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Train Formation Management. Part 2

Dmitry Yu. Levin
JSC NIIAS, Moscow, Russia.
✉ *levindu@yandex.ru.*

Dmitry Yu. LEVIN

ABSTRACT

The publication in this issue is the second, final part of the article that shares the vision of the approaches to creation of optimal conditions of train operation, control the load of marshalling stations, their interaction with freight stations, redistribution of cargo operations, and suggests final conclusions. As it was noted in the abstract of the first part, changes in management of train formation, which are put forward based on generalisation of a number of results of earlier author's studies and publications (the vast of majority of them have not been published in English) and newly formulated proposals for discussion, will make it possible to manage the transportation process in a fundamentally new way.

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

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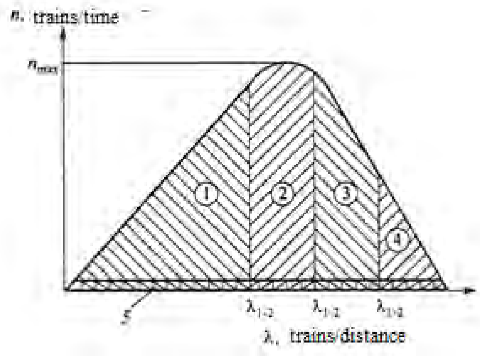
The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

Creating Optimal Conditions for Train Operation

Train formation management provides for creation of the conditions necessary to respect the traffic schedule, which include assessing saturation of sections with trains, predicting the approach of trains, solving the problem of regulating the saturation of a section with trains, developing measures to prevent and eliminate congestion in train traffic.

Modelling the train formation plan, it becomes possible to consider the saturation of sections with trains, depending on the mode of train operation (Pic. 4)[1].



Pic. 4. Train operation modes: 1 – normal, 2 – optimal, 3 – complicated, 4 – hard, 5 – emergency [compiled by the author].

The normal mode of train operation (Pic. 4, area 1) is characterised by respect of the norms of the train schedule. The optimal mode (Pic. 4, area 2) implements the maximum traffic. The complicated mode (Pic. 4, area 3) is characterised by oversaturation of the section with trains. In the hard mode (Pic. 4, area 4), oversaturation of the section with trains leads to a shortage in operating mode of locomotive crews [there are no extra locomotive drivers who can and is allowed to work] and thus to the need to «drop» trains at intermediate stations. In emergency mode (Pic. 4, area 5), movement of trains is stopped due to infrastructure and rolling stock failures or cargo shifts on open wagons.

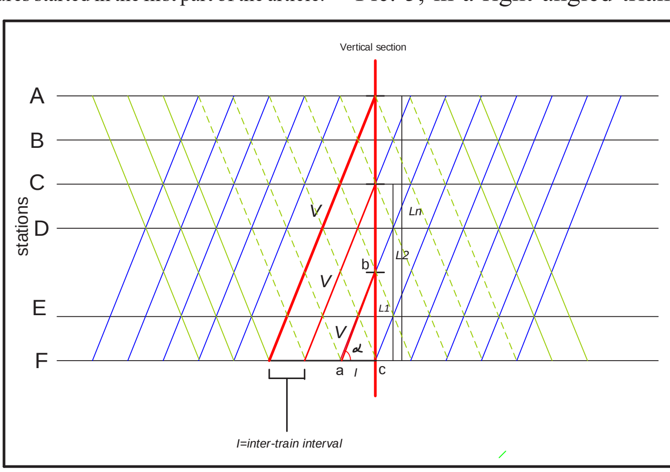
Depending on the mode of operation of the sections, the tasks of managing train operation to ensure compliance with the established standards of the traffic schedule and prevent oversaturation of the sections with trains are solved in the process of modelling the formation of trains. Creating and maintaining optimal conditions for train operation is one of the tasks of train formation management, which is used to regulate saturation of sections with trains.

An increase in the number of trains on the section by more than the maximum provided for in the train schedule not only does not contribute to an increase in the volumes of traffic, but also does not allow meeting the schedule standards and worsens the use of the section's capacity [20].

