MODELING OF UNPRODUCTIVE LOSSES IN THE OPERATION OF A SORTING STATION

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Abstract. To develop the most universal model for controlling the duration of the elements of the time spent by wagons at the sorting station. The methods of system analysis are used, comparing the performance of the sorting station, mathematical modeling. The concept of explicit and latent losses is introduced when processing wagons at the sorting station. The analysis of the existing standardization method for the time spent by the wagons and its disadvantage is carried out. A method of mathematical modeling of losses in the process of processing wagons at the sorting station was developed. The developed model makes it possible to evaluate the fulfillment of each element of the time that the wagons are at the sorting station and form statistical patterns of their non-fulfillment, and also makes it possible to develop action plans to reduce losses in the processing of wagon flows.

Key words: Sorting station, modeling of unproductive losses, the time spent by wagons at the station, duration, flow map, normalizing.

Introduction

In the work of any sorting station there is a certain level of unproductive losses (hereinafter - losses) [1-3]. Therefore, in the operation of the sorting station, it is very important to be able to calculate the amount of losses for all stages of the technological process, to monitor them, and also to timely predict changes in the causes of their appearance and magnitude in order to effectively reduce their level.

According to their nature, the losses in the operation of the sorting station, according to [1-2, 4], are divided into two groups: explicit and hidden.

Explicit losses, as a rule, include losses resulting from:

- finding wagons awaiting sorting and accumulation;

-accidents, defects and failures in the operation of technical equipment;

-damage to wagons (for example, when dissolving from a hill), etc.

In practice, they are easy to track at marshalling yards when performing operational work [3-6]

Hidden losses include losses resulting from:

– moving shunting locomotives at stations with reduced speed;

– irrational shunting movements (due to busy tracks in the parks of the station, overlapping of long-neck necks by trains, etc.);

– irrational movements of workers to the place of work;

– re-processing of wagons due to personnel errors;

– repeated inspections of trains after the formation of trains, etc..

Unlike obvious losses, the value of hidden losses is less obvious and, if no special measures are taken, it becomes an inevitable part of the technological process [3-6].

In this regard, the identification and reduction, as well as the modeling of such losses during the processing of wagons, is an urgent problem of the sorting station.

The level of research

Many scientists [7-19] dealt with the issues of accounting, analysis, reduction and modeling of losses at the sorting station, however they all used a different set of parameters and reveal individual aspects without offering a general approach.

For example, the authors J. Camaj, J. Lalinská, J. Masek [13] developed a technical and operational model for organizing the movement of wagon flows along the railway network of Slovakia for the rational formation of trains. This model supplements the theoretical problem of train formation with new approaches to assessing factors affecting the organization of car flows. However, when simulating the operation of the station, the values of factors are considered as inter-operational expectations, and not the causes of.

Maria Gisela Bardossy [14] developed a simulation model of the station, taking into account the length of the train and the time of arrival, to improve the process of disbanding trains at the sorting station. The disadvantages of the developed model include the difficulty of preparing the source data to create a model of a specific station.

Marin Marinov [15] has developed proposals to improve the organization, planning and management of train traffic in the railway network, including at the sorting station. This study discusses the forms of operation of trains, problems of railway traffic control and dispatching of trains, technical schemes of railway stations, as well as the development of train schedules. A description is also given of analytical methods, modeling methods for the analysis and evaluation of the operation of railway stations.

S.I. Muzykina, M.I. Muzykin, G.I. Nesterenko [16] developed methods for calculating the processing ability of a sorting slide in order to rationally organize car flows at Ukrainian stations. However, the authors in the development of the method did not take into account random factors arising from the processing of wagon flows on a sorting slide.

