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Development of Analytical Methods for Calculating Time Standards for Shunting Operations

Purpose. The article is aimed to conduct a historical analysis of the development of analytical methods for standardizing the duration of shunting operations, as well as assessing their compliance with the existing operating conditions of railway transport. **Methodology.** The research in this article was carried out on the basis of an analysis of literary sources and methods of the theory of the organization of the operational work of railways. **Findings.** The standardization of the duration of shunting operations is one of the most important tasks of the theory of operational work of railways. The existing method of standardizing the duration of shunting operations developed in the first half of the 20th century and is used to this day. The performed analysis shows that the scientific principles underlying it generally correspond to the modern conditions of the railway transport. Additional research in this area can be associated with assessing the influence of the initial location of cars on the tracks on the average duration of shunting operations, taking into account the influence of length restrictions of the cars groups being moved, as well as monitoring the implementation of established norms by statistical methods. The article also shows that the values of modern time standards for shunting operations, in many cases, are set for technical means and technologies that were used in railway transport in the 50–70s of the 20th century and do not correspond to the operating conditions of real stations and sidings of industrial enterprises. Therefore, they require revision. **Originality.** In this paper, based on historical analysis, the process of development of methods for setting the time for shunting operations is described and the factors influencing the current value of norms are established. **Practical value.** The research results make it possible to identify the reasons for the discrepancy between the existing time standards for performing shunting operations and the real operating conditions of stations and sidings of industrial enterprises, as well as to establish the main elements of the methodology for standardizing the duration of shunting operations that require revision.

Keywords: railway transport; railway station; private siding; shunting operations; time standards

Introduction

Shunting is one of the main elements of the freight railway transportation. Shunting operation is any movement of railway rolling stock along the station and other tracks in order to provide train operation and production activities of the enterprises. Shunting includes all movements of rolling stock along station tracks, including traveling outside the station, as well as displacements along the sidings, except for the movement of trains from and to the railway line. Shunting operation requires significant amount of time, fuel, and other resources. About 10% of expenditures associated with general rail transportations are accounted for by shunting operation. Moreover, a considerable amount of shunting operations is primarily performed at metallurgical and mining enterprises, as well as in the seaports. Recently, there have been significant changes in the operating conditions of railway transport. An increase in the share of own cars resulted in the need for additional selection of cars according to the owners, and the aging of the freight car fleet – according to the technical condition. Under these conditions, one of the most important tasks of the theory of operational work of railways is the regulation of the duration of shunting operations. The existing methodology for standardizing the duration of shunting operations was formed in the first half of the 20th century. During this time, significant changes have occurred, both in the conditions and

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technology of railway transport operations, as well as in the mathematical methods used to calculate the norms. Therefore, studies aimed at performing a historical analysis of the development of methods for standardizing the duration of shunting operations are relevant. The issues of standardizing can become even more relevant in the future with the adoption of the new Law of Ukraine «On Railway Transport». Its draft provides for the separation of station services into a separate type of additional and auxiliary services of the railway infrastructure, as well as the presence of technological processes of sidings operation at the enterprises.

Scientific methods of standardization of technological processes are based on their mathematical models. At present, the methods of simulation of technological processes on a computer are becoming increasingly popular when assessing the performance of railway stations and sidings of industrial enterprises [1, 3, 6, 33–35, 37]. However, this in no way diminishes the importance of developing analytical methods that establish functional dependencies between the performance indicators of railway transport and the factors influencing them. These methods make it possible to obtain the necessary estimates with insignificant labor costs; they can be directly used in optimization procedures, as well as make it possible to assess the influence of individual factors on certain operation indicators of the railway transport.

Purpose

The purpose of this article is to conduct a historical analysis of the development of analytical methods for standardizing the duration of shunting operations, as well as assessing their compliance with the existing operating conditions of railway transport.

Methodology

According to the definition, standardizing is the process of establishing maximum permissible or optimal regulatory values in various fields of activity. One of the most common rationing problems, which is solved in railway transport, is the standardizing the duration of shunting operations. In the general case, the value of the time standards for shunting operations depends on the calculation methodology applied, which establishes how and what operational indicators should be taken into account, and depends on the established time standards for their performing.

The regulatory and reference base that regulates the process of standardizing the duration of shunting operations in Ukraine is composed by the following documents:

– «Methodology instructions for calculating the time standards for shunting operation performed in railway transport» [10], which regulate the process of standardizing the duration of shunting operations in the traffic economy of Ukrzaliznytsia JSC;

– «Service regulations of railway sidings» [19], regulating the interaction of Ukrzaliznytsia JSC and the enterprises-owners of sidings;

– «Manual for the design of industrial railway stations (to Building Codes and Regulations 2.05.07-85)» [18], which regulates the procedure for determining the required technical equipment of the industrial stations under design;

– other normative and reference documents.

