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OPTIMIZATION OF TRACK DISTRIBUTION OF INDUSTRIAL RAILWAY STATIONS BETWEEN CAR DESIGNATIONS

Purpose. To improve the method for distributing the tracks of industrial railway stations for the accumulation of car groups between separate assignments. The optimization problem is to find such a distribution of classification work between the industrial marshalling yard and freight stations, as well as such a distribution of marshalling yard tracks between individual destinations, which ensures the minimum time expenditures on shunting work.

Methodology. The studies were carried out using the methods of the theory of railway operation, simulation modeling and dynamic programming.

Findings. The optimization problem of distribution of sorting work between the marshalling yard and freight stations of an industrial enterprise, as well as searching for such a distribution of marshalling yard tracks between individual destinations, which ensures the minimum time expenditures for shunting work, has been solved.

Originality. The paper proposes a method for formalizing and solving the problem of distributing the tracks of industrial railway stations for the accumulation of car groups between individual destinations as a dynamic programming problem. Unlike the existing methods, where the number of tracks is considered as a constraint, in the proposed method, the number of tracks is an objective function argument of minimizing the duration of shunting operations, which improves the quality of the solutions obtained.

Practical value. The method proposed in the paper, due to the rational distribution of the existing track arrangement of railway stations, makes it possible to reduce the time expenditures on the making- and breaking-up the trains and shunting transfers and, due to this, increase the carrying capacity of the stations, as well as reduce the cost of production of enterprises.

Keywords: *railway transport, industrial railway station, siding, shunting operations, accumulation of cars*

Introduction. Modern conditions for the operation of railway transport of industrial enterprises are characterized by a sharp increase in the shunting operation volume. In the post-Soviet countries, the railway infrastructure construction mainly took place in the Soviet time under conditions of planned economy. The arrangement of their sidings was designed to work with a small range of goods and carry out transportation in universal cars of one operator – inventory railway cars. Currently, the share of cargo transported in the specialized cars has increased significantly. Moreover, the universal car fleet is divided between many owners, and even the universal cars are not interchangeable. Therefore, despite the decline in the volume of work, there is a chronic shortage of tracks at industrial enterprises for the accumulation of shunting transfers and train sets, which is the result of the car destinations increase. This problem is especially acute for the enterprises of the mining and metallurgical industries [1, 2], as well as seaports, which were focused on using their own railway infrastructure to service loading and unloading operations. In this regard, the problem of organizing the work of railway transport in the conditions of a shortage of track capacity is relevant.

Literature review. Railway transport is a complex system. Herewith, the same operations can be performed by various technical means. Under these conditions, various tasks arise for the rational distribution of technical means in order to achieve the minimum cost of work or to maximize the volume of the work singled out. On the mainline transport, the task of distributing the sorting work on the network is solved as part of the development of a plan for the train making-up. In the process of moving along the public railways [3, 4], car traffic volumes go through several marshalling yards. The number of tracks available at marshalling yards is considered as a constraint on the solution of the problem. If there are not enough tracks for yard operation, this work is transferred to another marshalling yard. Due to the large size of the main railway network, when developing a problem formation plan of specialization of marshalling tracks, they are solved for each station separately. Considering the small number of stations in industrial enterprises, the methods used in mainline transport have limited application in industrial transport.

Compared to mainline rail transport, the transport systems of industrial enterprises are much smaller. Therefore, the task of rational organization of shunting work is limited to several stations and cargo fronts.

The articles by Bohlin, et al. [5], Belosevic & Ivic [6], Gestrelius, et al. [7], Zhou, et al. [8] are related to the organization of the process of breaking-up, accumulation, and making-up the trains at sorting yards with the limited amount of the tracks. The works by Kozachenko, et al. [9, 10], Sivitsky, et al. [11] are devoted to the tasks of making-up group trains. In the considered articles, the problem of making-up group trains under conditions of shortage of track capacity is solved within only one station. Herewith, the problem of optimizing the sorting of cars when passing through several stations is not considered.

The problem of classification work distribution in a port junction is considered in the work by Borodina, et al. [12]. In this work, the task of the classification work in the junction is formalized based on the condition for achieving a minimum of operating expenses; however, the methodology for solving this problem is not given. The work by Borodin & Panin [13] considers the task of distributing work between two stations: an industrial marshalling yard of a metallurgical enterprise and a mainline marshalling yard. It should be noted that in this work, when solving the distribution problem, the general task was divided into subtasks, which are solved sequentially. In this regard, the resulting solution, as a rule, is not strictly optimal.

