DISPATCHING OF CAR FLOWS: «MANAGEMENT BY OBJECTIVES»

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ABSTRACT

From automatic tracking of fulfillment of one of many variants of a plan for train formation, it is time to move on to a flexible operational system of its timely adjustment. The management of car flows should include two systems: long-term and operational. The long-term goal is to solve in advance issues related to direction and distribution of car flows, correspondence between the number of train assignments and loading of technical stations with possibilities of track development and processing ability. The operational system should react to changes in calculation standards and values of car flows, increase or decrease the technical capacity of structures, infrastructure devices and rolling stock, difficulties in operating work. The inclusion of dispatchers in organization of car flows will allow to optimize implementation of the plan for formation of trains.

Keywords: railway, organization of car flows, plan for formation of trains, dispatching management.

Background. *The process of organization of car flows suggests development of a plan for formation of trains and its implementation. All the attention of managers is concentrated, as a rule, on the first part of the process – development of a plan. The second part is provided as it were by itself and an automated system for monitoring the implementation of the plan. But the real situation is often very different from the normative conditions. This is one of the reasons for non-optimality of the implemented train formation plan and distribution of sorting work between the stations, which leads to a decrease in transit, an increase in the volume of processing of cars at stations, unreasonable delay in car flows, and underutilization of station facilities.*

Deviations of the current version of the train formation plan from the optimal one cause an increase in: the volume of processing of cars by 1,5–2 times, the time spent on processing and accumulation of trains – by 50 %, the number of assignments – 15–20 %.

Over 170 years of existence, the dispatch control has covered almost all issues of the operational work of the railways. The word «almost» is added not by chance. Because the dispatching management still does not cover a wide range of issues related to organization of car flows. In addition, the procedure for adjusting the train formation plan is very cumbersome, requires coordination with JSC Russian Railways, and in fact, there is no operational management of car flows.

Objective. *The objective of the author is to consider the issue of dispatching of car flows.*

Methods. *The author uses general scientific methods, comparative analysis, evaluation approach, statistical method, graph construction.*

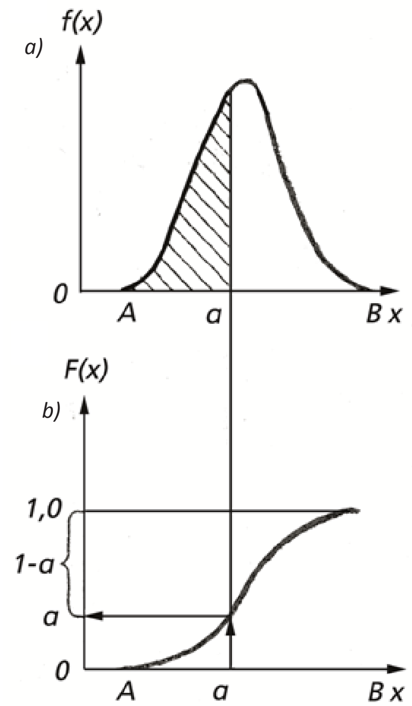
Results.

Deficiency of operational coordination

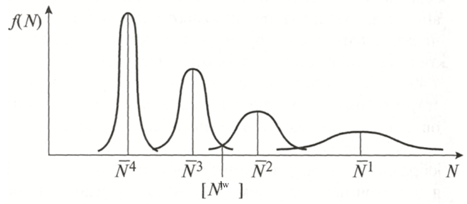
In the service area of a marshalling yard on most railways, the cargo stations do not periodically provide timely delivery of cars for cargo operations, but they do not have a dispatcher who could quickly disrupt the situation by temporarily introducing group trains with selection of cars at the marshalling yard.

During one of my business trips on the East Siberian railway there were ten «abandoned» trains assigned to the station Kitoy-Kombinatskaya. This station was not developed when there were many industrial enterprises around, and now they cannot always cope with the load. Analysis of the remains of unloaded cars at the end of the reporting day showed that all cars delivered with full terms for carrying out freight operations are timely unloaded. But the station does not have time to disband the arriving disassembling trains and deliver cars to three shunting areas. The instruction was given to Irkutsk-Sortirovochniy station to form three-group trains for Kitoy-Kombinatskaya station, and soon the «abandoned» trains were «raised» and unloaded, the situation returned to normal.

