marshalling yard; simulation model; train flows; factorial experiment

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THE RESEARCH OF EFFECT OF TRAIN FLOWS PARAMETERS AND TECHNICAL AND TECHNOLOGICAL PARAMETERS OF MARSHALLING YARD ON ITS INDICATORS BY SIMULATION

Summary. The structure of the functional simulation model of sorting station realized as a software product. Results of research of influence of parameters of train flows on the performance of the sorting station, made its use. Special attention was paid to the influence of the parameters of the train flows on the efficiency of the process of train making.

ИССЛЕДОВАНИЕ ВЛИЯНИЯ ПАРАМАТРОВ ПОЕЗДОПОТОКОВ НА ПОКАЗАТЕЛИ РАБОТЫ СОРТИРОВОЧНОЙ СТАНЦИИ МЕТОДАМИ ИМИТАЦИОННОГО МОДЕЛИРОВАНИЯ

Аннотация. Приведена структура функциональной имитационной модели сортировочной станции, реализованной в качестве программного продукта. Приведены результаты исследования влияния параметров поездопотоков на показатели работы сортировочной станции, выполненного с её использованием. Особое внимание было уделено влиянию параметров поездопотоков на эффективность процесса составообразования.

1. INTRODUCTION

In modern market conditions of rail transport operates in the conditions of fierce competition with other transport modes [1]. The level of competitiveness and attractiveness of the Railways on the transport market largely depends on the quality of rail stations.

The bulk of processing of traffic volumes produced in marshalling yards, so their performance depends on the efficiency of the transportation process as a whole. The process of train making in marshalling yards is an integral and one of the most important elements in the organization of traffic on the Railways. The efficiency of this process directly affects the quality of work of the respective marshalling yard, and on the performance of the railway areas in General. It is therefore advisable to perform a detailed study of the design, technical equipment and technologies existing marshalling yards with the aim of developing measures to further improve the process of train making.

2. LITERATURE REVIEW AND DEFENDING THE PROBLEM

Given the important role of train making in switchyards in the system for traffic organization, the research problem of this process and the search directions of its improvement have always been in the field of view of railway science. Special relevance of the research process of train making and search directions of its improvement acquired in modern conditions, characterized by a substantial reduction in traffic volumes, changes in patterns of traffic volumes, significant depreciation of technical equipment and a powerful level of competition from other modes of transport.

One of the first national publications to improve the technology of formation of trains in marshalling yards was the work of [2]. The publication, which was designed for the yardmasters, shunting dispatchers and chiefs of stations, were considered examples of carrying out shunting operations on the basis of the latest at the time of the methods of formation of trains. The main and only criterion for the quality of the execution of the dissolution-forming compositions in this work, we adopted the duration of the process; the economic component in the choice of the method into account not taken.

In [3] considered the rational organization of work with angular fluxes in the formation of local trains, which have significant impact on the technology and processing ability of bilateral marshalling yards. Indicated that their recycling significantly increases the volume of the sorting work on the hump. The disclosure of the benefit and economic efficiency of the joint and separate the formation of local trains.

In [4] indicated that the intensification of station processes should be directed primarily at increasing productivity, reducing costs and reducing the time spent by wagons at stations. Also noted that together with targeted action on the work of the hump and the process of accumulation of wagons needed in conjunction with these processes to achieve acceleration of the formation and rearrangement of compounds from a sorting yard in park admission and reducing the time to prepare them for shipment. To improve needs and schemes; reconstructive work will be directed towards the development of such schemes, which would correspond to the structure of wagon flows that is processed, and the pace of processing.

Proceedings of [5] is devoted to the solution of optimization problems in automated control systems of technological processes marshalling yards relatively rational planning maneuvers on the hill and in the area of formation. As noted in the work, through automation solutions to the challenges of the operational conditions for an optimum cost-time work plan separate shunting areas and hump.

In the study [6] shows a process model of making of local trains. This work gives recommendations to increase the quality characteristics of the processing wagons through changes in the technology of the station. At the same time, improvement of technical equipment of the stations and its influence on the efficiency of the processes of dissolution-formation trains not considered by the authors.

