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MODELLING OF TRANSPORT-AND-HANDLING SITES OPERATION WITHIN METALLURGICAL ENTERPRISES

Summary. In terms of existent regime of transport-and-handling sites operation, the necessity in enhancing the efficiency of production and transport interaction is justified. For this purpose simulation model of transport-and-handling site, which provides reception of raw materials, is developed.

МОДЕЛИРОВАНИЕ РАБОТЫ ТРАНСПОРТНО-ГРУЗОВЫХ КОМПЛЕКСОВ МЕТАЛЛУРГИЧЕСКИХ ПРЕДПРИЯТИЙ

Аннотация. Обоснована необходимость повышения эффективности взаимодействия производства и транспорта в рамках существующего режима функционирования транспортно-грузовых комплексов металлургических предприятий. С этой целью разработана имитационная модель транспортно-грузового комплекса приёма сырья.

1. INTRODUCTION

Large-scale metallurgical enterprises involve a range of technological points where production and transport interact. These points can be distinguished into two categories.

Technological points, which fall into the first category, provide interaction between production facilities and internal (industrial) transport within the framework of semi-finished products transportation.

On the other hand, technological points, which fall into the second category, provide interaction between production and external transport, namely reception of raw materials and finished products shipment. These points incorporate enterprises into supply chains and are called the transport-and-handling sites (THS).

Since both inbound and outbound cargo flows are of great volumes in terms of metallurgical enterprises operation, external transportations are predominantly carried out by railway transport.

It is necessary to note that all the internal transportations are stringently scheduled which practically eliminates disturbance by influencing factors.

In contrast to internal transportations, external transportations are influenced by different stochastic factors. These factors usually lead to disturbance of production rhythm, and as a result, cause inefficiency in interaction between production and transport.

Much of that inefficiency lies in the following. Large-scale metallurgical enterprises accept up to 8-12 unit trains (440-660 cars) with raw materials per day. After that, up to 40 % of the inbound rolling stock is used for shipment of finished products. The rolling stock is owned by different carriers, which

implies payment for its usage. The amount of payment depends on the time, which each car spends within the enterprise. From 2006 to 2012, there was a substantial increase in expenses for car usage, which exceeded 80 %. At the same time, up to 65 % of the whole duration of cars stay within the enterprise accounts for transport-and-handling sites processing the inbound cargo.

Hence, the core elements to asses are the transport-and-handling sites which provides reception of raw materials.

2. TRANSPORT-AND-HANDLING SITE UNDER STUDY

Transport-and-handling sites usually involve a freight station (Fig. 1) equipped with storage, shunting and unloading sidings, unloading facilities (car dumpers) and conveyor belts transporting unloaded raw materials to production shops. Transport service is carried out by shunting locomotives.
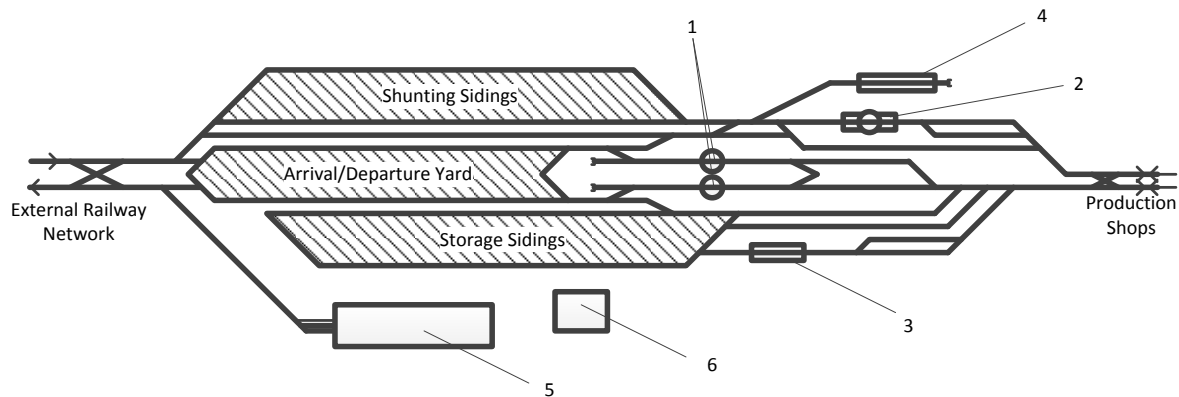