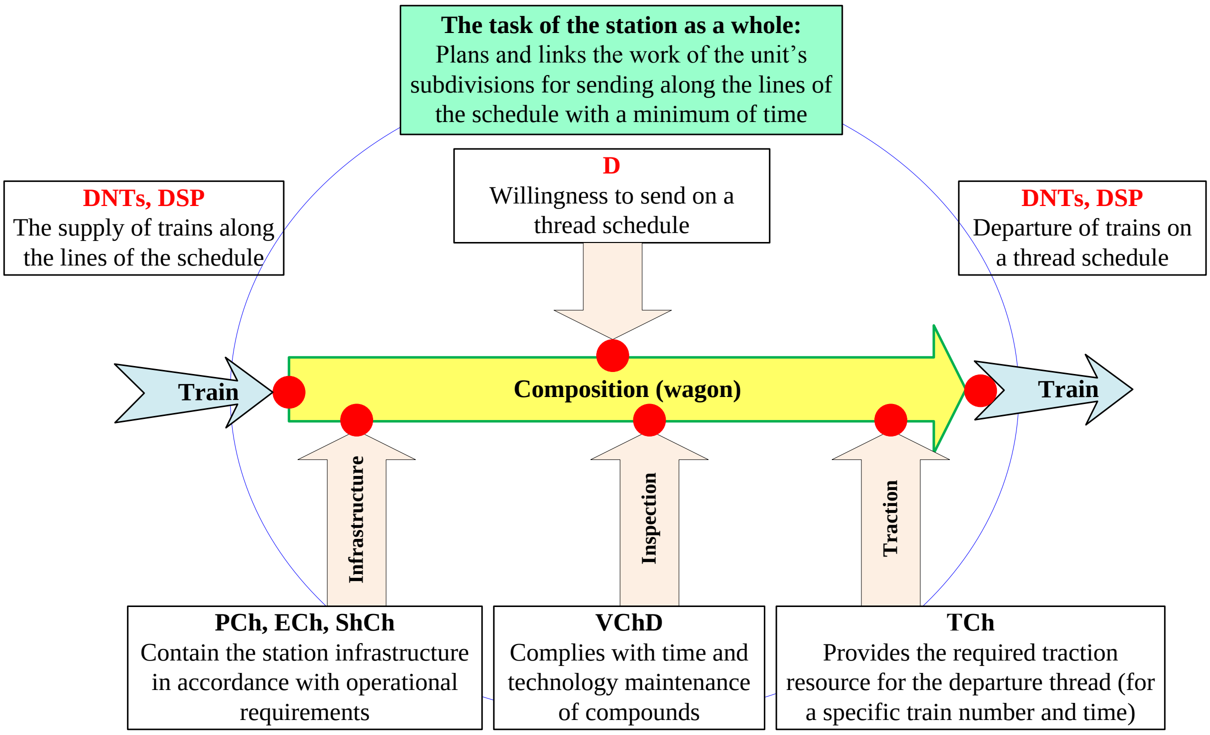
Rene Schönemann [17, 18] has developed methods to improve the quality of the organization of work of a sorting station based on events. However, the development did not take into account random factors affecting the performance of technical and operational indicators of the station.

Wenliang Zhou, Xia Yang, Jin Qin, Lianbo Deng [19] have developed a model that minimizes the average time spent by railcars, taking into account the restrictions on the minimum time intervals for trains to arrive at the train. However, the authors in the work did not take into account some causes of losses, which significantly reduces its adequacy.

At the same time, one could propose an approach to accounting, analysis, reduction and modeling of losses based on their normalization. Formally, such an approach should correspond to the technological standards for the duration of operations for processing cars at the stations established by the Standard technological process for the operation of sorting stations [20]. According to [20], the main quality indicator of the operation of marshalling yards is the time spent by transit cars with processing at the stations. Based on it, the effectiveness of the station operation technology is evaluated.

Issues of normalizing the time spent by wagons at the sorting stations

The main task of the sorting station is the processing of wagon flows and the formation of trains in the optimal mode so that the duration of the process of processing a transit car at the station is minimal and technologically justified (Fig. 1) [20].



Note: D – transportation management department; DNTs – train dispatcher; DSP – station duty officer; PCh – railway track section; ECh – Electrification and power supply distance; ShCh – alarm distance, centralization and blocking; TCh – locomotive depot; VChD – wagon depot.

Fig. 1. The tasks of the sorting station in the node. Interconnection of technological processes of subdivisions of a node

The duration of the processing a transit wagon at a station is most often normalized by constructing a daily schedule for the sorting station, and is set for a month [20]. According to the daily schedule, they are calculated by summing the wagon-hours per day, both the total for the station and the disaggregation by elements, and as a result we get a set of indicators characterizing the operation of the sorting station (Fig. 2)

Elements of the time of the wagons	Designation	Duration 1	2	3	4	5	6
Securing and fencing of the composition in the reception park	$t_{s/f}^{rp}$						
Waiting for processing at the reception park	$t_{wai}^{proc(rp)}$						
Processing composition in the reception park	t_{proc}^{rp}						
Waiting for disbandment	t_{wai}^{disb}						
Disbandment	t_{disb}						
Accumulation	t_{acc}						
Waiting for formation	t_{wai}^{for}						
The formation and rearrangement	$t_{for.rea}$						
Securing and fencing of the composition in the departure park	$t_{s/f}^{dp}$						
Waiting for processing at the departure park	$t_{wai}^{proc(dp)}$						
Processing compound in the departure park	t_{proc}^{dp}						
Providing train traction	t_{trac}						
Providing trains with brakes	$t_{wi.bra}$						
Waiting for departure	t_{wai}^{dep}						
Total duration	t_{proc}						

