Mathematical modeling of technological operations performed by trains at stations

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Abstract. The main purpose of the work is mathematical modeling of the sequence of technological operations performed by trains at stations. Methods of systematic analysis, analytical, regression and graphic modeling, flow mapping of the sequence of technological actions were used. The methods of normalizing the time of stay of trains at stations and their advantages, the degree of interconnections and disadvantages of technological actions were studied. At the station, the time spent on the technological actions performed with the train was analyzed and the factors that negatively affect their execution were determined. In order to increase the level of execution of station performance indicators, it was recommended that the method of basic normalization of the time for performing technological actions with shunting and train locomotives depends on the length of the half-trip, the number of connecting and disconnecting wagons and the speed of the shunting. This method allows you to analyze the indicators of the time spent on technological actions at stations and the graph of train traffic (GTT), as well as increase the carrying capacity of rail transport by 7-11%.

1 Introduction

The main tasks of organizing freight operations in rail transport consist of a sequence of technological actions performed by trains at stations. The correct organization of technological actions will create the basis for an increase in the transferring capacity of the station and the railway site. Therefore, when performing technological actions with the composition of the train, it is one of the important tasks to analyze the time standards based on optimal options [1, 2, 3].

The duration of technological operations performed at stations with train content depends mainly on the level of technical equipment of the station, the reception-operation of trains to the station, the time spent on fixing or emptying content on station tracks, the number of wagons disconnected and connected from the traffic content at the station, the performance of the work of the [4, 5, 7, 14]. Reducing the time spent on technological actions performed with the train composition will create an improvement in the performance of the station, as well as the possibility of timely execution of the indicators of the GTT [1, 8, 11].

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The effective organization of the movement of trains of different categories in railway plots is the disregard for the parameter of inefficient time losses, which gives rise to the reasons for the stay of trains at stations. Such a disadvantage in turn leads to the fact that the technical standards established in the operation of stations are practically not met, and the efficiency of the technology of transport operations of railway lines is reduced [3, 11, 17]. 50% of the time spent on the implementation of technological actions on the basis of the plan for the formation of trains at stations within railway lines corresponds to the contribution of picking trains [6, 7].

From the above, a new approach to the sequence of technological actions performed by train trains at railway stations requires the development. In turn, this approach should correspond to the technological norms established in the model station technological work processes (STWP) [9, 18, 19], the duration of activities (technological and interoperability expectations) performed by trains at stations along the way.

The fact that the picking trains remain at the stations beyond the norm coincides with the anticipation of the fulfillment of technological actions, the main reasons for which are the following [16, 17, 20, 21]:

- failure to follow the plan for the formation of freight trains when drawing up picking train formations;
- insufficient justification of the time standards spent on technological actions at stations;
- weakness of interaction between departments participating in the same technological practice.

To eliminate these shortcomings, it is advisable to constantly improve the composition of the national train and the methods of technological actions performed with them

2 Methods

In various years, many scientists have carried out scientific research work on the effective organization of technological actions performed by trains at technical and intermediate stations on railway lines, as well as the development of a theory of normalization of the values of GPP indicators. In particular, N.T. Alekseevna in his dissertation work [13] developed a computational system and algorithm for planning manoeure's work and normalizing the times of technological actions. In this, the author took into account such parameters as locomotive classification, composition length, weight, calculation slope and route preparation.

M.I. Shmulevich [15] insisted at work that the most effective method for normalizing the time of manoeure work at the station is an immitative model. As a result of the modeling, the team determined the time spent on the most performed maneuver half-trip with the composition of the trains.

$$t_{h|t}^{m} = \frac{3,6 l_{h|t}}{\vartheta_m} + \frac{\vartheta_m}{3,6a}, \ hour \tag{1}$$

There $l_{h|t}$ – half-trip length, m.

ϑ_m – permissible speed in maneuver movement, km / h;

a – acceleration and deceleration time, m/s2

D.M. Additional indicators of the operation of shunting locomotives at the station were analyzed by Kozachenko [11]. The station has proven that performance performance depends on the type of shunting locomotives, i.e. sorting and freight stations can affect performance up to ±15%, and passenger stations up to ±10%.

D.Y. Levin [14] in a scientific article analyzed the technological practices of train processing at stations and station workflows when organizing local work on railway plots. The station has specified optimal options indicators while ensuring movement safety in wagon load-download operations. This in turn makes it possible to process trains at stations nd determine the standards of time for trains to stand at the station.