Fig. 1. Freight station: 1 – rotary car dumpers; 2 – mobile rotary car dumper; 3 – tower car dumper;
4 – unloading platform; 5 – defrosting facilities; 6 – engine house
Рис. 1. Грузовая станция: 1 – роторные вагоноопрокидыватели; 2 – передвижной роторный
вагоноопрокидыватель; 3 – башенный вагоноопрокидыватель; 4 – эстакада; 5 – гаражи
размораживания; 6 – локомотивной хозяйство

To tackle the challenge of increasing the efficiency of interaction between production and transport within transport-and-handling sites, authors launched a study, which is aimed at modelling of the processes within THS with the purpose of evaluation of the freight station performances at the first stage of the study.

3. OBJECT OF STUDY

Issues related to dealing with and controlling the cargo flows play the crucial role in enhancing of efficiency of interaction between production and transport. It is known that being handled within transport-and-handling sites, cargo flows undergo the sequence of technological operations. These operations comprise receiving of inbound unit trains with raw materials, separation of inbound unit trains into groups of cars, shunting of groups of cars, pushing of cars to car dumpers, and unloading. The whole duration of cars stay within the THS can be divided into two constituents: the first one (t_{tech}) accounts for scheduled time of technological operations performance, and the second one (t_{dt}) accounts for downtime – time during which cars are waiting for being processed next. The last mentioned constituent is characterised as a stochastic quantity. Both t_{tech} and t_{dt} comprise the whole duration of cars stay within the THS [1]:

$$t = \sum t_{tech} + \sum t_{dt} \tag{1}$$

Hence, dealing with and controlling the cargo flows secure the reduction of losses at points of interaction between production and transport. Meanwhile, the reason of losses, related to production issues, is unreadiness of production facilities for raw materials reception. On the other hand, there is transport factor, which causes losses. It is related to increase in unit trains arrival rate, which in some instances can fully block the freight station operation and can cause delays in deliveries of the railway rolling stock for unloading operations performed within THS.

Within the framework of operational control of THS processes, the main purpose implies the increase in rate of technological operations performance, reduction in downtime, and, as a result, the decrease in overall duration of cars stay within the THS. At the same time the decrease in overall duration of cars stay within the THS should be based on systems thinking principles, and should be carried out in such a way that the indicators of production facilities operation wouldn't have been worsened.

Thereby, modelling of THS sets the following tasks, namely: justification of time standards of each operation performance, arrangement of efficient sequence of operations performance, the maximum reduction in downtime taking into account its nature.

At the same time, modelling should be based on the combination of both analytical solutions and computer simulation, which in turn allows demonstrating the technological sequence of processes, carried out within THS, in the most efficient way [2-5].

Computer simulation, being an empirical method of research, allows obtaining the results but does not explain them. Designing and carrying out the sequence of technological operations via simulation model is not enough – it is necessary to know which characteristics should be derived as well as to draw right conclusions. At the same time, analytical solutions allow identifying interdependence of parameters of technological processes, which in turn makes it feasible to purposefully select effective solutions.

4. EVALUATION APPROACH

As the first step in modelling of THS, identifying of operations performance has been made. It shows that on arrival, unit train (55 cars) goes through separation into three groups of cars (22+22+11 cars). Due to the order of technology, unloading operations with inbound unit trains are performed by two rotary car dumpers (each car dumper can serve a group of 22 cars per operation cycle). After being unloaded, empty cars leave the freight station.