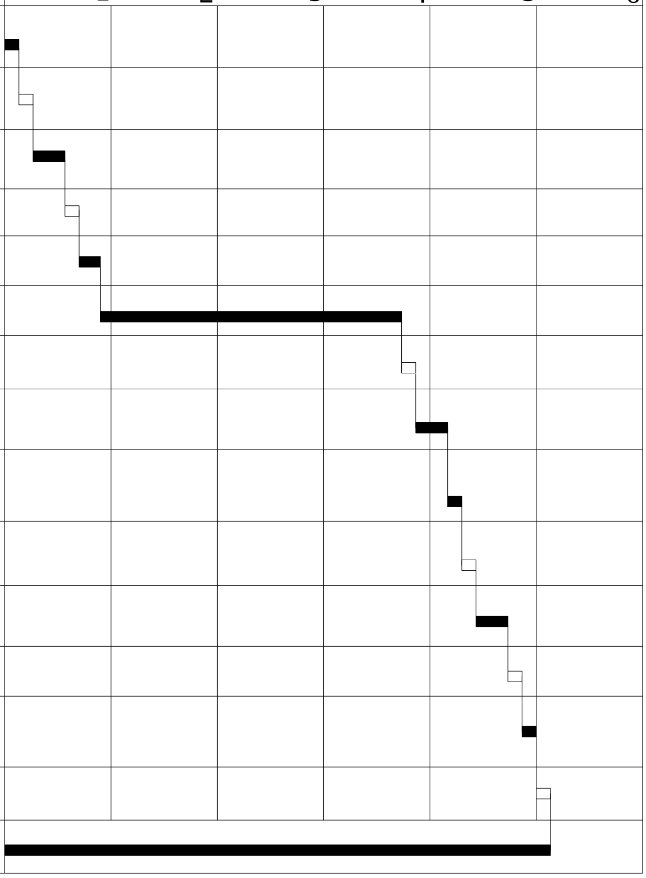


Fig. 2. Schedule of the duration of the processing of wagons at the sorting station

Summarizing separately the time spent on technological operations (t_{tech}) and on interoperational expectations (t_{wai}), we can obtain the following expression:

$$t_{tech} = t_{s/f}^{rp} + t_{proc}^{rp} + t_{disb} + t_{for.rea} + t_{s/f}^{dp} + t_{proc}^{dp} + t_{trac} + t_{wi.bra}, \text{hour}$$

$$t_{wai} = t_{wai}^{proc(rp)} + t_{wai}^{disb} + t_{wai}^{for} + t_{wai}^{proc(dp)} + t_{wai}^{dep}, \text{ hour}$$

So the duration t_{proc} is equal to

$$t_{proc} = t_{tech} + t_{wai} + t_{acc}, \text{ hour}$$

In general terms, this can be represented by a function of three arguments

$$t_{proc} = f\{t_{tech}, t_{wai}, t_{acc}\}$$

According to [20, 21], the duration t_{proc},) is directly dependent on the volume of processing wagons $-U_{proc}$, and with an increase in volume U_{proc}, the constituent parameters

t_{proc} change differently (Fig. 3). So, t_{tech} it depends on the level of technical equipment and technology of work and varies slightly with change U_{proc}. .The value t_{wai} substantially depends on U_{proc}, since, with an increase in the processing of wagons, their value increases, and the value t_{acc} is inversely related to the value U_{proc}.

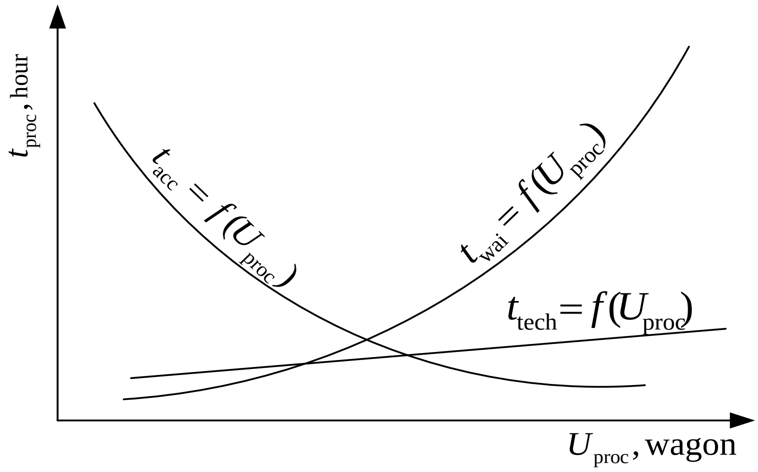


Fig. 3. Dependences of time spent on the amount of processing of wagons

Thus, when normalizing the time spent by cars, the workload of the sorting station, the parameters of the technical equipment and technology of work are taken into account.

This shows that the existing systems for technical regulation of the time spent by wagons at the sorting station do not take into account any causes of losses. Therefore, the current calculation procedure for normalizing the time spent by cars at sorting stations , as well as the procedure for calculating the analysis, need to be processed.

The research of the implementation of the duration $t_{\text{пер}}$ in practice

As noted above, the norm t_{proc} at the sorting station is set for a month, and in turn is the task for the day, i.e. in this case, $t_{\text{мон}}^{\text{plan}} = t_{\text{day}}^{\text{plan}}$. However, in practice, their actual values differ significantly from each other (see Fig. 4, a, b) $(t_{\text{мон}}^{\text{fact}} \neq t_{\text{day}}^{\text{fact}})$ (see Fig. 4, a, b)

The average daily and average monthly actual time spent processing wagons at the sorting station can be determined by the formula

$$t_{\text{day}}^{\text{fact}} = \frac{\sum_{q=1}^{N} U t_{\text{proc}}}{U_{\text{proc}}}, \text{hour}$$

$$t_{\text{мон}}^{\text{fact}} = \frac{\sum_{l=1}^{T} t_{\text{day}}^{\text{fact}}}{T}, \text{hour}$$

Where is $\sum_{q=1}^{N} Ut_{\text{proc}}$ – the cost of wagon-hours for all purposes N;

U_{proc} – number of processed wagons;

T – period of time i.e. day number.