Control of saturation of sections with trains consists in preventing the presence of more trains on the section than the maximum allowed simultaneously. The maximum number of trains that can simultaneously be on the section is determined by the vertical section of the maximum traffic schedule. The maximum traffic schedule is a schedule in which the «threads» of trains are laid at minimum intervals [21].

Let's consider the definition of the maximum number of trains that can simultaneously be on the section with a parallel two-track schedule. In Pic. 5, in a right-angled triangle *abc*, the slope

[1] The numbering of graphs, diagrams and tables continues the numbering of pictures started in the first part of the article.



Pic. 5. A fragment of the even-numbered train schedule and trigonometry of the vertical section [compiled by the author].

of the hypotenuse ab («thread» of the graph) characterises the speed of trains and determines the acute angle α. The leg *ac* corresponds to the inter-train interval. The leg *bc* is the share (length) of the vertical section per train (L_1). The trigonometric function of the acute angle α of the ratio of the opposite leg *bc* to the adjacent leg *ac* corresponds to the tangent *tgα*. We write the solution of a right-angled triangle *abc* in railway notation:

$tg\alpha = L_1/I = V_x$,

or $L_1 = I \cdot tg\alpha$,

$L_2 = 2I \cdot tg\alpha$,

…

$L_n = n'' I \cdot tg\alpha$,

$$n'' = \frac{L_n}{I \cdot \mathrm{tg} \propto},$$

or $$n'' = \frac{L_n}{I \cdot V_x},$$

where n'' – the maximum number of trains for an even direction;

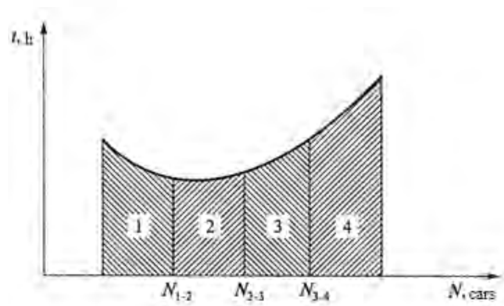
L_p – the section length (vertical section);

I – minimum inter-train interval;

V_r – running speed of trains.

Regulation of the Load of Marshalling Stations

The modern technological process of the marshalling yard operation contains two components: the sequence of operations and the norms of time for their implementation. Real operational work differs significantly from the normative daily schedule. An analysis of arrival of trains at marshalling yards by hourly periods indicates a significant intraday unevenness. For example, at Bekasovo-Sortirovochnoye, Orekhovo-Zuyevo and Sverdlovsk-Sortirovochny stations, the range of arrival had been from 0 to 10 trains per hour. What does this lead to? In some periods, due to the lack of trains, the marshalling yard is idle, and the processing capacity is irretrievably lost. At other times, due to the dense arrival of trains, the trains stand idle waiting for dissolution from the hump, and the time spent by the wagons at the station increases [22].



Pic. 6. Modes of operation of the marshalling yard [compiled by the author].

Thus, to maximize the use of the hump's processing capacity while minimising the time spent by wagons at the station, it is necessary to compare and align arrival of trains and the hump's processing capacity in advance. Thus, to create and maintain optimal operation conditions for the marshalling yard.

The operating conditions of marshalling yards at each moment of time are characterised by a mode that determines quantitative and qualitative indicators of the station.

The mode of operation of the marshalling yard depends on the volume of wagon processing, the intensity and uniformity of the approach of trains, the timeliness of providing the formed trains with locomotives, the removal of trains and determines the timeliness of the reception and departure of trains, the presence of inter-operational downtime of wagons.

Normal mode (Pic. 6, area 1) is characterised by station operating conditions, under which there are no train delays due to non-acceptance and inter-operational downtime of wagons, the time norms for performing technological operations are observed, and an increase in the volume of processing leads to a reduction in the time spent by wagons at the station. In the normal mode of train, sorting and shunting operations, the train schedule, the technological process of the station operation and the timely conduct of locomotives' maintenance are respected.