Modern automated control systems provide for modeling of the forthcoming process of accumulation of trains, this allows us to see in advance that, for example, 18 trains will be formed in 4 hours, and locomotives will be 17, locomotive crews – 16, «threads» of the traffic schedule – 20. In this case, the part of the formed trains will certainly remain unproductive in the park of departure while waiting for locomotives. While it is possible to temporarily introduce the formation of more distant assignments, and instead of unproductive idle time, the same cars could stand in the sorting park under the accumulation of trains, which will then further follow without processing by passing technical stations. But again there is no employee who has the right to promptly adjust the formation plan.



Pic. 1. Density (a) and function (b) of the normal distribution law.



Pic. 2. Graph of the distribution density of the car flow.

Often the sections and directions adjacent to the sorting station are oversaturated with trains, traffic slows down, the schedule is not executed. It is advisable to temporarily reduce the departure of trains to such points by adjusting the formation plan, but it is impossible to do it quickly today.

In all cases, the inability to promptly change the unfavorably developing operational situation is due to one reason – the lack of a dispatcher for organization of car flows, which by a temporary change in the formation plan could solve the issues that have arisen.

Only the appointment of a dispatcher for organization of car flows will not solve the problem. This dispatcher will be able to perform the duties assigned to him only by automating the collection and providing in advance the required information, as well as automating the algorithms for solving optimization problems.

The tasks that various dispatchers have to solve are closely related to each other and are aimed at a common end result – an uninterrupted transportation process. That is, the functions that are offered to the dispatcher in organization of car flows are interwoven with the duties of adjacent dispatchers.

For example, creation of conditions for implementation of the traffic schedule is associated with regulation of saturation of sections by trains, and the success of this regulation largely depends on management of the number of trains being formed at the stations. And it turns out that it is the imparting optimal conditions for train work that unites the efforts of the dispatchers: train, road and one that adapts the organization of car flows to the real situation.

The same picture is in another case. Reduction of idle time of cars at the sorting stations depends, among other things, on idle time of the formed trains in the departure park in anticipation of locomotives. It is possible to reduce downtime through formation of trains in an amount that is clearly designed for timely provision of locomotives. This is achieved by deliberate temporary cancellation of unnecessary existing assignments and introduction of more distant train assignments. The solution of this problem unites the efforts of already other dispatchers: station, shunting and organization of car flows.

In the context of many such tasks, in addition to the introduction of a dispatcher for organizing car flows, it is still necessary and correct to adjust the duties of adjacent dispatchers in order to more easily unite their efforts.

Fluctuations in car flows

If at any marshalling yard the moments of the completion of accumulation of trains within a day for several years are compared, then we will see that they never repeat. The accumulation time of trains of each assignment is in a very wide range. Fluctuations in the duration of processes in this case depend on many factors, primarily on the change in the average daily and hourly sizes of incoming car flows [1].

The formation plan, developed for a long time cannot provide for all situations in the sorting park, especially since they change every day and even during the shift.

The longer is the planning period, the greater is uncertainty of the sizes of car flows and duration of accumulation of trains. And on the other hand, we need a clear organization of car flows, a deterministic plan of formation.

What is the way out of this contradictory situation? More advanced dispatch control, development by equipotent dispatchers of methods of an estimation of casual situations on the basis of the normal law of distribution of car flows.

The distribution law establishes a connection between the possible values of a random variable (the size of the car flow) and the probabilities of their appearance. The normal distribution law helps to make optimal decisions (effective when assigning trains) in conditions of uncertainty (car flow fluctuations).

The normal law is based on distribution density (Pic. 1a) and distribution function (Pic. 1b).

The plot of the density of the distribution of the car flow x (Pic. 1a), being in the interval $A \le x \le B$, allows solving various problems. For example, it is possible to determine what is the probability that the random value of the car flow x will not be greater than the value that is beneficial for allocating the car flow a to an independent assignment: $P(x \le a)$. This probability is equal to the shaded area.

