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IMPROVEMENT OF THE METHOD FOR STANDARDIZING THE DURATION OF RAIL CARS SHUNTING

Purpose. To improve the method for calculating the time standard for shunting cars from track to track in order to take into account the local operating conditions of railway stations and railway sidings.

Methodology. During the research, the methods of theory of railway operation were used. The problem of calculating the time standard for shunting operation was solved as the problem of searching the optimal division of train set into the car groups to achieve minimal time consumption for shunting operation.

Findings. In the course of the study, the methods for calculating the time standards for initial and final operations, as well as movements performed when shunting cars from track to track were improved. It was proved that the minimum time spent on shunting cars from track to track was achieved when the train set was divided into the minimum possible number of parts and the cars were shunted in the longest possible groups and one remaining group. It was also established that with sufficient accuracy for engineering problems the duration of shunting train set from track to track can be represented by the piecewise linear function of the car number in it.

Originality. The work originality consists in improving the method for calculating the time standard for shunting cars from track to track, that, unlike the existing one, takes into account the length limitations of the car groups being shunted from track to track, as well as the actual composition of operations performed in the process of shunting.

Practical value. The use of the developed method allows setting time standards for shunting cars from track to track, taking into account the local operating conditions of railway stations and sidings of industrial enterprises. The method also makes it possible to simplify solving problems of searching the optimal order of performing more complex shunting operations, such as sorting cars into several tracks, collecting cars on one track, train formation, and others.

Keywords: *railway transport, railway station, railway siding, shunting operation, standardization*

Introduction. Shunting operation is any movement of railway rolling stock along the station and other tracks in order to ensure train service and production activities of industrial enterprise. Shunting operation requires significant time and fuel expenditures, as well as other resources. About 10 % of expenditures associated with general rail transportations are accounted for by this type of operation. A considerable amount of shunting operation is primarily performed at metallurgical and mining enterprises, as well as in seaports. In this regard, studies aimed at improving the organization of shunting operation are relevant both for mainline railway transport and for railway transport of industrial enterprises. One of the main directions of research in this industry is the improvement of methods for choosing the order of shunting operations, as well as the methods for standardizing their duration. This article deals with the elementary problem of standardizing duration of car shunting from one track to another using the lead track.

Literature review. As a result of performing shunting operation, the rolling stock location on the track is being changed. Herewith, as a rule, the same result can be obtained in different ways. Taking into account that the order of performing shunting operation affects consumption of time, fuel and other resources, a problem of searching the best order of performing shunting operations arises.

An important element of the scientific task of improving the order of performing shunting operations is the choice of a criterion for evaluating and comparing various options. An overview of the methods for multistage car sorting is performed in the article [1]. The minimum number of car sorting stages was selected as a criterion for the efficiency of organizing sorting operations. In the work [2], the problem of removing cars from the storage tracks is considered. In this case, the costs of shunting operation are estimated in proportion to the number of car groups that are being shunted. In the work [3], the system costs for sorting cars take into account the number of stages and the number of cars involved in shunting operations. The problem of this approach lies in the fact that, as a rule, there are many options for organizing shunting operation, which are implemented in the same number of stages and the number of cars, but differ in the consumption of time, fuel and other operational indicators. The minimum amount of time spent on performing shunting operations is used as an optimization criterion in many scientific works. The use of the criterion of minimum time expenditures instead of a minimum of the number of sorting operation stages or the number of cars being shunted results in a significant complication of the optimization algorithms and increase in the duration of the search for a solution. Examples of such works are [4], where the time-optimal order of a multi-group train formation is determined by the statistical methods; [5], where the same problem is solved by the methods of graph theory; [6], where a special method based on a multilayer constructive model was developed to search for the optimal order of multi-group train formation.