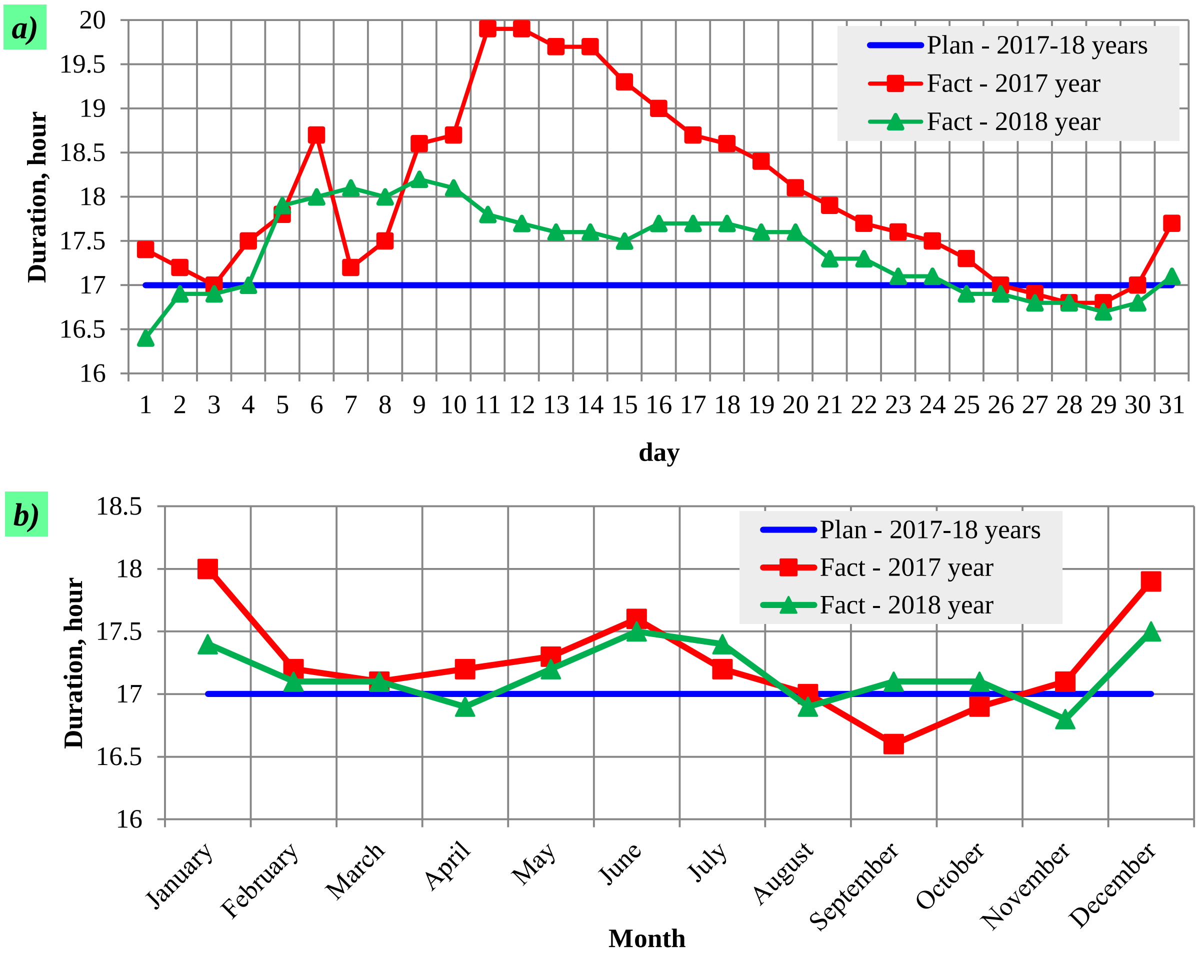


Fig. 4. Dynamics of implementation of the average daily (*a*) for the month of January and average monthly (*b*) durations t_{proc} at the station "Ch" (JSC "UTY")

Practice shows that the actual values every day (Fig. 4, a) and a month (Fig. 4, b) significantly deviate from their planned values adopted during technical normalization. Moreover, from Fig. 4, and it is clear that in 2017 only 33%, cases of the norm are lower than the established plan. 2018 - 33%, this indicator for annual periods in 2017 was 25%, and in 2018 - about 17%. There can be many reasons for such dynamics of change. The duration of the considered indicator of station operation .

Also, based on the data of daily reports on the fulfillment of the set standards for the downtime of cars at the sorting station "Ch" of UTY JSC and "SPSM" of JSC Russian Railways for one month of 2019, in order to identify "bottlenecks" in the operation of the sorting station, a step-by-step analysis of transit cars 'time from processing (Fig. 5).

In fact, exceeding the plan is a loss, the opposite is saving (Fig. 5) [22].