Knowing $P(x \le a)$, it is not difficult to establish the probability that the value of the car flow x will not be less than the value of the car flow a: $P(x \ge a)$. Obviously, $P(x \le a) + P(x \ge a) = 1$. Therefore, $P(x \ge a) = 1 - P(x \le a)$, which corresponds to the unshaded area in Pic. 1a.

It is also advisable to use another form of law – the distribution function F(x), the graph of which is shown in Pic. 1b and is related to the distribution density. The probability $P(x \le a)$, determined in Pic. 1a as the area of the curvilinear figure, in Pic. 1b is equal to the ordinate of the curve F(x). Therefore, $P(x \le a) = F(a)$, and hence $P(x \ge a) = 1 - F(a)$.

Depending on the ratio of the average daily value of the car flow $\bar{N}$ and the lowest value of the car flow $[N^{lw}]$ satisfying a sufficient condition, the flows can be divided into four categories (Pic. 2):

$\bar{N}_1 \gg \left[N^{\mathrm{lw}}\right]$ – fluctuations of the car flows do not affect the reduced ratio, since the design value of the car flow in terms of power is sufficiently high;

$\bar{N}_2 \geqslant \left[N^{\mathrm{lw}}\right]$ – stream of the car flow is allocated to an independent assignment, however, in connection with its fluctuations, this ratio can be violated in certain periods, and then allocation to an independent assignment is inexpedient;

$\bar{N}_3 < \left[N^{\mathrm{lw}}\right]$ – stream of the car flow is not allocated to an independent assignment, however, under the fluctuations, the above ratio can be periodically broken, and then its allocation into an independent assignment is expedient;

$\bar{N}_4 \left[N^{\mathrm{lw}}\right]$ – stream of the car flow is so small that even its increase to the maximum values under fluctuation does not allow to allocate the flow into an independent assignments.

Let us consider the influence of fluctuations in the sizes of the streams of the second and third categories of car flows on efficiency of allocation into an independent assignment. When solving the problem, it is necessary to know the distribution function *f (N)* (see Pic. 2).

To approximate the law of distribution of fluctuations in the sizes of car flows, statistical data were analyzed in the range from 20 to 500 cars per day. The analysis showed that the distribution of the average daily dimensions of the car flows obeys the normal law. From the graphs in Pic. 1 it follows that a change in the average daily value leads to a shift of the function *f*(N) along the abscissa axis.

Absolute dimensions of fluctuations are characterized by an average quadratic deviation σ(N) and increase with an increase in the average daily value of the car flow (Pic. 3). Using the rule of three sigma to determine the boundaries of the second and third categories of empty car flows, we get:

$$N_2 = \left[N^{\text{lw}} \right] + 3\sigma(N)\,; \tag{1}$$

$$N_3 = \left[N^{\text{lw}} \right] - 3\sigma(N)\,. \tag{2}$$

In general, the probability of allocating a car flow to an independent assignment can be determined by the formula

$$P(\left[N^{\text{lw}} \right] < \bar{N}_i < N^{\text{ht}}) =$$

$$= F\left(\frac{N^{\text{ht}} - \bar{N}_i}{\sigma(N)} \right) - F\left(\frac{N^{\text{lw}} - \bar{N}_i}{\sigma(N)} \right). \tag{3}$$

In accordance with (1) and (2), the last term in formula (3) is equal to F.

When the value of the car flow is equal to the minimum design size of the car flowstream, which is advantageously allocated to an independent assignment, the probability of efficiency of this assignment is 0,5.

Example: there are two streams of the car flow with average daily values $\bar{N}_1 = 75$ and $\bar{N}_2 = 85$. In accordance with the graph in Pic. 3, their mean square deviations σ(N_1) = 14,84 and σ(N_2) = 16,02.

Allocating to an independent assignment is beneficial if there are more than 80 cars in the stream. The first stream of the car flow belongs to the third category, the second one to the second category.