As shows the analysis of scientific studies on improvement of work of marshalling yards, the primary focus in most cases is given to optimize the parameters of humps and technologies disbandment of trains. At the same time, the study of the processes of accumulation and formation, as well as search directions of their efficient organization to reduce operating costs devoted much less work. With virtually no studies that address the problem of improving the process of train making comprehensively, including processes and dissolution, accumulation and formation of trains. A comprehensive solution to this problem requires a systematic approach and a comprehensive analysis of the processes of dissolution is the formation of trains taking into account all influencing factors and possible operating conditions.

Research of influence of parameters of train flows on the efficiency of the process of train making and performance of the railway stations is quite complex, so to run it effectively using simulation functional simulation. This purpose was developed by software simulation system that allows simulating the work of any yard in various operating conditions.

3. DEVELOPMENT OF SIMULATION MODEL OF MARSHALLING YARD

When developing a functional model of marshalling yard was viewed as a stochastic multi-phase multi-channel queueing system (QS) [7], consisting of a complex technological subsystems, each of which is modeled as CMO and is a separate universal simulation module. Thus, in the General structure of the model the sorting station were allocated the following modules:

- model of control system of station (MCS);
- model of neighboring stations (MNS);
- model of receiving yard (MRY);
- model of sorting yard (MSY);
- model of departure yard (MDY).

All of these models are built and implemented on digital computers using object-oriented approach. Also part of the functional model of the station (FMS) is the input stream generator (ISG). The General structure of the FMS and the interaction of its individual elements is shown in Fig. 1.

Input stream generator (ISG) is used to model the flow of trains arriving at a transfer station to service, including: moments of arrival of trains at the next station and the parameters of each train (number, category, number of wagons, carriages and the like).

An input stream of objects is a set of trains of different categories, arriving at a transfer station. The parameters of each object O_i are defined by the structure:

$$O_i = \{\mathrm{C}_t, T_a, \mathbf{B}, P, m, \mathbf{V}\}, \tag{1}$$

where C_t – category of trains; T_a is the time of arrival of the train at the station; $\mathbf{B}$ – vector of parameters of the service process trains at the station (the current operation, the moments of its beginning and end, the initiator of the transactions, etc.); P – General a simple composition on the station; m – the number of wagons in the train; $\mathbf{V}$ – vector of wagons in the train.

Each element of the vector $\mathbf{V}$ is determined by the following parameters:

$$v_j = \left\{C_t, N_a, L_c, Q_w, Q_c\right\}, \tag{2}$$

where C_t – wagon type; N_a, – appointment of the carriage in accordance with the Plan of formation of trains; L_c – conditional length of the wagon; Q_w – load of the wagon; Q_c – weight of the cargo. All of these parameters are modeled by GIF as a random variable with some distribution laws.

Model of neighboring stations (MNS) is designed to simulate the process of receipt of applications (trains and wagons) into the system, simulating the waiting trains' departure to a transfer station and departure. MNS is represented by a vector $Q = \{O_1, O_2, \ldots, O_n\}$, each element of which corresponds to a particular object (the train), located at the station. The number of elements in the vector Q corresponds to the number of paths on the adjacent station.

Model of receiving yard (MRY) is used to model the service process of the trains coming into disbanding.

Model of sorting yard (MSY) is the main element of the developed model of the station and intended to simulate the process of dissolution, accumulation and formation of compounds.

Model of departure yard (MDY) is intended to simulate service transit trains and trains its formation to prepare them for shipment.

Model of control system of station (MCS) is designed to organize the process of maintenance of trains at the station (choice of priority service, the choice of a way of reception or permutation composition, the choice of technological operations and the like).

The system station service includes gridiron, united in yards (receiving, sorting and departure), and performers of technological operations (maintenance crews, shunting and train locomotives, and the like).

