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Train Formation Management. Part 1

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ABSTRACT

Long-term regulatory and technological documents related to train formation are often so far from the changing actual operational situation that more trains are being formed than can be provided with locomotives and sent from the station in a timely manner, sections are oversaturated with trains, stations operate with an excess of car fleet, etc. Such unpredictable situations result in unproductive delays of trains, increase the goods delivery time, reduce the use of transit, transportation, and processing capacity of railways. At the same time, reducing the time of validity of regulatory and technological documents can significantly increase the efficiency of operational management of the transportation process. The purpose of the article is to show how the operational management of train formation instead of the passive uncontrolled process of accumulation of trains at marshalling yards expands the possibilities of the train formation plan, eliminates uncertainty and creates optimal conditions for train, marshalling and freight operations.

Changes in management of train formation, which are put forward on the basis of generalisation of a number of results of earlier author's studies and publications and newly formulated proposals for discussion, will make it possible to manage the transportation process in a fundamentally new way: to form such a number of trains that will be provided in a timely manner with locomotives and «threads» of the train schedule; send such a number of trains from the train assembling stations that will not lead to oversaturation of sections with trains; to ensure the arrival of such a number of trains at marshalling yards that will allow them to work in the optimal mode; to ensure the parity of arrivals of even and odd trains at locomotive change stations; to help in a timely manner with the selection of wagons cars in case of difficulties in the work of freight stations, etc. [1].

Keywords: *railway, train formation management, regulatory and technological documents, unproductive losses, optimal operative conditions, operational management of the transportation process.*

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INTRODUCTION

Analysis of the Current Conditions

In the context of widespread digitalisation, a process approach is being actively introduced on railways, which makes it possible to optimise the transportation process and increase the efficiency of the management system [2–4]. The train formation management technology considered in the article is one of the directions for the effective use of new technical means and software for the implementation process model of the transportation process.

The even parity and non-compliance of incoming groups of car flows with the norms of the length and weight of trains necessitate accumulation of cars to assemble a train. The duration of train formation depends on the number of cars assigned to go to a destination and the size of the assembled trains. The time spent on assembling of trains when calculating the plan for formation of trains determines the efficiency of separating a car flow into an independent assignment [5–6].

The duration of formation of trains is a significant part of the total time spent by transiting cars at marshalling and precinct stations. With the timely processing of car flows at technical stations (optimal operation), the demurrage of cars under accumulation accounts for more than 50 % of the time they are at the station. Under modern conditions, when inter-operational downtime in the total time spent by processed transit cars at the station is up to 40 %, the downtime of accumulated cars also accounts for about 40 % [7].

Such statistics testify to the great influence of idle cars under accumulation on respect of cargo delivery time and the efficiency of marshalling yards. This determines the great practical importance of the need for further optimisation of the accumulation process [6].

To accelerate the accumulation of wagons, the following measures were proposed: ensuring the priority of disassembling of trains with cars that complete the formation of trains; coordination of the supply of large groups of cars to the destinations stipulated by the plan of train formation; scheduling of loading of non-routable cargoes by enlarged groups; completion of cargo operations and inclusion of cars into the trains being assembled; acceleration of the transfer of cars from one sorting system to another (at two-way marshalling yards). But the effectiveness of these measures was small.

The process of accumulation of wagons for train formation is of a stochastic nature, i.e., the moments of completion of the accumulation never repeat, and the train schedule is deterministic. As a result of this contradiction, the assembled trains in the departure parks of stations first stand idle for an average of 2 hours waiting for train locomotives, and then for almost 2 more hours waiting for departure from the station. Passive flow of probabilistic processes of formation of trains inevitably provokes inconsistency with other processes. For example, more trains are assembled than the capacity of adjacent sections and routes, there are oversaturation of sections and train congestion. More trains are sent to destination stations than the processing capacity of those stations allows. There is an excess of rolling stock, causing inter-operational downtime [6].