The performed analysis shows that the problem of the optimal use of the railway infrastructure to perform shunting work is relevant and requires further research. The solution of this problem is associated with the use of methods of the theory of railways operation to estimate the time spent on performing various technological operations, as well as operations research methods to find optimal solutions [14].

To estimate the time expenditures on performing shunting operations, at present the simulation and statistical methods are mainly used. The first approach is based on solving the equations of motion and simulation of operations occurring in the process of shunting. This method makes it possible to estimate the duration of shunting operations with high accuracy. Such an approach, for example, was used by Nechay, et al. [15] when developing a system for managing the operation of railway transport of industrial enterprises, as well as in the work by Kuznetsov, et al. [16], Kozachenko, et al. [17] to evaluate the characteristics of a shunting locomotive. It should be noted that simulation models are very sensitive to the quality of the initial data. The solution of the tasks of planning shunting work is based on the average parameters of the predicted car traffic volumes. Under such conditions, the methods based on the use of simulation modeling of shunting movements become too cumbersome. The second approach to estimating the duration of shunting operations is based on the use of statistical, mostly linear, models to determine the duration of elementary shunting movements or complex operations [18, 19]. The construction of such models is one of the issues in the theory of railway operation. The methodology for estimating the parameters of a statistical model based on the results of a factorial experiment is given in the work [20].

The same result of shunting work can be achieved in different ways. In this regard, the tasks of finding the optimal use of the railway infrastructure, rolling stock and staff during shunting arise. To find the best solutions, heuristic methods are used, which are based on a comparison of options selected by experts. At the same time, the main attention is paid to the construction of adequate models for evaluating competing options. For example, the work by Hirashima [21] describes a simulation model for finding the optimal order of train making-up, and the work by Bohlin, et al. [22] presents a model for evaluating the operation of a marshalling yard. The disadvantage of heuristic methods is that the choice of options for comparison is subjective, so the solutions obtained by using it are not strictly optimal. Another approach is based on using operations research methods to find optimal solutions [23]. In particular, in the work by Falsafain & Tamannaei [24], it is proposed to use the dynamic programming method to improve the organization of a marshalling yard. In the work by Dorpinghaus & Schrader [25], it is proposed to use the methods of graph theory and linear programming to solve this problem. In accordance with the analysis performed in the work, statistical methods were chosen to estimate the duration of shunting operations, and methods of operations research were chosen for searching the best solution.

Purpose. The purpose of the article is to improve the distribution method of accumulation tracks for groups of cars between separate destinations.

Methods. The studies were carried out using the methods of the theory of railway operation and simulation modeling to assess the effectiveness of the specialization of accumulation tracks of cars for individual assignments, as well as the dynamic programming method to find the optimal distribution of tracks between the destinations of cars.

Presenting the main material. The railway infrastructure of large metallurgical enterprises includes industrial hump or flat yards, which ensure the handling of car traffic volumes coming from the public railway network and sent to it, as well as freight stations servicing various workshops. Between the stations of metallurgical plants, as a rule, train traffic is organized. The procedure for determining the number of sorting track was established by SNiP 2.05.07-91 "Industrial Transport". According to this regulatory document, the number of specialized sorting tracks for car accumulation at industrial stations and large cargo fronts is set from the condition of removing 150 cars from one track per day. Removal of cars from specialized sorting tracks intended for breaking-up the trains according to the grades of raw materials and fuel, types of car handling, the state of technical suitability of the rolling stock for loading bulk cargo, etc., is taken at the rate of 100–110 cars per day from one track. The removal of cars from non-specialized sorting tracks is 30–65 cars per day, depending on the number of accumulated destinations and the number of cars in the trains being reformed. One track is allocated for the accumulation of appointments with a daily number of no more than 200 cars. The significant difference between the daily number of cars that can be accumulated on specialized and non-specialized tracks makes it possible to formulate the task of rational distribution of accumulation tracks between the destinations of cars.

Unlike the design tasks, when the number of tracks required to master the given volumes of work is determined, in operation tasks it is necessary to find the most rational option for using the existing track arrangement to master the given volumes of work. An analysis of the work of industrial enterprises shows that the number of destinations formed at marshalling yards generally corresponds to the design conditions. At the same time, at freight stations, there is a need for additional handling of car traffic volumes due to an increase in the number of car destinations.