If the normal mode provides the minimum time spent by wagons at the station or minimal operating costs in the absence of delayed trains due to non-reception, then this mode is called *optimal* (Pic. 6, area 2).

Complicated mode (Pic. 6, area 3) is characterised by station operating conditions, when there is inter-operational downtime, which can be exacerbated by the uneven approach of trains, untimely provision of trains with locomotives and departure from the station. There are periodic delays of trains due to non-acceptance. An increase in the volume of processing causes an increase in the time spent by wagons at the station and in operating costs. Deviations in the time spent on the execution of technological operations cause difficulties in the current planning of the station.

Hard mode (Pic. 6, area 4) is characterised by an increase in inter-operational downtime, constant delays of trains due to non-acceptance and the maintenance of an excess of wagon fleet. If the hard operating mode of the station is not eliminated in a timely manner, then inter-operational downtime, the number and duration of train delays due to non-acceptance will increase even more, and there will be a shortage of train locomotives.

It is possible to create and maintain optimal operating conditions for marshalling yards in advance by managing train formation, when, at the stage of modelling accumulation of trains, arrival of trains at destination stations and the processing capacity of respective marshalling humps are brought into line.

Interaction of Marshalling and Cargo Stations

The operational management of train formation allows eliminating the existing shortcomings in organisation of local operations [mainly, loading, unloading, sorting operations within the station or adjacent stations] and ensuring the *timely* supply of wagons to cargo stations. The maximum use capacity of the loading and unloading tracks is achieved when, after completion of cargo operations, the wagons are immediately removed from cargo loading/unloading track and the next groups of wagons are supplied. The timely availability at the stations of these groups of wagons ready for delivery to the loading/unloading track should be the goal of local operations. The absence of wagons at the station by the time of delivery to the cargo unloading track results in an irreparable loss of unloading capacity. That is, the operational management of train formation should ensure availability of wagons at the stations for their timely and complete supply to the cargo loading/unloading track. These conditions characterise the optimal mode of operation of cargo loading/unloading tracks, under which the maximum volume of cargo operations is done [23].

In a mathematical formulation, it is advisable to formulate such a problem in terms of distribution of flows on graphs (Pic. 7). In this case, a weighted graph serves as an adequate mathematical model for organising work with local wagons, the «weight» of the vertices of the first part of which is the predicted time of arrival of the wagons at the station. At the same time, the numbering of peaks increases during the planned period (for example, shifts, days). The «weight» of the vertices of the third part of the graph is the time of delivery of wagons to the cargo loading/unloading track, which is determined by the quotient through dividing duration of the planned period by the time of carrying out cargo operations. The stochastically evolving predicted arrival of wagons at the station, not linked to the performance of cargo operations, does not always ensure the maximum use of the loading/unloading capacity of cargo loading/unloading tracks, i.e., part of the time the latter are idle waiting for work, and part of the time during crowded arrival the wagons are idle waiting for delivery of wagons. To timely respect the schedule for supplying wagons to the cargo loading/unloading track, the desired second part of the graph is built, the «weights» of the vertices of which characterise the necessary moments of time when the wagons should arrive at the station. The latter may coincide with the predicted time if they arrive on time, or otherwise an earlier arrival of wagons to the station is necessary. In this case, the «weight» of the vertices (arrival time) is determined by the difference in the times of delivery of wagons to the cargo loading/unloading track according to the schedule and the time required to perform technological and shunting operations.

Thus, the task of finding the «weights» of the vertices of the second part of the graph is reduced to synthesising the arcs connecting the vertices of different parts of the graph, and calculating the flows on them so that a solution between the sources (the predicted arrival of wagons at the station) and the sinks of the graph (the application for supply of wagons for unloading during the planned period) should be when the extremum of the functional is reached on the set of arcs of this graph:

$$F = \min\{M, P\}, \qquad (4)$$

where M – availability of local wagons for each loading/unloading track;

P – loading/unloading capacity of the loading/unloading track.

