Method of Determining the Minimum Required Number of Sorting Tracks, Depending on the Length of the Group of Wagons

Suyunbayev Shinpolat Mansuraliyevich[1]; Khudayberganov Sakijan Kabildjanovich[2];
Svetashev Aleksandr Aleksandrovich[3]; Jumayev Sherzod Bakhromugli[4]; Mikhayeva Dilyara Bakhromovna[5];
Olimov Azamat Rakhimovich[6]

[1]Candidate of Technical Sciences, Professor, Department of Organization of Transport Movement, Tashkent State Transport University, Tashkent, Uzbekistan.
[1]shinbolat_84@mail.ru

[2]Candidate of Technical Sciences, Associate Professor, Department of Organization of Transport Movement, Tashkent State Transport University, Tashkent, Uzbekistan.
[2]s.xudayberganov61@mail.ru

[3]Candidate of Technical Sciences, Associate Professor, Department of Organization of Transport Movement, Tashkent State Transport University, Tashkent, Uzbekistan.
[3]aleksandr-svetashev@bk.ru

[4]Candidate of Technical Sciences, Associate Professor, Department of Organization of Transport Movement, Tashkent State Transport University, Tashkent, Uzbekistan.
[4]shbjumayev_92@mail.ru

[5]Doctoral Student, Department of Organization of Transport Movement, Tashkent State Transport University, Tashkent, Uzbekistan.

[6]Doctoral Student, Department of Organization of Transport Movement, Tashkent State Transport University, Tashkent, Uzbekistan.

Abstract

This article, based on the study of local and foreign experience, identifies the need to seek comprehensive solutions for the effective organization of the wagon-flows in JSC "Uzbekistan Railways". Based on the processing of statistical data, it was determined that the length of a group of wagons in a one direction multi-group train is subject to the law "Erlang". Based on the use of Fibonacci numbers to search for the best scheme for the formation of multi-group trains, the method of determining the minimum required number of sorting tracks depending on the length of the group of wagons has been improved. As a result of the application of this method by JSC "Uzbekistan Railways" at station "Chukursay", the cycle time of the sorting hill was reduced by 12%, the time spent on sorting of transit trains was reduced by 5% and the processing capacity of the sorting hill was increased by 14%.

Key-words: Multi-group Trains, Shunting Operations, Group Length of Wagons, Number of Sorting Tracks, Fibonacci Numbers, Erlang Law.

1. Introduction

In the process of sorting the flow of goods on the world's transport corridors, a leading role is played by increasing the speed, setting time and optimizing technological processes, as well as improving the technical and operational methods of management assessment. Much attention is paid to the development of methods for the measurement, evaluation and elimination of various inefficient loss factors affecting the trunk and local transport networks of developed countries, including the United States, Germany, Sweden, China, India, Russia, Kazakhstan and similar countries [1-6].

In this regard, special attention is paid to the development of methods for calculating and determining the values of parameters of inefficient time losses in the processing of wagons at sorting stations, as well as technology for controlling the flow of wagons.

Statistics of Uzbekistan Railways show that today rail freight is not organized efficiently enough. One of the main reasons for this was that it was found that the wagon loaded during the delivery of the cargo spent most of its time standing at the loading station or recycling stations, rather than moving on the section. The time spent by the loaded wagon to deliver the cargo to its destination was studied in 2 types: the time spent on the movement of wagons on the railway site and the time spent on other types of operations.

In JSC "Uzbekistan Railways" this indicator is 13% and 87%, respectively. The situation of this indicator in other countries was also analyzed. For example, in France, a loaded wagon spends 26% on on-railway site traffic and 74% on other types of operations, while in the United States this indicator is found to be 40% and 60%, respectively [7, 8].

2. Materials and Methods

The analysis of the performance of the sorting station "Chukursay" under JSC "Uzbekistan Railways", including the analysis of the time of wagons at the station, showed that these indicators exceeded the norm for all analyzed periods. In turn, such inefficient waste of time in the operation of the sorting station leads to a decrease in the efficiency of operation technology for the organization and management of wagon flows not only at the station, but on the entire railway, and at the same time its competitiveness in the transport market. These, in turn, require the improvement of methods to reduce inefficient time losses in the operation of the sorting station in order to meet the technical and operational performance.

2.1. Search for Complex Solutions for the Effective Organization of the Flow of Wagons

The fact that the wagons loaded at JSC "Uzbekistan Railways" do not spend most of their time on the road leads not only to a decrease in the speed of delivery of goods but also to an increase in fines paid by the railway to the owner of the cargo. Delivery of goods to their destination on time is one of the main tasks of the railways to fulfil the contract of carriage, the non-fulfilment of which has a significant impact on the quality of transport services to users of railway services.

The research showed the need to find complex solutions for the effective organization of the wagon-flows in the conditions of disproportion in JSC "Uzbekistan Railways", taking into account the delivery time (Figure 1).

A study was conducted to improve the non-optimality parameters of the multi-group train formation process at the technical stations of the search for complex solutions shown in Figure 1.

Figure 1- Search for Complex Solutions for the Effective Organization of the Wagon-flows in the conditions of Imbalance in JSC "Uzbekistan Railways".
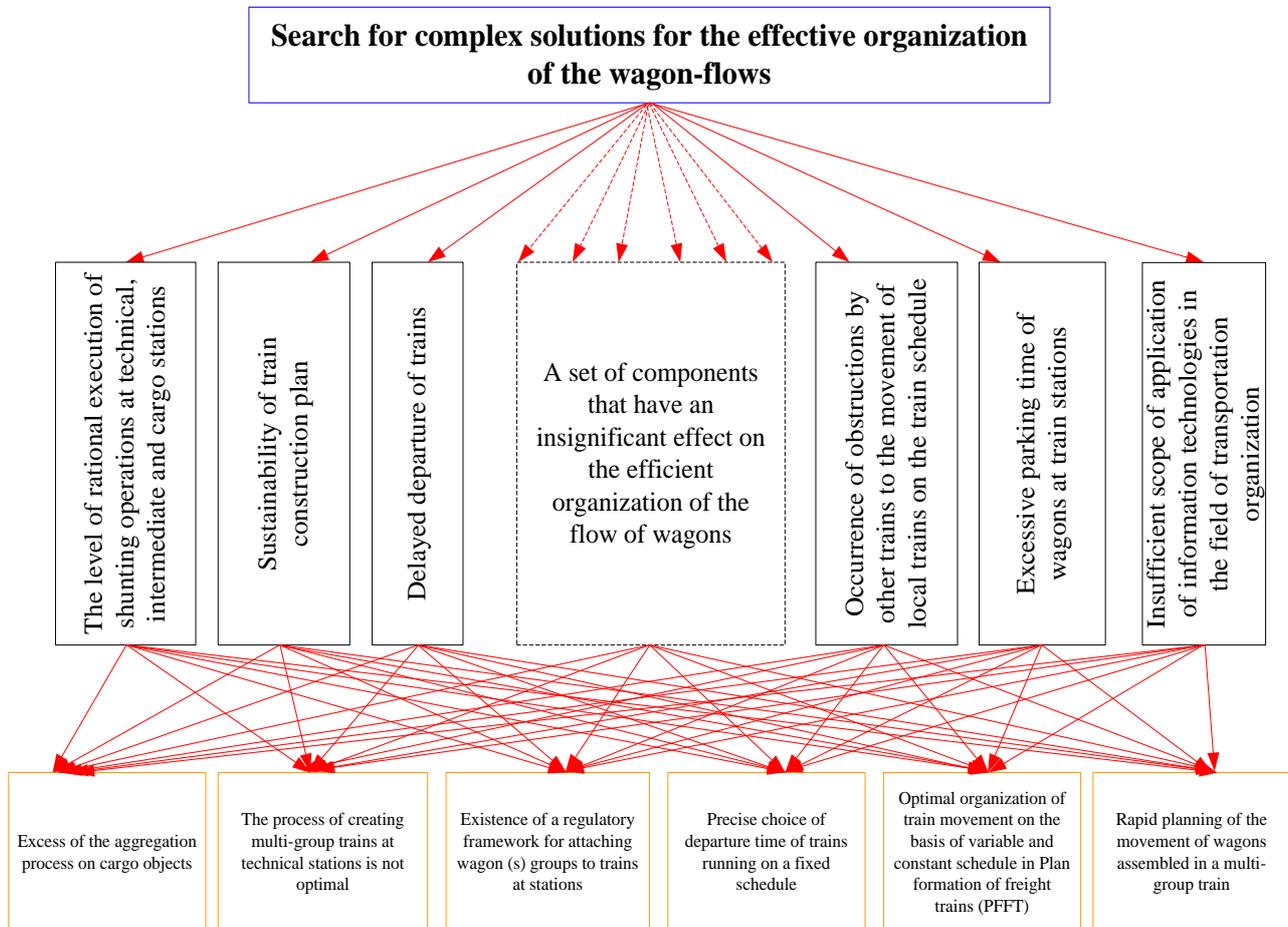
2.2. Determining the Length of a Group of Wagons in One Direction in a Multi-group Train