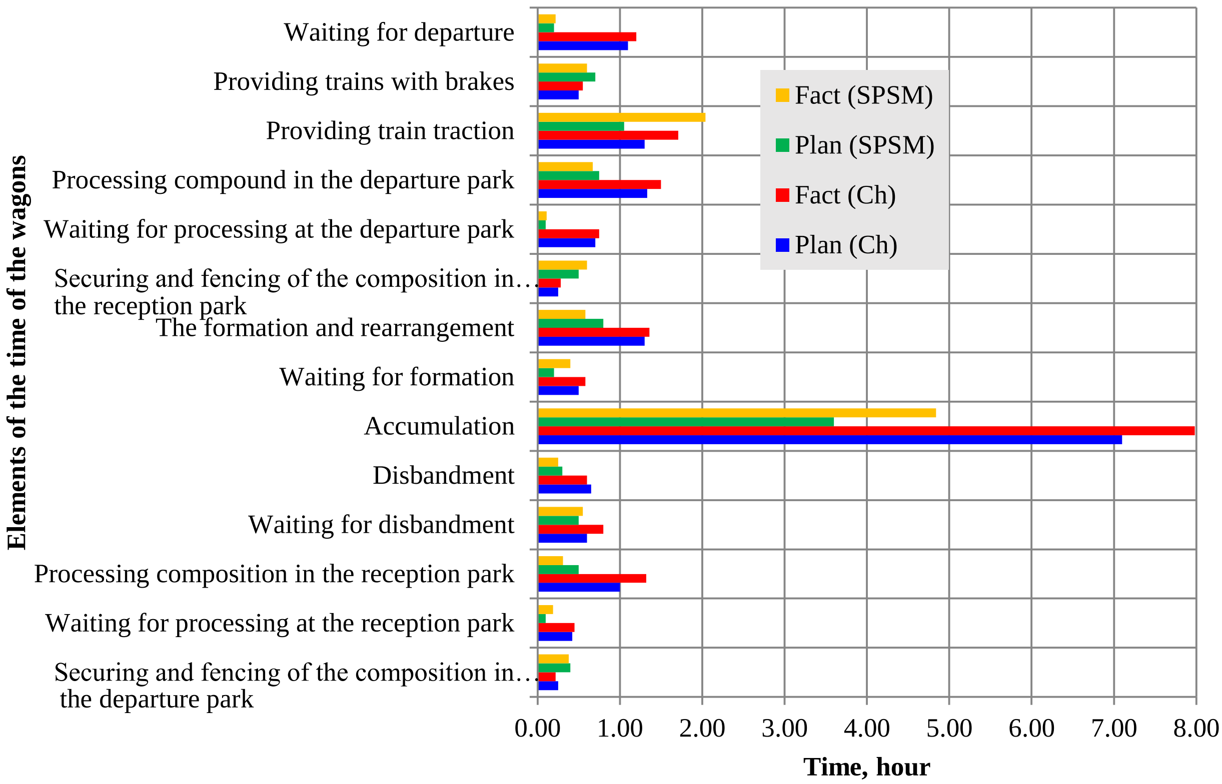


Fig. 5. Dynamics of the implementation of the average monthly duration of the elements at the station "Ch" (JSC “UTY”) and “SPSM” (JSC “Russian Railways”)

From Figure 5 shows that the duration of the elements t_{proc} is about 13.5% and 21.03% at stations "Ch" and "SPSM", cases of fact being higher than the established plan

Thus, from fig. 4 and 5, we can conclude that there can be many reasons for such a dynamics of change in the duration of the considered indicator of station.

Assessment of losses in the operation of the sorting station

Losses in the operation of the sorting station are such things that they require more careful study and consideration [3-6, 9-12.]. Therefore, the work studied in detail the process of processing cars at the sorting station “Ch” to identify losses in the station.

Above the study of activity, it was possible to identify the causes of losses (“bottlenecks”) associated with the location of cars at the sorting station, and also made it possible to evaluate the time loss in the operation of the station.

In fig. 6a, b, v present the frequency of occurrence of the cause of losses and their duration.