To implement the functional (4), we consider the algorithm, having previously introduced the following notation: S is the source of the graph; T is the sink of the graph; i, j, k are the vertices of the first, second and third parts of the graph, respectively; N is the flow of wagons on the arcs between the shares of the graph; N_{si} is the predicted flow of wagons arriving at the station; N_{kt} is the maximum number of wagons that can

Table 3

Initial data of the example [compiled by the author]

Forecast of arrival of wagons at the station	Arrival turn	1	2	3	4	5	6	7	8
	Time	17:30	21:00	2:00	7:00	8:00	10:00	11:00	12:00
	Number of wagons	30	15	10	40	15	20	50	40
Schedule for supply of wagons to the cargo loading/ unloading track	Delivery number	1	2	3	4	5	6		
	Time	20:00	0:00	4:00	8:00	12:00	16:00		
	Number of wagons	40	20	20	40	40	60		

be supplied to the loading/unloading track; t_{cargo} is the current time of the latest arrival of wagons at the station for use in a certain supply to the cargo Loading/unloading track; t_n is the time of delivery of wagons to the cargo loading/ unloading track; t_{tech} is the technological time [necessary for sorting and manoeuvring operations according to adopted technology] from arrival of wagons at the station to delivery to the cargo loading/unloading track.

The algorithm for performing calculations leads to streamlining the flow of arrival of wagons at the station to ensure the maximum possible volume of loading/unloading and determines the required schedule of their arrival. The optimal schedule of arrival of wagons at the station corresponds to finding the «weights» of the vertices of the second part of the graph.

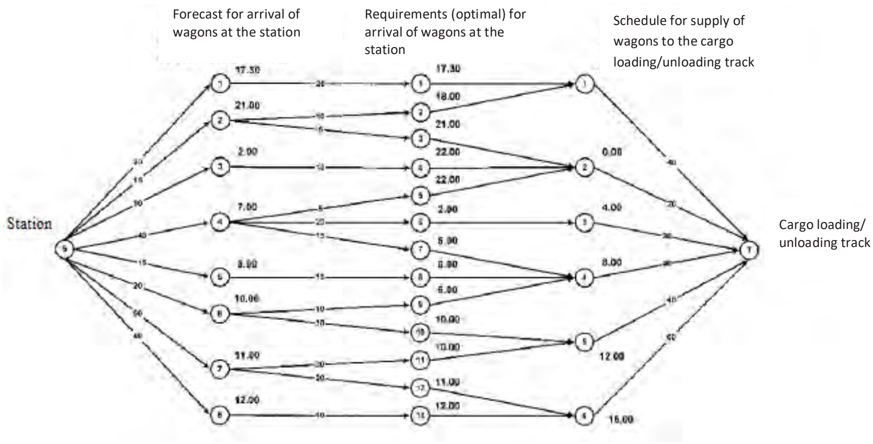
The algorithm for developing requirements for arrival of local wagons at the unloading station:

1. Let $i = k = 1, j = 0$.
2. If $N_{si} < N_{ki}$, then go to step 4; if $N_{si} = N_{kT}$, then – to step 5; if, $N_{si} > N_{kT}$ then – to step 3.
3. Let's calculate $N_{si} = N_{si} – N_{kT}$; $j = j +1$; $N_{ij} = N_{kT}$; t_i = min $\{t_i, t_k - \mathrm{t_{tech}}\}$; $k = k + 1$. If $\mathrm{k} > \mathrm{k_{max}}$, then go to step 6, otherwise – to step 2.
4. Let's calculate $N_{kT} = N_{kT} – N_{si}$; $j = j +1$; $N_{ij} = N_{si}$, t_j = min $\{t_i, t_k - \mathrm{t_{tech}}\}$; $i = i + 1$. If $i > i_{max}$, then go to step 6, otherwise – to step 2.
5. Let's calculate $j = j + 1$; $N_{ij} = N_{si}$, t_j = min $\{t_i, t_k - \mathrm{t_{tech}}\}$; $k = k + 1$. If $k > \mathrm{k_{max}}$, then go to step 6, otherwise $i = i + 1$. If $i > i_{max}$, then go to step 6, otherwise – to point 2.
6. We draw up a schedule for arrival of wagons at the station for all values of i and k, t_j = min $\{t_i; t_k - \mathrm{t_{tech}}\}$.