It is known that feasibility and technological calculations are carried out to optimize the processing of wagon flows in railway transport. In their implementation it is necessary to study the following most important parameters, which are inextricably linked:

Number of wagons in the train;

Number of interruptions in the train;

The number of routes in the train.

Determining the number of carriages on a train requires an independent study. It is also possible to calculate from the formula proposed in [9] for the standard deviation of the number of wagons arriving at the station (freight object) per day:

$$\delta_m = 1,06 * m_c^{0.64} \tag{1}$$

Here m_c is the average number of wagons in the train.

From formula (1) to calculate the coefficient of variation of the number of wagons in the train can be given the following expression.

$$\gamma_m = 1,06 * m_c^{-0.36} \tag{2}$$

To determine the number of wagons in the train, the formula is shown in the work [9] and formula (1) are used, then the modelled number of wagons in the distributed trains is obtained as follows:

$$m_i = 1,06 * m_c^{0.64} * \sqrt{2} * \left(\sum_{i=1}^{\delta} \xi_i - 3 \right) + m_c \tag{3}$$

One of the most important parameters is the average number of interruptions in this train. Some researchers recommend defining this with a general probability formula. However, calculations performed using this formula shows that there are significant differences between the actual data and the data obtained as a result of the calculations. In addition, the average number of interruptions indicates that the calculated parameters are irrational in the calculated part.

The most reliable results are obtained depending on the work [10]:

$$g_c = \frac{m_c}{r} * \left(1 - \sum_{i=1}^{k_c} p_i^2 \right) \tag{4}$$

where r - a coefficient characterizing the average number of wagons at interruptions due to load flows at stations. $r=1,4-1,8$ for average network conditions;

k_c - the maximum possible number of routes of wagons in the train;

p_i - the probability of the appearance of an i-way wagon on this train.

The value of k_c describes the number of cargo objects intended for the departure of wagons (shipped as part of a local train) or the number of stations to which the wagons go (for sorting and transmission trains - the number of groups). The probability of wagons appearing in the i-direction in the train.

$$p_i = N_i / \sum_{i=1}^{k_c} N_i \qquad (5)$$

where N_i -the wagon-flows (daily, monthly, etc.) directed to the i-cargo object (i-station).

The total calculations (more than 3.5 thousand trains) showed that $\sum_{i=1}^{k_c} p_i^2 = 1,33 / k_c$, so formula (4) can be expressed as follows:

$$g_c = \frac{m_c}{r} * \left(1 - 1,33 / k_c\right) \qquad (6)$$

The average number of directions can be determined by the formula of probability theory to give sufficiently reliable results [10]:

$$n_c = k_c - \sum_{i=1}^{k_c} \left(1 - p_i\right)^{g_c} \qquad (7)$$

Since one of the main parameters affecting g_c and p_c is the average number of wagons in the train (mc), it is assumed that the deviation and deviation of the number of carriages from the average value occur as a result of changes in the number of wagons in the train. This hypothesis is confirmed by general practical calculations, which allows the use of formulas (1) and (2) to calculate the numerical properties of the above indicators. Thus, after the corresponding changes, the standard deviation of the number of interruptions and the number of directions of the wagons in the train can be determined by the following expressions:

$$\delta = \frac{\delta_m * g_c}{m_c} \tag{8}$$

$$\delta_n = \frac{\delta_m * n_c}{m_c} \tag{9}$$

Figure 2- According to Erlang's Law, the Length of Wagon Groups of Multi-group Trains in One Direction depends on the Frequency of their Formation (when $l_{mid} = 112\ m$)
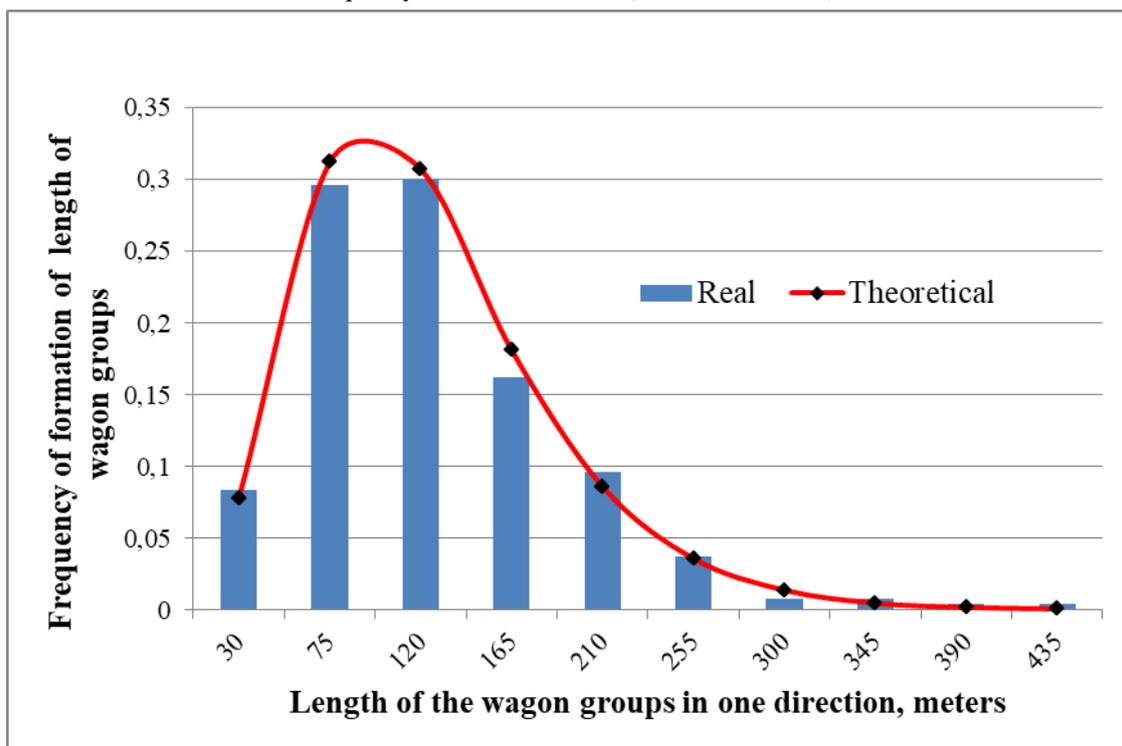
Excessive time spent on shunting operations performed by multi-group trains at technical and intermediate stations leads to a slowdown in the flow of domestic wagons. The reason for the excessive time spent on shunting operations with multi-group trains is the irregular placement of a group of wagons in the train of this train. The study found that the bulk of the time spent on shunting operations with multi-group trains was spent on sorting and reassembling groups of wagons. Also, another important feature of the location of wagons in a multi-group train is the distribution of the length of the group of wagons in a particular direction. Based on the processing of statistical data, it was determined that the length of a group of wagons in a single-track multi-group train is subject to Erlang's law (order 1-3) (Figure 2).