As previously highlighted. flexible operational system is needed for timely adjustment of the formation plan, which would respond to fluctuations in the size of car flows, possibility of providing assembled trains with locomotives and crews, removal of trains from stations, the need to redistribute marshalling work between stations, etc. In this situation, an automated system for monitoring the strict implementation of the formation plan is an anachronism. Thus, the passive, uncontrolled process of accumulation of trains causes a large number of negative consequences and unjustified costs [6].

Foreign Practices of Train Formation [8]

Train specialisation methods are being developed in Europe and the USA. Much attention is paid to the accounting of car flows. In different countries, most experts have come to the conclusion that train specialisation schemes should be based on reporting data on the structure of car flows for past periods. This is illustrated by some facts from recent railway history.

For example, historically, in the UK, car flows were audited 2–4 times a year for one week during the season, while traffic volume and schedule compliance statistics are currently compiled quarterly or every four weeks. A similar accounting is conducted in the USA.

The accounting of car flows in Germany was especially carefully organised and carried out according to two positions:

1. At large marshalling yards processing more than 2 000 cars per day, car flows are recorded monthly during a week, according to the appointments of the specialisation plan, as well as to allocated groups.

2. For each of 152 designated marshalling yards, car flows between the «local area» of this

station and the «destination areas» of the remaining 151 stations are considered. As a result, a «chessboard» of laden car flows between selected marshalling yards is formed.

Specialisation schemes provided for the use of reporting data on car flows: in the USA – below average with the appointment of additional trains with an increase in car flows; in the UK – for medium car flows; in Germany also for medium car flows while distinguishing «main» trains for the minimum car flows. France practices singled out «permanent» trains for below-average flows, with inclusion of «optional» trains as flows increase.

Specialisation schemes are determined empirically based on the experience of previous years. There are no railway-wide or even network calculations of train specialisation. However, prior to the introduction of a specialisation scheme, it is reviewed in detail at the level of the railway management.

At the same time, there are some provisions that are the basis for choosing specialisation schemes. Here, for example, are the provisions that have been developed for use on the road by the American Association of Railroad Engineers:

1. To ensure the selection and allocation of cars of the same destination as early as possible into groups for the further transit of such groups through passing marshalling yards (principle of «pre-marshalling»).

2. Sorting of all loaded and own railway's cars in accordance with the specialisation plan.

3. Organisation of inspection and repair of cars prior to their marshalling and adding to the train to avoid uncoupling along the route (technical and commercial inspection of cars in the arrival parks of marshalling yards).

4. Strict control over compliance with the train specialisation plan, assignment of a special agent for this purpose.

The principle of «pre-sorting» was given special importance. Enlargement of wagon groups at the initial stages, undoubtedly, facilitates the work of passing marshalling yards, especially those without humps.

The principle of concentration of sorting work has been developed. It is recognised that operation of a small number of large marshalling yards is less expensive than operation of many small marshalling yards. The unification of car flows that occurs due to that contributes to an increase in the number of single-group trains assembled for long distance routes. Therefore, the construction of the largest marshalling yards is underway [8].

Many scientific and research works (for example, [9–11]) are devoted to the issues of train formation planning and operation of marshalling yards in modern conditions, while separate study should be devoted to the analysis of those papers and works.

Problem Statement: How to Change the Situation?

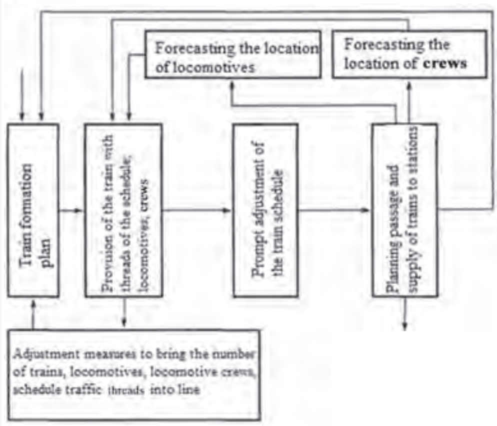
Planning of train formation and of transit of trains through sections are two key tasks for operational management of train operations on railways (Pic. 1). The output of each of these tasks is the input to another task. The joint iterative solution of these problems significantly expands the time frame for operational planning of train work [12].

