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Improving the Efficiency of Multi-Group Trains Formation

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Abstract

The formation of multi-group trains is one of the typical tasks solved in the process of operational work of railways. The purpose of this study is to reduce the time spent on shunting operations associated with the formation of multi-group trains. The studies are performed using the method of simulation modeling. The method of searching for a rational order of multi-group train formation was improved. It is based on the statistical evaluation of the variety of simulation modeling results of shunting movements, the sequence of which is determined using the various methods and formation schemes. The choice of the best method and the scheme of train formation makes it possible to reduce the duration of shunting by 7.1–23.3% when using a flat shunting neck and by 8–11% when using a sorting hump. The methods presented in this paper make it possible to develop software products for the automated preparation of shunting plans for the formation of multi-group trains at the stations.
KEY WORDS: *railways, shunting problem, optimization, multi-group trains, simulation*

1. Introduction

The multi-group trains formation is one of the typical tasks solved in the process of operational work of railways. Solution of this task is aimed to change the order of the cars` position at the railway tracks. The need to arrange the cars of a train in a certain order most often occurs when forming pick-up trains, as well as when car supplying to the points of cargo operations in seaports, transport and warehouse complexes and industrial enterprises. As a rule, the formation of multi-group trains is associated with large expenditures of time and fuel, and therefore, scientific research in this area is aimed at searching a rational order for performing the shunting operations.

The problem of developing formal methods for choosing the formation order of group trains has a rather long history. One of the first was the method proposed by Harry Futhner for the Liverpool station in 1880, where the number of available classification tracks was significantly lower than the number of car destinations in a train [1]. The main disadvantage of Futhner`s method is the rigid connection between the number of classification tracks and the number of destinations that can be sorted there.

Later, a significant number of methods that make it possible to solve the task of arranging the sequence of cars in a train according to the destinations were developed [1-7]. Among the most well-known methods, the following ones can be noted: the combinatorial and the distributive methods, the special method, the modified special method, the method of unified groups, the simultaneous method, general step method and double step method and others.

The studies aimed at comparing the efficiency of methods are the natural consequence of the development of various methods of multi-group trains formation. In particular, similar studies were performed in [1, 8, 9]. At this, the main research methods are simulation modeling and mathematical statistics. Analysis of the results of these studies shows that among the considered methods, it is impossible to choose definitely the best one. In some cases, depending on the initial location of cars at the classification tracks, different methods give the best results. In this regard, the methods for solving the problem of forming multi-group trains require improvement. The purpose of this study is to reduce the time spent on shunting operations associated with the formation of multi-group trains.

2. Solution Methodology

When solving the problem, the trains consisting of cars with different destinations are considered; at the same time, each i-th car is assigned to a number of its destination g_i.

The formation of multi-group trains is performed by one shunting locomotive using a sorting device (flat shunting neck or sorting hump) and m sorting tracks, the number of which does not exceed m_{max} ($m \leq m_{max}$). It is assumed that before start of the formation, the multi-group train is located at one of the classification tracks and the destinations of the cars g_i are not arranged. When the formation is completed, the cars of a train should be connected at one of the classification tracks; at the same time, the numbers of their destinations g_i should form a non-decreasing

sequence. The studies were performed using the method of simulation modeling, which makes it possible to determine the duration of forming a separate multi-group train and to choose the best variant for the formation.

To represent the developed model of the multi-group train formation, we introduce some definitions. By formation, the work means the process of rearranging the cars in a train to ensure the specified order of their destinations g_i. Changing the order of cars in a train is achieved by performing the operations of sorting and collecting. In the case when the number of classification tracks is less than the number of cars` destinations in a train, the formation process is carried out in several stages. The number of classification tracks, to which the cars are directed at different stages of sorting, are determined by the destination codes. The destination code $\psi(g)$ is represented by a number; each r-th figure of the code sets the number of classification track, to which the car is directed at the r-th stage of formation; the final $r+1$ stage represents the collection of cars to the one track. The group is the cars of a train or shunting composition having one destination code $\psi(g)$.

The method of formation M will be called a set of rules determining the order of generation of destination codes and the order of car collecting from the classification tracks.

