and industrial transport enterprises [*Issledovanie effektivnosti ispolzovaniya podvizhnogo sostava pri vzaimodeistvii operatorskikh kompanii i predpriyatii promyshlennogo transporta*]. *Bulletin of the Ural State University of Railway Transport*, 2014, Iss. 3, pp. 71–75.

11. Popov, A. T., Suslova, O. A. Optimization of the technological process of industrial railway transport of a metallurgical plant [*Optimizatsiya tekhnologicheskogo protsessa pro/myshlennogo zheleznodorozhnogo transporta metallurgicheskogo kombinata*]. *Promyshlenniy transport XXI vek*, 2006, Iss. 5–6, pp. 37–40.

12. Loginova, I. A., Sukhikh, K. G. Development of a material incentive system under modernization [*Razrabotka sistemy materialnogo stimulirovaniya v usloviyakh modernizatsii*]. *Kazanskaya nauka*, 2010, Iss. 4, pp. 72–77.

13. Parunakjan, V., Sizova, E. Designing of logistical chains inside production and transport system of metallurgical enterprise. *Transport problems*, 2013, Vol. 8, Iss. 1, pp. 35–45.

14. Bowersox, D. J., Closs, D. J. Logistics: Integrated Supply Chain [*Russian title: Logistika: Integrirovannaya tsep' postavok*]. 2nd ed. Moscow, Olymp-Business, 2008, 640 p. ●