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THE ORGANIZATION OF THE TRAIN FLOWS MOTION ON THE RAILWAY NETWORK WITH THE CONSIDERATION OF THE TRAFFIC CAPACITY OF THE LINES

Summary. There was researched the influence of the railway line load onto the main indexes of the train running. The value of the rational load of the main trespass of Dnepropetrovsk railway junction was determined.

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Streszczenie. Here write an abstract of the article in Polish. The word 'Streszczenie' shall remain bold, rest of the text according to the style. Persons who will not provide the titles and abstracts of their articles in Polish, please contact the organizers so such translation could be arranged.

1. INTRODUCTION

In the times of highly developed economic connections between the countries, railway transport faces the problem of increasing the volume of the transportations, both freight and passenger ones. That means that railway lines may not handle the volumes of transportation because of the insufficient traffic capacity. That is why the problem of the forming the effective way of decision making, directed towards the rational usage of the means of transport and energy resources, is becoming urgent under the conditions of the market economy. Choosing the criteria of decision making is a very complicated task. The solution of this task can provide a great advantage in front of the other means of transport. It will also help railway transport to become more competitive and attractive. Optimal route selection is a complicated and multicriterion task that has not been solved yet. As a rule, dispatchers and managing stuff are facing this problem every day, but unfortunately, they do not possess the precise algorithm to use when choosing the optimal route of the train passing.

The analysis of the recent researches and studies showed that the task of the defining the optimal routes of the train running has not a complete decision yet. When researching the railway line [1–2] a lot of factors are being ignored, such as the interconnection between the arrival and departing intensity under the conditions of the instant increase of the railway line saturation.

When simulating the operation of the railway line [1] a train is regarded as single unit, which means that the influence of the ahead and behind running trains is being ignored. Actually, the running regimes depend on the intensity of the trainflow, which means the indexes of the train running may differ. That is why the research should be made with the help of the simulating model, which allows simulating running the flow of the trains [3–5].

2. CHOOSING THE CRITERIA OF OPTIMALITY

When solving this task of determining the optimal route of the trains in the railway junction or on the railway network, the authors of the researches [8, 10] offered to use different optimal criteria for defining the optimal route of the trains, such as: route length, time of the train running, mechanical work losses, the costs of the train running, signal facilities, traffic capacity, railway line load and others. In order to solve the task of the determining the optimal route of the trains there were chosen the following criteria of optimality in this research: time of the train running and mechanical work losses [8]. This choice is based on the following consideration: time of the train running determines the duration of the freight delivery, which should be useful for the clients; mechanical work losses provide necessary information when calculating the cost of delivery. Thereby, in order to attain this priority task of determining the optimal route of the trains passing, it is necessary to choose a multiple criterion which should consist of several components, so there can be possible to consider a group of factors.

3. THE BASIC SCIENTIFIC STATEMENTS

Nowadays, one of the most powerful mechanisms which helps to research the railway network functioning is modern mathematical apparatus that is based on the multicriterion optimization. In the sphere of program system of the optimization methods a lot of attention is paid to the theory of graphs. Railway network is being presented as an oriented connected graph that has its initial and final vertexes. In this article there was offered to treat railway network as a multigraph (see fig. 1) – the graph in which there may be more than one arc between two adjoining vertexes.