Basing on the identified sequence of technological operations, the simulation experiment has been undertaken. The simulation was carried out using Matlab R2010b. This application allows visual creating of the freight station processes (Fig. 2).

The source data used for modelling was the arrival rate of unit trains with raw materials and duration of technological operations performance. Since the arrival rate of unit trains is a stochastic quantity, its distribution has been examined (Tab. 1):

$$f(x) = 0,006554 \cdot e^{-0,006554 \cdot x}$$

(2)

Table 1

Theoretical distribution of intervals between inbound unit trains occurrence

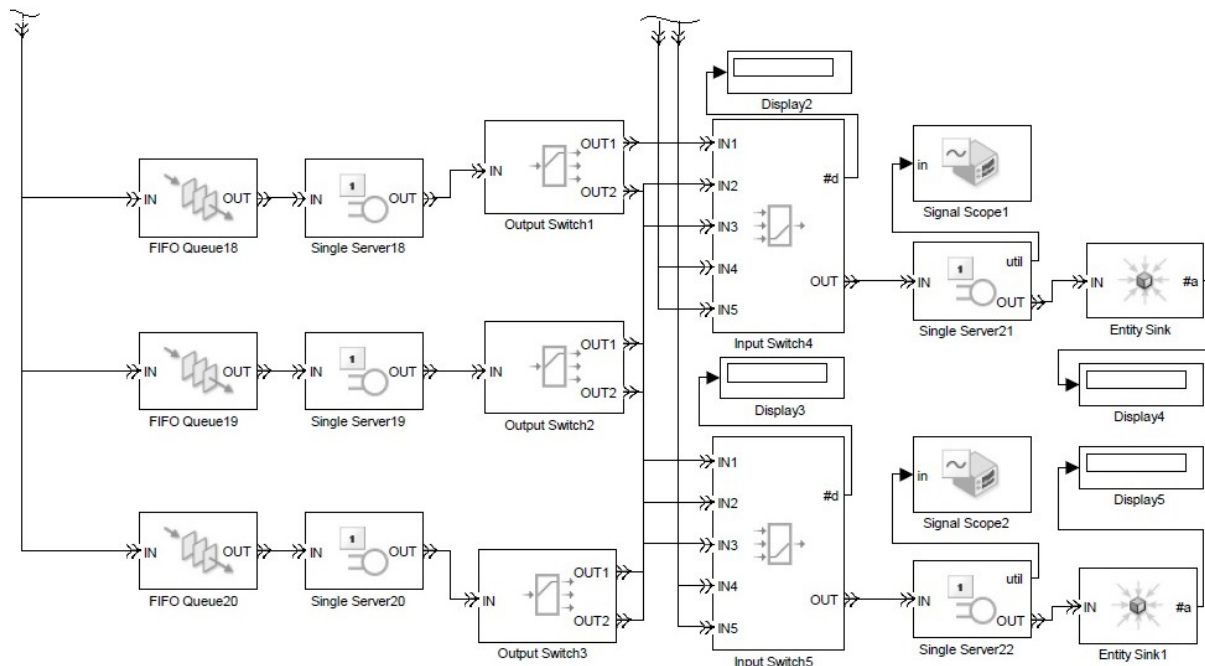| Numerical characteristics	Statistycal hypothesis testing justifying exponential distribution
$\bar{x} = 152,58$ min $x_{min} = 10$ min $x_{max} = 860$ min	$\chi^2_{stat} = 12,9$ $\chi^2_{20\%} = 13,44$
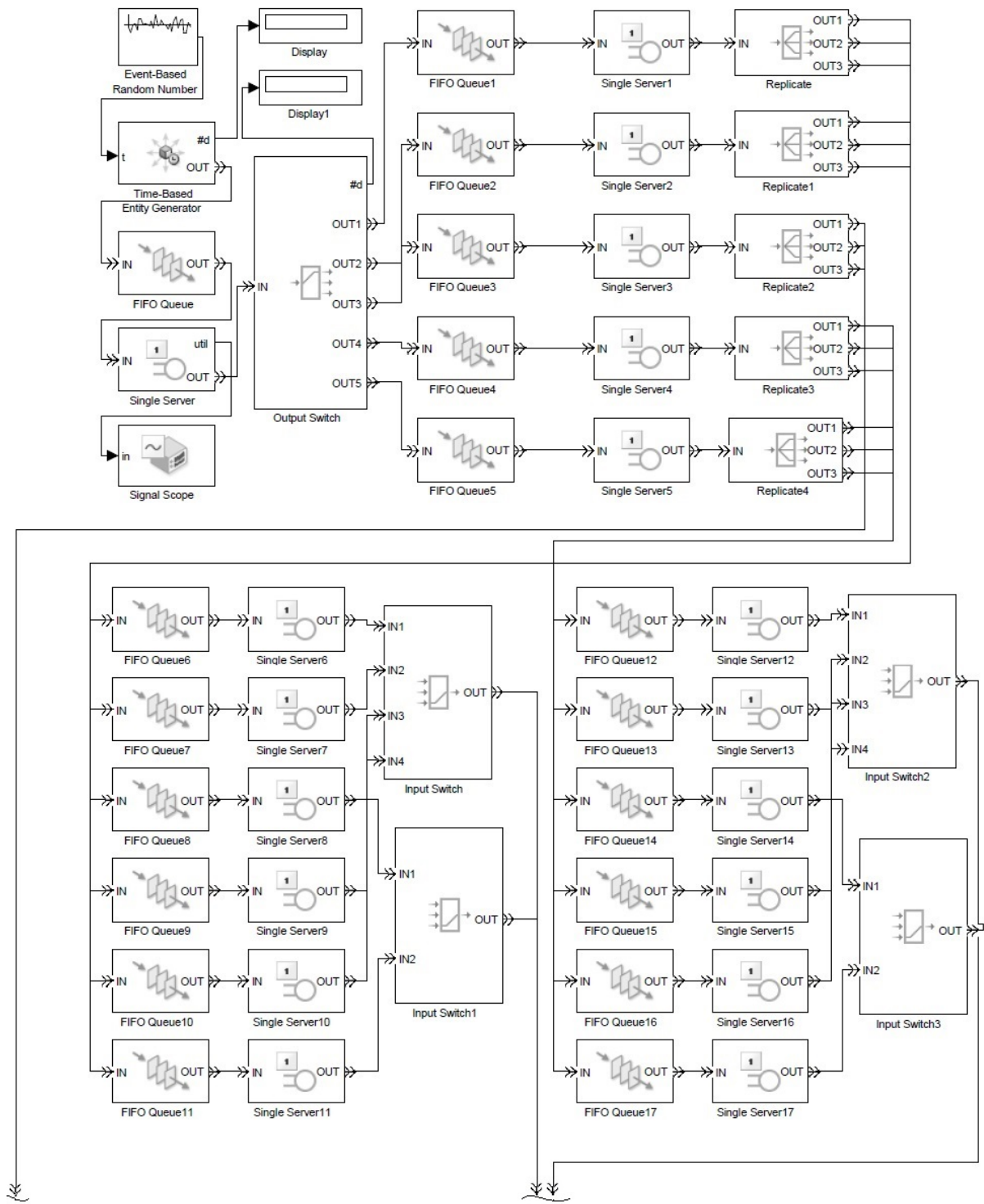
Fig. 2. A Matlab R2010b model of Transport-and-Handling Site operation
Рис. 2. Модель работы транспортно-грузового комплекса, выполненная в программной среде Matlab R2010b