Breaking-up and making-up the trains and shunting transfers is the main activity of industrial marshalling yards. To perform this shunting work, sorting humps and turnout tracks of a special profile are being built to perform car sorting by pushes. Unlike marshalling yards, freight stations of industrial enterprises, as a rule, are not designed for car sorting. The selection of cars into groups at these stations is carried out by pushing, when the cars are moved by the locomotive to the stopping point. This leads to a significant fuel and time consumption for shunting work, as well as to overloading shunting locomotives and turnouts. Reducing the loading of technical means of freight stations can be achieved by enlarging groups of cars at marshalling yards and sending group trains to freight stations.

The time spent on shunting operation for breaking-/making-up the trains and shunting transfers depends on the number of allocated tracks for the accumulation of cars. In this regard, the problem of distributing the available tracks between different car destinations arises. In this problem, a part of the process of handling freight cars on the siding of a large industrial enterprise is considered, which includes the breaking-up of the trains coming to an industrial marshalling yard, the making-up of the trains or shunting transfers, the breaking-up of trains or shunting transfers at freight stations. When specializing the tracks of a marshalling yard, it is necessary to determine how many tracks are allocated for the accumulation of cars assigned to each freight station and what type of trains (single or group one) is formed to its address. Given that the redistribution of shunting work occurs within the same enterprise, a natural indicator can be used to assess the effectiveness of the decisions made – the minimum time spent on shunting work. The restrictions in this problem are the total number of tracks allocated for the accumulation of cars at the marshalling yard, as well as the processing capacity of the marshalling yards and freight stations.

The mathematical formulation of the task is as follows. Let i be the conditional number of the freight station $i=\overline{1,k}$ (here k is the number of freight stations). The parameters of the car traffic volume running between the marshalling yard and the i^{th} freight station are characterized by the assignment of cars arriving to the address of the station d_i, the daily car traffic volume N_i, the number of cars in the train m_i. Let the variable x_i denote the number of tracks that are allocated at the marshalling yard for the accumulation of cars to the address of the i^{th} freight station. The variable x_i can take integer values, while $0 < x_i \le W$ (here W is the number of tracks allocated for the accumulation of cars at the marshalling yard). Let us designate a sign of train group formation at the marshalling yard to the address of the i^{th} freight station as Boolean variable b_i. In this case, if $b_i = 0$, then one-group trains are sent from the marshalling yard to the i^{th} freight station, where the cars are arranged in random order, and if $b_i = 1$ then from the marshalling yard to the i^{th} freight station group trains are sent, where the cars are selected into groups according to their destinations.

The time expenditures on shunting work with the car traffic volume to the address of the i^{th} freight station include the time spent at marshalling yard S_i and the time spent at the freight station F_i

$$T_i(N_i, m_i, d_i, x_i, b_i) = S_i + F_i.$$

The values S_i and F_i functionally depend on the parameters of the car traffic volumes and the values x_i and b_i

$$S_i = f_S(N_i, m_i, d_i, x_i, b_i); \quad (1)$$

$$F_i = f_F(N_i, m_i, d_i, b_i). \quad (2)$$

Let us denote the admissible duration of occupation of shunting vehicles of marshalling yards by D_S, the admissible duration of occupation of shunting vehicles of freight stations by D_i.

In general, the problem of distributing the tracks of an industrial marshalling yard for the accumulation of car groups between separate destinations lies in the search for such values of the variables x_i and b_i with the given values of $N_i, m_i, d_i, (i = \overline{1,k})$ that minimize the value of the objective function

$$\sum_{i=1}^{k} T_i\left(x_i, b_i\right) \to \min, \quad (3)$$

under restrictions

$$\begin{cases} \sum_{i=1}^{k} f_S(x_i, b_i) \le D_S \\ f_F(b_i) \le D_i, \quad i = \overline{1,k} \\ 0 < x_i \le W, \quad i = \overline{1,k} \\ \sum_{i=1}^{k} x_i \le W \end{cases}. \quad (4)$$