A detailed estimate of the time spent on performing shunting operation can be obtained as a result of numerical modeling of the transport objects functioning. Description of the simulation model is given in the work [7], a seaport – in the work [8], a multimodal transport terminal – in [9]. Simulation models make it possible to estimate in detail the time spent on performing shunting operations, however, due to their complexity, the direct use of these models in solving optimization problems is difficult. It should also be noted that the options providing the minimum duration of shunting operations, in many cases do not coincide with the options providing a minimum of operating costs, in particular fuel consumption [10], to perform shunting operations. Considering the fact that the procedure for performing a separate shunting operation affects the occupation of tracks, shunting locomotives and, as a rule, the downtime of cars awaiting their release, then to obtain an objective evaluation of the operating costs of railway stations associated with the performing of a separate shunting operation is a rather difficult task. Therefore, to date, optimization of the order of performing shunting operations according to the criterion of minimum operating costs is possible only for certain technological processes occurring on the sidings of industrial enterprises. In this article, the minimum time consumption is chosen as a criterion for comparing the efficiency of various options for performing shunting operations.

Scientific research in the field of standardizing the duration of shunting operations has been under way since the end of the *19*th century and remains relevant today. A historical review of the development of methods for standardizing the duration of shunting operations is carried out in the article [11]. The evaluation of the time spent on shunting operations in Ukraine is carried out based on "Methodological guidelines for the regulation of shunting operation", in Azerbaijan based on "Methodology instructions for calculating the time standards for shunting operation performed in railway transport", in the Russian Federation – on "Time standards for shunting operation performed at the railway stations of Russian Railways JSC, the standards for the number of shunting locomotive crews". The time standards for shunting operations are also set out in the "Service regulations of railway sidings" and other regulatory documents.

Shunting cars from one track to another is a basic operation when standardizing more complex shunting operations, in particular when standardizing the time for collecting cars from different tracks, as well as when standardizing the time for assembling of one- and two-group trains, whose consists are accumulated on two tracks. In both cases, the time standard in minutes for car shunting from track to track is calculated as

$$T_{sh} = P + Em_c. \tag{1}$$

The values of the parameters P and E were set equal to $P =$ = 1.8 min and E = 0.3 min/car as early as in 1978 and are still the same.

The use of the existing technique for an adequate evaluation of the duration of complex shunting operations is associated with a number of difficulties, the main of which are the following. Firstly, the calculation of time standards is based on the average conditions for the railway network, which in many cases do not take into account the local peculiarities of the operation of railway stations and sidings of industrial enterprises. Secondly, the time standards for the railway network were set back in the middle of the *20*th century, when cars with slider bearings were operated, and shunting masters had assistants. Over the past time, the operating conditions of railway transport have changed, which in many cases, was reflected in the list and duration of elementary operations performed in the process of shunting operation. Thirdly, when deriving formulas for determining the duration of complex shunting operations, it was assumed that if the need for train set division into parts arises, then these parts have the same length. Such assumptions were criticized; however, this issue was uninvestigated in scientific papers. As a result of the compliance analysis of the actual duration of shunting operations performed on the sidings in Ukraine (Poltava Mining and Processing Plant OJSC, Northern Mining and Processing Plant PJSC, Zaporizhstal PJSC, ArcelorMittal Kryvyi Rih PJSC, Transinvestservice LLC) and in Azerbaijan (AzMetal Trade Service LLC, Service Invest LLC, Metal MVS LLC) with the standard values, it was established that the current time standards for shunting movements do not correspond to the real operating conditions of railway transport and require revision. Therefore, the problem of standardizing the duration of rail car shunting from track to track has not been finally resolved and it requires additional research.

Purpose. The article is aimed to improve the method for calculating time standards for shunting of cars from track to track taking into account local operating conditions of railway stations and railway sidings.

Methods. When formalizing the task of calculating time standards for cars shunting from track to track, we will use the following assumptions. Shunting operation is performed in the station park, which consists of one lead track, a lead and two sorting tracks. One shunting locomotive is used for car shunting. We assume that before shunting operation there are m_c cars connected to each other on track 1.We will call the group of coupled cars a train set. The train set must be shunted to track 2 free of cars. It is assumed that all cars have the same mass and length. Shunting of cars from track to track can be carried out in z stages ($1 \le z \le m_c$), while the number of cars in the group that is being shunted at the i^{th} stage is m_i ($i = 1; z$). The maximum number of cars in group $m$max that is being shunted can be limited by the length of the lead track, the power of the shunting locomotive, braking conditions, and so on. Uncoupling and coupling of cars, as well as their fixation are performed by a shunting master. When the cars are moving forward, the shunting master must be on the first car in the movement direction. When an empty locomotive moves between the tracks, the shunting master is in the locomotive. Maximal speed during shunting operations may be limited by the value $v$max. The cars that are on the track without a shunting locomotive must be fixated with brake shoes on the side opposite to the lead track.