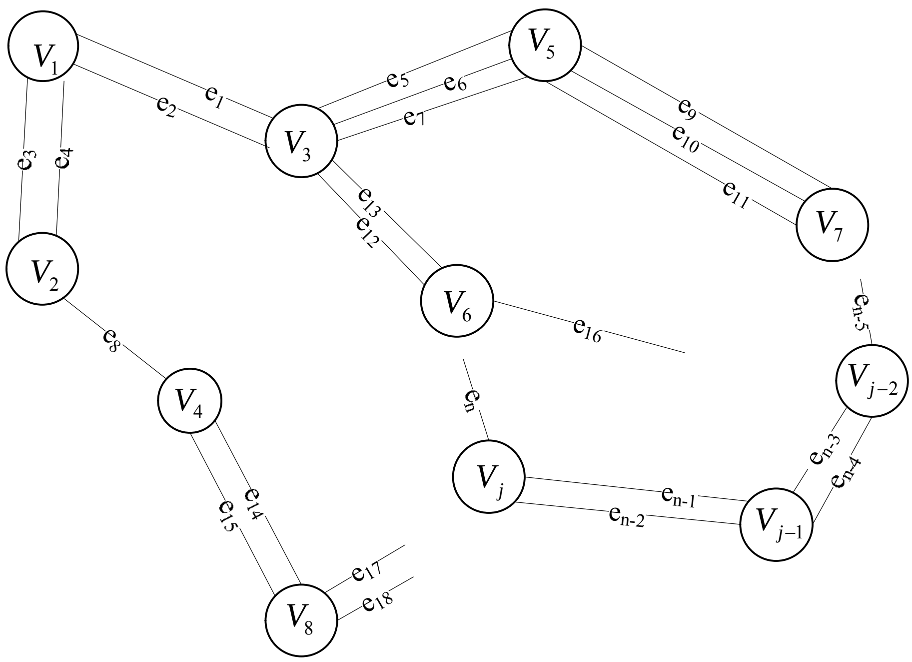

Fig. 1. Railway network model

The symbols that are used:

- e_n – arc of the multigraph, $e_n \in E$;
- $t(e_n)$ – time of the train running on the arc e_n;

- $r(e_n)$ – the value of the chosen criteria on the arc ɉ$_n$;
- $l(e_n)$ – length of the arc ɉ$_n$;
- $N(e_n)$ – traffic capacity of the arc ɉ$_n$.

This will provide us the possibility to consider a multitrack railway lines.

In this article the assignment of the rational train flows distribution on the railway network is treated as a task of vector optimization [16]. Let $G(V,E)$ be the oriented graph with the list of vertexes V and arcs E; $R(e)$ corresponds to each arc. Graph $G(V,E)$ has definite flows P_{ij}, $i, j \in V$. Let W_{ij} be the list of possible ways from i to j, and ω is a possible way out of W_{ij}. Than let $X_{ij\omega}$ be a part of the flow P_{ij} which may follow the way ω; in this case the following condition takes place

$$\sum_{\omega \in W_{ij}} X_{ij\omega} = P_{ij} \tag{1}$$

Let us choose the indicator of the arc e on the way ω, it means that

$$I_{\omega}(e) = \begin{cases} 1, \text{ if } e \in \omega; \\ 0, \text{ if } e \notin \omega, \end{cases} \tag{2}$$

than the cumulative flow on the arc e for the list of ways W_{ij} equals

$$\sum_{\omega \in W_{ij}} X_{ij\omega} \cdot I_{\omega}(e), \tag{3}$$

and the total flow on this arc e equals

$$N(e) = \sum_{i,j \in V} \sum_{\omega \in W_{ij}} X_{ij\omega} \cdot I_{\omega}(e); \; e \in E. \tag{4}$$

If $\bar{N}(e)$ is the maximum allowable flow for the arc, than the following restraint concerning the traffic capacity takes place:

$$N(e) \le \bar{N}(e), \; e \in E. \tag{5}$$

Let $l(\omega)$ be the length of the way ω, $l(\omega) = \sum_{e \in \omega} R(e)$, in this case the significant

$$Pr = \sum_{i,j \in V} \sum_{\omega \in W_{ij}} X_{ij\omega} \cdot l(\omega) \tag{6}$$

characterizes the rationality of the distribution of the traffic flows P_{ij}, $i, j \in V$ on the graph $G(V,E)$.

Let E_* be the array of the arcs that were used to build the list of the possible ways between all the vertexes, than the significant

$$L(E_*) = \sum_{e \in E_*} R(e) \qquad (7)$$

characterizes the length of the network.

In this case, there is a task to determine the definite distribution of the flow $X_{ij\omega}$ that provides the minimum of the significants $Pr(E_*)$ i $L(E_*)$ under the conditions of the restraints (2) and (6).

Thereby, the assignment of the rational train flows distribution on the railway network is treated as a task of vector optimization

$$\begin{pmatrix} L(E_*) \\ Pr(E_*) \end{pmatrix} \rightarrow \min \qquad (8)$$

under the conditions of (1) and (5).

In case graph $G(V,E)$ is treated as a railway network model, in which railway stations are the vertexes, the lengths of the railway lines $R(e)$ and the train flows P_{ij} are the parameters of the graph, than the whole length of the railway network $L(E_*)$ and the time of the freight transportation $Pr(E_*)$ will be the components of the optimization vector.

It is necessary to add, that any needed criteria may be chosen as a component in the task (8), the result will be estimated basing on several factors simultaneously.