To identify the parameters of functions (1 and 2), the methods of the railway operation theory were used. The number of tracks allocated at the marshalling yard for the accumulation of cars of a certain assignment affects the time spent on both breaking-up and making-up the trains. During the breaking-up of the trains or shunting transfers, their cars go to the accumulation tracks. After the train accumulation is completed, this train for some time is idle on the accumulation track under technological operations and waiting for them. If for the train accumulation of a specific assignment one track is allocated, then the cars arriving when the accumulation track is full are sent to the screening track and are subject to re-sorting. To avoid re-sorting, if there are two or more tracks, the accumulation process starts on another accumulation track. To assess the dependence form between the daily number of cars coming to the accumulation track and the number of cars sent to the screening tracks, a series of computational experiments with a simulation model was performed. During the experiments, the filling of the accumulation track with cars was simulated. The cars were arriving in groups. When the accumulation track was full, the excess cars were sent to the screening track for re-sorting. An example of the results of computational experiments is shown in Fig. 1.

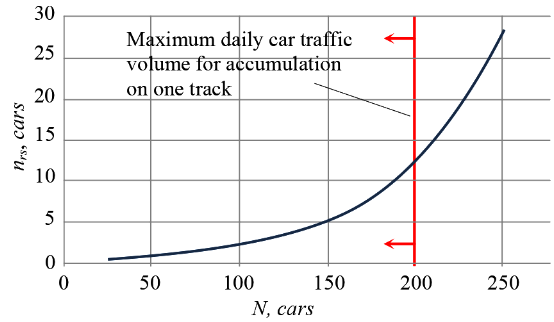

Fig. 1. Relationship between the number of cars coming to the accumulation track and the number of cars sent to screening tracks

On the basis of statistical processing of the results of computational experiments performed using the simulation model of the station [26], it was found that the dependence of the car number directed to the screening track $n_{rs,i}$ on the daily number of cars of the i^{th} destination coming to the processing is a quadratic

$$n_{rs,i} = \begin{cases} a_0 + a_1 N_i + a_2 N_i^2 & \text{at} \quad x_i = 1 \\ 0 & \text{at} \quad x_i > 1 \end{cases},$$

where a_0, a_1, $a_2$are polynomial regression coefficients.

The time expenditures on shunting operation for the resorting of cars can be determined from the expression

$$T_{rs,i} = t_{rs} n_{rs,i}(x_i, N_i, m_i),$$

where t_{rs} is average time expenditures on re-sorting per car, min.

The formation of a train or shunting transfer at an industrial marshalling yard consists in connecting separate groups of cars by pulling them, as well as in arranging the cars in the order as part of group trains. The time expenditures for pulling is defined as

$$T_{pul} = 0.08 m_c,$$

where m_c is the number of cars on the track.

Taking into account the fact that the value T_{pul} depends only on the total number of cars, it does not change when the different track specialization is changed and can be excluded from the objective function (3) and the P_S value in the constraint system (4).

The time expenditures on the arrangement of cars in the train depend on the number of tracks allocated for the accumulation of the train. When dispatching single-group trains, the cars in them are not arranged. If one track is allocated for the accumulation of cars for a certain purpose, then the selection of cars into groups includes car sorting at the track ends according to their purpose, as shown in Fig. 2, *a* and their subsequent assembling on one track, as shown in Fig. 2, *b*. As a result, the cars in the train will be assembled into groups, as shown in Fig. 2, *c*. If the number of tracks allocated for the accumulation of group train cars is equal to the number of appointments, then it is enough to combine the accumulated car groups on one track. The formation of the group train in this case is illustrated in Figs. 3, *a*, *b*. A mixed variant of selecting cars into a group is also possible, when the number of tracks allocated for accumulation is more than 1, but less than the number of car assignments.

In general, the arrangement of cars in a group train includes shunting work on sorting cars to different tracks according to their destinations and their subsequent collection to one track

$$t_{a,i} = t_{s,i} + t_{col,i} \quad \text{at} \quad b_i = 1.$$

The duration of sorting a train of m_c cars and g cuts is determined by the formula