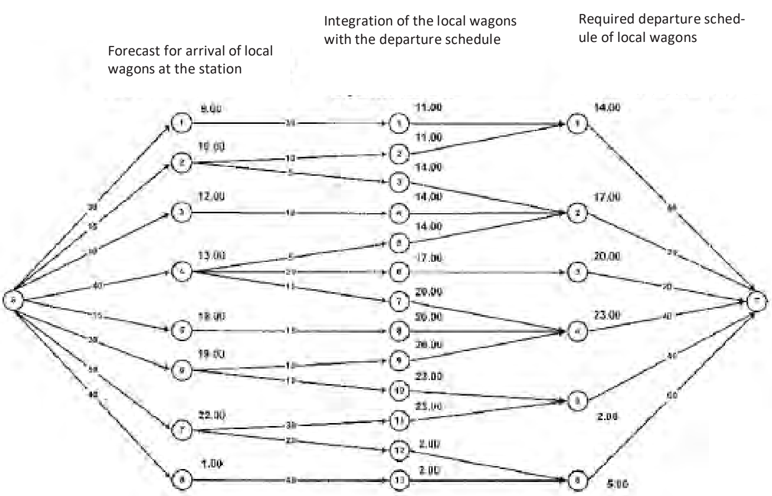
Example. The task is to optimise arrival of wagons at the station to be further moved to the cargo loading/unloading track with a loading/ unloading capacity of 220 wagons per day (Pic. 7). The execution time of technological and shunting operations from arrival of wagons at the station to delivery to the cargo loading/ unloading track is 2 hours. Table 3 sets the forecast for arrival of local wagons at the station and the schedule for supplying them to the cargo loading/unloading track.

The optimisation of the estimated arrival of local wagons for individual cargo loading/ unloading tracks is generalised for the stations of the entire section. Considering transit time of local wagons to the unloading station, the required time for their departure from technical stations is determined (Pic. 8). The possibility of earlier departure of local wagons from the technical station depends on the forecast of the time of arrival at it. The verification consists in comparing the time required to perform technological operations for the processing of wagons at the station and the time available from the moment of arrival to departure. As a result of this verification, those wagons are identified that can be sent from the technical station earlier than the predicted time. In other words, situations are identified when local wagons are idle at the technical station, and at this time there are no wagons at cargo stations for delivery to the cargo loading/unloading tracks.

As a result of automation of the operational planning of local and cargo operations, an operational plan is being developed for delivery of local wagons to stations and their delivery to the cargo loading/unloading tracks. Such a plan includes the technology of train formation and the schedule of trains with local wagons and allows controlling the progress in its implementation. The wagons delivered to the cargo loading/unloading tracks within the terms allowing performance of cargo operations before the end of the shift or day, make up the planned amount of unloading for the corresponding period of time. Additional local wagons arriving during the day are used to fill incomplete deliveries to the cargo loading/ unloading tracks.



Pic. 7. Flow model for optimising arrival of local wagons at the unloading station [compiled by the author].



Pic. 8. Flow model for optimising the departure of local wagons from the technical station [compiled by the author].

The operational management of train formation will make it possible to significantly increase the efficiency of management of the transportation process due to the actual transition from informing to managing automated systems.

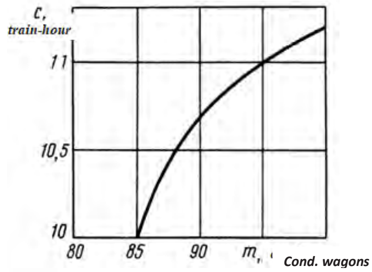
Tools of Train Formation Management

Simulation of the process of accumulation of wagons for trains of different lengths and weights makes it possible to control the duration and moments of completion of accumulation of wagons.