By the formula (3) we determine the probability of the purposefulness of allocation of the first stream of the car flow into an independent assignment

$$P_1(80 < \bar{N}_1 < N^{\text{ht}}) = 0{,}5 - F\left(\frac{80\ -75}{14{,}84} \right).$$

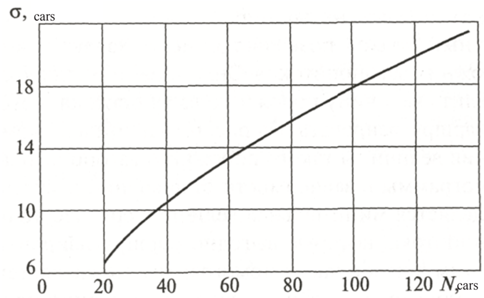
We find: F (0,336) = 0,13, then $P_1(\bar{N}_1) = 0{,}5 - 0{,}13 = 0{,}37$.

For the second stream of the car flow

$$P_2(80 < \bar{N}_2 < N^{\text{ht}}) = 0{,}5 - F\left(\frac{80\ -85}{16{,}02} \right).$$

We find: F (-0,3125) = -0,12, then $P_2(\bar{N}_2) = 0{,}5 + 0{,}12 = 0{,}62$.

Consequently, the first stream of the car flow is effective 135 days a year, although its allocation to an independent assignment by the current formation plan is not stipulated. At the same time, the second stream, whose allocation to an independent assignment is provided for in the formation plan, is ineffective 139 days a year.



Pic. 3. The graph of change in the mean square deviation, depending on the average daily car flow.

Uneven accumulation of trains

In the course of operative planning of the work of the stations, before the beginning of the process of accumulation of trains, it is necessary to predict the fluctuations in the car flow of assignment and the cost of accumulation. On the basis of prognosis to decide on the effectiveness of assignments.

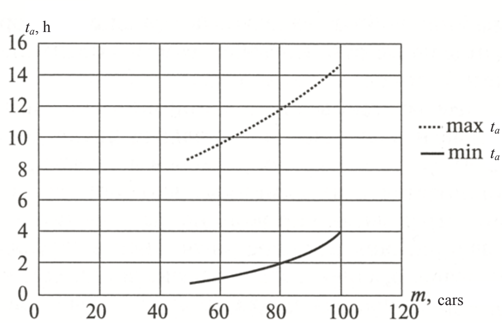
Modern ACS contain models of the accumulation process and, based on the approach of trains, allow estimating in advance the efficiency of accumulation of trains of various purposes. So, there are all prerequisites for the operational management of train formation.

Modeling of accumulation of trains of different norms of length and weight helps to estimate the change in the average, minimum and maximum length of train idle time [2].

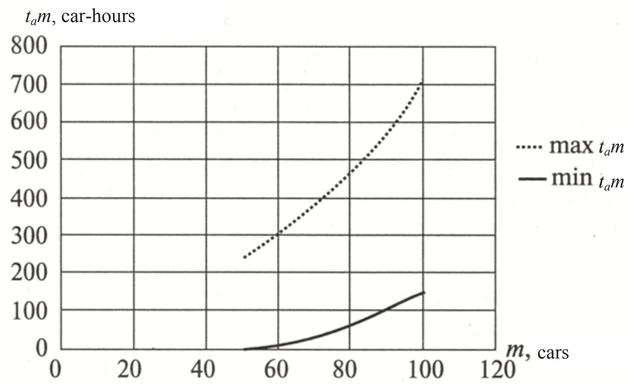
Distributions are obtained, graphs of the spread of the minimum and maximum values of time (Pic. 4) and the costs of car-hours (Pic. 5) on accumulation of trains are plotted.

It is established that the relationship between the length of time and the costs of car-hours accumulation of trains is not monotonic. For example, to accumulate one train of 70 cars it took 5 hours and 25 minutes at a cost of 173,7 car-hours, and for another of the same length and similar purpose – 3 hours 55 minutes and 196,5 car-hours. This suggests that you need to compare the savings and costs not in hours, but in car-hours.