The density function of the Erlang distribution law has the following form

$$f_k\left(L_{gr}\right) = \frac{(\lambda \cdot k)^k L_{gr}^{k-1}}{(k-1)!} e^{-\lambda \cdot k \cdot L_{gr}} \qquad (10)$$

In this L_{gr} is the average length of a group of wagons in the formation of multi-group freight trains, m;

λ is the density of the Erlang distribution law (magnitude inverse to the mathematical expectation);

k is a parameter of the Erlang distribution law.

Accurate identification of the basic parameter laws and numerical characteristics in the distribution of wagon flow allows us to assess the possibilities of development tracks of local sorting systems and speed up the process of sorting train trains.

2.3. A Method of Determining the Minimum required Number of Sorting Tracks depending on the Length of the Group of Wagons
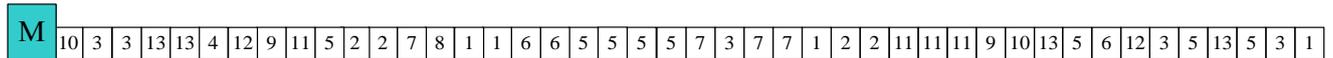
The scattered location of railway stations and freight facilities leads to the formation of a group of wagons in the prescribed manner, that is, in the group under formation, the location of wagon stations or freight facilities is required to match the sequence. These, in turn, require the determination of the minimum number of shunting flights and the selection of the sequence of their execution in the formation of a group of wagons in the prescribed manner. The problem of inefficient use of sorting routes during train distribution and assembly causes several problems in the distribution of multi-group trains.

In the process of creating multi-group trains on the combinatorial method of sorting local wagons, the number of groups in the train and the number of available tracks play an important role. In the field of railway transport, the main problem was to determine the relationship between the number of groups formed in different years and the number of existing tracks. To find a solution to this problem, it is advisable to focus on a higher mathematics course. The theory of numbers was proved to science by the great mathematician of his time, Fibonacci (1170-1250). The main problem is to adapt this theory to the process of distribution of multi-group trains. Studies have shown that there is a law of dependence of the number of groups in a multi-group train on the required tracks by means of Fibonacci numbers [11].

This can be seen in Figure 3 below. As can be seen from Figure 3, the greater the number of groups in the train, the greater the number of tracks required. This in turn leads to an increase in shunting flights [12].

However, in practice, the issue of efficient use of existing roads comes first. Considering the required number of sorting tracks or the level of occupancy of existing tracks, it is important to select a group of wagons in a multi-group train using the Fibonacci numbers.

Figure 3- The Law that the Number of Groups in a Multi-group Train depends on the Required Tracks

Figure 4 shows the technology of the group selection of wagons using the shunting locomotive "TEM-2" according to the combinatorial sorting method using multi-group trains using Fibonacci numbers.
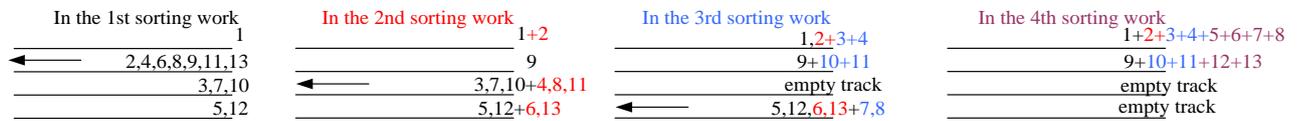
Figure 4- The Technology of Sorting the given Train in Accordance with the Combinatorial Sorting method Using Fibonacci Numbers
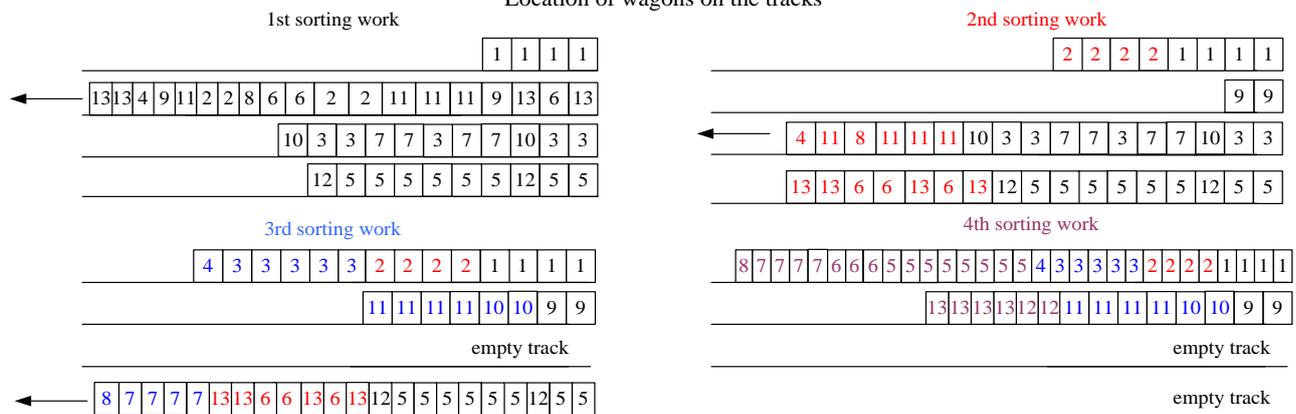
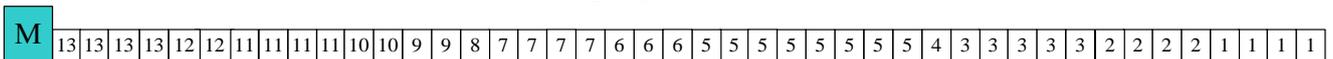The state before the distribution of the train

M | 10 | 3 | 3 | 13 | 13 | 4 | 12 | 9 | 11 | 5 | 2 | 2 | 7 | 8 | 1 | 1 | 6 | 6 | 5 | 5 | 5 | 5 | 7 | 3 | 7 | 7 | 1 | 2 | 2 | 11 | 11 | 11 | 9 | 10 | 13 | 5 | 6 | 12 | 3 | 5 | 13 | 5 | 3 | 1