It is expedient to begin unraveling this «tangle» by increasing the depth of formation. And what depth of composition formation should be, and how is it determined?

With the so-called «no-call» system of attendance of locomotive crews, common on the railway network, up to 25 % of them come to work when there are no assembled trains at the stations and, conversely, there are no locomotive crews for the already formed trains in a timely manner. This is explained by the fact that the schedule for arrival of locomotive crews to workplaces is drawn up for 1 month. The contractor of the locomotive depot plans the departure of locomotive crews according to the turnout schedule on average 1 day before, when there is no plan for formation yet [1; 12; 13].

The need to increase the depth of train formation planning is necessary for shift-daily planning of train work. In the absence of the necessary depth of planning of train formation, the sizes of train traffic through sections are expertly determined, on the basis of which locomotive depots are given tasks for the next day to maintain the operated fleet of locomotives; neighbouring roads are informed of the planned exchange of trains at junction points, and duty teams are given the task regarding transit and transfer of trains. In connection with unreliable initial information, unjustified additional costs arise [6].

To solve these and many other issues, a formation planning depth of 24–30 hours is required. The use of automated control systems for operational organisation of car flows was indicated in [14]: «In connection with development and implementation of automated control systems, an opinion appeared



Pic. 1. Flowchart of the technological process for operational management of train work [compiled by the author].

that the formation plan should not be stable, but flexible and adjusted depending on the current operational situation with car flows. It is proposed to carry out such adjustments not only for a day, but even for a specific situation within a day».

Unfortunately, for implementation of a reasonable proposal for operational organisation of car flows then there were no necessary opportunities. They still do not exist today, so it is necessary to develop automated systems. The technical means necessary for that should indicate in a reliable manner approach of trains informing on the destination of the cars, the depth of formation for at least 24–30 hours, and the possibility of early (before the cars arrive at the station) simulation of formation of trains for various purposes.

Early modelling of train formation will make it possible:

• To create a train formation management system.

• To identify promptly train assignments that require temporary cancellation.

• To identify timely train assignments that are not included in the formation plan, while it is advisable to temporarily assign them.

• To regulate timely provision of trains with locomotives and locomotive crews and, in case of their shortage, provide for formation of later trains.

• To provide timely trains with the «threads» of the schedule.

• To regulate the loading of marshalling yards and, if necessary, to redistribute marshalling work.

• To regulate the saturation of sections with trains and, if necessary, introduce the formation of later trains.

• When providing time intervals and other breaks in movement of trains, to proceed with formation of later trains.

• To distribute train flows along branched sections of the network and, if necessary, to form trains of a different weight and length.

• To use adjustment measures to maintain the efficiency of train destination assignments (with a decrease in car flow).

• To introduce temporally group trains with a collection of cars to assist cargo stations [15].

RESULTS

Let's consider the stages of achieving planning train formation for the period of 24–30 hours. With «manual» planning of train formation, a shunting dispatcher achieved a depth of 3–4 hours, which often did not allow timely provision of trains with locomotives. In the early 1980s, with the help of the automated control system of the marshalling yard (ACSMY), it became possible to obtain the «Station Operation Plan», which issued a train formation plan for next 6–8 hours. The unreliability of the machine forecast of the approach of trains to the station distorted the planning of train formation. Deviations of the actual arrival of trains, for example, at Orekhovo-Zuevo station, from the machine forecast ranged from -2 to +8 hours. The machine forecast, based on the norms for the time of train travel in sections and downtime at stations, did not provide reliability of the forecast for arrival of trains. It became obvious that participation of the train dispatcher in planning the supply of trains to the station was necessary. In the early 2000s, the traffic control centre of Moscow Railway organised transfer of information from ACSMY of Orekhovo-Zuevo station to the automated workplace (AWS) of train, locomotive and railway dispatchers. But before adding tasks to the train dispatcher, he was freed from manually filling out the appendix to the executed traffic schedule, automating this process. This measure freed up more than 20 % of the train dispatcher's time. To get a train formation plan for next 8 hours, it turned out to be enough to plan the approach of trains for next 1–1,5 hours [13].