A graphic representation of the accumulation process is a triangle in which the hypotenuse is not a straight line, but a concave or convex line (Pic. 6). This suggests that it is necessary to compare savings and costs not in hours, but in car-hours.



Pic. 4. Graph of dependence of minimum and maximum duration of accumulation of trains t_a on the length of trains m.



Pic. 5. Graph of the dependence of the minimum and maximum costs of the car-hours when accumulating the trains t_a on the length of the train m.

There are more questions than answers

Every day the real operational situation differs significantly from the normative requirements: the sizes of streams of car flows, the processing volumes at stations fluctuate, difficulties arise such as interruptions in movement of trains on sections («windows», failures, etc.), slowing of train traffic, non-provision of trains with locomotives, etc.

In order to make up for these changing conditions, the existing gap in the dispatch control of the operational work and to ensure the adaptability of the train formation plan, the dispatcher for organization of car flows is needed. Its main tasks should be:

– post-situation temporary cancellation of ineffective train assignments;

– prompt temporary introduction of effective assignments not included in the formation plan;

– redistribution of sorting work between stations, if necessary;

– introduction of formation of more distant train assignments in case of:

• lack of locomotives or locomotive crews;

• providing «windows», time intervals for repair and maintenance operations;

• train traffic interruptions;

• oversaturation of sections or directions by trains;

– regulation of saturation of areas (directions) by trains due to:

• temporary formation of more distant train assignments;

• deviations of car flows, including formation of trains of different weight and length;

• use of other regulatory means to preserve the effectiveness of train assignments;

– temporary introduction of group trains with a selection of cars to assist the freight stations.

Time deficit will not allow the dispatcher for organization of car flows to solve such a variety of tasks in the «manual mode». In addition, at the end of the shift, the dispatcher must justify all his decisions on adjusting the train formation plan. Therefore, for its effective operation and optimal organization of car trains it is necessary:

a) to classify all arising problems;

b) to develop methods of solution for each of them;

c) to automate the early collection of initial data;

d) to automate decision-making processes;

e) to automate the transfer of decisions to performers;

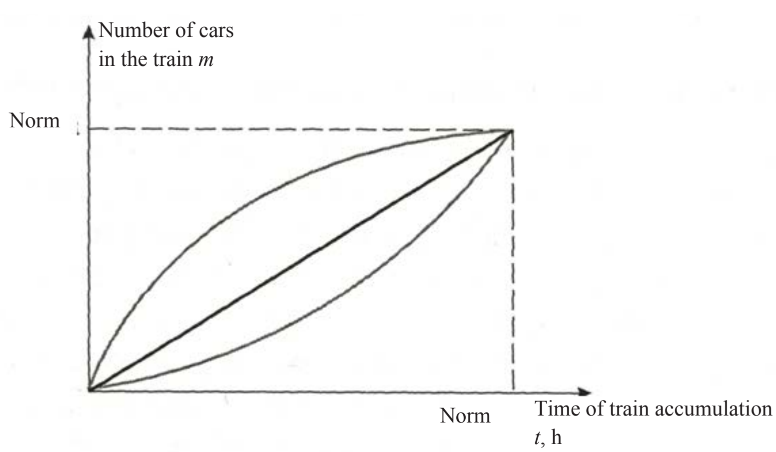
f) to automate the archive of justifications for the decisions made.

To obtain answers to questions that the dispatcher faces during organization of car flows, one should have models for accumulating trains, providing them with locomotives, loading marshalling yards, and saturating the sections (directions) with trains. At the same time, all questions can be combined into two conditional groups:

– what happens if ...?

– what is necessary to ...?

The operative adjustment of the train formation plan should be preceded by the forecast of deviations from the normative values of the design data, the sizes of car flows, the condition of the structures, infrastructure devices and rolling stock. Based on the forecast, the need is determined for adjusting the plan to adapt it to the actual operational situation. The type of operational adjustment is chosen and justified. The



Pic. 6. Graph of accumulation of trains.