The formation scheme of a train σ by certain method is called the permissible set of destination codes, which allows forming a train in a specified number of stages.

The condition of the station in a model is represented by the lists of destinations of cars attached to the shunting locomotive w_0 and standing at the classification tracks w_j, $j = 1…m_{max}$. The process of train formation is modeled as a staged process of redistribution of cars between the specified lists.

The modeling is performed at three levels. At the lower level, the task of calculating the duration of shunting operations t_f is solved in accordance with the given order of performing the operations of collecting and sorting of cars. At the middle level, the order of performing the operations of collecting and sorting of cars is determined according to the specified method and the car destination codes. At the upper level, destination codes are assigned to individual cars.

At the lower level, at each stage of the train formation, two operations are performed: collecting of cars from the m_c tracks to the draw-out track or sorting hump and sorting them from the draw-out track or sorting hump to m_s tracks.

The operations of collecting and sorting of cars, in turn, consist of elementary shunting movements, as a result of each of them the number of cars at one of the classification tracks w_j, and in the shunting composition w_0 is changing. The duration of the implementation of these elementary movements depends on the number of cars in a train and is determined in accordance with the methodology described in the works [9, 10].

The order of operations of collecting and sorting cars for the lower level is set at the middle level in accordance with the specified method and destination codes of cars. Five well-known methods of forming multi-group trains were chosen for research: combinatorial method (CM) [5, 6], distributive method (DM) [6], general method (GM) [1, 7], double step one (DSM) [7], and modified special method (MSM) [1, 7].

As an example, let us consider the formation of train of 6 cars 503142 by the distributive method [6] using 2 classification tracks.

When using this method its representation in the number system with the m_{max} base is used as a code for a separate destination. A fragment of the table of destination codes for the distributive method is presented in Table 1. The collecting of cars at each stage of formation is carried out from all tracks in the order of descending of their numbers.

Table 1

Destination codes for multi-group train formation at two tracks by the distributive method

Destination	0	1	2	3	4	5	6	7	8
Destination code	0	1	10	11	100	101	110	111	1000

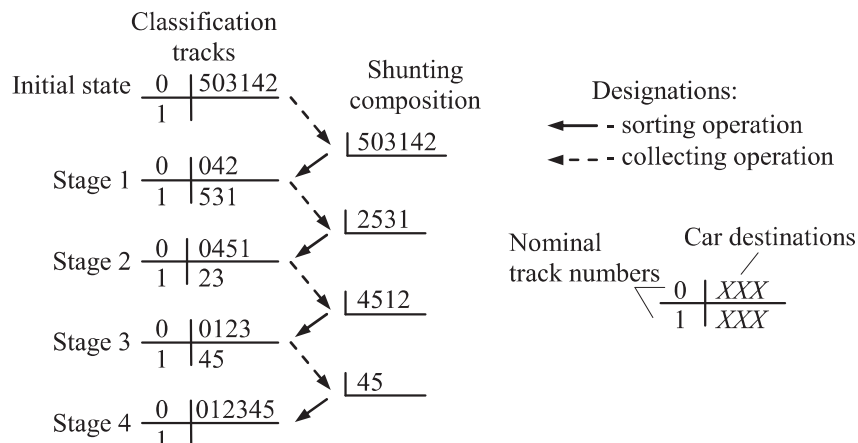The process of train formation is shown in Fig. 1

Fig. 1 The order of train formation of 6 cars at 2 tracks

At the upper level, it is performed the generation of a set of possible schemes for train formation for a given method, the number of classification tracks and groups of cars and assignment of destination codes to cars of train in accordance with this.

It should be noted that in many cases the formed trains are partially arranged. Therefore, in order to identify the initial arrangement of a train and replace the initial numbers of destinations g_i by the nominal numbers γ_i, we will read the destination numbers of cars in a train sequentially in non-decreasing order. The nominal destination number is determined as

$$\gamma_i = b_i - 1 , \tag{1}$$

where b_i – is the number of reading at which the i-th car destination number was read.

An example of the replacement of the initial destination numbers of cars in a train by the nominal ones is presented in Table 2.