Table 2

Description of the Matlab R2010b model of Transport-and-Handling Site operation

№	Name of the block	Block description	Parameters
1	Event-Based Random Number	The block sets time gaps between trains arrivals to the station	Time gaps are determined by their previously identified probability distribution $\rho=0{,}006554\cdot e^{-0{,}006554\cdot x}$ (Pearson's chi-squared test: $\{\chi^2_{stat}=12{,}9\}<\{\chi^2_{20\%}=13{,}44\}$)
2	Time-Based Entity Generator	The block sets the signals which imitate sequence of inbound unit trains occurrence at the railway station	Basing on the time gaps this block imitates sequence of inbound unit trains occurrence at the railway station $A=\{a_1, a_2,…,a_i\}$
3	FIFO Queue	The block sets the order of service of inbound unit trains (First In, First Out). Here, handling capacity accounts to amount of unit trains (groups of cars) which can be contained within the queue	This block sets handling capacity of the element of the station (the even neck of the railway station), and represents the number of trains which can be served simultaneously. A=1.

4	Single Server	The servicing facility which serves inbound unit train during certain time (the route is being set up), after which the train occupies a certain track	The block imitates the process of setting up the route of a train within Arrival/Departure Yard of the railway station. The duration of the process takes $t_1=12$ minutes. Departure of the request from the block (moving the train to one of the five tracks depending on their priority) is carried out just on condition that one of the blocks Single Server 1-5 is free.
5	Signal Scope	The block visualizes process of modelling, graphs the process characteristics of unit trains (groups of cars) servicing within the time gaps	The block generates the graph of dynamics of handling capacity of the railway station neck (Fig. 3, a)
6	Display	The block shows the number of requests for service	The counter showing the number of accepted inbound unit trains
7	Output Switch	The block directs the unit trains (groups of cars) to the certain tracks of the station and technological facilities, which are connected to its outbound ports	The block allows transferring the request (unit train) to one of the five tracks (p_1, p_2, p_3, p_4, p_5), on condition that they are free ($S_p=0$ condition)
9	Single Server1-5	The servicing facility which carries out technical and commercial inspections of inbound unit trains with their further decomposition into groups of cars (22+22+11)	The block imitates the process of technical and commercial inspections of unit trains. The duration of the process accounts for $t_2=30$ minutes. After that, the unit train $A=\{a_1, a_2,\ldots,a_i\}$ is decomposed into three groups of cars $B=\{b_1, b_2, b_3\}$ to be unloaded further. The block's conversion to the $S_p=0$ condition is carried out right after all the three car groups departure.
10	Replicate	The block allows multiplying requests at all the outputs (in our case 3 outputs are required, as all the unit trains are decomposed into three groups)	The block imitates the process of decomposition of the unit train into three groups for their further delivery to the unloading tracks
12	Single Server6-20	The servicing facility which carries out delivery of groups of cars to the unloading tracks	The block imitates the process of delivery of a group of cars $B=\{b_1, b_2, b_3\}$ to the unloading tracks, on condition that they are free ($S_f=0$ condition). Duration of the process accounts for $t_3=12$ minutes.
13	Input Switch, 1-5	The block allows arrival of the trains (groups of cars) either from different tracks or technological facilities to one of the unloading tracks	The block allows delivering a group of cars from Arrival/Departure Yard tracks to unloading tracks: $\{p_1, p_2, p_3\}\rightarrow\{f_1\}$; $\{p_3, p_4, p_5\}\rightarrow\{f_2\}$.

| 14 | Single Server21-22 | The servicing facility which carries out unloading operations with a group of cars | The block imitates unloading process. Duration of the process accounts for t_4=100 minutes. On completion of the unloading operations, the condition of the block changes form S_f=1 to S_f=0, which allows the next group of cars to be unloaded |
| 15 | Entity Sink, 1 | The unit receiving unloaded groups of cars | The block imitates delivery of unloaded empty cars to the special Yard designed for cleaning the cars |

The model adequacy check was carried out via F-test (Tab. 3).

Basing on the data from the F-test table, we can evaluate the following:

$$F_{crit} = 5,05 \text{ at } p_\alpha = 0,05 \tag{3}$$

$F < F_{crit} \rightarrow$ the model adequacy is justified.