Table 1

Causes and methods of the dispatching adjustment of the train formation plan

No.	Prediction of difficulties	Rapid adjustment of the plan	Expected result	Efficiency
1.	Exceeding the rate of downtime under accumulation	Temporary cancellation of inefficient use of trains	Realization of the optimal version of the formation plan	Reduction in idle time, acceleration of delivery
2.	Increase in the car stream, not included in the plan	Temporary introduction of efficient assignment of trains	Increase in the transit traffic of car flows	Reduction of processing on passing service stations, acceleration of cargo delivery
3.	Some of the trains are not provided with locomotives in the planned period.	Formation of additional long-distance train assignments	Temporary reduction of formed trains	Reduction in idle time in anticipation of locomotives
4.	Reduction in traffic in adjacent areas.	Formation of additional long-distance train assignments.	Adjustment of the number of trains to be formed and the possibilities of sending them	Reducing idle time in anticipation of departure
5.	The station does not ensure the timely processing of car flows	a) redistribution of car flows between train assignments; b) formation of routes from empty cars at nearby freight stations	Reducing the volume of processing at a station experiencing difficulties	Timely processing of cars at the station
6.	Thickening of unloading of cars in one of the periods of the day	Consideration of expediency of routing in the period of thickened unloading	Increase in the level of routing of empty car flows	Increase in transit speed, acceleration of turnover
7.	Oversaturation of sections by trains, maintenance intervals, failures	Temporary introduction of more distant train assignments	Increase in transit traffic of car flows	Lowering the loading of sections
8.	Cargo station does not provide timely delivery of cars to freight fronts	Temporary assignment of group trains with a selection of cars	Reduction of shunting work at the freight station	Reduction in the idle time of cars, increase in loading and unloading

expected result and the planned effect are called (Table 1).

Dispatcher in online mode

As movement of trains on the sections is controlled by train dispatchers, and the dispatchers must also manage the operational organization of car flows. And they should be in the staff of not of the marshalling yard, but of the road dispatching transportation control center (DTCC). This will avoid misuse of the operative adjustment of the formation plan on the part of the stations and will enable the situational management of train formation.

The actual accumulation time is a variable quantity that depends not only on the fluctuations of the car flow, the assignment being considered, but also on the change in the reduced saving when the car flow is handled without processing at the station and the actual length of the train.

Comparison of normative and actual time spent on accumulation of trains on the basis of the approach of trains will allow the dispatcher to see the change in the sizes of car flows in advance and, even before the cars arrive at the station, make a decision on adjusting the formation plan.

The need for redistribution of sorting work between technical stations occurs when the intensity of the supply of trains and the possibility of their processing at the station do not match. And this discrepancy may arise both because of the change in the intensity of the supply of trains to the station, and the processing capacity (changes in the number of sorting tracks, untimely export of trains from the station, repair work on the hump, etc.). The proposed method of load redistribution reduces the volume of processing of cars at one of the stations, but does not cause it to increase by the same amount at other stations. As a rule, this is accompanied by a decrease in the total volume of processing.

Sorting work is redistributed due to allocation of streams of car flows to additional further assignments than provided for by the formation plan, or redistribution of cars between train assignments. The formation of additional, more distant train assignments is advisable, both in the case of an increase in car flow (N), which provides for an excess of savings from passing trains without processing at associated technological stations (T_{sav}) over the costs of accumulating trains (tr) and increasing T_{sav} due to the increased volume of processing and a reduction in the cost of accumulation of trains with a thickened supply of cars. Changes in the power of streams of car flows or specifications of the formation plan are sufficient grounds for allocating additional assignments when $NT_{sav} \geq tr$.

The change in the loading of marshalling yards due to redistribution of cars between the assignments of trains is based on the fact that streams of car flows allocated for independent assignments often exceed considerably the minimum for this purpose. At the same time, the shorter streams adjacent to them, for the expediency of allocating them into separate assignments, lack a small number of cars. Therefore, they are combined with even shorter streams, and the car flows are further processed at passing technical stations. If it is necessary to reduce the load of passing technical stations, the transit of trains can be increased by redistributing cars between adjacent streams due to some disaggregation of more distant assignments for replenishment of short streams.