These documents contain calculation methodologies, time standards for shunting movements, preparatory and final operations, and complex shunting operations.

It should be noted that the methods for calculating the time standards for shunting operations set forth in these documents have both common features and differences. As an example, the formula for time standard for train sorting can be considered. According to [10], this standard should be established from the expression

$$T_c = Ag + Bn, \quad (1)$$

and according to [18] from the expression

$$T_c = 1,2\left(Agk_g + Bnk_n\right)k_{cur} + t_{cp}, \quad (2)$$

where A, B – are constant coefficients, depending on the method of performing shunting operation, measured respectively in min/cut and min/car; g, n – respectively, the number of cuts and cars in the train; k_g, k_n – repeat coefficients of sorting cuts and cars; k_{cur} – coefficient that takes into account increase in the time of sorting cars when the lead track is located in the curves of a small radius; t_{cp} – time for coupling groups of cars on the track, min.

Both of the given expressions represent linear dependences of the duration of the shunting operation on the number of cuts and cars in the train.

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However, expression (2) takes into account a larger number of factors and has a more complex structure than expression (1). In addition, the presence of a factor of 1.2 and a larger value of the coefficient B leads to the fact that the calculation by formula (2) for the same conditions gives a significantly longer time standard for sorting cars as compared to expression (1). Taking into account that both expressions describe the same process, documents [10] and [18] require agreement. It should be noted that the time standards for performing shunting operations are directly or indirectly used to solve the following tasks:

– substantiation of the sufficiency of technical equipment for the development of the planned volume of work, or the need for its development;

– technical regulation of the work of railways;

– setting standards for the time and cost of transport services during the preparation of contracts for transport services between Ukrzaliznytsia JSC and enterprises, as well as between enterprises.

Under these conditions, the problem of the adequacy of time standards for shunting operations that really occur in railway transport becomes very relevant.

The research in this article was carried out based on analysis of literary sources and methods of the theory of organizing the operational work of railways. The problem of standardizing the duration of shunting operations has more than 100 years of history, and many prominent scientists in the field of railway transport have devoted their work to its solution. Separate articles are devoted to the study of the scientific contribution of these scientists, which contain additional information on the essence of the issue [16, 25, 26].

Findings

The issue of standardizing the duration of shunting operations has always been relevant for the organization of the operational work of railways. According to [4], engineer Rikhter I. I., assistant of the head of the Nikolayev railway proposed the first standards for the organization of shunting operations at stations in 1877. I. I. Rikhter emphasized the importance of the problem of organizing shunting operation in his work «Notes on the reorganization of stations on the Nikolayev railway» published in 1878, where he indicated that about 40% of train delays are associated with unsatisfactory organization of shunting operations at stations.

According to [5], in the 30s of the 20th century, there already existed a «Manual on the organization of shunting operation at large stations.»

Subsequently, based on the prevailing theory of shunting operation, the standard station of the Ministry of Railways of the USSR in 1955 developed (in accordance with [27]), approved in 1956, and in 1957 published the «Guide for the technical standardization of shunting operation»[20] (hereinafter referred to as «Guide»). Subsequently, the «Guide» was reprinted several times in the USSR [21–24], and after its collapse in the Russian Federation [11, 13] and in Ukraine [10]. An important factor that must be taken into account when analyzing the change in the time standards for shunting operations is that until 1978 the standardization unit was an accounting two-axle car with an estimated length of 7.5 m [20–23]. At the same time, in the problems of rationing and planning, a four-axle car was taken into account as two two-axle cars, a six-axle car – as three, etc. After 1978, the standardization of the duration of shunting operations began to be performed for a four-axle car with an estimated length of 15 m [24].

Scientific research aimed at developing methods for setting the duration of shunting operations started at the end of the 19th century and have not lost their relevance to this day.

One of the main indicators that is subject to standardization when performing shunting operation is the duration of shunting movement. To normalize this indicator at the early stages of the development of railways, the formula for the duration of uniform movement was used. Thus, in [15, 17], to determine the duration of shunting operations in minutes, the following formula was used

$$t_{mov} = \frac{0.06 l_{mov}}{v_{mov}}, \quad (3)$$

where l_{mov} – length of movement route, m; v_{mov} – movement speed of shunting train, km/h.