<div align="right">Table 2</div>

Replacement of initial destination numbers by the nominal ones

Initial destination numbers, g_i		5	0	3	1	4	2
Numbers of reading	1		+		+		+
	2			+		+	
	3	+					
Nominal destination numbers, γ_i		2	0	1	0	1	0

As a result, the replacement of the initial numbers by the nominal numbers of destinations in a train was reduced from 6 to 3, which, in accordance with Table 1, makes it possible to reduce the length of destination codes by 1 and, accordingly, to reduce the number of stages of a train formation. The codes obtained on the basis of nominal numbers of destinations are presented in Table 3.

<div align="right">Table 3</div>

Destination codes for multi-group train formation at two tracks by the distributive method

Destination	0	1	2	3	4	5
Nominal destination number	0			1		2
Destination code	0			1		10

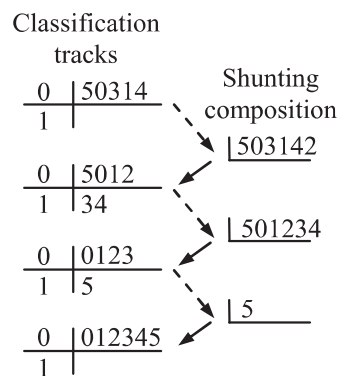Example of the train formation using the nominal destination numbers is presented in Fig. 2.

Fig. 2 The order of train formation using the nominal destination numbers

The basic factors affecting the duration of the train formation are the number of stages of its formation and the number of cars participating in shunting at individual stages. Considering that the number of stages in the train formation is determined by the number of figures in the biggest destination code, varying the number of codes for nominal group numbers within certain limits will not lead to a change in the number of formation stages. Thus, with the number of nominal groups 2 or 3, a train formation will be carried out in 3 stages; when the number of nominal groups from 4 to 7, a train formation will be carried out in 4 stages (see Table 1). Then, for the considered example, when forming a train using the distributive method in two stages, it is possible to use 7 formation schemes with different order of destinations coding (see Table 4).

Changing the formation scheme makes it possible, using the same method, to reduce the number of cars participating in shunting movements and thereby speed up the formation process. Thus, train formation by the distributive method according to the scheme 2 is shown in the following Fig. 3.

Table 4

Train formation schemes

Destinations		0	1	2	3	4	5
		Destination codes					
Formation schemes	1	0	0	0	1	1	10
	2	0	0	0	1	1	11
	3	0	0	0	1	10	11
	4	0	0	0	10	10	11
	5	0	0	1	10	10	11
	6	0	1	1	10	10	11
	7	1	1	1	10	10	11
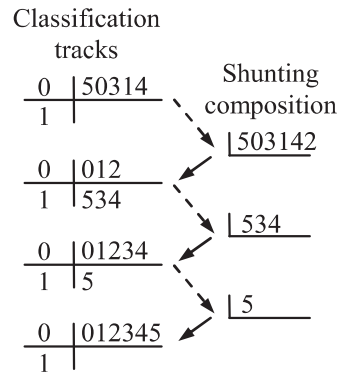
Fig. 3 The order of train formation using the nominal destination numbers according to the scheme 2

According to the results of research, the number of stages of formation has a greater influence on its duration than the number of cars participating in shunting movements; however, in some cases, it is advisable to increase the number of stages to obtain a larger set of formation schemes.

Thus, varying the destination codes for cars in train leads to a change in the order of performing the shunting work with a train during its formation and, accordingly, the duration of its performing.

Due to the fact that the order of performing the shunting work on multi-group train formation may be different, the problem of optimization of this process arises; in this case, the formation time T_f was taken as the criterion of optimality. Duration of a train formation depends on the chosen method M. In addition, due to the presence of a set of Z formation schemes σ the order of shunting operations performing with a train, and, accordingly, the time of its formation T_f, can vary significantly even when using the same method. Therefore, it is possible to choose from the set Z of the method under consideration M of the rational scheme, with the realization of which the train formation time T_f is minimal. In this case, if Z is not enough, the minimum value of T_{fmin} can be found by the method of complete enumeration. However, in many cases, the value Z is large enough and it is impossible to calculate T_{fi} for all $i = 1,..., Z$ in a reasonable time; in such cases, it is proposed to use a statistical approach to search for a quasi-optimal solution.