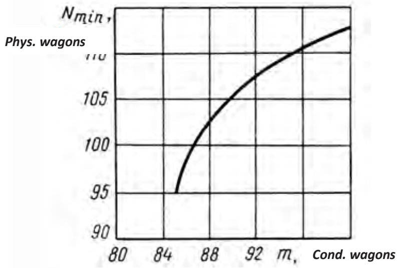
Pic. 9 shows the influence of the number of wagons in the trains being formed on the accumulation parameter, and Pic. 10 demonstrates the effect of changing the train length *m* on the minimum volume of the wagon flow, which is advantageous to allocate to an independent destination.

The use of deviations from the set value of the composition of trains makes it possible to control the accumulation time (Pic. 11) and the accumulation parameter (Pic. 12).

With an increase in the allowable deviations from the set length of trains, the cost of wagon hours regarding accumulation is reduced (Pic. 13), and the more intense, the greater is the deviation. This is due to the increase in the process of accumulation of the number of intervals between the accumulated trains (Pic. 14) and average values of the closing (Pic. 15) and final (Pic. 16) wagon groups. But the reduction in the cost of wagon-hours for accumulation with an increase in the allowable deviations from the established length of the trains leads to an increase in the volume of train traffic (Pic. 17), and this, with a high level of filling the throughput capacity of the segments

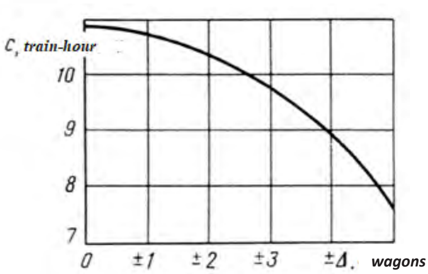


Pic. 9. Dependence of the accumulation parameter c on the average number of wagons m in the trains being formed [compiled by the author].

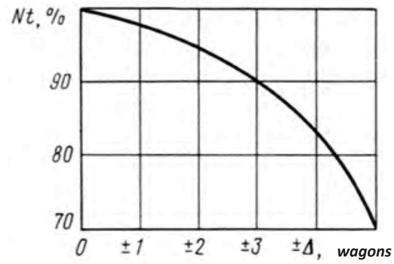


Pic. 10. Dependence of the minimum wagon flow, N_{min}, favourable for allocation to a separate destination, on the average number of wagons m in the train [compiled by the author].

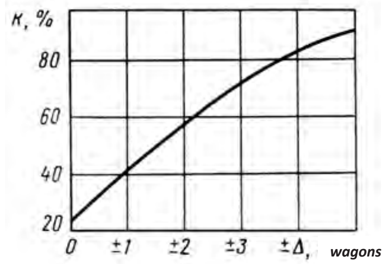
Pic. 11. Influence of permissible deviations from the set length of trains ±Δ on the accumulation time t_a [compiled by the author].



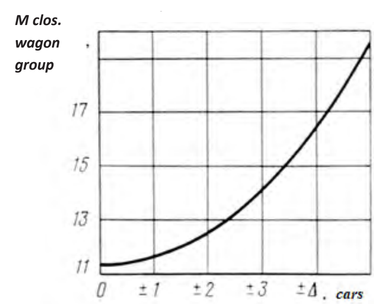
Pic. 12. Influence of permissible deviations from the set length of the trains ±Δ and the accumulation parameter c [compiled by the author].



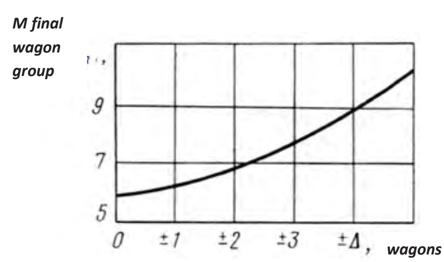
Pic. 13. Influence of permissible deviations from the set length of trains ±Δ on the expenditures of wagon-hours of accumulation N_t [compiled by the author].



Pic. 14. Interdependence of the rate of permissible deviations from the established length of trains ±Δ and the proportion of intervals between trains in the accumulation process [compiled by the author].