Pengling Wang et al [17] in the paper analyzed factors affecting the direction of train travel and calculated quantitative indicators of the electricity used in train traffic along the route.

To this end, a mathematical model of the norms of time spent on the sequence of technological actions performed by trains (on the example of a train train) has been developed at the stations. For this, mathematical expressions for determining the norms of time spent on each technological implementation and the number of brake shoes are cited. The time of reception and departure of trains to the station is determined by the following expression [17, 21].

$$t_{q.q.j.} = \frac{0{,}06 \cdot (l_m + l_{entr.traf} + l_{brake})}{\vartheta_{average}} + t_{sig.open} + t_m \; minute \tag{2}$$

there t_m – minutes of time to open the entrance traffic light and prepare the procession;
$l_t -$ Train length $(l_p = l_l + l_v \cdot m),\ m;$
$l_l -$ the length of the train locomotives, m;
$l_w -$ the average length of the wagons in the train, m;
$m -$ number of wagons in the train;
$l_{entr.traf} -$ the distance from the entrance traffic light to the border column of the road or to the isolation space, m;
$l_{brake} -$ length of the brake path, m;
$\vartheta_{average} -$ average installed speed when receiving and sending to the station, km / h:
$t_{sig.open} -$ machinist's time to advance the opening signal, minutes.

Fastening the structure of movement to the station tracks is carried out in accordance with [18, 19]. [19] by the standards of paragraphs 1.2.1÷1.2.3, the number of brake shoes for fastening the structure of movement to station roads is determined by the following expression:

$$K = \frac{n}{200}(1.5 \cdot i + 1) \tag{3}$$

$$K = \frac{n}{200}(4 \cdot i + 1) \tag{4}$$

there K – the necessary number of brake shoes;
n – number of axis in the composition (group);
i – the average magnitude of the slope of a road or road segment in millennia;
(1.5 i +1) – the number of brake shoes per 200 axis (one type by weight);
(4 i+1) – the number of brake shoes per 200 axis (each different in weight).

(3) and (4) - the number of necessary brake shoes required to fasten the traffic content to the station tracks in terms of expressions is indicated in the technical management act of the station.

The norms of time spent on fastening or emptying the contents of the movement to the station tracks are determined by the following expression [19, 20]:

$$t_{braking}^{content} = K \cdot t_b + t_{collect} + \sum t_{dialogues} \;\; minute \tag{5}$$

there $t_b -$ the time it takes to place and take one brake shoes, minutes.;
$t_{collect} -$ the employee responsible for fixing the structure of movement on station roads is required to collect brake shoes from the workplace,

move to the designated place and place the brake head with a "rol" (0.29+0.12+0.01·*lpas*) are the times spent, minutes;

$\sum t_{dialogues}$ – the sum of the time spent on dialogues and commands that are carried out during the period of fastening or emptying the contents of the action, minutes.

It is also not necessary to disconnect the train locomotive from the line-up if the train wagons are connected (disconnected) from behind the line-up under the plan to build trains at the stations. Therefore, it is not necessary to calculate both the Times that go to fix the composition of the action, namely (3)÷(5)-expressions. When manual work is carried out by connecting wagons from the picking train head and disconnecting the train locomotive when disconnecting wagons from behind the train, the time spent on disconnecting the train locomotive from the traffic content on the opened route is determined as follows [19, 20]:

$$t_{ac.dec.} = 0.06 \cdot \frac{L_{mar}}{\vartheta_{allow}} + 0.08 + 0.12\, minute \quad (6)$$

there 0.06 – the necessary time coefficient, which takes into account the change in the speed of movement of the locomotive by 1 km/h in the duration of deceleration and acceleration;

ϑ_{allow} – allowed speed at running time, km / h;

0.12 – time spent to separate the brake hose;

0.08 – time to disconnect the train locomotive from the line-up.

The time of commercial inspection of wagons disconnected from the train structure is determined by the following expression [20]:

$$t_{commercial} = \tau_v \cdot \frac{m}{K_{br}} minute \quad (7)$$

there τ_v – average time of commercial inspection of one wagon, minutes;

m – number of wagons disconnected from the line-up;

K_{br} – number of brigades conducting commercial inspection of wagons.