In order to estimate the given mathematical procedure of the rational train flows distribution, the research was made on the example of Dnepropetrovsk railway junction.

In this case, as the components of the vector of optimization there were chosen the time of the train running and mechanical work losses in the junction.

The research was made with the use of the simulating model that allows considering the speed of the running trains [6], mechanical work losses, resistance force losses, retarding regimes and electric power losses. The relation between the time of the train running and the length of the railway line is shown on the fig. 2.

The analysis of the obtained dependences shows that the time of the train running according to a schedule is overrated, especially on the parallel line of the railway junction. That is why it is possible to concede that the actual time of the train running might be 15 minutes less compared to the time in the train schedule. That means that the time of the train running on the main line has a very little difference compared to the one on the parallel line (34,8 min and 30,8 min). Taking into account that the length difference of the main and parallel line is approximately 11 km, the time difference of 4 min could be ignored.

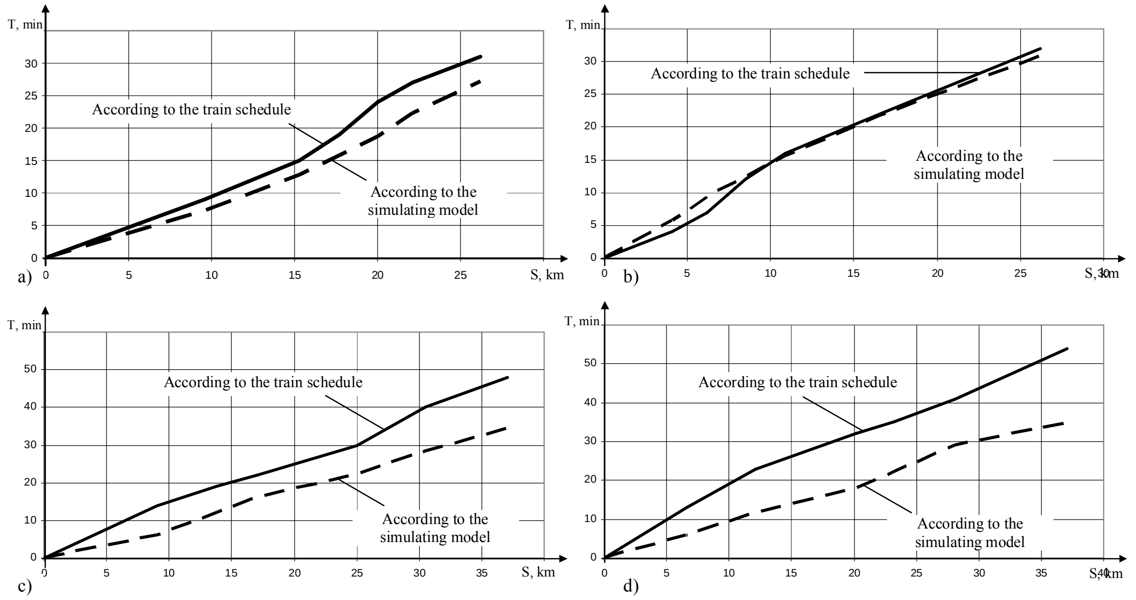

Fig. 2 – Dependence between the time of the train running and the length of the railway line
a) even direction of the main line; b) odd direction of the main line;
c) even direction of the parallel line; d) odd direction of the parallel line

On the basis of the simulating results there was also obtained the dependence between the mechanical work losses and the length of the railway line. This dependence is shown on the fig. 3.