In general, the expediency of allocating streams of car flows into separate assignments, replenished by a further stream that meets a sufficient condition, is determined by inequality

$$\sum_{i=1}^{n}\sum_{j=1}^{l} N_i T_{\text{sav j}} - \sum_{i=1}^{n}\sum_{j=1}^{l} N_i^{\text{lack}} T_{\text{sav j}} >$$
$$> \left[(k-1) + \frac{N_S - \sum_{i=1}^{n} N_i^{\text{lack}}}{N_S} \right] tr, \qquad (4)$$

where N_S – car flow stream, satisfying a sufficient condition; N_i – size of a stream i, replenished by cars of assignment N_S; T_{savj} – received or eliminated reduced saving of car-hours when passing the car flow i without processing at the station; N_i^{lack} – lack of cars in the stream i to fulfill a sufficient condition; k – number of additional train assignments.

For replenishment, streams of car flows, initially satisfying a sufficient condition, can be used, but in which excess cars are less than a defect in an adjacent stream.

Automation of planning of train formation allows to simulate the process of accumulation of trains for 8 hours, and in the future up to 24–30 hours ahead, i.e. even before the cars arrive at the station. The forecast of organization of cars under the current formation plan in conjunction with the train schedule provides an opportunity not only to timely implement regulatory measures to provide trains with locomotives, crews, but also to reveal in advance when at what point after the implementation of these measures not all trains may again be in short supply with locomotives or without real «threads» of the traffic schedule. In this case, in order to adjust the number of trains, locomotives, crews and «threads» for the planned period, operational control of organization of car flows will again be required.

It is possible to temporarily reduce the number of trains to be formed by introducing additional more distant train assignments. When drawing up a train formation plan for a year, these assignments were not allocated, because they are ineffective:

$NT_{sav} < tr$,

where N – average daily car flow rate; T_{sav} – total time savings, reduced per car, while handling the flow N without processing at the station; tr – expenses for accumulation of trains.

But in operational conditions with sufficiently long idle trains awaiting departure, the possibility of its reduction can so increase the saving of the reduced car-hours, which will exceed the costs:

$$NT_{sav} + m'\Delta T^{a}_{sav} + \frac{\Delta t_l e_{MN} + \Delta t_{cr} e_{Mh}}{e_{nH}} \geq tr, \qquad (5)$$

where m¢ – number of cars, the idle time of which will be reduced at the station in anticipation of departure; T^a_{sav} – time by which idle time of a car is reduced; Δt_l, Δt_{cr} – reduction in idle time, respectively, of locomotives and locomotive crews; e_{MN}, e_{Mh}, e_{nH} – present value rates of 1 locomotive-hour, 1 crew-hour, 1 car-hour.

When this condition is met, the operative adjustment of the formation plan and the temporary introduction of an additional, more distant assignment are justified.

The methods of temporary reduction of the number of formed trains due to the introduction of additional more distant train assignments are advisable to be applied when over-graphical warnings about speed limitation, «break-in» after major overhaul of the track or «window» significantly reduce the size of train traffic on adjacent sections. Currently, in the instructions for provision of a «window» for repair and construction work, the «threads» of traffic schedule are listed, along which movement of trains is canceled. Such trains are not sent to the section, but no one cancels their formation, and they are idle in the departure park in anticipation of the end of the «window». For this period it is worthwhile to think about the possibility of forming trains for more distant assignments than foreseen by the plan. If elimination of idle time of trains in anticipation of the end of the «window» will ensure that the saving of the reduced car-hours exceeds costs by condition (5), then there is no reason to refuse such decisions.

Conclusions.

1. Fluctuations in the streams of car flows on average by 50–70 %, maximally up to 500 % of the average daily values, cause a wide variation in accumulation time of trains and loading of the sorting stations.

2. The accepted train formation plan is one of the many options for organization of car flows, which, due to fluctuations in the dimensions of their streams, often does not correspond to actual operational work.

3. For continuous adjustment to the optimal state and implementation of the train formation plan, it is proposed to introduce a dispatcher for organization of car flows into the staff of the road dispatch transportation control center.

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