Scheme of location on the tracks along the routes

In the 1st sorting work	In the 2nd sorting work	In the 3rd sorting work	In the 4th sorting work
1	1+2	1,2+3+4	1+2+3+4+5+6+7+8
2,4,6,8,9,11,13	9	9+10+11	9+10+11+12+13
3,7,10	3,7,10+4,8,11	empty track	empty track
5,12	5,12+6,13	5,12,6,13+7,8	empty track

Location of wagons on the tracks

1st sorting work

																		1	1	1	1
13	13	4	9	11	2	2	8	6	6	2	2	11	11	11	9	13	6	13			
								10	3	3	7	7	3	7	7	10	3	3			
								12	5	5	5	5	5	5	12	5	5			

2nd sorting work

														2	2	2	2	1	1	1	1
																				9	9
4	11	8	11	11	11	10	3	3	7	7	3	7	7	10	3	3					
13	13	6	6	13	6	13	12	5	5	5	5	5	5	12	5	5					

3rd sorting work

4	3	3	3	3	3	2	2	2	2	1	1	1	1
11	11	11	11	10	10	9	9						

empty track

8 7 7 7 7 13 13 6 6 13 6 13 12 5 5 5 5 5 5 12 5 5

4th sorting work

8	7	7	7	7	6	6	6	5	5	5	5	5	5	5	5	4	3	3	3	3	3	2	2	2	2	1	1	1	1
13	13	13	13	12	12	11	11	11	11	10	10	9	9																

empty track

empty track

Assembling wagons from 2nd and 1st tracks

M | 13 | 13 | 13 | 13 | 12 | 12 | 11 | 11 | 11 | 11 | 10 | 10 | 9 | 9 | 8 | 7 | 7 | 7 | 7 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1

Using Fibonacci numbers, we determine the amount of time spent on the given train sorting technology according to the combinatorial sorting method using Table 1.

Table 1- Determining the Amount of Time Spent on Train Sorting Technology According to the Combinatorial Sorting Method using Fibonacci Numbers

No.	The name of the process	Number of wagons (m_c), wag.	Formula and elements of process calculation	Time spent min.
1 cycle	The shunting locomotive leads to the track where the train is without wagons	0	$t_{lead} = 2.44 \cdot v/2 + 3.6 \cdot L_{distance}/v$ $v = 10 \text{ km/h}, Ldistance = 338 \text{ meter}$	2,23
	Connecting the shunting locomotive to the wagons	44	$t^{connect} = 0.06 \cdot m_c$	2,63
	The shunting locomotive pulls the train to the top of the sorting hill	44	$t_{half\ flight} = (2.44 + 0.1 \cdot m_c) \cdot v/2 + 3,6 \cdot L_{half\ flight}/v$ v=5 km/h, $L_{half\ flight}$=338 meter	2,20

	Sorting the train at the top of the sorting hill	44	$t^{sort} = \left(0,06 \cdot m_c \cdot l_{wag}/v_{sort}\right) \cdot \left(1 - 1/g_{interrupt}\right)$	7,44
			l_{wag}=14,7 meter; v_{sort}=5 km/h; $g_{interrupt}$ =24	
2 cycle	The shunting locomotive moves towards the 2nd track without wagons	0	$t_{\text{lead}} = 2.44 \cdot v/2 + 3.6 \cdot L_{\text{distance}}/v$	2,23
			v=10 km/h, $L_{distance}$ =338 meter	
	Connecting the shunting locomotive to the wagons	19	$t^{connect} = 0.06 \cdot m_c$	1,14
	The shunting locomotive pulls the trains from 2nd track to the top of the sorting hill	19	$t_{half\,flight} = (2,44 + 0,1 \cdot m_c) \cdot v/2 + 3,6 \cdot L_{half\,flight}/v$	3,15
			v=7 km/h, $L_{half\,flight}$=338 meter	
	Sorting the train at the top of the sorting hill	19	$t^{sort} = \left(0,06 \cdot m_c \cdot l_{wag}/v_{sort}\right) \cdot \left(1 - 1/g_{interrupt}\right)$	3,01
			l_{wag}=14,7 meter; v_{sort}=5 km/h; $g_{interrupt}$ =10	
3 cycle	The shunting locomotive moves towards the 3rd track without wagons	0	$t_{\text{lead}} = 2.44 \cdot v/2 + 3.6 \cdot L_{\text{distance}}/v$	1,99
			v=10 km/h, $L_{distance}$ =299 meter	
	Connecting the shunting locomotive to the wagons	17	$t^{connect} = 0.06 \cdot m_c$	1,02
	The shunting locomotive pulls the train from the 3rd track to the top of the sorting hill	17	$t_{half\,flight} = (2,44 + 0,1 \cdot m_c) \cdot v/2 + 3,6 \cdot L_{half\,flight}/v$	2,80
			v=7 km/h, $L_{half\,flight}$=299 meter	
	Sorting the train at the top of the sorting hill	17	$t^{sort} = \left(0,06 \cdot m_c \cdot l_{wag}/v_{sort}\right) \cdot \left(1 - 1/g_{interrupt}\right)$	2,66
			$l_в$=14,7 meter; v_{sort}=5 km/h; $g_{interrupt}$=9	
4 cycle	The shunting locomotive moves towards the 3rd track without wagons	0	$t_{\text{lead}} = 2.44 \cdot v/2 + 3.6 \cdot L_{\text{distance}}/v$	1,86
			v=10 km/h, $L_{distance}$=277 meter	
	Connecting the shunting locomotive to the wagons	22	$t^{connect} = 0.06 \cdot m_c$	1,32
	The shunting locomotive pulls the train from the 4th track to the top of the sorting hill	22	$t_{half\,flight} = (2,44 + 0,1 \cdot m_c) \cdot v/2 + 3,6 \cdot L_{half\,flight}/v$	2,64
			v=7 km/h, $L_{half\,flight}$=277 meter	
	Sorting the train at the top of the sorting hill	22	$t^{sort} = \left(0,06 \cdot m_c \cdot l_{wag}/v_{sort}\right) \cdot \left(1 - 1/g_{interrupt}\right)$	3,44
			l_{wag}=14,7 meter; v_{sort}=5 km/h; $g_{interrupt}$=9	
Groupage flight	The shunting locomotive moves towards the 2nd track without wagons	0	$t_{\text{lead}} = 2.44 \cdot v/2 + 3.6 \cdot L_{\text{distance}}/v$	2,23
			v=10 km/h, $L_{distance}$=338 meter	
	Connecting the shunting locomotive to the train wagons	14	$t^{connect} = 0.06 \cdot m_c$	0,84
	The shunting locomotive pulls the trains from 2nd track to the top of the sorting hill	14	$t_{half\,flight} = (2,44 + 0,1 \cdot m_c) \cdot v/2 + 3,6 \cdot L_{half\,flight}/v$	3,1
			v=7 km/h, $L_{half\,flight}$ =338 meter	
Groupage flight	The shunting locomotive travels from the traffic light №MG3 to the 1st track with the group of wagons	14	$t_{half\,flight} = (2,44 + 0,1 \cdot m_c) \cdot v/2 + 3,6 \cdot L_{half\,flight}/v$	2,34
			v=10 km/h, $L_{half\,flight}$ =338 meter	
	Connecting the shunting locomotive to the wagons	44	$t^{connect} = 0.06 \cdot m_c$	2,63
Total:				52,9

The frequency of formation of the length of the group of wagons received at the station depends on the required number of sorting tracks, the degree of filling of existing tracks or the number of empty tracks. Determining the required or empty number of sorting tracks is done in the following order. Once the group of wagons previously admitted to the station has been placed at their addresses on the qualifying park tracks, the filled portion of the useful length of the assembly track is determined. The length of the filled part of the sorting tracks is determined by the sum of the lengths of the group of wagons thrown from the sorting hill:

$$L_{(i)\text{fill}} = \sum_{l=1}^{j} L_l^{\text{discon}} \qquad (11)$$

where $L_{(i)fill}$ – i- is the length of the filled part of the sorting track that specializes in the direction, m.