Each yard in FMS is represented by a vector $P = \left\{p_1, p_2, \ldots, p_k\right\}$, each element of which is set in correspondence to a specific track and yard and is determined by the structure:

$$p_i = \{N_t, N_g, N_{tr}, S_t, T_{op}, T_{tot}, L_{max}, L_{c\max}\}, \quad (3)$$

where N_t – the number of the tracks in the yard; N_g – the number of the yard; N_{tr} – the number of the train on the track; S_t – the current state of the track (1 – track is occupied, 0 – track is free); T_{op} – the end of the previous operation on the track; T_{tot} – the total time of the route; L_{max} is a useful length of track (in conventional wagons); $L_{c\max}$ – total conditional long wagons, which are on the tracks at the moment. For the tracks of a sorting yard introduces an additional parameter L_{sp} – the total length of unproductive space on the track.

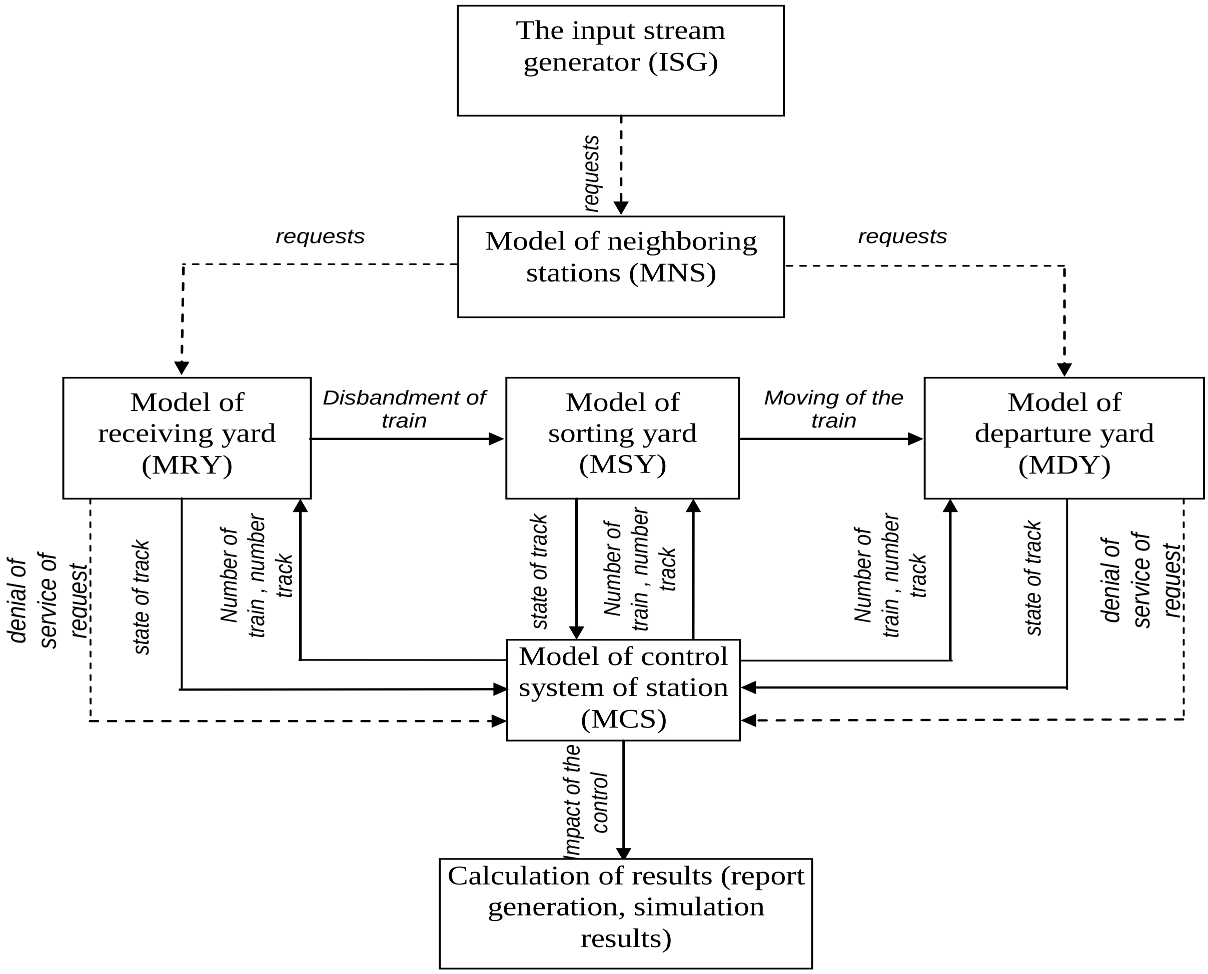

Fig. 1. The general structure of the functional system model
Рис. 1. Общая структура функциональной модели станции

Performers of technological operations in the model of the station are determined by the following parameters:

$$E_i = \{w, \mathbf{D}, K_t, T_t, T_w\}, \quad (4)$$

where w is the specialization of the performer; $\mathbf{D}$ is the vector of parameters of the performer; K_t – number of trains, which were serviced by the performer; T_t is the instant of termination of service of the previous train; T_w – total time of work of the performer during the period of the simulation.