For this purpose, a non-parametric one-sided tolerance limit can be applied, based on the minimum T_f value in a sample of volume n_0. The value n_0 is the minimum sample volume at which, with statistical reliability β, it can be argued that, at least, the proportion α of the general population exceeds the smallest value in the sample. Thus, when $Z > n_0$ from the general population Z, it is necessary to select n_0 formation schemes randomly and take the minimum T_{fmin} value found in this sample as the minimum for a given train, and consider the corresponding scheme quasi-optimal. In this case, with the probability β, it can be argued that the proportion of the general population of T_f values will exceed T_{fmin}.

According to [11] with $\beta = 0.95$ and $\gamma = 0.99$ $n_0 = 299$. Thus, for $Z > 299$, out of the general population Z, it is necessary to select randomly 299 formation schemes and take the minimum value T_{fmin} found on this sample as the minimum for a given train, and the corresponding scheme is to be considered quasi-optimal. In this case, with a probability of 0.95, it can be argued that 99% of the general population of T_f values will exceed T_{fmin}.

In general, in this study, the optimization task is to choose a method and a formation scheme that ensure the minimum duration of shunting work with a train:

$$T_f\left(M, \sigma\right) \to \min . \tag{2}$$

3. Research Results

The studies of the multi-group train formation were performed using the developed simulation model; at the same time data on flows of 200 trains, which differ in the number of cars, were preliminary prepared; at this, the number of groups in a train is random.

When forming a train using a randomly chosen scheme, the duration of the formation can be evaluated by its average value:

$$\bar{t_f} = \frac{1}{n_0} \sum_{i=1}^{n_0} t_{fi} \ .$$ (3)

Evaluation of the optimization efficiency of the train formation is performed using the following expression:

$$e = \frac{\bar{t_f} - t_{fmin}}{t_{fmax}} \cdot 100\% \ ,$$ (4)

where t_{fmax}, t_{fmin} – is the duration of train formation, correspondingly, according to the best and worst of the n_0 schemes of the sample.

The evaluation results of the effect of searching the optimal scheme for the considered methods during the train formation with the number of cars $n = 15$, 25 and 35 when using $m_{max} = 2$, 3 and 4 tracks and different types of sorting devices are given in Table 5.

Table 5

Effect from optimization of train formation schemes

Type of sorting device	n	m_{max}	CM	DM	GM	DSM	MSM
Flat shunting neck	15	2	4.6	10.6	-	8.1	7.7
		3	6.8	13.2	8.2	15.9	8.8
		4	8.1	11.4	10.7	15.5	9.5
	25	2	8.6	12.1	-	-	6.8
		3	9.3	14.9	5.7	17.3	9.3
		4	10.4	14.9	11.4	15.4	11.2
	35	2	9.5	10.1	-	-	5.6
		3	10.7	10.7	-	17.2	9.1
		4	10.7	14.5	10.1	14.9	12.3
Hump	15	2	3.8	11.5	-	7.0	6.2
		3	5.4	13.5	10.9	13.9	11.8
		4	7.2	12.2	12.7	13.8	12.2
	25	2	6.2	11.0	-	-	6.5
		3	7.6	15.1	7.9	15.4	14.4
		4	9.0	14.2	13.1	15.5	16.1
	35	2	6.2	8.4	-	-	5.8
		3	7.3	9.5	-	15.2	17.1
		4	7.5	11.7	12.2	15.3	18.8

As can be seen from Table 5, the search for the optimal scheme of train formation makes it possible to reduce its duration by 5-20%. In this regard, in further studies for each train, the minimum formation time, which can be achieved under specified conditions and the choice of the optimal scheme was taken as the calculation one.

Further, a comparative evaluation of the efficiency of the considered formation methods was performed. According to the studies with each combination of the parameters m_{max} and n there is a method $\hat{M}\left(m_{max}, n\right)$, the frequency f of which is higher than that of the other methods. At the same time at the humps, it is usually a combinatorial method.

At the draw-out tracks, most often the DSM, MSM and GM methods were used; the choice of the best method $\hat{M}\left(m_{max}, n\right)$ is determined by the combination of the parameters m_{max} and n.