The problem of using expression (3) to normalize the duration of shunting operations is associated with the complexity of estimating the value v_{mov} depending on the operating conditions. Therefore, expression (3) is used, as a rule, only in educational

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literature, and in the practice of railways, other approaches are used.

The world's first scientific research related to the study of shunting at railway stations was carried out in the Russian Empire by an engineer (later professor) A. N. Frolov. In 1899, he performed the timing of the duration of shunting operations at the stations Rtishchevo and Atkarsk [29, 30]. Based on the statistical processing of the results of these observations, A. N. Frolov established a relationship between the number of cars in a shunting train and the time spent on a shunting trip (movement of a locomotive or locomotive with cars with a change in direction)

– in the daytime

$$t_{mov} = 3.6 + 0.10n\,;$$

– in nighttime

$$t_{mov} = 4.5 + 0.12n\,;$$

– in average

$$t_{mov} = 4.07 + 0.112n\,.$$

Professor I. I. Vasilyev performed an analysis and generalization of theoretical studies based on the traction calculations of engineers M. M. Protodyakonov, A.M. Gribanov, and others, as well as field observations of the operation of real stations. Based on the studies performed, it was concluded that the duration of shunting semi-trips (shunting movement without changing direction) and shunting trips (shunting movement with changing direction) is linearly dependent on the number of cars in the train.

$$t_{mov} = a + bn\,, \qquad (4)$$

where a, b – coefficients, the values of which are determined based on observations of the station operation, measured respectively in min and min/car.

The results of these studies are published in [2]. This work also noted a significant difference in the value of the coefficient a of expression (3), obtained by Prof. Frolov A. N. based on time observations and traction calculations. It is indicated that it is caused by additional operations performed during shunting movements, such as coupling and uncoupling cars, transmitting and receiving commands, changing locomotive operating mode, etc. The method for estimating the parameters a and b of the model (4) based on time observations is given in [2, 21]. At the same time, it was noted that during observations, one should record idle period and cases of irrational methods of its performing. The implementation of these provisions of the methodology is associated with a significant amount of subjectivity. Moreover, in different conditions, locomotive drivers can perform shunting at different speeds, which is not fixed by the methodology [2, 21]. Therefore, the collection and interpretation of statistics on the duration of shunting operations is time-consuming and must be performed by qualified observers. «Guide» [21] also gives the network time standards a and b for the semi-trips of displacement. The value of the coefficient a was set depending on the movement distance, and b on the movement distance and the state of the brakes of cars in the train (engaged or disengaged). Starting from the 3rd edition of the «Guide» [22], only network time standards a and b began to be published without a methodology for obtaining them for each station. As a result, the connection between the time standards for car displacement and the local operating conditions of railway stations and sidings was lost. Formula (4) was adopted as the main method for standardizing the duration of shunting movements since 1964 [21] and was used until the collapse of USSR, as well as in the Russian Federation until 1998 and in Ukraine until 2003. The values of the coefficients a and b were slightly corrected in 1972 in [23]. In 1978, the values of the coefficients b were doubled due to the transition to calculation in four-axle cars instead of two-axle cars [24].

Modern studies of the dependence of duration of shunting movements on the number of cars in the train, the route length and the maximum allowable speed [36], carried out based on the methods of planning factorial experiments, indicate that there is no reason to reject the linear dependence of the duration of car rearranging on these factors.

In addition to the coefficients a and b for calculating the time standards for displacement of cars, the coefficients a and b were also given in [20] to determine the duration of cars movement performed as part of complex shunting operations, such as pushing, pulling, pulling back, idle trips, as well as time standards for acceleration and braking of trains during displacements and kicks. In [21], these standards were transferred to the appendix, and, starting from [22], they were no longer published.

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Alternative approach to assessing the duration of shunting movements is based on performing traction calculations. In accordance with [2], engineer M. M. Protodyakonov performed the first in the USSR traction calculations for shunting operation in 1929 and published in the work «Method for comparing types of small stations». Due to the cumbersomeness of traction calculations and the lack of accurate data for their implementation, the methods for determining the duration of shunting movements, based on a simplified solution of the motion equation, were developed, such as the method of Professor L. V. Odintsov [15]. In this case, the process of movement is divided into three elements: acceleration, movement at a constant speed, braking, and the total time spent on moving locomotives and cars is determined by the formula

$$t_{mov} = t_{ab} + \frac{0,06\left(l_{mov} - l_{ab}\right)}{v_c} + t_{ext}, \qquad (5)$$

where t_{ab} – time spent on acceleration and braking, min; l_{ab} – distance of acceleration and braking, m; v_c – constant speed movement; t_{ext}– extra time spent on coupling and uncoupling a locomotive or locomotive with cars to the train, taken equal to 0.20–0.25 minutes.