Synchronization of all modules of the FMS is the system time that varies with a certain step. Developed software complex simulation allows predicting the values of all necessary operational indicators marshalling yard and its individual subsystems. In the modeling process provides a log of the station, according to which it is possible to automatically build a schedule full of movement for a detailed analysis of the work station and identify bottlenecks. A fragment of a full schedule of trains is presented in Fig. 2.

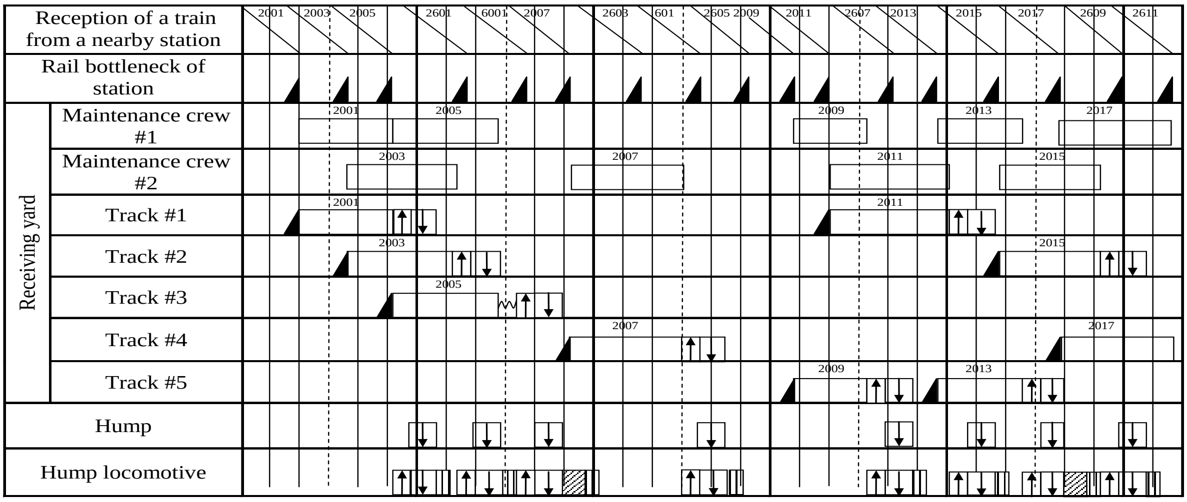

Fig. 2. Fragment of schedule of railway station operation
Рис. 2. Фрагмент графика выполненного движения

To determine the suitability of simulation models to solve practical research has been carried out its identification and assessment of adequacy. To identify the model has performed a comprehensive study on one of the large marshalling yards of Ukraine, the results of which determined the laws of distribution of random variables duration of technological operations, as well as the statistical characteristics of the input stream of trains and carriages. A comparison of the performance of the sorting station, obtained on the real object and the result of simulation-based parametric Mann–Whitney U test allowed us to conclude on the adequacy of the developed model of the real and the possibility of its use for solving applied problems.