Shunting operation is time-consuming. Therefore, the problem of choosing the order of cars shunting from track to track can be formulated as the problem of optimizing the number of parts z into which the shunting train set should be split and the number of cars m_i in each of these parts at which the total duration of cars shunting will be minimal

$$\sum_{i=1}^{z} T_{sh}(m_i) \to \min, \tag{2}$$

with the limitations

$$\begin{cases} z \in \{1, 2, \dots, m_c\} \\ \sum_{i=1}^{z} m_i = m_c \\ m_i \in \{1, 2, \dots, m_{\max}\} \end{cases}. \tag{3}$$

The subsequent parts of the article are devoted to the concretization and study on the properties of the function $\sum_{i=1}^{z} T_{sh}(m_i)$.

The variables z and m_i are integer-valued and their values are limited. Therefore, the total number of options for solving the problem is limited and the minimum value of the objective function (5) can be found by exhaustive enumeration of all possible options. For train sets of m_c cars, the number of possible options for their shunting from one track to another is

$$N = \sum_{j=1}^{m_c} \frac{(m_c - 1)!}{(j-1)!(m_c - j)!} = 2^{m_c - 1}.$$

Considering that in the 1520 mm railway network the standard length of station tracks is 57–86 cars, it is impossible to enumerate all options for shunting long trains from track to track. Moreover, the time spent on evaluating the duration of cars shunting from track to track should also be minimized for short trains, as this problem is repeatedly solved as part of more complex problems of searching the optimal order of performing complex shunting operations, such as sorting, collecting cars, train formation, and others [5, 6, 9]. Therefore, it is necessary to develop a method for solving the problem (2) under limitations (3), which requires a minimum amount of computational work.

The time spent on performing the shunting operation can be divided into the time spent on the initial and final operations T_{se} and the time spent on the shunting movements T_m

$$\sum_{i=1}^{z} T_{sh}(m_i) = \sum_{i=1}^{z} T_{se}(m_i) + \sum_{i=1}^{z} T_m(m_i). \quad (4)$$

The total duration of the initial and final operations includes the time spent on operations associated with the beginning and end of shunting movements T_r, coupling of car groups to the locomotive T_{cc} and their uncoupling T_{uc}. The duration of shunting movements includes the time spent on the movement of shunting locomotive with and without cars between the station tracks T_m.

To shunt the train set from one track to another in one group, two shunting movements should be performed. When dividing the train set into parts, to shunt each additional group of cars from track to track, two movements of the locomotive without cars and two movements of the locomotive with cars should be performed. The total number of shunting movements when dividing the train set into z parts is

$$K_{sh} = 4z - 2.$$

Each of the shunting movements K_{sh} is associated with the time expenditures t_{rt} on preparing their routes, as well as the time expenditures on transmitting commands and reports between the station attendant, the shunting master and the locomotive driver. The total duration of all these operations is

$$T_r = (4z - 2)t_{rt}.$$

If the shunting operation is performed without engagement of car brakes, then the total time spent on performing all operations on coupling car groups to the locomotive on track 1 can be calculated using the formula

$$T_{cc} = z(t_s + t_{cl} + t_{uc}) + t_{uf} - t_{uc} + m_c t_{sc}, \quad (5)$$

where t_s is the time standard for the shunting master to come down from the footboard of a car or locomotive to the ground and to climb from the ground onto the footboard of a car or locomotive, min; t_{cl} is time standard for coupling locomotive to the car group, min; t_{uc} is time standard for uncoupling cars, min; t_{uf} is time standard for removing fixation of cars, min; t_{sc} is time standard for passage of shunting master along one car, min.

If the shunting operation is carried out with the engagement of the car brakes, then the time spent on filling the brake system of the cars with air and testing the automatic brakes must be taken into account. In addition, the time standards for coupling and uncoupling groups of cars to a locomotive should take into account the time expenditures on connecting and disconnecting the brake line of the locomotive and cars.