Pic. 15. Influence of permissible deviations from the established length of trains ±Δ on the average value of the closing group m_{clos} [compiled by the author].



Pic. 16. Influence of permissible deviations from the established length of trains ±Δ on the average value of the final group m_{fin} [compiled by the author].

of the network, leads to a decrease in the train speed at the section (Pic. 18).

In connection with the change in the conditions of train traffic through the section (Pic. 20), it became obvious that when determining the permissible deviations from the established length of trains during formation of trains, it is necessary to compare reduction in the expenditures of wagon-hours during accumulation with the increase in wagon-hours in motion, as well as locomotive- and crew-hours reduced to the cost of 1 wagon-hour:

$$\Delta Nt_a = \Delta t_{mot} n m_{act} + \frac{\Delta t_{loc} e_{MH} + \Delta t_{br} e_{Mh}}{e_{nH}},$$

or $$\Delta cm \geq \Delta t_{mot} n m_{act} + \frac{\Delta t_{loc} e_{MH} + \Delta t_{br} e_{Mh}}{e_{nH}},$$

where $\Delta Nt_a = \Delta cm$ − reduction in the cost of wagon-hours for accumulation of trains;

$\Delta t_{mot} = \Delta v_{sec}/L$ increase in the time spent by trains on the section;

n − volume of train traffic on the section;

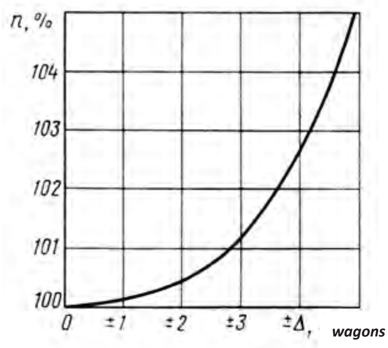
m_{act} – the actual number of wagons in trains;

Δv_{sec} − decrease in the train speed at section;

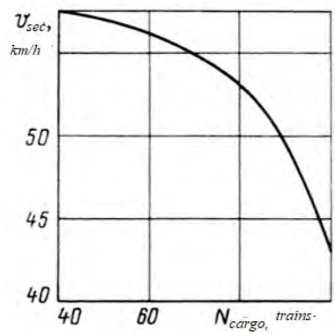
L – length of the section.

Let's consider, for example, feasibility of increasing the permissible deviations from the established length of trains of 50 wagons from ± 1 to ± 3 at the expenditures for accumulation of wagons equal to 550 wagon-hours per day, the traffic volume on the section is 80 trains, and the length of the section is 200 km. According to the schedule (Pic. 11), we determine that the expenditures of wagon-hours for accumulation will be reduced by 7,7 %, or by 42,35 car-hours, the traffic volume (Pic. 17) will increase by 7,6 trains, and this will cause a decrease in the section speed (Pic. 3 (2.3)) by 2,5 km/h, i.e., will increase the time spent by trains on the section by 0,19 hours. Thus, the reduction in wagon-hours for accumulation of wagons for trains (by 42,35 car-hours) exceeds the increase in the time spent by wagons in motion by 9,5 car-hours. This means that in this section it is advisable to increase the allowable deviations from the established train length by ±3 wagons. If the use of the capacity has reached a high level, it is advisable to form the trains that will be at the same time full in length and weight, so as not to cause a further increase in the volume of train traffic.

When forming trains with loaded wagons, the entire car flow intended for a given destination is involved in the accumulation process. The peculiarity of formation of trains with empty wagons is their withdrawal in the process of accumulation for loading at the station and adjacent areas. Thus, cargo stations, as a rule, send fewer empty wagons than they unload, and technical ones – less than they receive. At cargo stations, the parameter of accumulation of empty wagons c_e for a single destination was recommended to be equal to 7. However, the value of c_e is affected by the volume of cargo operations at the station. The daily empty wagon



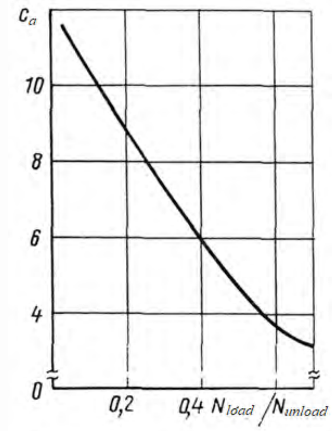
Pic. 17. Influence of permissible deviations from the established length of trains ±Δ on the number of accumulated trains [compiled by the author].