4. METHODOLOGY AND RESULTS OF STUDIES

The simulation model was used to determine the effect of some technological parameters marshalling yard on the efficiency of the process train making. To this end the model was a series of factorial experiments [8]. As the response function when doing research selected number of freight wagons of various categories at the station and in its separate parks: Y_1 – simple transit wagon with the processing in the arrival yard; Y_2 is a simple transit wagon with processing under accumulation; Y_3 is a simple transit wagon with recycling in the departure yard; Y_4 – simple transit wagon with the processing in the whole station; Y_5 – simple transit wagon with the processing in station.

On the basis of expert estimates obtained from the results of a survey of experts from the transport sector, the main factors that most significantly affect the process of train making stations (tab. 1).

On the basis of processing results of the factorial experiments were obtained from an analytical model that allows determining the influence of each factor on the indicator of the station (tab. 2). To obtain models 3 and 5 used a complete factorial experiment. Models 1, 2 and 4 were obtained during the fractional factorial experiment using different replicas drabbest.

Analysis of the first model shows that the idling of transit wagon with the departure park of the station (Y_1) has the greatest impact precision sighting braking of cuts solution of the composition with hump (X_8 factor). This is because when there is insufficient precision sighting braking of cuts significantly increases the amount of shunting work on backup of wagons on the roads of a sorting yard that leads to delays in the dismantling of structures and, consequently, to increase the duration of their stay in the receiving yard. Model Y_2 revealed a significant dependence of idle wagons under accumulation (the number of shunting locomotives in the tail of a sorting yard (X_2 factor). Models Y_3, Y_4 and Y_5 have shown that downtime transit wagon with recycling and without recycling in the departure yard and the station in General depend strongly on the availability of the ready for departure of trains train locomotives (X_1 factor).

Tab. 1

Characteristic of the main factors

Code of factor	Name of factor	Units of measurement	Range of variation	Levels of factors		
				lower	basic	upper
X_1	Duration of waiting of train locomotive	minutes	100	0	100	200
X_2	Number of shunting locomotives	locomotives	–	1	–	2
X_3	Number of hump locomotives	locomotives	–	1	–	2
X_4	Number of maintenance brigades in departure yard	crew	–	1	–	2
X_5	Number of groups in maintenance brigades in departure yard	group	1	2	3	4
X_6	Number of maintenance brigades in receiving yard	crew	–	1	–	2
X_7	Number of groups in maintenance brigades in receiving yard	group	1	2	3	4
X_8	Precision sighting braking of cuts at disbanding of trains	percent	25	50	75	100
X_9	Frequency of performing jumping after disbanding of trains	number of disbanding	1	3	2	1
X_{10}	Length of train during re-sorting of wagons	percent	25	50	75	100

Tab. 2

Mathematical models obtained as the result of the study

Number of experiment	Mathematical model
1	$y_1 = 0{,}71 - 0{,}009\,x_3 - 0{,}005\,x_6 - 0{,}02\,x_7 - 0{,}056\,x_8 + 0{,}011\,x_{10}$
2	$y_2 = 5{,}295 + 0{,}034x_1 - 0{,}198x_2 + 0{,}107x_3 - 0{,}02x_8 - 0{,}004x_9 - 0{,}169x_{10}$
3	$y_3 = 2{,}152 + 1{,}019\,x_1 + 0{,}1x_2 - 0{,}049\,x_4 - 0{,}098\,x_5$
4	$y_4 = 8{,}072 + 1{,}256\,x_1 - 0{,}226\,x_2 - 0{,}102\,x_4 - 0{,}181\,x_5 + 0{,}149\,x_8 + 0{,}12\,x_9 + 0{,}027\,x_{10}$
5	$y_5 = 1{,}875 + 0{,}671x_1 - 0{,}035x_2 - 0{,}073x_4 - 0{,}119x_5$

Therefore it can be considered that the most appropriate way to improve the efficiency of the process train making in marshalling yards is the development of methods of optimization of distribution train locomotives to reduce unproductive downtime ready for the departure of trains in the Park administration. Another direction of improving the process train making is to improve the accuracy of the braking of cuts at the dissolution of the compositions, including through the introduction of modern automated control systems of dissolution.