The distance covered by the shunting train during acceleration and braking, as well as the time spent on acceleration and braking, were determined by the formulas

$$l_{\text{ab}} = \frac{4.17 v_{\text{c}}^2}{f_{\text{t}} - w_{\text{m}}} + \frac{4.17 v_{\text{c}}^2}{f_{\text{b}} + w_{\text{m}}}, \qquad (6)$$

$$t_{ab} = \frac{v_c}{2\left(f_t - w_m\right)} + \frac{v_c}{2\left(f_b + w_m\right)},$$

where f_t, f_b – respectively, the specific traction force and the specific braking force, kg/t (the dimension is given in accordance with the system of measurements used by the USSR); w_m – specific motion resistance, kg/t.

If $l_{mov} > l_{ab}$, then the shunting movement includes all three elements (acceleration, movement with constant speed, braking) and the time spent is determined by expression (5). Otherwise, shunting movement includes only two elements (acceleration and braking). In this case, from expression (6), the maximum permissible acceleration speed v_c is established, and the duration of shunting movement was determined from expression

$$t_{mov} = t_{ab} + t_{ext}.$$

The proposed approach is rather cumbersome and has not been applied in the practical work of railways.

The formula that takes into account the permissible movement speed during shunting, as well as the procedure for its derivation, is given in [20] (for the sake of commonality in this article, the time was calculated in minutes, and in the original work [20] the calculation was performed in seconds)

$$t_{mov} = \frac{\left(\alpha + \beta n\right) v_{\max}}{120} + \frac{0.06 l_{mov}}{v_{\max}}, \qquad (7)$$

where α – coefficient taking into account the time required to change the locomotive speed by 1 km/h during acceleration, and the time required to change the locomotive speed by 1 km/h when braking sec/km/h; β – coefficient taking into account the extra time to change the speed of each car in the shunting train by 1 km/h during acceleration and the extra time to change the speed of each car in the shunting train by 1 km/h when braking, sec/km/h per car; $v_{\max}$ – permissible movement speed during shunting, km/h.

In [20], the values of the coefficients were also presented, which were $\alpha = 2.40$ sec/km/h (including 1.00 sec/km/h acceleration and 1.40 sec/km/h braking) and $\beta = 0.10$ sec/km/h per car (including 0.04 sec/km/h acceleration and 0.06 sec/km/h braking of 1 car in the train).

In [28], expression (7) is somewhat modified and presented in the form

$$t_{mov} = \frac{\left(\alpha + \beta n\right) v_{\max}}{120} + \frac{0.06 l_{mov}}{v_{\max}} + t_{pf},$$

where t_{pf} – the time standard for preparatory and final operations, which, according to [28], for semi-trips of displacement is 0.2 minutes.

When deriving expression (7), it is assumed that the shunting movement includes three elements (acceleration, movement at a constant speed and braking). Therefore, this expression gives an incorrect result for short distance movements, which consist

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only of acceleration and braking. To solve this problem, in [20], a figure was presented with the dependences of the maximum speed of shunting movement on the number of cars in the train and the length of the route of displacement $v_{\max}\left(l_{mov},n\right)$. The principles of constructing these dependencies are not given in [20]. A derivation of formula (6) similar to [20] is given in [9]. It is also indicated here that the maximum possible value of the acceleration speed $v_{\max}$ is set from the condition of the ratio of the power and traction force of the locomotive. The fact that the maximum permissible acceleration speed when moving over short distances is also limited by the braking conditions is not mentioned in [9]. Moreover, the dependences $v_{\max}\left(l_{mov},n\right)$ in [20] are determined only at distances of more than 100 m. Therefore, it is difficult to fully use the methodology described in [20] for practical purposes.