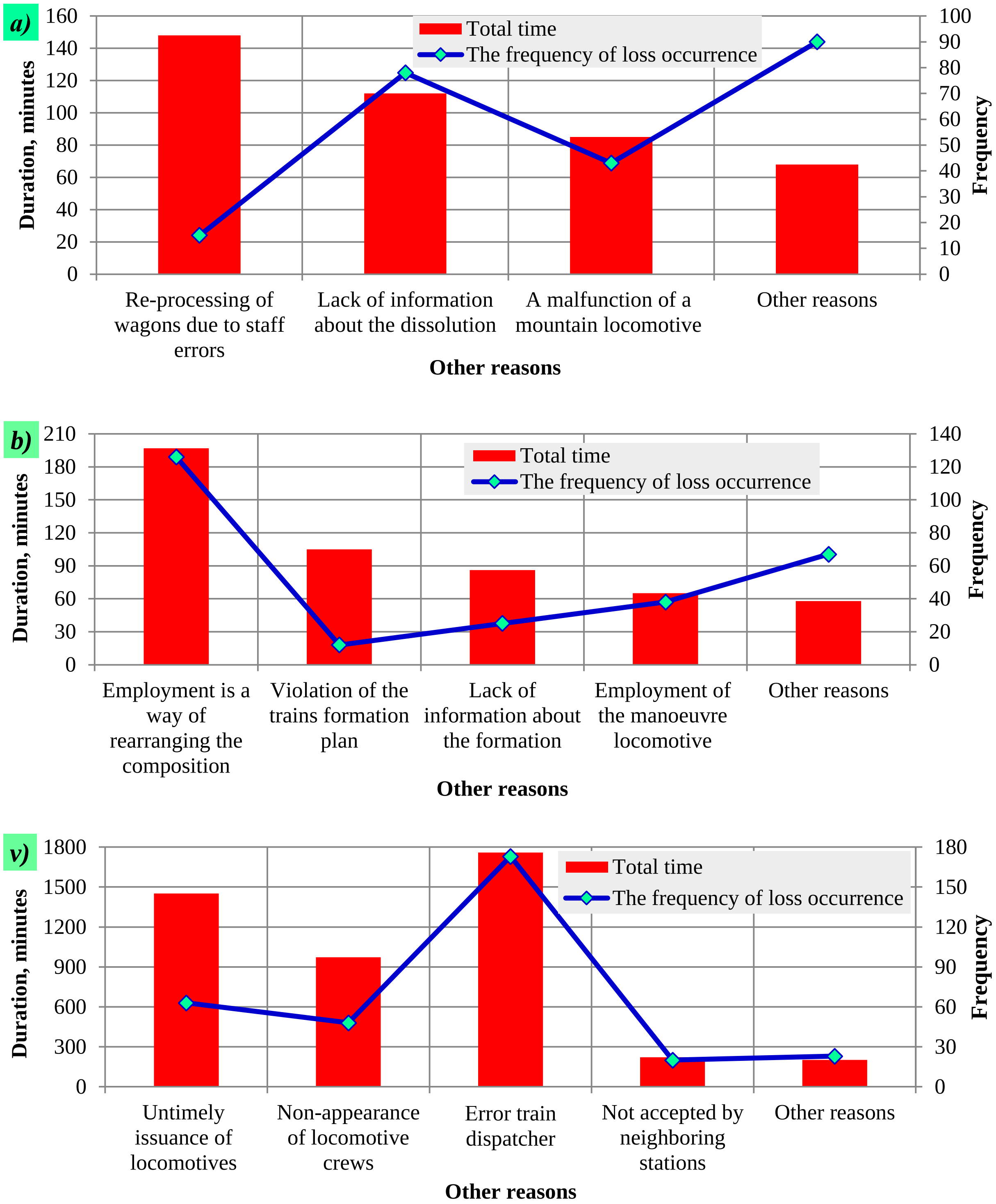


Fig. 6. Monthly frequency of occurrence of the cause of losses and their total time in the receiving Park (*a*), sorting park (*b*) and departure park (*v*)of the sorting station "Ch"

The nature of the cause of the losses shows that some of them (for example, the re-processing of wagons due to personnel errors) and their values are very noticeable. Therefore, in the operation of the sorting station, special attention should be paid to such causes of losses.

Thus, a regular analysis of the operation of the station makes it possible to identify "bottlenecks" and allows you to generate statistical patterns of non-fulfillment of the duration t_{proc} of the elements and to build technological processes for processing cars without losses.

In general, they show the importance and relevance of finding common approaches to accounting, analysis and reduction of losses during the processing of wagons at the sorting station on the basis of their normalization, as well as the development of a mathematical model for controlling the duration of elements t_{proc}.

Developing a mathematical model for managing elements t_{proc}

The standard duration of the processing a transit wagon at a sorting station can be represented in many

$$L = \{l_i, i \in I\},\ i = [1,...,I],\ I = 5,$$

where $i-$ is the index of the sub-process of carriage processing (type of processing), for example, the set of operations for the reception and processing of cars in the reception park $(i=1)$, disbandment $(i=2)$, accumulation $(i=3)$, the formation of $(i=4)$, in the departure park $(i=5)$.

Each duration of the sub-process l_i (excluding the l_3 sub-process) includes a set of durations of technological operations (o_j) and inter-operational expectations (k_z) and their elements (h_g), that must be implemented for the processing of wagons

$$O = \{o_j,\ j \in J\},\quad j = [1,...,J],\quad J = 10,$$

$$K = \{k_z,\ z \in Z\},\quad z = [1,...,Z],\quad Z = 6,$$

$$H = \{h_g^1, h_g^2, g \in G\},\ g = [1,...,G],\ G = 115,$$

where $j-$ is the index of the technological operation, for securing and fencing the train in the reception park $(j=1)$, , handling the train in the arrival park $(j=2)$, arrival $(j=3)$, thrust $(j=4)$, dissolution $(j=5)$, upsetting $(j=6)$, formation and rearrangements $(j=7)$, fastening and fencing the train in the departure park $(j=8)$, handling the train in the departure park $(j=9)$, providing the train with brakes $(j=10)$;