3 Results and discussion

The total time spent on technological operations with a shunting locomotive at the station can be expressed as follows:

$$t_{m.w} = \sum t_{sh.l} + \sum t_{h/t} minute \quad (8)$$

there $\sum t_{sh.l}$ – total time, minutes spent on the arrival of the shunting locomotive in front of the connecting and connecting wagons;

$\sum t_{h/t}$ – total time spent on maneuver half-trip, minutes.

Technological actions performed by trains at the station (the arrival of the locomotive of the maneuver in front of the movement composition and the times of the maneuver half-trip) using the least squares method of regression modeling (Exsel program) were mathematically modeled for the conditions of the "Uzbekistan Railways" JSC (table 1). The arrival of the maneuver locomotive in front of the action composition and the maneuver half-trip times are determined based on the expressions presented in Table 1.

In this case, the implementation of manual work also depends on the norms established in the STWP and the professional skills of the employees involved in this practice.

Table 1. A mathematical model of the locomotive coming to the front of the motion composition and determining the timing of the maneuver half-trip

Speed of movement, ϑ_m km/hour	Outline of expressions		Parameter change indicators	
	Arrival of the locomotive, *minute*	Maneuver half-trip time, *minute*	$l_{h\|t}, m$	m
Passing from one way to another				
15	$t_{lok}^{dep} = 0.92 + 0.00323 \cdot l_{h\|t}$	$t_{h\|t} = 0.112 + 0.0024 \cdot l_{h\|t} + 0.0193 \cdot m$	50...1500	1...60
25	$t_{lok}^{dep} = 0.214 + 0.00211 \cdot l_{h\|t}$	$t_{h\}t} = 0.12 + 0.00217 \cdot l_{h\|t} + 0.0178 \cdot m$	100...2800	
40	$t_{lok}^{dep} = 0.339 + 0.00115 \cdot l_{h\|t}$	$t_{h\|t} = 0.34 + 0.00103 \cdot l_{h\|t} + 0.0297 \cdot m$	300...3500	
60	$t_{lok}^{dep} = 0.94 + 0.002 \cdot l_{h\|t}$	$t_{h\|t} = 0.67 + 0.002 \cdot l_{h\|t} + 0.0392 \cdot m$	1000...4000	

The timing of connecting and disconnecting wagons to a train at the station depends on which track the wagons are located on, the number of wagons to connect and disconnect, and the length of the half-trip time.

Because, the times of arrival of the locomotive in front of the disconnected and connected wagons and the lengths of the shunting half-trip will be of different lengths. Therefore, the time of arrival of the locomotive and the time spent on the half-trip lengths is calculated by the installed shunting speeds (Table 1).

Using a flow map (Figure 1) and mathematical expressions (Table 1), in which a sequence of technological actions performed by trains at stations was developed, a change diagram of the time norms spent on the mill train-operated millimeter lengths was calculated taking into account parameters such as half-trip speeds, number of wagons and half-trip lengths.

In this case, the norms of time spent on shunting half-trip, which are performed with a picking train at technical and intermediate stations, the speed of shunting (=15÷60 km/h), the half-trip lengths (=50÷3800 meters) and the number of wagons (m=1÷60) were determined by variation (Figures 1, 2, 3, 4).

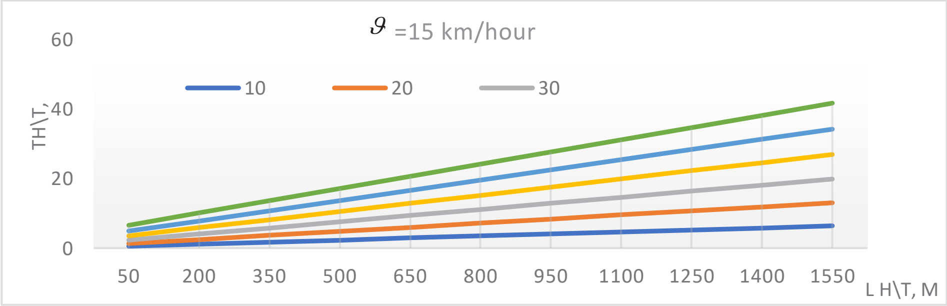

Fig. 1. At 15 km/h, the number of wagons in the traffic structure (m=10...60) and the half-trip lengths (50...1550) dynamics of variation of half-trip times in terms of increase.