Since 1964, after the publication of the second edition of the «Guide» [21], expression (7) has not been used to standardize the duration of shunting operations. Expression (7) started to be used again after the introduction of «Methodological guidelines for calculating the time standards for shunting operations performed in railway transport» [11] in the Russian Federation in 1998. In 2003, Ukraine published its «Methodological guidelines for calculating the time standards for shunting operations performed in railway transport» [10], which practically repeated the text of the Russian analogue. The methodologies [10, 11] established the values of the coefficients $\alpha = 2.44$ sec/km/h and $\beta = 0.10$ sec/km/h per car. In contrast to [20] in [10, 11], there are no indications on the choice of the maximum permissible acceleration speed in (7), and tables 5.1–5.4 in these regulatory documents contain incorrect standards for traveling over short distances. This fact is indicated in [7, 31]. To solve the problem, it was proposed in [7] to calculate the time standard for movement over distances less than

$$l_{\text{ab}} = \frac{(\alpha + \beta n) v_{\max}^2}{7.2}$$

according to formula

$$t_{\text{mov}} = \sqrt{\frac{l_{\text{mov}}(\alpha + \beta n)}{500}} .$$

Additional questions to the methodology described in [10, 11] arise due to the fact that the value of the coefficient $\beta = 0.1$ sec/km/h for a four-axle car with roller bearings exactly repeats the value of the coefficient β in [20], established for a two-axle car with slider bearings. It should be noted that the standards [10] are still in force in Ukraine. At the same time, in 2007, the Russian Federation published the «Time standards for shunting operation performed at the railway stations of Russian Railways JSC, the standards for the number of shunting locomotive crews» [13]. Here the tabular values of the time standards for displacement of cars for short distances, as well as the values of the coefficients $\alpha = 0.73$ sec/km/h and $\beta = 0.13$ sec/km/h per car were corrected. In [13], there is no information about the locomotives for which the value of the coefficient α was obtained, however, the accelerations that these locomotives must realize during the displacement significantly exceed the values of the accelerations described in the literature, which are realized by shunting locomotives during intensive acceleration and braking during kicks in the process of sorting cars.

An important element of shunting operation is preparatory and final operations, such as switching of points, uncoupling and coupling a locomotive, coupling and uncoupling cars, inspecting cars, engaging and testing cars brakes, fixing cars with shoes and removing them, giving commands, reports and their perception, etc. Also, significant time expenditures are associated with the passage of workers from one place of performing operations to another. The need to account for these operations is indicated both in the scientific and educational literature during the formation of the theory of shunting operation in railway transport, however, no significant attention was paid to the problem of standardizing and accounting for such operations. In particular, in [2] it is indicated that 0.2–0.25 minutes should be added to the duration of the semi-trips to give commands and change the locomotive movement direction. In [15] it is indicated that it is necessary to add 0.2 minutes to the duration of the semi-trips for coupling and uncoupling of the locomotive to the train, etc. As specified in [27], according to the data of standard station of the USSR Ministry of Railways, the time spent on preparatory and

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final operations when performing shunting of displacement was set to one semi-trip, and the time standards for preparatory and final operations during sorting, collecting, pushing and inspecting of cars to one accounting two-axle car. Also, the duration of individual preparatory and final operations during the validity period of the 1st [20] and 2nd [21] editions of the «Guide» can be estimated from the tables with examples of calculating time standards for the stations. The third edition of the «Guide» [22] contains a table «Standards of time, min, for performing other operations» with standard duration values of preparatory and final operations for the railway network. The number of operations in this table was supplemented from edition to edition, and if in [22] only 9 operations were indicated, then in [13] 36 operations is indicated.

Considering that standard technical means are mainly used in railway transport, the duration of elementary preparatory and final operations can be estimated by the methods of mathematical statistics and are recommended for use throughout the entire railway network. At present, it is advisable to revise the standards that have been in force since 1967, which in many cases were established administratively.

It should be noted that the standards include both the time standards for elementary and complex preparatory and final operations. Considering that there is no description of the actions performed in the process of these operations, it is rather difficult to establish their compliance with the operating conditions of a certain station. In particular, it is possible to trace the change in the time standards for operations associated with the engagement of brakes of the cars in the shunting train.

In [20], there is no time standard for engagement and testing automatic brakes. The example shows the calculation formula

$$t_{ab} = 1.5 + 0.25n .$$

In [21], there is also no time standard for engagement and testing automatic brakes. The example shows the calculation formula

$$t_{ab} = 2.19 + 0.30n .$$

After 3 years, the 3rd edition of the «Guide» was published [22], starting from which the duration of the operation of «engagement and testing automatic brakes of cars in a shunting train» started to be normalized. In [22], the time standard was established

$$t_{ab} = 3.0 + 0.07n . \quad (8)$$

In [23], the time standard was established

$$t_{ab} = 3.0 + 0.10n .$$

In [24], with the transition to standardizing for four-axle cars, the standard was established

$$t_{ab} = 3.0 + 0.14n . \quad (9)$$

The same standard has been preserved in [10, 11, 13], but the name of the operation has changed and, at present, it sounds like «charging the brake line and testing the autobrakes of cars in a shunting train». The absence of a list of elementary operations that the standard developers took into account as part of the complex operation «engagement and testing automatic brakes of cars in a shunting train» or «charging the brake line and testing the autobrakes of cars in a shunting train» does not allow explaining the significant difference in the observed values indicated in [20, 21] and the normative values in [22], the difference in examples on the standardization of shunting operation with local cars between [24] and [10, when, while preserving in [10] the standard (9) from unchanged [24] (and in fact (8) from [22]) a significant number of operations associated with the automatic brakes engagement were added to the example.