To increase the planning depth of train formation for more than 8 hours, it is necessary to increase the time of forecasting of the approach of trains. Practice has shown that in this way it is possible to bring the depth of formation planning to 15 hours. Moreover, with an increase in duration of the train approach forecast, reliability of the train formation plan decreases. Therefore, to obtain a formation planning depth of more than 15 hours, it is necessary to switch from performing calculations for individual marshalling yards to performing complex calculations for marshalling yards of a railway or network's region in the Information and Computing Centres of railways. Then the calculations will be performed in two stages. At the first stage, the calculations are performed in the same way as before, separately for each marshalling yard. The formation plan at marshalling yards is nothing more than a distant approach to other marshalling yards. If, at the second stage, we continue modelling the accumulation process based on a long-range approach, then we can bring the depth of train formation planning to 24–30 hours.

Such a depth will allow, even before arrival of cars at the station, to simulate the process of accumulating trins of all possible destinations, which will allow optimising the number of assembled trains, in accordance with fluctuations in the size of car flows, to timely provide them with train locomotives, «threads» of the traffic schedule, to create optimal operating modes for sections, marshalling and cargo stations.

By the end of 2021, at 56 marshalling yards, it was planned to put into operation modules for planning and monitoring the execution in the framework of a digital railway station [16]. Within the framework of this software package, operational management of train formation can be implemented.

The operational management of train formation significantly expands the functions of the train formation plan and will allow the dispatching team, instead of recording past and ongoing events, to manage the upcoming operational work (Pic. 2).

Reducing the term of the formation plan will make it possible to manage train formation and expand the scope of organisation of car flows (to increase the number of tasks to be solved). The formation plan will not be limited only to assign the trains being formed for destination stations but will be able to provide «threads» of the train schedule, regulate the loading of sections and stations, and become the initial information for regulating the locomotive fleet and the use of locomotive crews. The elements and gravity flow of train traffic will be replaced by an optimally controlled transportation process.

Modern real-time information is not enough for management (Pic. 2). The dispatching staff with its help can only record and analyse events. This shows that real-time information for management is not enough. There is no object to control – there is nothing to control. Upcoming events can become such a subject for management. Therefore, to increase the efficiency of train dispatchers, they must be positioned several hours ahead of the events. Simply put, so that they have a «subject» for control. That is why movement of cargo trains occurs under conditions of uncertainty, when a cargo train departs from the initial station according to the schedule, and it will arrive at the final station of the section in a certain time range [17]. As L. M. Kaganovich, People's Commissar of Railways, frankly expressed at one of the meetings back in 1935: «*... schedules and timetables exist only on paper, but in reality trains run according to the* «*law of gravity*» [18]. This is true even today. That is why the actual time of arrival of trains at marshalling yards differs significantly from the computer forecast made according to schedule standards.

Provision of Trains with Locomotives

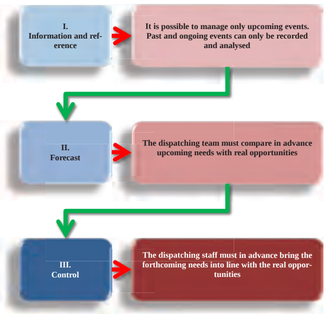
Train formation management will be the basis for effective regulation of the locomotive fleet. When regulating the locomotive fleet, it is advisable to use optimisation criteria: «reserve» mileage of locomotives (when it runs separately, without the train), their overrun between scheduled types of repairs, timely assignment of locomotives intended for maintenance and repair, downtime of trains ready for departure, reduction in the volume of car processing at the station and untimely arrival of trains.

The objective function can be minimisation of downtime of trains at local stations waiting for departure, «reserve» mileage of locomotives, downtime of locomotives at stations waiting for trains. It is possible to consider the irreducible availability of locomotives at technical stations and the limitations on the operating fleet of locomotives [13].