L_l^{discon} – is the length of the group of wagons which sort from the sorting hill, m

Once the length of the filled part of the sorting path is determined, the complete assembly of the train is checked if the useful length of the track is not less than the set length of the train formed by the value of the filled part $L_{fill} \geq L_{\text{content}}$.

When sorting by the proposed method, the following conditions are first checked. (12) shows that the train can be rationally formed if the sum of the filled part of the i-sorting track and the length of the group of wagons sorted from the hill is greater than the length of the formed train, the train is considered filled according to the established norm:

$$L_{(i)\,fill} + \lambda_i \cdot L_l^{discon} \geq L_{train} \qquad (12)$$

In this λ_i - a logical variable that reflects the dependence of the length of a group of wagons on the sorted train on the length of the specialized sorting track.

$$\lambda_i = \begin{cases} 1, & \text{specialized throwing a group of wagons} \\ & \text{on the track or looking for} \\ & \text{the track closest to that track;} \\ 0, & \text{the trains were filled before} \\ & \text{this group of wagons was dropped off} \end{cases}$$

(12) means that the train is formatted rationally. Expression (13) also implies that the next group of wagons or train is distributed.

$$L_{(i)\,fill} + \lambda_i \cdot L_l^{\text{int}\,errupt} < L_{train} \qquad (13)$$

When the condition (12) is met, the process of removing the assembled train is simulated: some groups of wagons on the assembly track, that is, "moving" to the boundary pile at the exit of the assembly track in question, are left uninterrupted. After that, the following indicators are determined:

The value of the busy length of the track after removing the train:

$$L_{\text{busy}} = L_{fill} - L_{train} \qquad (14)$$

The value of the empty length of the path after removing the train

$$L_{emp} = L_{usef} - L_{busy} \qquad (15)$$

If the sorting is carried out according to the proposed method if the trains are not filled with the same group of wagons thrown from the sorting park, the condition of the empty ($L_{emp} = L_{usef} - L_{busy}$) and busy ($L_{basy} = L_{fill} - L_{train}$) roads is taken into account and the process is repeated from the beginning.

According to experts of the All-Russian Research Institute of Railway Transport (ARIRT), the reduction of shunting flights is the most effective in the assembly of multi-group trains. Therefore, regardless of the number of groups in the assembled train, the total time spent on re-sorting the wagons gives the best result when the number of sorting tracks does not exceed 4. Therefore, the technology developed by ARIRT specialists for the assembly of wagons determines the sequence of operations on 3 possible options (if there are 2, 3 and 4 sorting tracks) [13].

As a result of the research, the method of determining the minimum required several sorting tracks depending on the length of the group of wagons was improved based on the use of Fibonacci numbers to search for the best scheme for the formation of multi-group trains. When selecting and formatting multi-group trains, a block diagram of determining the required number of sorting tracks depending on the length of the group of wagons can be seen in Figure 5.

Figure 5- Block Diagram for determining the Required Number of Sorting Tracks depending on the Length of the Group of Wagons
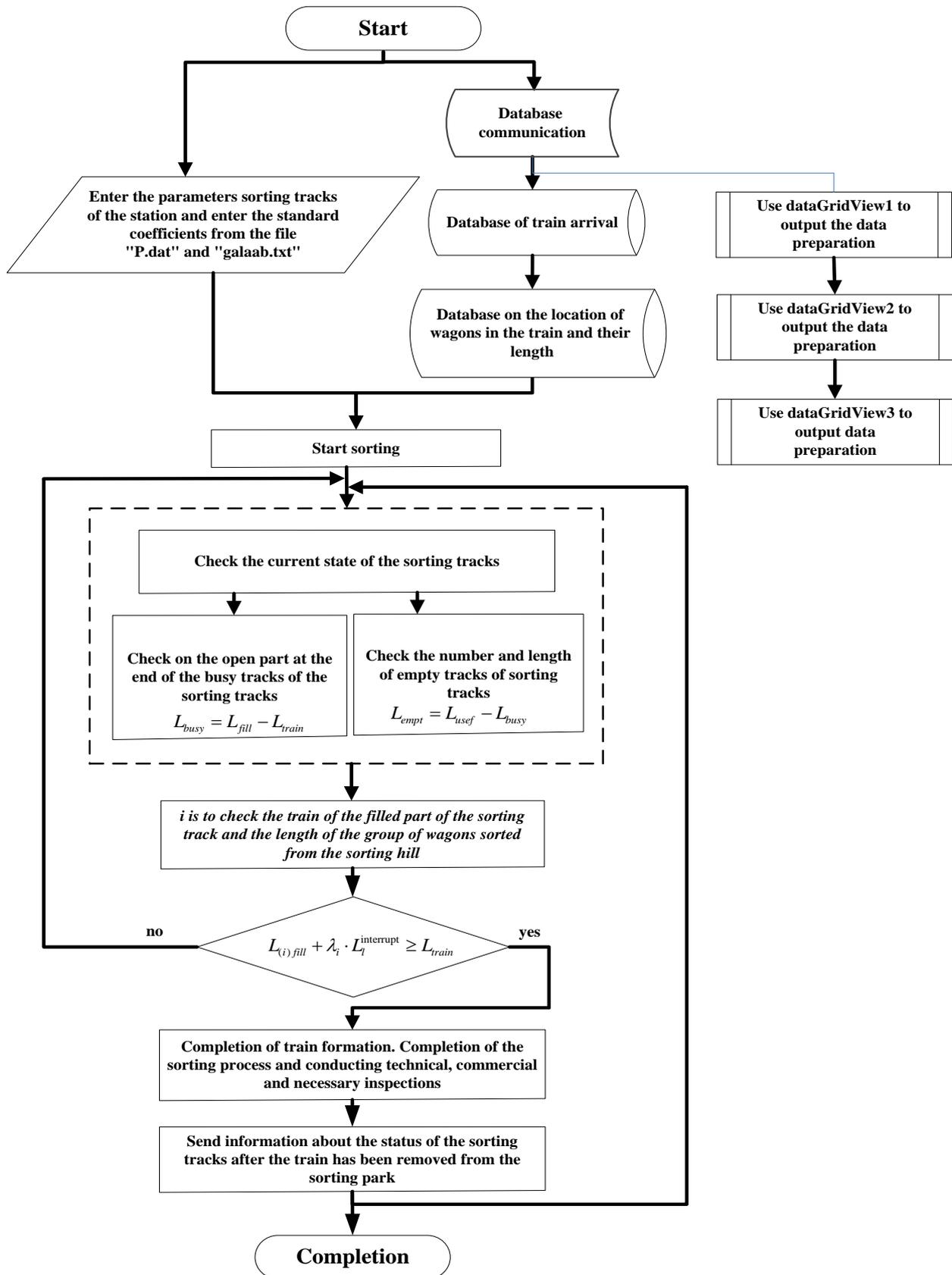
It was observed that the time spent on the distribution and assembly of multi-group trains using this method studied above is not the same as the current sorting method, and the number of shunting flights performed based on these methods is also different. At the same time, the combinatorial sorting method took 52.9 minutes, and the process consisted of 4 cycles, 2 groupage flight. From these indicators, it was found that the smaller the number of cycles and the number of flights performed to create a multi-group train, the smaller the time spent on this technology.