$$t_c = Ag + Bm_c, \quad (5)$$

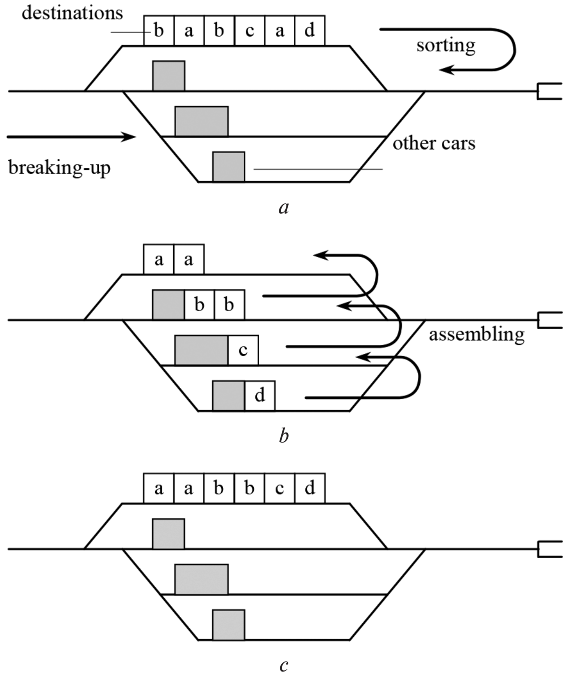

Fig. 2. Formation of a group train under conditions when one track is allocated for the accumulation of its cars:

a — accumulation and sorting of cars according to their destinations; b — assembling of cars; c — formed train

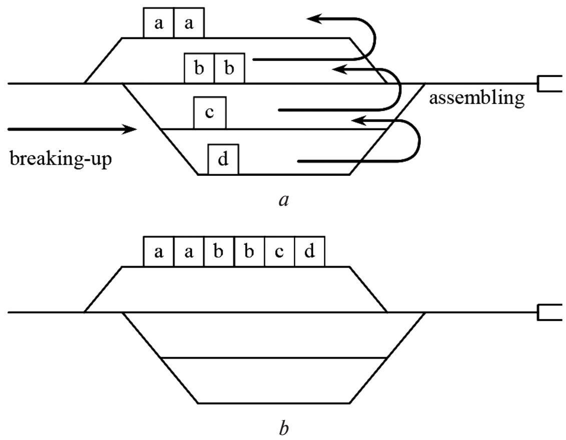

Fig. 3. Formation of a group train under conditions when one track is allocated for the accumulation of its cars:

a — accumulation and assembling of cars; b — formed train

where *A, B* are the coefficients depending on the technical equipment of the station, min/cut and min/car.

In accordance with the "Manual for the Design of Industrial Railway Stations", there is a statistical dependence between the number of cars in m_i and the number of car assignments arriving at the station d_i on the one hand, and the average number of cuts g_i and the number of car assignments q_i that are part of the train on the other hand. In this regard, the average number of cuts in a train can be determined from the expression

$$g = a_g m_s; \quad q_i = a_q a,$$

where a_g, q_i are coefficients, respectively car/cut and assignment/cut.

Then the sorting time of the train can be found as

$$t_s = R m_s,$$

where R is the coefficient depending on the technical equipment of the station, min/car.

The total time spent on the sorting of cars accumulating on several tracks is proposed to be determined by the formula

$$S_{c,i}(x_i,b_i) = \begin{cases} 0 \text{ at } b_i = 0 \\ \dfrac{(q_i - x_i + 1)}{q_i} R_S M_i m_i \text{ at } b_i = 1,\; x_i < q_i, \\ 0 \text{ at } b_i = 0 \text{ at } b_i = 1,\; x_i \ge q_i \end{cases} \quad (7)$$

where R_S is the coefficient depending on the technical equipment of the marshalling yard, min/car.

The collection time of a train of m_S cars for one track, which was sorted on z tracks, is determined by the formula

$$t_{col} = zP + \frac{(z-1)}{z} E m_S, \quad (8)$$

where P, E are coefficients depending on the technical equipment of the marshalling yard min/track and min/car.

When deriving expression (8), it is assumed that there is the same number of cars on all tracks.

The total time spent on assembling cars from several tracks is determined by the formula

$$S_{col,i}(x_i,b_i) = \begin{cases} 0 \\ x_i P \dfrac{M_i}{m_i} + \dfrac{(q_i - 1) E N_i}{q_i} \text{ at } b_i = 1, x_i < q_i. \\ q_i P \dfrac{M_i}{m_i} + \dfrac{(q_i - 1) E N_i}{q_i} \text{ at } b_i = 1, x_i \ge q_i \end{cases} \quad (9)$$

After the train arrival at the cargo station, it should be sorted. The duration of the train sorting at the cargo station is determined by (5). Considering that the total number of cars does not change when they arrive in single-group and group trains, the second addend in expression (5) can be excluded when comparing during the calculation of the objective function (3) and the restriction P_i (4). As a result, the time spent on sorting cars at the freight station can be determined from the expression

$$F_i(b_i) = \begin{cases} A_{F,i} \dfrac{N_i}{\alpha_g} \text{ at } b_i = 0 \\ A_{F,i} \dfrac{N_i}{\alpha_g \alpha_q} \text{ at } b_i = 1 \end{cases}, \quad (10)$$

where $A_{F,i}$ is the coefficient depending on the technical equipment of the i^{th} freight station, min/cut.