The total time spent on performing all operations to uncouple groups of cars from the locomotive on track 2 can be calculated using the formula

$$T_{uc} = z(t_s + t_c + t_{ul}) + t_f - t_c + m_c t_{sc}, \quad (6)$$

where t_c is time standard for coupling two groups of cars, min; t_f is time standard for car fixation, min; t_{ul} is time standard for uncoupling locomotive from cars, min.

Local conditions, primarily the number of people in the shunting crew and the requirements for fixation of cars on the tracks, can lead to some change in the list of operations, which are taken into account by expressions (5, 6).

In general, the duration of the initial and final operations linearly depends on the number of parts into which the train set is divided during shunting from track to track, as well as on the total number of cars in the train set

$$\sum_{i=1}^{z} T_{se}(m_i) = T_{se} = a_{se} + b_{se} z + \tilde{n}_{se} m_c, \quad (7)$$

where a_{se}, b_{se}, c_{se} are constant coefficients

$$a_{se} = t_f + t_{uf} - t_c - t_{uc} - 2t_r;$$

$$b_{se} = 4t_r + 2t_s + t_{cl} + t_{ul} + t_{cc} + t_{uc}; \quad c_{se} = 2t_{sc}.$$

The splitting of train set into parts in the process of its shunting from one track to another leads to a change in the conditions for the acceleration and braking of groups of cars, as well as to a change in the distances that a shunting locomotive overcomes with cars and without cars. In this case, the simplest task is to compare the time spent on shunting the whole train set from track to track in one stage and shunting of the two parts of the train set in two stages.

Currently, for standardizing the duration of shunting movements in minutes, the following formula is used

$$t_{sm} = \frac{0.06 l_{sm}}{v_{\max}} + \frac{(\alpha + \beta m_c) v_{\max}}{120}, \quad (8)$$

where α is the coefficient taking into account the time spent on changing the locomotive movement speed by 1 km/h during acceleration and time spent on changing the locomotive movement speed by 1 km/h during braking s/km/h; β is the coefficient taking into account the extra time to change the speed of each car in the shunting train set by 1 km/h during acceleration and the extra time to change the speed of each car in the shunting train set by 1 km/h when braking, s/km/h per car; $v$max is maximum permissible movement speed during shunting, km/h; l_{sm} is length of movement route, m.

The first summand in (8) is the time required to cover the distance l_{sm} with the maximum permissible speed $v$max, and the second one is the extra time to accelerate the train set to the speed $v$max at the start of movement and braking from the speed $v$max until stopping at the end. It should be noted that when deriving expression (8), it is assumed that shunting movement includes three elements (acceleration, movement at a constant speed and braking). Therefore, expression (8) gives an incorrect result for the movements at distances less than

$$l_{ab} = \frac{(\alpha + \beta m_c) v_{\max}^2}{7.2}, \quad (9)$$

since these movements consist only of acceleration and braking elements.

There are also more complex methods for evaluating the time spent on performing shunting movements. In particular, in the work [12], the duration of shunting movements is established on the basis of observations. The method of traction calculations was used to calculate the duration of shunting movements in the work [13] when estimating the characteristics of a shunting locomotive with a hybrid power plant. In the work [14] this method was used to estimate the characteristics of a mining locomotive with a new transmission, in the work [15] when selecting the optimal characteristics of a shunting locomotive, etc. However, as a rule, due to their cumbersomeness, these methods are not used directly for solving the problems of standardization, but used only to estimate the parameters α and β of the model (8).

Dividing the train set into two parts leads to an increase in the total distance traveled by the locomotive. At the same time, when the train set is divided, the acceleration and braking of each of its parts is more intensive than that of the whole train set. This allows developing a high movement speed and, potentially, may reduce the total time of the shunting operation. Considering that the acceleration of the individual train set parts more intensive than that of the whole train set, the presence of the speed limitation *v*max leads, first of all, to an increase in the movement duration of the train parts and only then of the whole train set. This fact definitely worsens the performance of the option with the train set division. Therefore, the study considers in detail the option without movement speed limitation. To determine the duration of shunting movements, consisting only of acceleration and braking, it is necessary to substitute the equality in expression (8)

$$v_{\max} = \frac{0.12 l_{sm}}{t_{sm}}.$$

After transforming the expression, we obtain a formula for estimating the duration of shunting movements when moving at distances less than (8)

$$t_{sm} = \sqrt{\frac{l_{sm}(\alpha + \beta m_c)}{500}}. \quad (10)$$

To simplify further calculations, the shunting distances from track to track will be measured in conventional cars of length l_c. As a result, expression (10) can be represented as

$$t_{sm} = 0.012\sqrt{d_{sm}(\alpha + \beta m_c)}, \quad d_{sm} = l_{sm}/l_c.$$

The design scheme for determining the train set shunting duration from track to track is shown in Fig. 1.