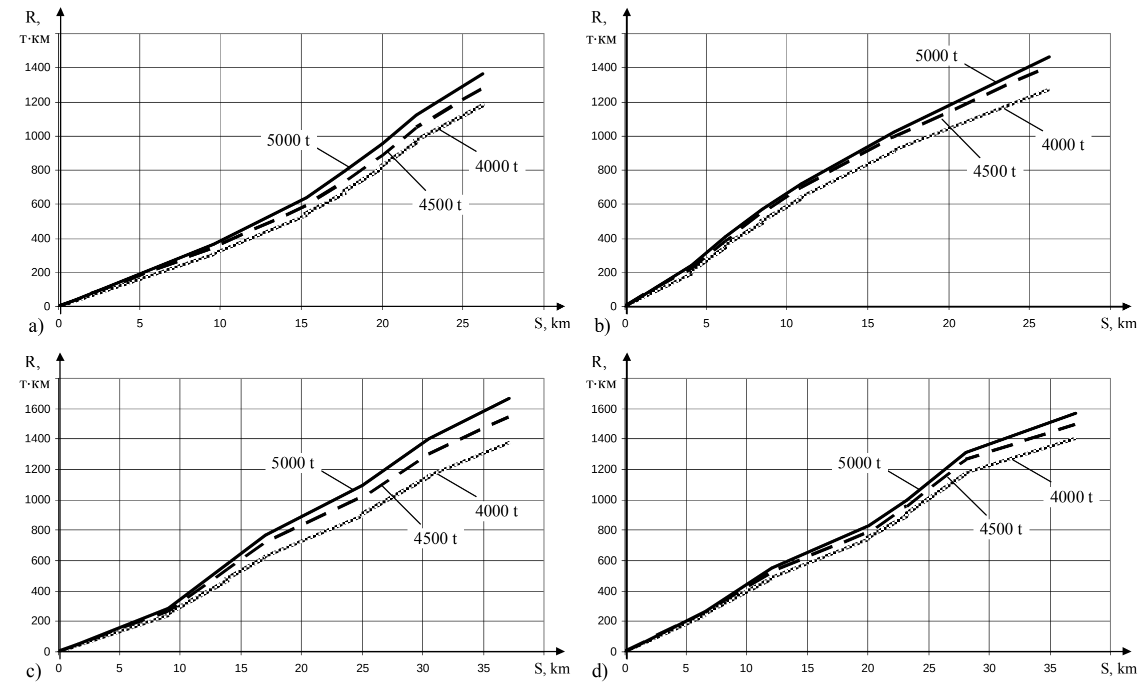

Fig. 3 – Dependence between mechanical work losses and the length of the railway line
a) even direction of the main line; b) odd direction of the main line;
c) even direction of the parallel line; d) odd direction of the parallel line

When simulating the operation of the railway line, a train is usually regarded as single unit, which means that the influence of the ahead and behind running trains is being ignored. In this occasion, the research should be made on a simulating model that allows simulating running the flow of the trains. The model of this type was used for researching the operation of the Dnepropetrovsk railway junction. The change in the indexes of the train running is shown on the fig. 4.

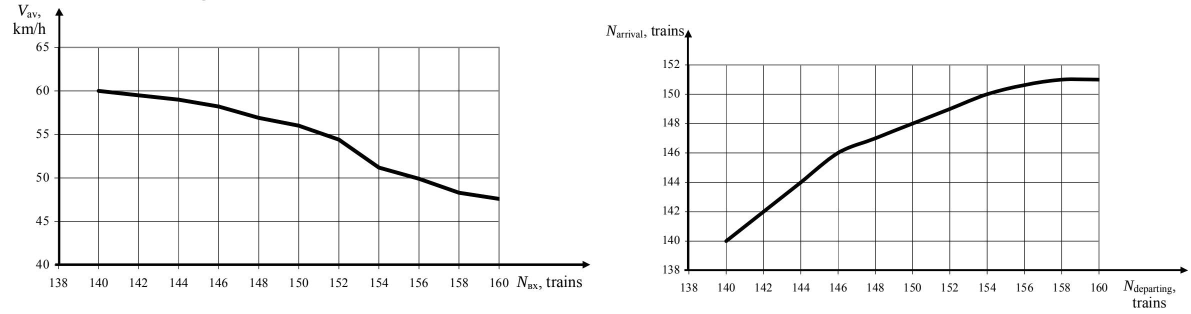

Fig. 4 – reaction of the railway line onto the increasing the arrival intensity
a) dependence between the average speed of the train running and the arrival intensity
b) interconnection between the arrival and departing intensity

A number of experiments were made with a help of this simulating model. The arrival intensity varied from 140 to 160 trains per 24 hours. The speed of the trains was executed with an accuracy 5 %, which allowed considering the so-called "human-factor". There was figured out that increasing the quantity of the trains in the arrival intensity causes the dramatic decrease of the speed of the running trains (fig. 4a). In addition, when the saturation point of the traffic capacity is reached, any further increasing the arrival intensity causes decreasing the quantity of departed trains (fig. 4b). This circumstance is caused by the following: the more trains are on the railway line the less is the distance between them, which causes that the trains face the yellow and red traffic lights more often.