In the 20s of the 20th century in the USSR professor I. I. Vasilyev, engineers V. S. Larionov, N. A. Morshchikhin, and others investigated the problems of standardizing the duration of complex shunting operations. In the course of these studies, based on analytical calculations, calculation formulas were obtained for assessing the duration of such complex operations as sorting cars of a train into several tracks, collecting cars from several tracks into one train, blocking of trains, etc. The existing methodology of standardizing the duration of complex shunting operations is mainly based on the research of Professor I. I. Vasilyev, the results of which are detailed in [2]. This methodology is based on the assumption of a linear dependence of the duration of the shunting movement on the number of cars in the shunting train (4), as well as the equal number of cars on each of the tracks. Professor Vasilyev examined the method of sorting cars by flat

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shunting and various methods of sorting cars by shocks loose shunting. At the same time, flat shunting means when vehicles are continuously moved from one place to another with engine attached. Loose shunting means pushing vehicles by kicks with the help of an engine and allowing them to roll with engine unattached.

In particular, under such assumptions, the minimum duration of sorting trains by flat shunting will be determined by the formula (the formula from [9] is given)

$$T_s = 2a_s g + b_p n + 2\sqrt{(a_p + a_l - a_s) b_s n g} \quad (10)$$

or

$$T_c = A' g + B' n + C' \sqrt{ng} . \quad (11)$$

where a_s, b_s – shunting parameters for sorting and pulling back semi-trips, min and min/car; a_p, b_p – shunting parameters for pulling semi-trips, min and min/car; a_l – shunting parameters of trips of a single locomotive for the next group of cars, min; A', B', C' – constant coefficients.

The time standards for loose shunting can also be reduced to form (11).

The time expenditures on other complex shunting operations can also be calculated by analogy with (11). In particular, the time expenditures on collecting cars from several tracks to one can be established by formula

$$T_{col} = U'p + F'n + P'\sqrt{np} . \quad (12)$$

where p – the number of tracks from which the cars are collected; U', F', P' – constant coefficients.

Taking into account that the dependence $\sqrt{ng}$ is close to linear, then expression (11) can be simplified and presented in the form of expression (1). Similarly, when the dependence is close to linear, expression $\sqrt{np}$ (12) can be represented as

$$T_{col} = Up + Fn . \quad (13)$$

It is the expressions (1) and (13) that are practically used in the operational work of railways.

In [32], a formula was derived for assessing the time of sorting cars on the basis of expression (7). As a result, it was established that the duration of sorting cars can be determined by a linear dependence (1). It was also assumed in the study that the coefficients A and B in formula (1) significantly depend on the length of the station necks.

The assumption of the equality of the number of cars in cuts, when deriving formula (10), was accepted without justification, and in the 30s of the 20th century there was a rather intense debate about the possibility of reducing the duration of car sorting by taking into account the real size of the car groups [12]. However, from a scientific perspective, this issue has not been fully investigated. Also, the methodologies for standardizing complex operations given in [2, 20, 21] do not take into account the various restrictions that may occur in the operational work of railway stations, such as the length of the lead tracks, the power of locomotives, etc.

Expression (10) contains only the time expenditures on shunting movements. However, sorting of cars includes a significant number of preparatory and final operations. Mostly the number of these operations is proportional to the number of shunting movements. Some preparatory-final operations are associated with the passages of shunting master along the train, and the number of such operations is proportional to the number of cars. In [2] it is recommended to take into account the time spent on preparatory and final operations by increasing the coefficients a. However, according to [20], the time spent on preparatory and final operations was attributed to one car of the train. In particular, during the train breaking-up, extra time expenditures per car were set at c_{ext} = 0.12 minutes, when forming one-group and two-group trains – c_{ext} = 0.2 min., multi-group – c_{ext} = 0.3 min. With this approach, the order of performing shunting operations during the sorting process and the number of parts into which the train is divided does not affect the time spent on preparatory and final operations, which somewhat does not correspond to the real process. However, in the then operating conditions of the railways, the error in estimating the time for car sorting was insignificant.