The operation of shunting the whole train set from track 1 to track 2 includes $K_{sh} = 2$ movements with a total length

$$D_1 = d_1 + d_2 + 2m_c,$$

and total duration

$$T_{m1} = 0.012\sqrt{(\alpha + \beta m_c)}\left(\sqrt{(d_1 + m_c)} + \sqrt{(d_2 + m_c)}\right). \quad (11)$$

The operation of shunting two train set parts m_1 and m_2 ($m_1 + m_2 = m_c$) from track 1 to track 2 includes $K_{sh} = 6$ movements with a total length

$$D_2 = 3d_1 + 3d_2 + 4m_c,$$

and total duration

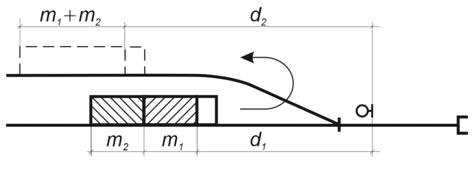

Fig. 1. Design scheme for determining the duration of train set shunting from track to track

$$\begin{aligned} T_{m2} &= 0.012\sqrt{(\alpha + \beta m_1)}\left(\sqrt{(d_1 + m_1)} + \sqrt{(d_2 + m_{\tilde{n}})}\right) + \\ &+ 0.012\sqrt{(\alpha + \beta m_2)}\left(\sqrt{(d_1 + m_c)} + \sqrt{(d_2 + m_2)}\right) + \\ &+ 0.012\sqrt{\alpha}\left(\sqrt{(d_1 + m_1)} + \sqrt{(d_2 + m_2)}\right). \end{aligned} \quad (12)$$

To estimate the possibility of reducing T_m value by dividing the train set into two parts, let us estimate the difference in the movement duration squares of locomotive with the cars when the train set is being shunted in two groups and one group along track 1 $(t_{21} + t_{22})^2 - t_{11}^2$, and along track 2 $(t_{23} + t_{24})^2 - t_{12}^2$ (here t_{11}, t_{12} – locomotive movement duration with cars, respectively, along tracks 1 and 2 when shunting the whole train set from track to track; t_{21}, t_{22} – locomotive movement duration with cars along track 1 of the *1st* and *2nd* train set parts, respectively; t_{23}, t_{24} – locomotive movement duration with cars along track 2, respectively, of the *1st* and *2nd* train set parts). After substitution and simplification of expressions, we obtain

$$\begin{aligned} (t_{21} + t_{22})^2 - t_{11}^2 &= 0.000143\big((d_1 + m_1)\alpha + \\ &+ 2\sqrt{\alpha + \beta m_1}\sqrt{\alpha + \beta m_2}\sqrt{d_1 + m_1}\sqrt{d_1 + m_c} - 2\beta m_1 m_2\big). \end{aligned}$$

Taking into account that

$$(d_1 + m_1)\alpha > 0; \quad \sqrt{d_1 + m_1}\sqrt{\alpha + \beta m_1} > m_1\sqrt{\beta};$$
$$\sqrt{d_1 + m_c l_c}\sqrt{\alpha + \beta m_2} > m_2\sqrt{\beta}, \quad \text{then } (t_{21} + t_{22})^2 - t_{11}^2 > 0.$$

Therefore $t_{21} + t_{22} > t_{11}$. Similarly, it can be proved that $(t_{22} + t_{26})^2 - t_{12}^2 > 0$ and, respectively, $t_{23} + t_{24} > t_{12}$. Since $t_{21} + t_{22} > t_{11}$, $t_{23} + t_{24} > t_{12}$, and the time spent on the movement of a single locomotive is a positive number, then

$$T_{m2} > T_{m1}. \quad (13)$$

Considering that the presence of the movement speed limitations when shunting leads, first of all, to a speed decrease in performing shunting operations with individual train set parts, then expression (13) is also valid in the presence of movement speed limitations.