In general, the value of the objective function (3) can be set based on the expressions (7, 9 and 10) as

$$\sum_{i=1}^{k} T_i(x_i,b_i) = \sum_{i=1}^{k} S_{c,i}(x_i,b_i) + S_{col,i}(x_i,b_i) + F_i(b_i) \to \min. \quad (11)$$

The restriction on the maximum permissible duration of shunting operations at the marshalling yard in system (4) can be represented as

$$\sum_{i=1}^{k} S_{c,i}(x_i,b_i) + S_{col,i}(x_i,b_i) \le D_S - G_S, \quad (12)$$

and at the freight stations as

$$F_i(b_i) \le D_i - G_i, \quad i = \overline{1,k}, \quad (13)$$

where G_S, G_i are the constant time expenditures on shunting operations at marshalling yard and freight stations, independent of x_i and b_i, min.

Results. Function (11) is a non-linear function of two variables, while its arguments can only take integer values. An example of the dependence between the time expenditures on shunting work, on the one hand, and the type of the trains dispatched, as well as the number of tracks allocated for their accumulation, is shown in Fig. 4.

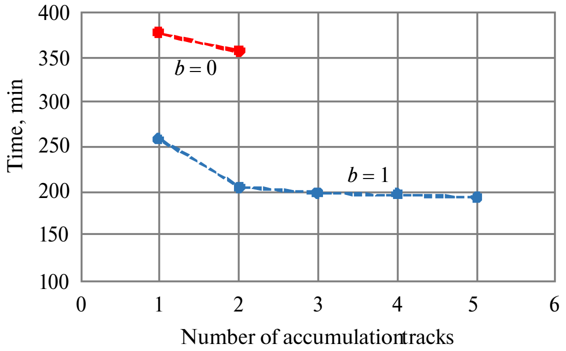

Fig. 4. The relationship between the time expenditures on shunting work, on the one hand, and the type of the trains dispatched, as well as the number of tracks allocated for their accumulation

Taking into account the nature of the objective function (11), the problem of the track distribution for the car groups accumulation between individual destinations can be reduced to a dynamic programming problem.

Restriction (13) for an individual freight station depends only on its parameters. Therefore, the variable b_i for the freight stations, where condition (13) is not satisfied, can be set equal to 1 before the optimization start, and the restriction (13) itself can be excluded from the conditions of the task.

The solution of the problem can be obtained in two stages. At the first stage, the values of the variables x_i and b_i are determined, which ensure the achievement of the minimum of the objective function (11) without taking into account the restriction (12). To solve the task, a recurrence relation is introduced, which allows solving the set problem in general terms. This recurrence relation when searching for the minimum value of the objective function (11) is written as follows

$$T_k(W) = \min\left[H_k(x_k) + T_{k-1}(W - x_k)\right], \quad x_k = \overline{1, W};$$
$$T_{k-1}(W) = \min\left[H_{k-1}(x_{k-1}) + T_{k-2}(W - x_{k-1})\right], \quad x_{k-1} = \overline{1, W};$$
$$\ldots$$
$$T_2(W) = \min\left[H_2(x_2) + T_1(W - x_2)\right], \quad x_2 = \overline{1, W};$$
$$T_1(W) = \min\left[H_1(x_1) + 0\right], \quad x_1 = \overline{1, W}.$$

The solution obtained using the above recurrence relation is the global minimum of the function (11). If the obtained value satisfies condition (12), then it is the solution to the task. If condition (12) is not satisfied, then the solution of the task will be such a set of variables x_i and b_i that ensures the fulfillment of condition (12) and results in a minimal increase in the value of the objective function relative to the global minimum. It should be noted that when the global minimum of the objective function (11) is reached, it is impossible to achieve a decrease in the value of the left side of the expression (12) by using additional sorting tracks, since this simultaneously leads to a decrease in the value of the objective function (11). Therefore, a decrease in the left side of expression (12) can be achieved only by refusing from forming the separate group trains. Given the limited number of destinations for which trains are formed by industrial marshalling yards, this problem can be solved by enumeration of possibilities.