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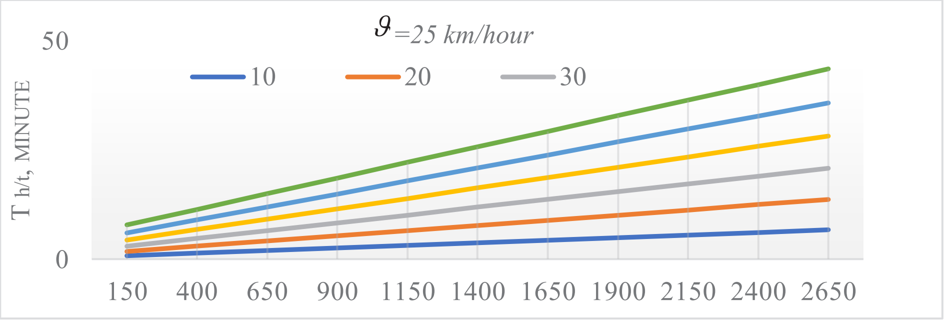

Fig. 2. At 25 km/h, the number of wagons in the traffic structure (m=10...60) and the half-trip lengths (150...2650) dynamics of change in the manoeuvre half-trip on increasing

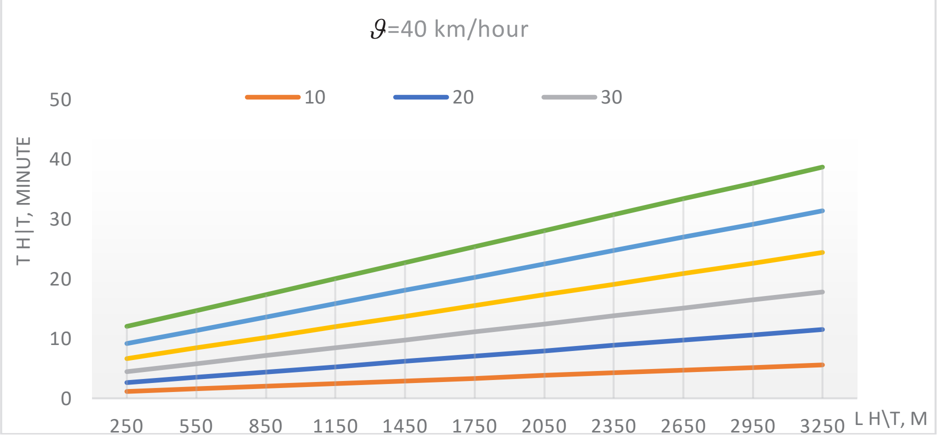

Fig. 3. At 40 km/h, the number of cars in the traffic structure (m=10...60) and the half-trip lengths (250...3250) dynamics of change in the manoeuvre half-trip in terms of increasing

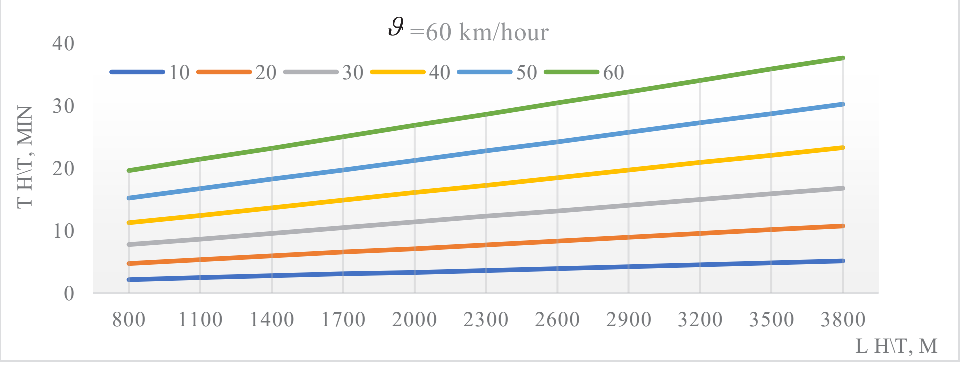

Fig. 4. At 60 km/h, the number of wagons in the movement composition (m=10...60) and the lengths of the half-trip (800...3800) dynamics of change in the manoeuvre half-trip in terms of increase.