Train set division into parts during shunting from one track to another is mandatory if $m_{\max} < m_c$. In this case, when shunting the train set of two parts in two stages, the variable m_1 can take on values belonging only to the set

$$m_1 \in \{m_{\min}, m_{\min} + 1, \ldots, m_{\max}\},$$

where $m_{\min} = m_c - m_{\max}$. In this case, the following condition must be satisfied $m_c/2 \le m_{\max} < m_c$.

In the process of shunting with different division of *m*c cars between the given number of their groups *z*, the shunting locomotive always covers the same distance, and the number of cars in the groups m_i affects only the conditions of their acceleration and braking. The total duration of shunting the train set from track to track in two stages can be determined as

$$T_2(m_1) = B_1(m_1) + E_1(m_1) + B_2(m_1) + E_2(m_1), \quad (14)$$

where $B_1(m_1)$, $B_2(m_1)$ are respectively, the duration of the shunting the cars of the first and that of second parts of the train set from track to track, depending on the number of cars m_1; $E_1(m_1)$, $E_2(m_1)$ are respectively, the movement duration of a single shunting locomotive along track 1 and along track 2, depending on the number of cars *m*1.

If there are no movement speed limitations, the values $B_1(m_1)$ and $E_1(m_1)$ nonlinearly increase with an increase in the number of cars m_1. At the same time, the growth rate of the duration of shunting from track to track with an increase in the number of cars somewhat decreases due to the increase in the shunting distance and the possibility of achieving a higher movement speed. And vice versa, the values $B_2(m_1)$ and $E_2(m_1)$ decrease nonlinearly with an increase in the number of cars in the first group m_1. In this case, the rate of decrease in the shunting duration increases with increasing value m_1. An example of dependencies $B_1(m_1) + E_1(m_1)$, $B_2(m_1) + E_2(m_1)$ and $T_2(m_1)$ is shown in Fig. 2.

Given the form of the dependencies $B_1(m_1)$, $B_2(m_1)$, $E_1(m_1)$ and $E_2(m_1)$, their sum $T_2(m_1)$is a function convex upward. The minimum of this function is achieved at one of the limitations $m_1 = m_c - m_{\max}$ or $m_1 = m_{\max}$ when shunting the train set of the maximum permissible length at one of the stages, and the rest of the cars at the other stage. At which of these two limitations the minimum of function (14) will be attained depends on the ratio of the lengths d_1 and d_2.

In the case when all shunting movements achieve the speed *v*max, the value $T_2(m_i)$does not depend on m_i as, according to expression (8), for all options of dividing the train set into groups, both the time spent on acceleration and braking and the travel distance at a speed *v*max coincides.

In general, with a decrease in the permissible speed of shunting operation *v*max, the difference in the duration of shunting the train sets from one track to another for different options of car division between the given number of car groups *z* decreases (Fig. 3). The train set division into parts in the process of its shunting from track to track leads to an increase in the time spent on both initial and final operations, and shunting movements. Therefore, if there are no operational limitations, the division of the train set into parts in the process of its shunting from one track to another is irrational. Considering that under conditions of the train set length limitation, in order to achieve the minimum duration of the shunting operation, the train set of the maximum length must be shunted from track to track, then, if there are length limitations on the groups of cars being shunted, the train set must be divided into the minimum number of parts.

The minimum time required for shunting train sets in parts is achieved when the value of $z - 1$ groups of cars is $m_{\max}$ of cars, and the rest is shunted at the first or last stage.

Results. The studies presented in Section 4 are of a general nature. However, a number of simplifications can be adopted for the current operating conditions of railway stations, such as time standards for elementary operations, the possible number of cars in train sets, the length of locomotives and cars, the length of the leads and station tracks when estimating the time on shunting the train sets from track to track.

An example of the dependencies of the duration of car shunting from track to track on the number of cars is shown in Fig. 4.

In general, if there are no length limitations of the car groups being shunted from track to track, with accuracy sufficient for practical purposes, we can assume that the dependency $T_{sh}(m_c)$ is linear and can be represented by function (3). At the same time, the values of the parameters *P* and *E* in expression (3) significantly depend on the local operating conditions of the stations and sidings. Depending on them, the value of parameter *P* can vary from 4.9 to 14.4 min, and parameter *E* – from 0.39 to 1.17 min/car.