The optimization part of the research concerns defining the necessary quantity of the trains, which provides minimum of the time running (*t*) and minimum of the mechanical work losses (*R*) simultaneously, under the conditions of the traffic capacity guaranty [10–11]. Taking into account that the indexes of the train operation depend on the level of the traffic capacity usage, it is necessary to analyze the tendency of their changes. In order to estimate the distribution of the trains on the lines of the railway junction is shown on the fig. 5.

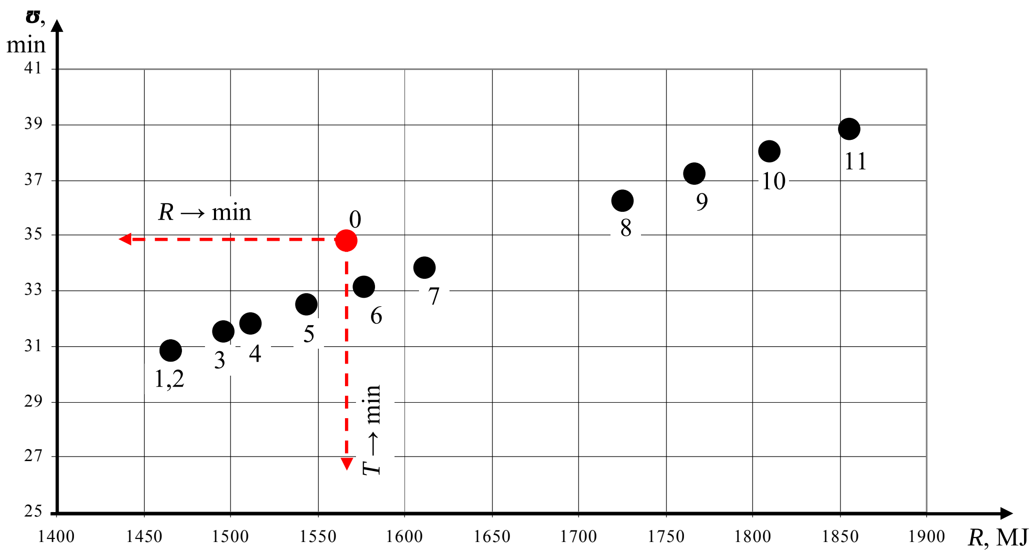

Fig. 5 – Comparative analysis of the train distribution in the railway junction

Each variant of the trains' distribution corresponds to its own parameters of time and mechanic work losses. Thus, variant 1 corresponds to 140 trains running on the main line in the odd direction; variant 2 – 142 trains and on. Variant "0" corresponds to appropriate time and work losses when directing the train in the odd direction of the parallel line. It is obvious that variants 6–11 are “worse” than variant “0”. That means if the quantity of the trains in the arrival stream is more than 148 trains per 24 hours, it becoming more rational to transfer part of the trains to the parallel line that has a reserve of the traffic capacity.

4. CONCLUSIONS/SUMMARY

There were determined the value of the time of running the trains and mechanic work losses of running the trains of the different mass in Dnepropetrovsk railway junction. The analysis of the obtained dependences shows that the time of the train running according to a schedule is overrated, especially on the parallel line of the railway junction.

There were determined the dependence between the cost of the train running and the length of the railway line in correspondence to the mass of the train. It was figured out that the cost of running the 5000 tonn train on odd direction of the main line has a little difference compared to the cost of running the 4000 tonn train on the parallel line.

There was researched the influence of the railway line load onto the main indexes of the train running. There was figured out that increasing the quantity of the trains in the arrival intensity causes the dramatic decrease of the speed of the running trains. That means it is important to define the rational quantity of the trains on each railway line; every extra train on the line causes an increase of the time and work losses. So, it is necessary to consider different variants of directing the trains in the railway junction when reaching the saturation point of the traffic capacity.

The value of the rational load of the main trespass of Dnepropetrovsk railway junction was determined. It equals 148 trains per 24 hours.

The results obtained in this research may be useful when choosing the route of directing the trainflow in the railway junction, railway direction or railway network on the whole at the time of the summer schedule, increasing the arrival intensity of the trains or at the time when one track of the railway direction is closed. In terms of the economic point of view the described method of distributing the trains in the railway junction will help to decrease maintenance costs connected with the transferring the trains on the routes of the railway network.

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