$z-$ inter-operational expectations index, for example, waiting for processing in the reception park $(z=1)$, waiting for disbandment $(z=2)$, waiting for formation and rearrangement $(z=3)$, waiting for processing in the departure park $(z=4)$, providing the train with traction $(z=5)$, waiting for the departure $(z=6)$;

$g-$ index of the operation element, for example, issuing commands to consolidate the composition on the paths of the reception park receiving transport documents from the train driver $(g=2)$, delivery of transport documents to the STC $(g=3)$, permission to depart from the station $(g=114)$, control the passage of the train along the departure route $(g=115)$;

(Note: a list of operations related to the processing of transit wagons at the sorting station is presented in [4]);

$h_g^1, h_g^2 -$ operation elements characterizing the type of parallelism (h_g^1) and sequences $(h_g^2),$ for example, issuing commands to fixing the composition on the ways of the reception park $(h_1^2),$ receiving shipping documents from the driver of the train $(h_2^1),$ delivery of shipping documents in the STTs $(h_3^1).$

Taking into account the above the problem of loss normalization can be formulated as follows: it is necessary to establish such a duration of operation elements $(h_g^1, h_g^2),$ which will ensure compliance with technological norms.

Mathematical model for managing elements of the duration of technological operations (o_j) and inter-operational waiting (k_z)

$$M_{\text{о}} = u^{(\text{о})}(t);\ x_{ij}^{(\text{о})} = \sum_{g=1}^{G} \varepsilon_{jg}(t) u_{ijg}^{(\text{о})};\ x_{ij}^{(\text{о})}(t_0) = 0;\ x_{ij}^{(\text{о})}(t_f) = o_j;\ \sum_{g=1}^{G} u_{jg} \le o_j^{(\text{о})};$$

$$u_{jg}^{\text{о}}(t) \in \{0, P\}; \quad u_{ij}^{\text{о}} \left(\sum_{g=1}^{G} x_{ijg}^{(\text{о})} - \sum_{g=1}^{G} o_{ijg}^{(\text{о})} \right) = 0;$$

$$M_{\text{м}} = u^{(\text{м})}(t);\ r_{iz}^{(\text{м})} = \sum_{g=1}^{G} \varepsilon_{zg}(t) u_{izg}^{(\text{м})};\ r_{iz}^{(\text{м})}(t_0) = 0;\ r_{iz}^{(\text{м})}(t_f) = k_z;\ \sum_{g=1}^{G} u_{zg} \le k_z^{(\text{м})};$$

$$u_{zg}^{(\text{м})}(t) \in \{0,1\}; \quad u_{iz}^{\text{м}} \left(\sum_{g=1}^{G} r_{izg}^{(\text{м})} - \sum_{g=1}^{G} k_{izg}^{(\text{м})} \right) = 0,$$

where $x_{ijg}^{(\text{о})}, r_{izg}^{(\text{м})} -$ actual value characterizing the duration of technological operations $(o_j^{(\text{о})})$ and inter-operational waiting $(k_z^{(\text{м})})$ inbox in the composition l_i;

$\varepsilon_{ij}(t) -$ known matrix temporal function with the help of which space-time constraints associated with the interaction of elements are set h_g^1 and h_g^2 this function takes the value ,,1'', if h_g^1 falls into a given area of interaction with operations $h_g^2,$,,0'' – in the opposite case;

$P -$ the value of the reserve that characterizes the duration of losses in the operation of the sorting station;

$\sum_{g=1}^{G} x_{ijg}^{(\text{о})} - \sum_{g=1}^{G} o_{ijg}^{(\text{о})} = 0,\quad \sum_{g=1}^{G} x_{ijg}^{(\text{о})} - \sum_{g=1}^{G} o_{ijg}^{(\text{о})} < P,$ if the duration of technological operations $x_{ijg}^{(\text{о})}$ meets the technological requirements of the norm $(o_j^{(\text{о})}),$ $\sum_{g=1}^{G} x_{ijg}^{(\text{о})} - \sum_{g=1}^{G} o_{ijg}^{(\text{о})} > P -$ in the opposite case;

$\sum_{g=1}^{G} r_{izg}^{(\text{м})} - \sum_{g=1}^{G} k_{izg}^{(\text{м})} = 0,\quad \sum_{g=1}^{G} r_{izg}^{(\text{м})} - \sum_{g=1}^{G} k_{izg}^{(\text{м})} < P,$ if the duration of interoperational waiting $r_{izg}^{(\text{м})}$ meets the technological requirements of the norm $(k_z^{(\text{м})}),$ $\sum_{g=1}^{G} r_{izg}^{(\text{м})} - \sum_{g=1}^{G} k_{izg}^{(\text{м})} > P -$ in the opposite case.

Also, a flow map was constructed of the processing of wagons at the sorting station (fig. 7) in order to clearly demonstrate the conditions for fulfilling the developed mathematical model.