Table 3

The F-test table

Experimental run	Состояние системы		
	Delivery of two groups of cars for unloading via car dumpers, $\left(y_1/y_1^*\right)$	Delivery of one group of cars for unloading via car dumper, $\left(y_2/y_2^*\right)$	None of the groups of cars is delivered for unloading via car dumpers, $\left(y_3/y_3^*\right)$
1	42/44	66/67	128/126
2	40/43	64/65	126/121
3	44/48	68/71	129/125
4	38/41	62/65	125/121
5	41/43	65/67	126/124
The mean	41/43,8	65/67	126,8/123,4
D_{on}/D_n^*	14,8/6,7	10/6	20/5,3
F	2,21	1,67	3,77

5. RESULTS

After having conducted simulation trials that consist of substantial number of runs, statistical data was obtained. The data is plotted on the graphs (Fig. 3). These graphs show the utilization degree of capacity of the main elements of the station (neck of the freight station and tracks of the Arrival/Departure Yard).

The graph showing changes in coefficient of capacity utilization of the freight railway station neck (Fig. 3, a) has markers, which represent occurrence of events that is the beginning of shunting operations, which takes place at the freight railway station neck. Vertical lines of the graph refer to increases (decreases) in coefficient of capacity utilization. Horizontal lines refer to duration of shunting operations and waiting time before new event occurrence that is a new shunting operation. If the railway station neck is free right after shunting operations are finished, the graph represents this as coefficient of capacity utilization decrease, and otherwise. Thus, analyzing the graph it can be concluded that capacity utilization of the freight railway station neck accounts for 70-80 % within the whole number of runs of the model.

The graphs presented on Fig. 1, b-g show that the maximum concentration of processed trains is on the track 3, since this track is chosen as the most priority, and serve both of the unloading tracks of the station. Markers on these graphs also refer to occurrence of events that is delivery of trains to the

tracks of the Departure/Arrival Yard. Horizontal lines refer to duration of processing trains on arrival (including inspection of the train). Vertical lines of the graph refer to time during which the groups of cars wait for being moved to unloading tracks.

Thus, the coefficient of utilization of neck of the freight station fluctuates, and accounts for $k_u=0.7$-0.8 (Fig. 3, a). The analysis of duration of inbound unit trains service at the main tracks of the freight station (Fig. 3, b-g) shows the following. Just 18 % of instances account for simultaneous unloading of two groups of cars via rotary car dumpers. Another 28 % of instances account for unloading of one group of cars, and the rest 54 % of instances account for waiting of unit trains for being separated and unloaded. It appears that the freight station suffers a queue problem. Preliminary results, which the model provides, show that in case of potential increase in production volumes up to 10-15 %, the server, i.e. the freight station, will not be able to handle the increasing cargo flow and potentially lead to collapse of the transport-and-handling site.