3. Results and Discussion

The structure of multi-group trains is one of the most difficult elements in the process of processing wagons at stations, which significantly affects the delivery times of cargo. Hence, one of the urgent issues is to improve the structural processes of multi-group structures in order to reduce the downtime of wagons at stations in conditions of changing freight flows. An improved method for optimizing the distribution and assembly of multi-group trains has been introduced in universities, laboratories of research institutes, design institutes and technical stations in the railway transport industry. At the station "Chukursay" under the management of JSC "Uzbekistan Railways" introduced a method (proposed method) developed based on the law that the number of groups in a multi-group train depends on the required number of tracks. After the introduction of this method, it can be said that the station "Chukursay" has achieved several economic benefits in the field of transportation. We calculate the indicators that affect the economic efficiency of the station "Chukursay". A total of arrived trains $N_{arr.total}$=35 per day arrives to station "Chukursay" for processing. Of these, $N_{multi\text{-}group\ train}{}^{1}$=10 (it accounts for 28% of the total number of trains arrived to the station) are multi-group trains, $N_{single\text{-}group\ train}{}^{2}$ =25 (72%) are single-group trains. According to the current sorting method, the average time $t^{sorting}_{on\ existing\ technology} = 60$ minutes (assumed to be 100%) is allocated to the station to sort the trains that arrived for processing. According to the proposed method, the average time $t^{sorting}_{proposed\ method} = 53$ minutes (88%). The time saved from the train sorting process is as follows:

$$\Delta t^{sorting}_{pr.\ meth.} = t^{sorting}_{on\ ex.\ tech.} - t^{sorting}_{pr.\ meth.} \quad (16)$$

$$\Delta t^{sorting}_{pr.\ meth.} = 60 - 53 = 7 \ \text{min.}$$

---

[1] The word "multi-group trains" is abbreviated as "m-gr.tr" in the following formulas
[2] The word "single-group trains" is abbreviated as "s-gr. tr" in the following formulas

Therefore, as a result of the practical application of the proposed method, the time spent on sorting can be reduced by 7 minutes (12%).

The economic benefit of waiting for a single-group train to sorting. According to the economic benefits of waiting for a single group of trains to qualify, the average waiting time for a single train of this type is $t_{average}^{waiting\ to\ sorting} = 42$ minutes when sorting trains arrived for recycling at the station according to the current sorting method [14]. So, as a result of the application of the proposed method, the time to wait for the sorting of a single train:

$$\Delta t_{pr.\ meth.}^{waiting\ to\ sorting} = t_{average}^{waiting\ to\ sorting} \cdot 12\ \% \qquad (17)$$

$$\Delta t_{pr.\ meth.}^{waiting\ to\ sorting} = 42 \cdot \frac{12}{100} = 5\ min.\ \text{can save.}$$

As a result of the practical application of the proposed method, the average downtime of single-group trains per day is reduced:

$$\Delta T_{pr.\ meth.(s-gr.tr)}^{waiting} = N_{s-gr.tr} \cdot \Delta t_{pr.\ meth.}^{waiting\ to\ sorting} \qquad (18)$$

$$\Delta T_{pr.\ meth.(s-gr.tr)}^{waiting} = 25 \cdot 5 = 125\ minute$$

Currently, the average number of wagons in a single-group train is $m_{c(s-gr.\ tr)}=57$. Therefore, according to the proposed method, from the average stopping time (wagon-hour) of wagons in a single-group train per day:

$$\Delta T_{pr.\ meth.(s-gr.tr)}^{waiting\ (wag-h)} = N_{s-gr.tr.} \cdot m_{c(s-gr.tr)} \cdot \Delta t_{pr.\ meth.}^{waiting\ to\ sorting} \qquad (19)$$

$$\Delta T_{pr.\ meth.(s-gr.tr)}^{waiting\ (wag-h)} = 25 \cdot 57 \cdot \frac{5}{60} = 119\ wag-hour\ \text{saved.}$$

For single-group trains, the following benefits can be obtained over time from the practical application of the proposed method.

$$E_{pr.\ meth.(s-gr.tr)}^{wag-hour} = e_{wag-hour} \cdot \Delta T_{pr.\ meth.(s-gr.tr)}^{waiting\ (wag-h)} \cdot K_{year}\ \text{uzs} \qquad (20)$$

Where $e_{wag-hour}$ − rate of one wagon-hour, UZS

$$E_{pr.\ meth.(s-gr.tr)}^{wag-hour} = 971 \cdot 119 \cdot 365 = 42175385\ \text{UZS}$$

The economic benefit of waiting for a multi-group train to sorting. As a result of the practical application of the proposed method, the average downtime of multi-group trains per day is reduced:

$$\Delta T_{\text{pr. meth.}(m-gr.tr)}^{waiting} = \left(N_{m-gr.tr} - 1\right) \cdot \Delta t_{\text{pr. meth.}}^{waiting\ to\ sorting} \tag{21}$$

$$\Delta T_{\text{pr. meth.}(m-gr.tr)}^{waiting} = \left(10 - 1\right) \cdot 5 = 45\ min.$$

Currently, the average number of wagons in a multi-group train is $m_{c(m-gr.\ tr)} = 57$. Therefore, according to the proposed method, the average stopping time of wagons in a multi-group train per day (waiting for one multi-group train during the selection of other multi-group trains) is from (wagon-hour):

$$\Delta T_{\text{pr. meth.}(m-gr.tr)}^{waiting\,(\text{wag--h})} = N_{m-gr.tr} \cdot m_{c(m-gr.tr)} \cdot \Delta t_{\text{pr. meth.}}^{waiting\ to\ sorting} \tag{22}$$

$$\Delta T_{\text{pr. meth.}(m-gr.tr)}^{waiting\,(\text{wag--h})} = \left(10 - 1\right) \cdot 57 \cdot \frac{5}{60} = 43\ \text{wag} - \text{h}\ \text{saved.}$$

For multi-group trains, the following benefits can be obtained over time from the practical application of the proposed method.

$$E_{\text{pr. meth.}(m-gr.tr)}^{wag-hour} = e_{wag-hour} \cdot \Delta T_{\text{pr. meth.}(m-gr.tr)}^{waiting\,(\text{wag--h})} \cdot K_{year},\ \text{uzs} \tag{23}$$

$$E_{\text{pr. meth.}(m-gr.tr)}^{wag-hour} = 971 \cdot 43 \cdot 365 = 15\,239\,845\ \text{UZS}$$

Economic benefits from the screening of multi-group trains. When sorting multi-group trains according to the proposed method, the following benefits can be obtained in terms of time.

$$E_{\text{pr. meth.}(m-gr.tr)}^{sorting\,(wag-hour)} = e_{wag-hour} \cdot N_{m-gr.tr} \cdot m_{c(m-gr.tr)} \cdot \frac{\Delta t_{\text{pr. meth.}}^{sorting}}{60} \cdot K_{year}\ \text{uzs} \tag{24}$$

$$E_{\text{pr. meth.}(m-gr.tr)}^{sorting\,(wag-hour)} = 971 \cdot 10 \cdot 57 \cdot \frac{7}{60} \cdot 365 = 23\,568\,598\ \text{UZS}$$

Economic efficiency generated from the fuel of shunting locomotives. When manoeuvring with existing technology at the station, shunting locomotives use an average of 420 litres of fuel per day, and their daily net operating time is 21 hours [15]. Based on the above, the shunting locomotive

consumes 20 litres of fuel per hour. Hence, when a single train was selected by the proposed method, $\Delta t_{\text{pr. meth.}}^{sorting} = 7$ minutes were saved. In 7 minutes $\Delta F_{\text{pr. meth.}}^{\text{fuel}} = 2.3$ litres of fuel saved.