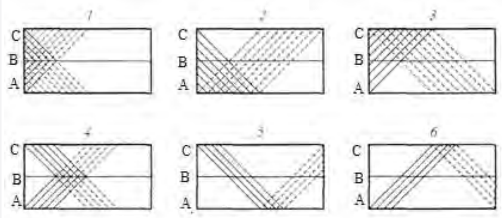
1. The initial data are:

a) Normative schedules for movement of trains within the sections or a plan of train traffic, the norms for the time of turnover (stay) of locomotives at stations, the technological time from the formation of the train to departure from the station.

b) A plan of delivery of locomotives for various types of maintenance, current and overhaul (based on the task or norms of overhaul periods and runs), the standard time for its implementation and the plan for completion of repairs and maintenance.



Pic. 2. Stages of development of dispatch control [compiled by the author].



Pic. 3. The sequence of integration of trains into the «threads» of the schedule at the stations of the locomotive section [compiled by the author].

c) Location of trains, trains, locomotives on hauls, at stations and depots at the initial moment of planning.

d) Plan of train formation at the stations of the locomotive section [12].

2. In accordance with the plan of train formation, arrival and departure of trains is balanced at all stations of the locomotive section for the planned period (day, shift, any period of time for which the initial information is available) (Table 1).

3. The moments of completion of the formation of trains (t_{acc}) at stations, taking into account the technological standard for preparing the train for departure (t_t), are integrated into the nearest «thread» of the traffic schedule (t_p) from the condition:

$$t_p \ge t_{acc} + t_t. \quad (1)$$

Integration starts from the stations with the smallest number of formed trains and further as the number of formed trains at the stations increases. In the example from Table 1 the sequence looks like this: station *B*, station *A*, station *C* (Pic. 3).

4. According to the completed «threads» of the traffic schedule, into which the train is integrated, transit of trains and arrival of locomotives at the station are preliminarily planned.

5. Locomotives scheduled for arrival are integrated into the «threads» of the traffic schedule, according to which the trains are scheduled to depart, from the condition:

$$t_p \ge t_{post} + t_n, \quad (2)$$

where t_{post} – time of arrival of the locomotive at the station or exit from repair;

t_n – technological turnaround time (staying) of the locomotive at the station.

The integration of locomotives into the «threads» of the traffic schedule begins with stations that have an excess of locomotives, then those that have a shortage of them in accordance with Table. 1. If there are several such stations, then the priority is established for the station with the smallest departure sizes to the station with the maximum departure sizes, i.e., integration order for the case under consideration: station *A*, station *B*, station *C*.

6. At stations with an excess of locomotives, before making a decision on integration of a locomotive into the «thread» of the traffic schedule, the expediency of its staying as reserved one is considered:

a) if all subsequent locomotives satisfy condition (1), then it is planned to assign the locomotive to be in reserve;

b) if condition (2) is not met for one or more locomotives, then the trains scheduled for them are reintegrated into later «threads» of the traffic schedule. If in this case condition (2) is satisfied, then reduction in locomotive-hours causes additional costs of car-hours (Table 2). Therefore, it is necessary to perform technical and economic calculations:

$$\sum N(t'_p - t_p)e_{c-h} \le \sum L\Delta t_{loc}(e_{l-h} + e_{br-h}), \quad (3)$$

where N – the number of cars in the trains that are reintegrated into other «threads» of the traffic schedule;

L – the number of locomotives for which the downtime while waiting for departure is reduced;

$t'_p - t_p$ – additional idle time of cars due to re-assignment of the train to a later «thread» of the traffic schedule;

Δt_{loc} – reduction of the locomotive stay at the station due to reintegration into an earlier «thread» of the traffic schedule;

e_{c-h}, e_{l-h}, e_{br-h} – expenditure rates for the cost of car-hour, locomotive-hour and crew-hour, respectively [12].