The development of methods for standardizing the duration of shunting operations took place in the period of the 30–50s of the 20th century, when the crossing and carrying capacity of railway transport significantly lagged behind the needs of the economy in transportations. Therefore, there was an urgent need to intensify labor productivity, which had

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a significant influence on the value of the time standards that were set for railway stations. The process of performing field experiments to estimate the value of the coefficients a and b of expression (10) is described in [2]. These coefficients were established for the conditions of sorting cars with slider bearings in sorting yards without taking into account the operation of securing when switchers switch points individually and give visual commands to the locomotive drivers. In fact, the obtained coefficients a and b represent the minimum possible time spent on shunting movements in the most favorable conditions. However, even under these conditions, the value of the standard values of the coefficients A and B in expression (1) is significantly lower than the value of these coefficients, which can be obtained by direct calculation according to the data of educational and scientific literature. Explanation of the reason for this discrepancy can be found in [20] and [21]. The method of sorting cars by flat shunting in the works of the 30-50s of the 20th century was described as outdated and at that time, there was propaganda aimed at the widespread use of various methods of sorting by loose shunting. In accordance with the 1st edition of the «Guide» [20], when setting the time standard for sorting cars by flat shunting, it was taken into account that 50% of the sorting semi-trips were carried out by flat shunting, and 50% by loose shunting. Further, in accordance with the 2nd edition of the «Guide» [21], it was taken into account that only 25% of the sorting semi-trips were carried out by flat shunting, and 75% – by loose shunting. Starting from the 3rd edition [22] of the «Guide», the methodology for deriving formulas was no longer published, however, the values A = 1.01 min/cut and B = 0.25 min/car given in it correspond to the condition when 89% of shunting is performed by loose shunting and only 11% by the flat one. It should also be noted that due to the difference in time expenditures on preparatory and final operations, in the 1st, 2nd and 3rd editions of the «Guide» [20–22], the coefficients A and B were indicated for the train breaking-up, as well as large, in relation to them, time standards for the formation of group and pick-up trains. In the 4th edition [23] of the «Guide», only lower values of the coefficients A and B were left. In the 5th edition of the «Guide» [24], the time standards for complex operations were recalculated from two-axle cars into four-axle cars. Considering that two-axle cars were excluded from operation as early as 1965, in 1978 there were no significant changes in the operational work of railways associated with a change in the structure of the car fleet. Also, a comparison of the «Guides» of 1972 [23] and 1978 [24] shows that the time standards for movement and preparatory and final operations calculated according to them have not changed significantly. At the same time, the standards of time for complex operations were reduced by 19–25%. At present, in many cases, sorting by loose shunting is prohibited because the safety requirements of railway workers, the safety of rolling stock and cargo cannot be ensured. Flat shunting is performed entirely in accordance with the definition of this method, when the cars are moved by locomotive until they stop on the tracks. Under such conditions, the values of the time standards for sorting cars given in [10] do not even correspond to the physics of the processes performed during shunting. Moreover, since the 1950s, significant changes have taken place in the operation of railway transport. In particular, at present, in most cases, the switching of points is performed not manually, but remotely, which undoubtedly increased the safety level of shunting operation, but led to the fact that the assessment of the situation by workers is not carried out directly, but according to data of devices, while visual commands were replaced by verbal ones. Therefore, the time spent on the preparation of routes has increased in comparison with that adopted in [24]. Moreover, in the case when the sorting of cars takes place under conditions of electrical centralization of switches and signals, the shunting train should pass behind the oncoming signal, not behind the switch of changing the movement direction, which increases the movement distance in comparison with [24]. The transition of rolling stock from slider bearings to rolling ones made it possible to significantly reduce the movement resistance of cars and reduce the cost of train traffic, but this resulted in an increase in the standards and a change in the order of train fixation. And, finally, the introduction of radio communication allowed one shunting master to carry out shunting operation without an assistant, but at the same time the number of movements of the shunting master between the work sites increased significantly and the possibility of parallel execution of preparatory and

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final operations was lost. For these and other reasons, the application of 70–40 year old time standards leads to significant differences between the estimated and observed duration of shunting operations.

The performed analysis shows that at present, when calculating the time standards for complex shunting operations, it is accepted that their duration linearly depends on the number of elementary operations performed and the number of cars taking part in them. These assumptions generally correspond to the operating conditions of railway transport; however, they require clarification for shunting operations occurring under various restrictions.