Taking into account the fact that $N_{m-gr.tr} = 10$ multi-group trains are sorted at station "Chukursay" per day, these types of trains save an average of $\Delta F_{\text{pr.meth.}}^{\text{fuel}} = 23$ litres of fuel per day. The annual benefit of shunting locomotive fuel savings is as follows:

$$E_{\text{pr. meth.}(m-gr.tr)}^{\text{fuel}} = e_{\text{fuel}} \cdot \Delta F_{\text{pr. meth.}}^{\text{fuel}} \cdot K_{year} \qquad (25)$$

where e_{fuel} − rate of 1 litre of fuel in industry, UZS

$$E_{\text{pr. meth.}(m-gr.tr)}^{\text{fuel}} = 5797 \cdot 23 \cdot 365 = 48\,665\,815 \text{ UZS}$$

The economic effect of locomotive-hours of shunting locomotives. Given that the time saved from sorting one multi-group train was 7 minutes, a total of $\Delta t_{\text{pr.meth.}(m-gr.tr)}^{sorting} = \Delta t_{\text{pr.meth.}}^{sorting} \cdot N_{m-gr.tr} = 7 \cdot 10 = 70$ minutes (i.e., $\Delta t_{\text{pr.meth.}(m-gr.tr)}^{sorting} = \frac{70}{60} = 1,17$ hours per day) were saved from sorting these trains, given that 10 trains arrived at the station per day. The annual gain from the savings of the locomotive-hour of the shunting locomotive is as follows:

$$E_{\text{pr. meth.}(m-gr.tr)}^{lok-hour} = e_{lok-hour}^{shunt} \cdot \Delta t_{\text{pr. meth.}(m-gr.tr)}^{sorting} \cdot K_{year} \qquad (26)$$

where $e_{lok-hour}^{shunt}$ − rate of one locomotive-hour cost of shunting locomotive with a brigade, UZS

$$E_{\text{pr. meth.}(m-gr.tr)}^{lok-hour} = 218913 \cdot 1,17 \cdot 365 = 93\,220\,452 \text{ UZS}$$

The total economic effect of the application of the proposed method in practice is equal to the sum of economic indicators generated from all processes:

$$\sum E_{\text{pr. meth.}}^{total} = E_{\text{pr. meth.}(s-gr.tr)}^{wag-hour} + E_{\text{pr. meth.}(m-gr.tr)}^{wag-hour} + E_{\text{pr. meth.}(m-gr.tr)}^{sorting(wag-hour)} + E_{\text{pr. meth.}(m-gr.tr)}^{\text{fuel}} + E_{\text{pr. meth.}(m-gr.tr)}^{lok-hour} \text{ uzs} \qquad (27)$$

$$\sum E_{\text{pr. meth.}}^{total} = 42175385 + 15239845 + 23568598 + 48665815 + 93220452 = 222870095 \text{ UZS}$$

As a result of the application of the improved method at the station "Chukursay" of JSC "Uzbekistan Railways", the cycle time of the sorting hill was reduced by 12%, the time spent on sorting of transit trains was reduced by 5% and the processing capacity of the sorting hill was increased by 14%. This can be seen in Figures 6-8.

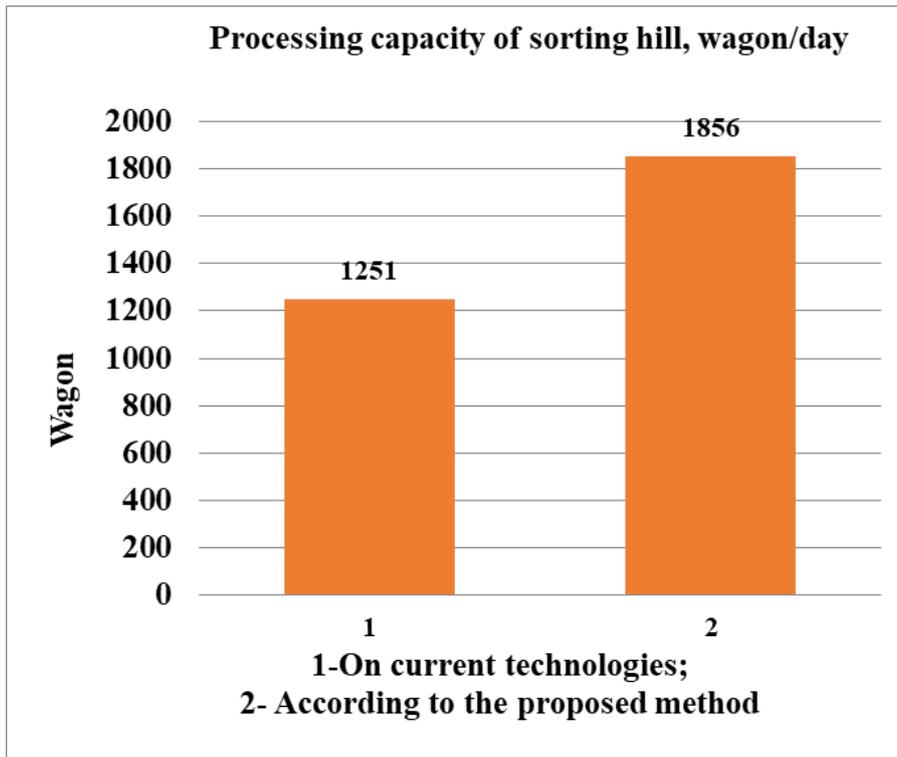Figure 6- Changes in the Processing Capacity of the Sorting Hill