Th|t, min depending on the results of the standards of time spent on the performance of the shunting half-trip with the composition of the train at the station, as a result of the changes in the length of the half-trip (50÷3800) and the amount of wagons (10÷60), the speed of the shunting varies, that is, in 15 km/h-1÷42 minutes, 40 km/h-1÷39 minutes, 60 km/h – 2÷37 minutes.

It can be seen, then, that the time standards spent on the half-trip depend on the values of the speed of the maneuver, the number of wagons, and the half-trip nodes. Above, a sequence of technological actions in which trains are performed at stations is developed flow map (Figure 5), and based on the expressions presented in Table 1, a basic normalization of the times spent on technological actions in which trains are performed bilam determines the possibility of increasing the indicators of rail transport operations and train traffic graphs.

The station used the following conditional marks on the flow map (Figure 5), which covers technological actions performed by the train (from reception to departure):

a) signs of material flow

– production process; external sources; - expectations;

- the transition of exploitation work from one stage to another;

- moving of picking trains ;

b) information flow symptoms

– information; - electronic information flow; - manual information data.

As can be seen from Figure 5, the technological actions on the processing of the picking train are performed according to the STWP. In this, the structure of the train-working personnel is formed in cooperation from several performing service facilities such as D, TCh, Sh, Ch, etc. So, the duration of the activities performed with the train depends on the performance of the train, as well as the effectiveness of the work activities of these employees.

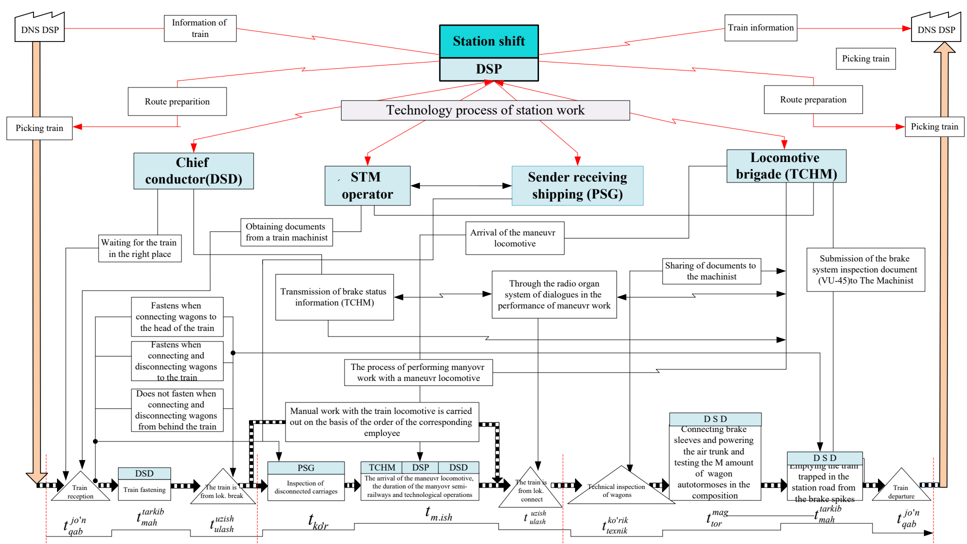

Fig. 5. Flow map of the sequence of technological operations performed with a train at the station

4 Conclusion

Technological activities performed by trains at specific stations located on railway lines are at the expense of technical and intermediate stations. Inefficient time losses at these stations occur in the performance of technological actions.

As a result of mathematical modeling of the sequence of execution of technological actions performed by trains at stations, the following were dissolved:

- reception of trains of different categories to the station-a reasonable normalization of the time spent on shipment;
- setting time standards for fixing or emptying content on station roads based on the train layout plan.;
- determination of the times spent on them, taking into account the number of brigades conducting technical and commercial inspections of trains at stations;
- setting time standards for staying at the station, taking into account the number of wagons disconnected from the traffic structure and connected;
- installation of manoeuvre actions taking into account the time spent on manoeuvre work is carried out with a manoeuvre or train locomotive;
- normalization of the timing of manoeuvre half-trip, taking into account the speed of manoeuvre and the number of wagons connected and disconnected to the content.

The advantage of the proposed method is the ability to analyze the delivery of goods on railway lines by the standards of time spent on technological actions at stations, the permeability of railway sections and the analysis of the flow of local wagons at stations in the cross-section of times of staying trains, to determine GTT indicators. The result is a 7-11% increase in the carrying capacity of rail transport.

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