In fig. 7 to the group of "triangular" operations (k_z) are those that add value to the final service, that is, promote it to the final state. All other operations on the flow map are technological operations (o_j), that consume resources, but do not create value for the railway. And, according to [23], the following notation is used:

a) material flow symbols

– manufacturing process; – external sources; – stocks;

– the movement PL and composition of individual wagons and other results of operational work; – train movement;

b) information flow symbols

– information; – electronic information flow;

– manual information flow.

And also in fig. 7 the following abbreviations are used:

DNTs – train dispatcher; DSP – station duty officer; DSTs – shunting dispatcher; DSPP – park attendant; DSPG – duty on the hill; RSDV – wagon speed regulator; IVTs – information and computing center; STTs – station technological center; PKO – point of commercial inspection; PTO – technical service point; LB – locomotive team; PL – train locomotive; TO – current inspection; TCh – locomotive depot; ShCh – alarm distance, centralization and blocking; VCh – wagon section.

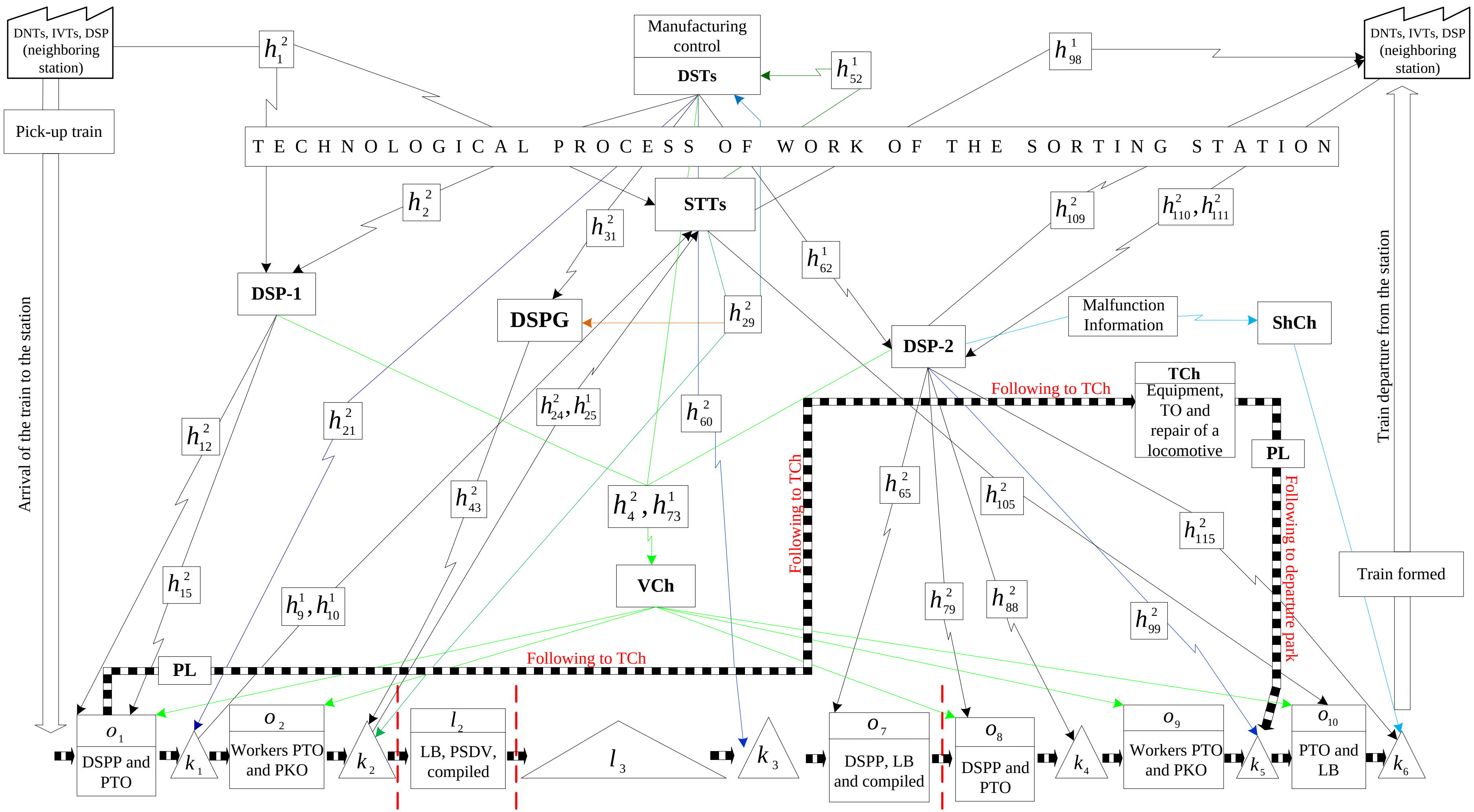


Fig. 7. Flow map of the processing of wagons at the sorting station.

Conclusion

The basis of mathematical modeling is the formalization of the assessment of the standardization state, the duration of the processing of wagons at the sorting station, described by the traditional factor analysis tool, which makes it possible to evaluate the fulfillment of each parameter, technological operation and interoperational waiting. The next step is mathematical modeling of the duration of technological operations and interoperational expectations, taking into account the weight of the cause of the loss in the operation of the station.

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