As an example, the problem of specialization of 7 marshalling tracks of an industrial marshalling yard for the formation of trains assigned to 5 freight stations is considered. The corresponding parameters of car traffic volumes are given in Table.

The total time spent on shunting work at marshalling yards and freight stations during the formation of single-group trains is 1800 minutes. As a result of the optimization, it was found that when allocating 1, 2, 2, 1 and 1 tracks for the accumulation of cars at freight stations, respectively, and forming group

Table

Parameters of car traffic volumes of freight stations

i	N_i	m_i	g_i	q_i
1	80	20	8.9	4.7
2	150	20	7.9	3.6
3	70	15	7.5	2.9
4	16	10	7.0	5.8
5	43	15	7.1	5.0

trains at the freight station, the total time expenditures on shunting work can be reduced by 25.4 % to 1342 minutes.

In general, the originality of the work lies in the fact that it proposes an improved method for estimating the duration of shunting operations for the formation of train sets and shunting transfers, depending on the number of tracks allocated for their accumulation. Also, the paper proposes a method for formalizing and solving the problem of tracks distribution for the accumulation of car groups between individual destinations as a dynamic programming problem.

Practical value of the work lies in the fact that the method proposed in it, due to the rational distribution of the existing track arrangement of railway stations, allows reducing the time expenditures on the making- and breaking-up the trains and shunting transfers and, as a result, increasing the crossing capacity of the stations, as well as reducing the enterprises' production cost.

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

1. At present, the sidings of industrial enterprises experience an acute shortage of track capacity for the accumulation of trains and shunting transfers. The reason for this is the increase in the number of car assignments, which is caused by the division of the car fleet between individual owners and the increase in the share of specialized cars used for loading. The work of railway transport of industrial enterprises in such conditions requires the resorting of cars. Therefore, often, railway transport becomes an element that restricts the volume of production output and increases its cost. The solution to the problem may lie in the rational distribution of technical means of industrial stations, in particular, their track development for performing shunting work.

2. The optimization problem of the track distribution of the industrial railway stations for the accumulation of car groups between separate assignments consists in finding such a distribution of sorting work between the industrial marshalling yard and freight stations, as well as such a distribution of marshalling yard tracks between individual destinations, which provides the minimum time expenditures for shunting work. To solve this applied problem, the dynamic programming method is adapted in the work.

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Оптимізація розподілу колій промислових залізничних станцій між призначеннями вагонів

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Мета. Удосконалення розподілу колій промислових залізничних станцій для накопичення груп вагонів між різними призначеннями. Оптимізаційна задача полягає в пошуку такого розподілу сортувальної роботи між промисловою сортувальною й вантажними станціями, а також розподілу колій сортувальної станції між окремими призначеннями, що забезпечує мінімальні витрати часу на виконання маневрової роботи.

Методика. Дослідження виконані із застосуванням методів теорії експлуатації залізниць, імітаційного моделювання й динамічного програмування.

Результати. Вирішена оптимізаційна задача розподілу сортувальної роботи між сортувальною й вантажними станціями промислового підприємства, а також пошуку такого розподілу колій сортувальної станції між окремими призначеннями, що забезпечує мінімальні витрати часу на виконання маневрової роботи.

Наукова новизна. У роботі запропоновано метод формалізації й розв'язання задачі розподілу колій промислових залізничних станцій для накопичення груп вагонів між окремими призначеннями як задачі динамічного програмування. На відміну від існуючих методів, де число колій розглядається як обмеження, у запропонованому методі число колій є аргументом цільової функції мінімізації тривалості маневрових операцій, що дозволяє підвищити якість одержуваних рішень.

Практична значимість. Запропонований у роботі метод за рахунок раціонального розподілу наявного колійного розвитку залізничних станцій дозволяє зменшити витрати часу на формування й розформування составів поїздів і маневрових передач і, за рахунок цього, підвищити пропускну спроможність станцій, а також знизити собівартість продукції підприємств.

Ключові слова: *залізничний транспорт, промислова залізнична станція, під'їзна колія, маневрові операції, накопичення вагонів*

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