If there are length limitations of the car groups being shunted from track to track, the dependency $T_{sh}(m_c)$ is described by a piecewise linear function with different values of the parameters *P* and *E* for different intervals. Due to the significant difference in the parameters *P* and *E*, the use of their average network values does not allow obtaining adequate time standards for shunting train sets from track to track for a particular station. Therefore, it is advisable to set the values of the parameters *P* and *E* by calculation for each station or siding separately.

At present, the shunting of cars from track to track is carried out under conditions of limiting the movement speed *v*max at the level of 10–25 km/h. It should be noted that, based on expression (9), an increase in the number of cars in a train set when performing shunting operation at speeds up to 31.75 km/h leads to a decrease in the distances d_1 and d_2 necessary to achieve the maximum permissible movement speed *v*max. As a result, now most of the movements for car shunting from track to track occur when reaching the speed *v*max, and, with the same value of *z*, the difference in the shunting duration when varying the values of *m*i is insignificant. Therefore, to create favorable conditions for the operation of locomotives, shunting the train sets from track to track can be performed in parts close to *mc*/*z*.

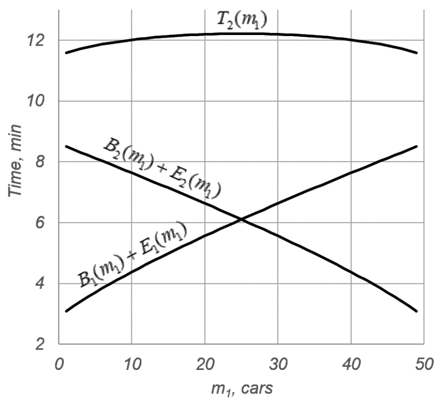

Fig. 2. Dependencies of the duration of shunting a train set from track to track in two stages on the number of cars m_1

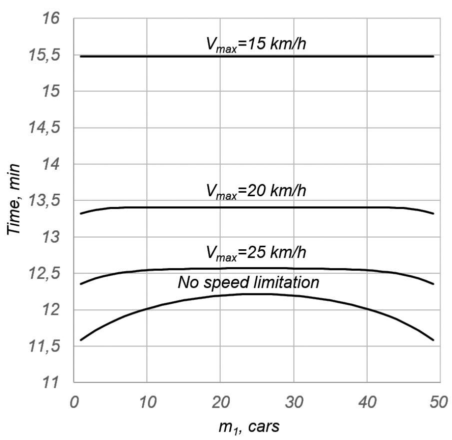

Fig. 3. Dependencies of the duration of shunting a train set of 50 cars from track to track in two stages on the number of cars m_1 for different values of the permissible speed of shunting

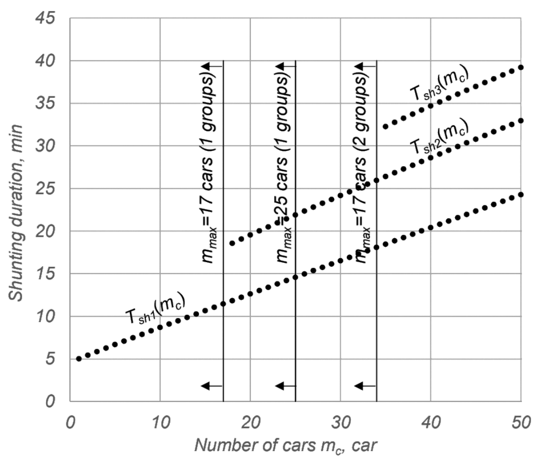

Fig. 4. Dependencies of the duration of car shunting from track to track on the number of cars in the train set

The duration of the initial and final operations when performing shunting of cars from track to track without engagement of auto-brakes of cars is

$$T_{se} = 0.4 + 3.2z + 0.28m_c,$$

and in the case of performing shunting operation with engaged auto brakes of cars, it is

$$T_{se} = 0.4 + 7.4z + (0.14 + t_{br})m_c,$$

where t_{br} is time spent on filling the braking system of one car with air, min/car.