Also with the use of developed software performed the investigations of the influence of parameters of the input traffic flow on the performance of the station. Thus, the results of a study of the effect of the number of wagons trains received at the dissolution, and its formation, the residence time of transit of the wagon with the processing at constant input and output stream unchanged and wagon flows depicted in figure 3. Trains coming in and the disbanding of its formation, in the simulation consisted of a constant number of wagons: $m = 40$ *wagons* for the first group of experiments, $m = 50$ *wagons* and $m = 60$ *wagons* for the second and third, respectively. The simulation was performed at constant wagon flows $M = 3300$ *wagons per day*.

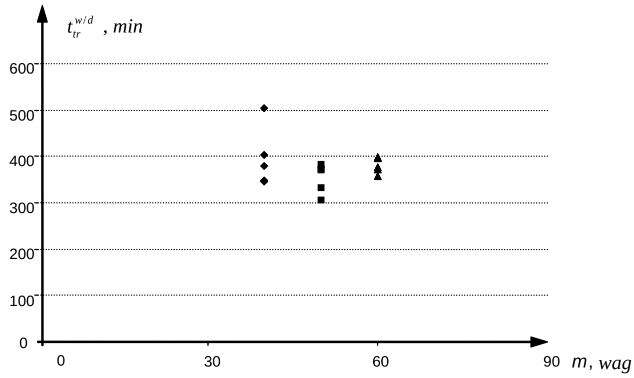

Fig. 3. The set of function values $t_{tr}^{\text{w/d}}$ at constant wagon flow and constant input and output stream

Рис. 3. Множество значений функции $t_{mp}^{\text{c}/n}$ при постоянном вагонопотоке и постоянном входящем и выходящем потоке

Such a parabolic form of dependence proves that there is a limit from below by the largest number of wagons, leading to a sharp increase in the number of paths in parks and foster directly gradual increase of the turnover of the wagon for overload performers and service devices.

A similar study was conducted with increasing or decreasing the daily wagon flow to determine the impact of workload on the $t_{tr}^{\text{w/d}}$ value. The simulation results are presented in Fig. 4

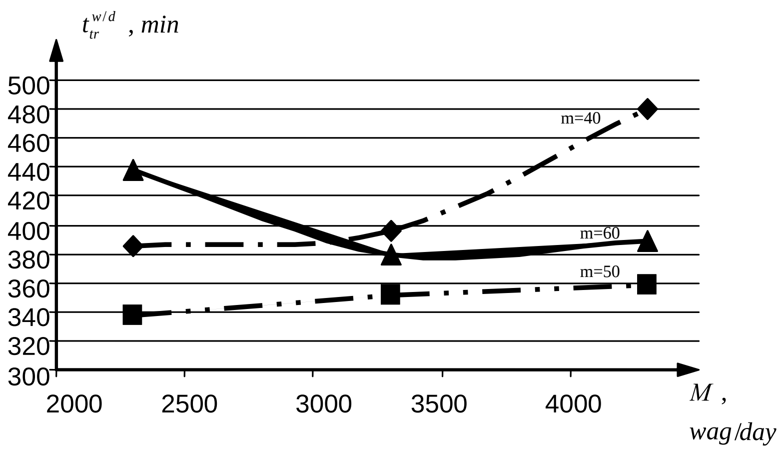

Fig. 4. The influence of wagon flow on a simple transit wagon with the processing station

Рис. 4. Влияние вагонопотока на простой транзитного вагона с переработкой на станции

Thus, there is a linear increase of downtime in the formation and disbandment of train's number of wagons $m = 50$ *wag/train*; an exponential dependence with the increase and decrease of the number of wagons ($m = 40$ *wag/train* and $m = 60$ *wag/train*).