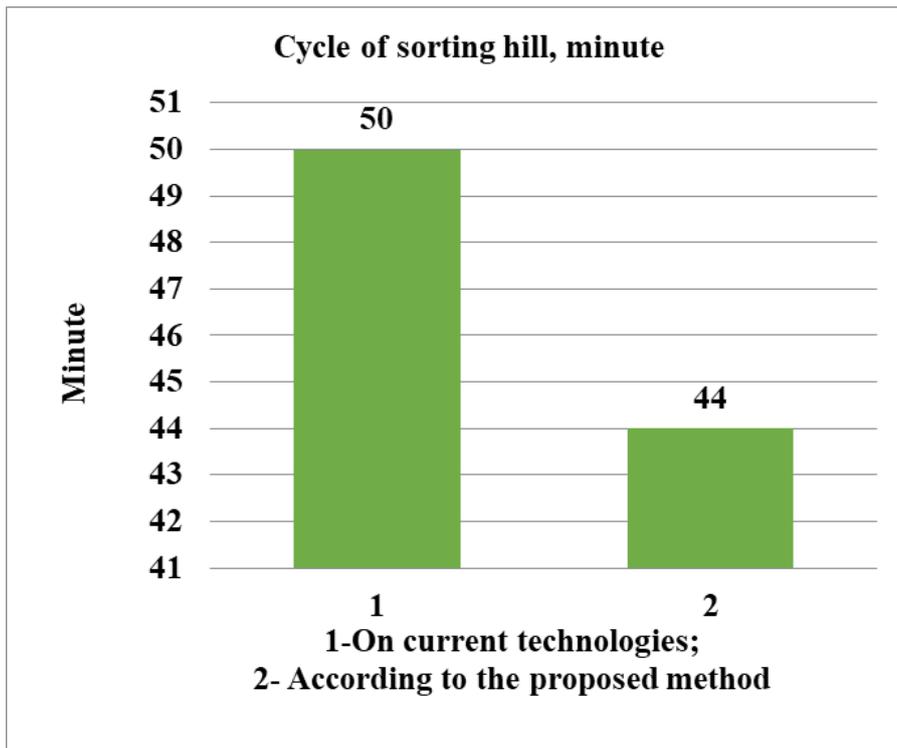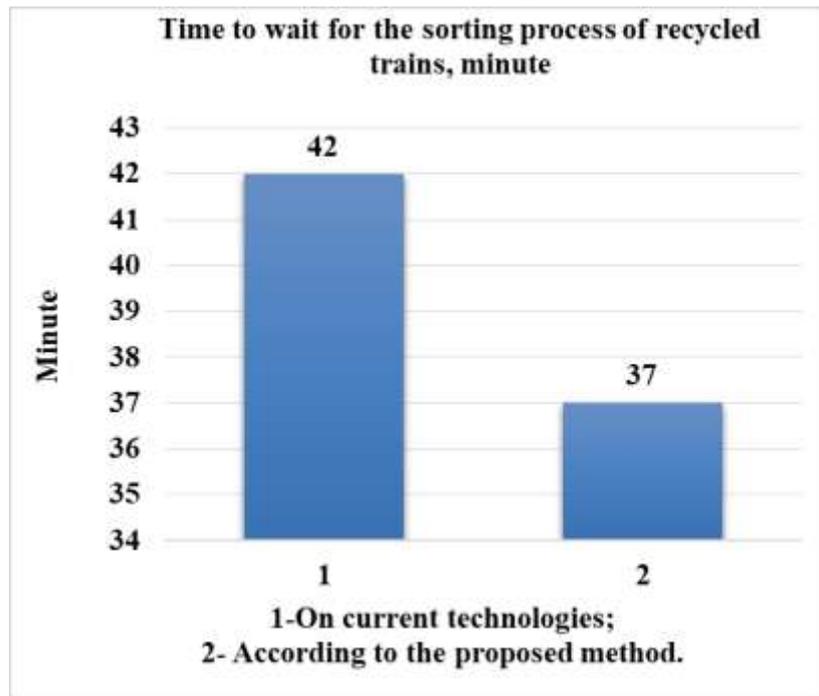Figure 7- Changes of the Cycle of Sorting Hill

Figure 8- The Change in Time Spent on the Sorting Processes of Recycled Trains

4. Conclusion

As a result of the research, a block diagram was developed to determine the required number of sorting tracks depending on the length of the group of wagons. Based on the use of Fibonacci numbers to select the most convenient option for the formation of multi-group trains, the method of determining the minimum required a number of sorting tracks depending on the length of the group of wagons was improved. This method can be used in the selection of the optimal number of shunting flights and the sequence of their execution in the formation of a group of wagons in the prescribed manner at the stations where the railway operations. This method determines the following indicators of shunting operations on the basis of possible options for the placement of wagons in the group, as well as in the formation of a group of wagons in the prescribed manner:

The number of sorting tracks and the required length, depending on the length of the group of wagons to be distributed;

The number of sorting operations in the formation of a group of wagons in the prescribed manner;

The optimal number of shunting flights when forming a group of wagons in the prescribed manner;

In the i-sorting of the group of wagons in the prescribed manner, the sequence number of the group directed to the j-track and the sequence of shunting flights, etc.

References

Nong, J., Ji, L., Yie, Y., & Liu, Z. (2008). Distributed algorithm for the optimization of railway car flow routing. *China Railway Science, 3.*

Lingaya, N., Cordeau, J. F., Desaulniers, G., Desrosiers, J., & Soumis, F. (2002). Operational car assignment at VIA Rail Canada. *Transportation Research Part B: Methodological, 36*(9), 755-778.

Baxodirovich, D. B., Kobiljonovich, S. K., & Mansuralievich, S. S. (2020). Modeling of Unproductive Losses in the Operation of a Sorting Station. *European Journal of Molecular & Clinical Medicine, 7*(2), 2020.

Zhang, J., Yang, H., Wei, Y., & Shang, P. (2016). The empty wagons adjustment algorithm of Chinese heavy-haul railway. *Chaos, Solitons & Fractals, 89,* 91-99.
   http://dx.doi.org/10.1016/j.chaos.2015.10.011

Bekzhanova, S.E., Issina, B.M., Zhaksybaeva, A.Z., & Suyunbayev, S.S. (2020). Introduction of a single intellectual management system and automation of production processes on railway transport. *Jour of adv research in dynamical & control systems,* 12,(6 Special Issue), 706–712.

Wang, B., He, S., Song, R., & Wang, B. (2007). Stochastic dependent-chance programming model and hybrid genetic algorithm for car flow routing plan. *Journal of the China Railway Society, 29*(4), 6-11.

Butunov, D.B., & Kotenko, A.G. (2018). Estimation of non-productive losses in the operation of the sorting yard. *Bulletin of the Petersburg University of Railways,* 15(4).

Barotov, J.S. (2020). *Improving the technology of organization of freight transportation, taking into account the delivery time in railway transport.* A dissertation for the degree of Doctor of Philosophy (PhD) in technical sciences - Tashkent: TDTrU. 118.

Bukhalo, G.I. (2000). *Complex optimization of parameters of local sorting systems:* Dis .... Cand. tech. sciences. M: RGOTUPS. 159p.

Sivitsky, Y.S. (2017). *Improvement of methods for calculating the parameters of sorting devices for a multi-group selection of cars.* (Doctoral dissertation, Novosibirsk: SGUPS, 191s).

The Fibonacci Numbers is ... Access mode: https://economic-definition.com Other_ branches_ of_ mathematics / Chisla _ Fibonachchi _ Fibonacci _ Numbers __ eto .html

Khudayberganov, S.K., & Suyunbayev, S.M. (2019). Results of application of the methods "sologub" and combinator sorting in the process of forming multi-group trains at the sorting station. *Journal of Tashkent Institute of Railway Engineers, 15*(4), 62-72.

Instruction of the Ministry of Railways No. Г-26737 dated 26.08.85. On the introduction of a new technology for the formation of multi-group trains. Moscow: MPS, 1985.

Butunov, D.B. (2019). *Improvement of methods of technical and operational assessment of the organization and management of car traffic of marshalling yards: author.* dis. ... Cand. tech. sciences. - Tashkent: TashIIT, 48.

Kh. R.M. (2019). *Organization of railway transportation: theory and practice: monograph.* Tashkent: Ilm-ziyo zakovat, 400.