When shunting cars from track to track, the duration of the initial and final operations exceeds the duration of shunting movements. Therefore, when evaluating the load on the technical means of stations and sidings, the time spent on these operations should be taken into account as necessary. In particular, when evaluating the loading of shunting locomotives, the total duration of the operation, which is determined by formula (4), should be taken into account. At the same time, when evaluating the leads occupancy, only a part of the duration of shunting from track to track should be taken into account, determined by the formula

$$\sum_{i=1}^{z} T_{sh}^{*}(m_i) = \sum_{i=1}^{z} T_r(m_i) + \sum_{i=1}^{z} T_m(m_i).$$

The originality of the work consists in improving the method for calculating the time standards for shunting cars from track to track, which, unlike the existing one, takes into account the length limitations of the car groups being shunted, as well as the actual composition of operations performed in the process of shunting work. The use of the developed method makes it possible to set the time standards for cars shunting from track to track, taking into account the local operating conditions of railway stations and sidings of industrial enterprises, as well as to simplify solving the problems of finding the optimal order of performing more complex shunting operations, such as sorting cars into several tracks, collecting cars on one track, trains formation, and others.

Conclusions. The studies performed allow us to draw the following conclusions:

1. The minimum duration of cars shunting between two tracks is achieved by dividing the trains into the minimum possible number of parts.

2. When solving the problem of standardizing the duration of shunting operations if there are length limitations for groups of cars being shunted from track to track, the time calculation must be performed to shunt the car groups of the maximum permissible size and one group from the rest of the cars. Under operational conditions, with modern values of the speed limitations for performing shunting operations, it is permissible to divide the train set into groups of close lengths, since the difference in the duration of the shunting operation in this case slightly differs from the minimum possible.

3. Modern typical time standards for collecting cars, as well as for the completion of train formation, were developed in 1978 and by now, they no longer correspond to the operating conditions of railway transport. In this regard, the methodology for standardizing the duration of the car shunting from track to track and the time standards for complex shunting operations depending on it should be revised in order to take into account the peculiarities of the operation of railway stations and sidings. The duration of the shunting operation of cars shunting from one track to another linearly depends on the number of cars involved, as is assumed by the current methodology; however, due to the significant scatter in the values of the linear model coefficients, they must be set for each station and siding individually.

4. When shunting cars from track to track, the duration of the initial and final operations that can be performed within the useful track length exceeds the duration of shunting movements. Therefore, when evaluating the loading of the leads of railway stations and sidings, the time spent on these operations should be taken into account as necessary.

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Удосконалення методу нормування тривалості перестановки вагонів

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Мета. Удосконалення методу розрахунку норм часу на маневрову операцію перестановки вагонів із колії на колію для можливості врахування місцевих умов роботи залізничних станцій і під'їзних колій.

Методика. У ході досліджень використані методи теорії експлуатації залізниць. Задача розрахунку норм часу на виконання маневрової операції перестановки вагонів вирішена як задача пошуку оптимального розподілу состава на групи вагонів з метою досягнення мінімуму витрат часу на маневрову роботу.

Результати. У ході дослідження вдосконалені методи розрахунку норм часу на початкові й кінцеві операцій, а також на маневрові пересування, що виконуються у процесі перестановки вагонів. Доведено, що найменші витрати часу на перестановку вагонів завжди досягаються за поділу состава на мінімально можливу кількість частин і при перестановці вагонів групами максимально можливої довжини та однієї групи залишку. Установлено, що з достатньою для вирішення інженерних задач точністю тривалість перестановки вагонів може бути представлена кусочно-лінійною функцією.

Наукова новизна. Полягає в удосконаленні методу розрахунку норм часу на перестановку вагонів із колії на колію, що, на відміну від існуючого, ураховує наявність обмежень довжини груп вагонів, які переставляються, а також фактичний склад операцій, що виконуються у процесі маневрової роботи.

Практична значимість. Використання розробленого методу дозволяє встановлювати норми часу на перестановку вагонів із колії на колію, що враховують місцеві умови роботи залізничних станцій і під'їзних колій промислових підприємств, а також спростити вирішення задач пошуку оптимального порядку виконання більш складних маневрових операцій, таких як сортування вагонів на декілька колій, збирання вагонів на одну колію, формування составів та інші.

Ключові слова: *залізничний транспорт, залізнична станція, під'їзна колія, маневрова робота, нормування*

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