Table 2 shows the results of an example of integration and re-integration of trains, schedule threads, and locomotives. It should be considered that additional car-hour expenditures arise only for those trains that are overstacked, and locomotive-hour savings arise when locomotives

Table 1

Balance table of arrival and departure of trains at the stations of the locomotive section [compiled by the author]

Arr.		Station A		Station B		Station C		Total	Adjustment gap
		Dep.	Arr.	Dep.	Arr.	Dep.			
Station A	Arr.	–	–	6	–	45	–	51	+11
	Dep.	–	–	—	8		54	62	
Station B	Arr.	8	–	–	–	9		17	-5
	Dep.	–	6	–	–	–	6	12	
Station C	Arr.	54	–	6	–	–	–	60	-6
	Dep.	–	45	–	9	–	–	54	

Table 2

The results of integration of trains, «threads» of the traffic schedule and locomotives [compiled by the author]

Train formation plan	«Threads» of the traffic schedule		Arrival of locomotives		Expenditures of train-hours		Expenditures of locomotive-hours	
	Initially	After re-integration	Initially	After re-integration	Initially	After re-integration	Initially	After re-integration
8:46	9:54	9:54	7:35	7:54	1,133	1,133	2,333	2,000
9:19	10:18	10:18	7:54	8:09	1,000	1,000	2,400	2,150
9:54	10:58	10:58	8:09	8:31	1,067	1,067	2,812	2,450
10:37	11:40	11:40	8:31	8:58	1,050	1,050	3,150	2,700
11:08	12:18	12:18	8:58	9:35	1,167	1,167	3,333	2,717
11:26	12:32	12:32	9:35	9:56	1,100	1,100	2,950	2,600
11:49	12:51	13:39	9:56	11:18	1,033	1,667	2,933	2,183
12:37	13:47	14:04	11:18	11:35	1,167	1,450	2,483	2,483
13:09	14:19	14:36	11:35	11:57	1,167	1,450	2,733	2,650
Amount					9,884	11,084	25,127	21,933

are assigned to be in reserve and apply to all subsequent locomotives until the end of the planning period. Therefore, the fragment of the example given in Table 2, fully reflects the expenditures of car-hours, and to obtain the entire savings of locomotive-hours, it is necessary to continue Table 2 till the end of the planning period.

c) if conditions (2) and (3) are not met, the locomotive is planned for the train and integrated into the «thread» of the traffic schedule.

7. At stations where the number of departing trains is greater than arrival of locomotives with trains, but the number of locomotives assigned to be in reserve and going through the station exceeds their shortage, the above method is used. If it is necessary to change the linkage of trains to the «threads» of the traffic schedule (to reduce the expenditures of locomotive-hours), condition (3) must additionally take into account all changes that will occur not only at one station under consideration.

8. After completing paragraphs 5 and 6, in order to reduce the expenditures of locomotives, it is advisable to consider the effectiveness of the later (timely) arrival of locomotives in reserve, due to the earlier departure, which had to be reattached to some of the trains of later «threads» of the traffic schedule:

$$\sum_{st.B} L \bullet \Delta t_{loc} \left(e_{l-h} + e_{br-h}\right) + \\ + \sum_{st.A} N\left(\mathrm{t'_p} - \mathrm{t_p}\right) \bullet e_{c-h} \geq \sum_{st.A} N\left(\mathrm{t'_p} - \mathrm{t_p}\right) \bullet e_{c-h}.$$

9. At stations with a lack of locomotives, the possibility of attachment is determined by condition (2). If condition (2) is not met, then the expediency of re-integration of the trains into later «threads» of the traffic schedule is considered, or, according to condition (2), the integration of the locomotive into the next «thread» with the attached train is checked, and the missed «thread» of the traffic schedule remains for the locomotive, which will come as a reserve.

10. After the completion of the integration of trains, «threads» of the traffic schedule and locomotives at all stations of the section, the possibilities of reducing the expenditures of train-hour and locomotive-hour due to re-integration are considered [17].

The final part of the article will be published in the next issue of the journal

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Editorial note: The review article by professor, D.Sc. (Eng) Dmitry Levin is the author's generalisation presenting also a new understanding of the earlier works of the scientist. Given the author's expertise in developing the topic of railway operation, including that reflected in numerous publications, the work, in our opinion, is of great interest and practical value, especially that with the rapidly growing volumes of railway transportation, the problem of managing train formation is more than relevant.