As follows from Table 6, the maximum frequency f_{max} (bold table cells) varies within sufficiently wide limits (from 26 to 88%), however, in all cases it is less than 100%. Consequently, there is no method that would be the best for all trains of the flow under any given conditions of formation and parameters of trains. From here, it can be concluded that in order to minimize the time of train formation at the station, it is necessary to choose the best method and formation scheme for each of them.

In order to evaluate the efficiency of this approach, two possible options for organizing the train formation at the station were considered. In the first variant, the formation of each of the flow trains is carried out using the method and scheme of formation, requiring minimal time to perform shunting work. In the second variant, the formation of all the trains of the flow is carried out by the same method without choosing the best scheme. The results of the efficiency evaluation of the selection of method and formation scheme are given in Table 7.

Table 6

Use frequency of different methods of train flow formation

Type of sorting device	n	m_{max}	CM	DM	GM	DSM	MSM
Flat shunting neck	15	2	14.9	9.6	-	19.3	**56.3**
		3	19.6	4.4	4.4	**43.9**	27.6
		4	23.9	13.7	14.9	**26.3**	21.1
	25	2	21.0	11.8	-	-	**67.3**
		3	7.4	9.0	5.5	**61.9**	16.2
		4	9.0	13.6	**41.6**	11.4	24.4
	35	2	15.8	4.0	-	-	**80.3**
		3	14.0	1.8	-	**57.5**	26.8
		4	3.8	5.8	**46.0**	8.5	35.9
Hump	15	2	27.4	4.2	-	**42.6**	25.7
		3	**45.9**	8.6	6.7	25.3	13.6
		4	**71.2**	7.0	7.8	8.3	5.7
	25	2	**65.8**	9.8	-	-	24.5
		3	**38.2**	8.3	5.1	32.8	15.6
		4	**81.0**	2.5	8.4	5.7	2.5
	35	2	**77.5**	8.0	-	-	14.5
		3	**54.6**	2.3	-	26.3	16.8
		4	**87.7**	0.1	7.9	1.1	3.1

Table 7

Efficiency evaluation of the schemes optimization and selection of the optimal method for each train

Type of sorting device	n	m_{max}	CM	DM	GM	DSM	MSM
Flat shunting neck	15	2	17.4	26.4	-	21.9	**12.1**
		3	14.2	22.4	17.4	**20.4**	14.5
		4	13.9	18.1	16.2	**21.4**	14.6
	25	2	22.3	28.1	-	-	**9.2**
		3	17.4	24.0	15.7	**21.7**	15.8
		4	19.1	22.8	**15.2**	23.2	15.7
	35	2	23.3	28.4	-	-	**7.1**
		3	20.4	23.7	-	**23.3**	14.0
		4	20.8	23.8	**13.7**	23.3	16.3
Hump	15	2	9.6	23.0	-	**11.0**	12.0
		3	**8.4**	14.5	20.7	22.0	19.8
		4	**8.4**	22.8	20.7	22.0	20.2
	25	2	**8.7**	20.5	-	-	15.1
		3	**9.7**	25.2	17.3	19.8	21.1
		4	**10.4**	27.0	21.2	26.1	26.1
	35	2	**8.0**	17.7	-	-	19.5
		3	**9.0**	21.4	-	20.9	27.6
		4	**8.5**	26.2	21.6	28.1	30.3

In Table 7 the cells corresponding to the most frequently used method are in bold (see Table 6).

Comparison of the data in Tables 7 and 5 shows that the use of different methods when searching for the optimal variant of multi-group train formation makes it possible to further reduce the duration of shunting by 1.5–6.1% when using a flat shunting neck and by 1.0–4.0% when using a sorting hump. In general, the choice of the best method and scheme for the train formation makes it possible to reduce the duration of shunting by 7.1–23.3% when using a flat shunting neck and by 8–11% when using a sorting hump.

The methods presented in this paper make it possible to develop software products for the automated preparation of shunting plans for the formation of multi-group trains.

4. Conclusions

Originality of the work consists in improving the technology of multi-group train formation by varying the methods and schemes of formation, which makes it possible to reduce the duration of shunting work. The use of the improved method makes it possible to reduce the duration of shunting by 7.1-23.3% when using a flat shunting neck and by 8-11% when using a sorting hump.

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