To date, a significant number of differences in the work of railway transport have accumulated from the conditions for which the time standards for complex operations were established in [20–24]. For this reason, in order to obtain reliable time standards, it is not enough to carry out a proportional increase in the norms, as it was done in [18], but it is necessary to comprehensively revise the standardizing methodology itself. Obtaining general standards for public railway stations and sidings of industrial enterprises is impossible due to significant differences in technical equipment, staffing and operation technology. In these conditions, it is advisable to return to the practice of calculating individual standards, which was performed during the period of validity of the «Guidelines» of the 1st and 2nd editions [20, 21]. At the same time, methodological materials for the calculation should contain process charts for all elementary and complex shunting operations.

An important scientific problem in the field of rationing the duration of shunting operations, which has also not been resolved to date, is the determination of which value of the indicator is the norm. In the general case, the duration of shunting operation is a random variable, which is influenced by a significant number of random factors. Ignoring this fact leads to situations that are described, for example, in [12], when the value close to the minimum possible is set as a standard and, further, its deviations are recorded. In this regard, it is advisable to consider the possibility of adaptation and application of statistical methods for controlling technological processes based on Shewhart's charts [8] in the process of shunting operation. These methods imply the establishment of a set of control limits instead of one standard value. The presence of such limits makes it possible to establish not only the compliance of the duration of individual operations with the established standards, but also the compliance of the standards with the ongoing technological process.

Originality and practical value

In this work, based on historical analysis, the process of development of methods for standardizing the time for shunting operations is described and the factors influencing the current value of the standards are established.

The research results make it possible to identify the reasons for the discrepancy between the existing time standards for performing shunting operations and the actual operating conditions of stations and sidings of industrial enterprises, as well as to establish the main elements of the methodology for standardizing the duration of shunting operations that require revision.

Conclusions

1. Scientific methods of standardizing the duration of shunting operations, which are used in the railway transport of Ukraine, were developed in the 30s of the 20th century. They are based on a linear representation of the dependences of the duration of shunting operations on the number of elementary operations and the number of cars participating in them. Modern time standards for shunting operations were mainly established in the 50–70s of the 20th century.

2. To date, significant changes have taken place in the operation of railway transport compared to the conditions of its operation during the period of establishing the time standards for the duration of shunting operations. In this regard, it is necessary to carry out a comprehensive revision of these standards. For the existing operating conditions of railway transport, it is advisable to move away from the practice of applying general network time standards for complex shunting operations and return to the calculation of individual standards for individual stations and sidings of industrial enterprises.

3. The applied calculation methods allow setting the time standards for shunting operations with sufficient accuracy for practical purposes. The issues of standardizing the duration of shunting operations under conditions of limiting the length of shunting

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trains, assessing the influence on the value of the time standard of the initial distribution of cars on the tracks, as well as standardizing the duration of shunting movements under conditions of using statistical methods of control technological processes require additional research.

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Розвиток аналітичних методів розрахунку норм часу на маневрові операції

Мета. Автори статті ставлять за мету проведення аналізу розвитку аналітичних методів нормування тривалості маневрових операцій, а також оцінку їх відповідності наявних умовам роботи залізничного транспорту. **Методика.** Дослідження в цій статті виконано на підставі аналізу літературних джерел і методів теорії організації експлуатаційної роботи залізниць. **Результати.** Нормування тривалості маневрових операцій є однією з найважливіших задач теорії експлуатаційної роботи залізниць. Наявна методика нормування тривалості маневрових операцій склалася в першій половині XX століття й використовується до наших днів.

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Проведений аналіз показує, що наукові принципи, закладені в основу зазначеної методики, у цілому відповідають умовам роботи залізничного транспорту. У той же час із розвитком математичних методів з'явилася можливість отримувати більш точні оцінки витрат часу на маневрові операції. У статті показано, що застосовувані зараз значення нормативів часу на маневрові операції у багатьох випадках установлено для технічних засобів і технологій, які використовували на залізничному транспорті в 50–70-ті роки XX століття, тому вони не відповідають сучасним умовам роботи станцій і під'їзних колій промислових підприємств та вимагають перегляду. **Наукова новизна.** У цій роботі на підставі аналізу описано процес розвитку методів нормування часу на маневрові операції та встановлено фактори, що впливають на сучасну величину норм. **Практична значимість.** Проведені дослідження дозволяють виявити причини невідповідності між наявними нормативами часу на виконання маневрових операцій і реальними умовами роботи станцій та під'їзних колій промислових підприємств, а також установити основні елементи методики нормування тривалості маневрових операцій, що вимагають перегляду.

Ключові слова: залізничний транспорт; залізнична станція; під'їзна колія; маневрова робота; норми часу

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