Since the existing processes of formation of freight trains provide for the accumulation of the compositions by weight or length, then in the model was the possibility of formation of freight trains with the number of wagons in the range of $m \in [m_{\min}; m_{\max}]$, where $m_{\min}$ - the norm on the accumulation, $m_{\max}$ – the maximum number of wagons per train. The study was conducted under the following conditions:

1) at constant input wagon flow and variable output stream in the range of $m \in [m_{\min}; m_{\max}]$;

2) at variable input and output streams.

With constant daily wagon flow of $M = 3300$ wagons/day for marshalling yard and the variable range of the number of wagons in the train of its formation, in each of the experiments with conditions of $m_{out} \in [40;50]$, $m_{out} \in [40;60]$ and $m_{out} \in [50;60]$ and obtained the following results (Fig.5). Each point in the figure corresponds to one experience during the settlement period is 3 days.

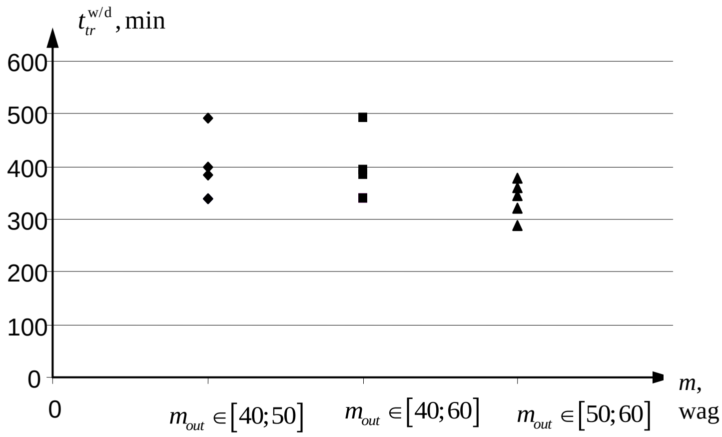

Fig. 5. The set of $t_{tr}^{w/d}$ function values at constant wagon flow and variable range in the number of wagons in trains of its formation

Рис. 5. Множество значений функции $t_{mp}^{c/n}$ при постоянном вагонопотоке и переменном диапазоне количества вагонов в поездах своего формирования

The results of the experiments showed that in the range of $m_{out} \in [50;60]$ detention of freight wagons at the station is minimal.

5. CONCLUSIONS

The analysis of scientific works on train making on the Railways of Ukraine has shown that in modern conditions there is no comprehensive approach to improving the efficiency of the process of train making in marshalling yards. Most scientific papers consider the problem from the point of view of the functioning of the individual subsystems marshalling yard, not the entire station. To study the influence of parameters of train flows on the efficiency of the process of train making and key performance indicators of marshalling yard was developed a simulation model of marshalling yard, which allows you to perform a comprehensive practical study of the work of marshalling yards.

The studies showed that the greatest impact on the efficiency of the process of train making in marshalling yards is simple unproductive ready for the departure of trains in the departure yard in anticipation of the train locomotive. Another factor that significantly affects the process of train making is accuracy braking of cuts disbandment of trains.

Another series of studies aimed at studying the influence of the parameters of train flows on the performance of marshalling yards, allowed to reveal the dependence of the duration of downtime transit wagon-loads processing from the number of wagons in the trains coming into disbanding. It has been proven that there is a limit from below by the largest number of wagons, leading to a sharp increase in the number of paths in parks and foster directly gradual increase of the turnover of the wagon for overload performers and service devices. Another study showed that increasing the daily wagon flows resulted in a linear increase in the length of downtime transit wagon with the processing in the formation and disbandment of trains number of wagons m = 50 *wag/train*. When you increase and decrease the number of wagons (m = 60 *wag/train* and m = 40 *wag/train*) are exponential dependence.

The results can be used in the development and selection of the most rational organizational and technical measures directed on increase of efficiency of technological processes in marshalling yards.

Developed functional simulation model of marshalling yard can be further implemented as a structural element of a more global model. Such a model will allow us to determine the relationship between the parameters of train flows and key performance indicators of railway tracks.

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