Hence, it is necessary to provide improvements in the existing operation of THS. These improvements should lie in adaptation of utilization capacity of the THS facilities, which is going to be the next stage of the study.
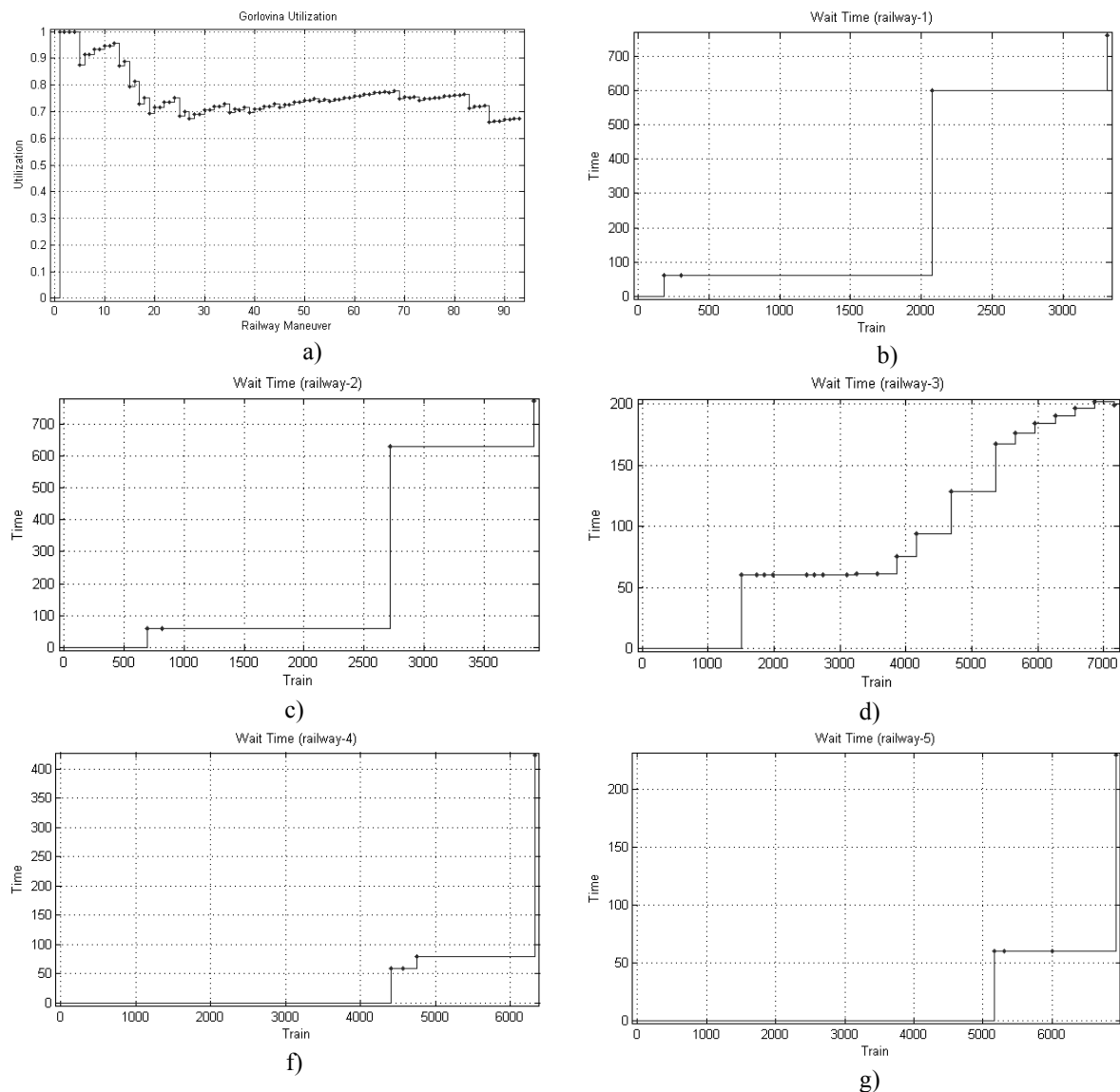

Fig. 3. Results of modelling: a) freight station neck utilization; b), c), d), f), g) railway tracks (1-5) utilization
Рис. 3. Результаты моделирования: а) загрузка горловины грузовой станции; b), c), d), f), g) загрузка путей (1-5) станции

6. CONCLUSIONS

This paper provides the first step of a study aimed at increasing the efficiency of interaction between production and transport within metallurgical enterprises. Existing inefficiency lies in considerable duration of inbound unit trains processing within transport-and-handling sites, which in turn causes increase in payment for usage of freight cars.

With the purpose of estimation of transport-and-handling site operation, its simulation model was developed. It allowed identifying existing utilization parameters of the main handling facilities of THS.

Results of modelling showed that in case of increase in production volumes up to 10-15% the freight station, being the main servicing element of THS, will not be able to operate in a proper way.

The solution to identified problem lies in adaptation of utilization capacity of the THS facilities.

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