Pic. 18. Change in speed at section depending on the volume of cargo trains traffic [compiled by the author].

flow N_{emp} is the difference between the volumes of unloading and loading of a certain type of wagons. Therefore, a daily wagon flow, for example, of 50 wagons can be obtained by unloading 50 wagons, as well as by unloading 500 and loading 450 wagons. Accumulation costs in both cases $c_e m_e$ = 7•50 = 350 wagon-hours. However, in the first case, the daily cost of accumulation actually amounts to $c_e m_e = N_{emp} t_H$ = 50•12 = 600 wagon-hours, and in the second case, it is possible, by concentrating the supply after unloading groups of wagons or entire groups, to accelerate the accumulation process in some cases to a minimum − t_H = 1,2 hours, and then the cost of accumulation will be several times less than in the first case, i.e. $N_{emp} t_H$ = 50•1,2 = 60 wagon-hours.

In accordance with the necessary condition for routing, with the value of $\sum T_{ek} + \sum T_{ek}^{sl} + t_{assign} = 6$ of the reduced wagon-hour/wagon, in the first case it is inappropriate to route an empty car flow, since 50•6 < 600, in the second case it is advisable since 50•6 > 60. The previously existing method for estimating the expenditures of accumulation did not consider these features of formation of an empty wagon flow. Therefore,



Pic. 19. Dependence of the parameter of accumulation of empty wagons c_a for train formation on the volume of the cargo operation [compiled by the author].

in both considered cases, it was impractical to form empty routes (50•6) < 350. Consequently, the accumulation time with empty wagons depends not only on the amount of daily wagon flow, but also on the volume of cargo operations at stations. Based on studies of the features of the process of accumulation of empty wagons for train formation, an accumulation formula was obtained:

$$c_a = \frac{\left(N_{unload} - N_{load}\right)^2 t_a}{N_{unload} m_a} + 0,76e^{1,338\left(1+\frac{N_{load}}{N}\right)}.$$

To facilitate its practical application, Pic. 19 shows a graphical dependence of the values of the accumulation parameter for trains with empty wagons on the ratio of the volume of the cargo operations at the stations.

Redistribution of Sorting Operations

If there is a dispatcher for organisation of wagon flows and if the intensity of supply of trains does not match the possibility of their processing, it will be possible to temporarily redistribute sorting operations between technical stations. Moreover, this discrepancy can arise due to a change both in the intensity of supply of trains to the station and in processing capacity. The latter may be caused by a change in the number of sorting tracks in operation, untimely removal of trains from the station, repair works on the hump, etc. The need to redistribute marshalling work arises when drawing up and adjusting the plan for formation of trains, shift-daily planning of train work, repair and construction works at stations and hauls. The methods for redistributing wagon flows for these tasks are the same. Let's consider them using an example of management of the load of technical stations during the operational planning of train operations. It should be noted right away that the proposed method of reducing the volume of wagon processing at one of the stations does not cause its increase by the same amount at other stations. As a rule, this is accompanied by a decrease in the total volume of wagon processing operations.

Sorting work is redistributed due to allocation of streams of wagon flows to additional longer-distance destinations than provided for by the formation plan, or redistribution of wagons between train destinations. The formation of additional longer-distance train assignments is advisable both with an increase in wagon traffic (N), which ensures that the savings from trains in transit without processing at passed technical stations (T_{ek}) exceed the costs of accumulating wagons for train formation (cm), and with an increase in T_{ek} due to the increased volume of processing and reducing the cost of accumulation of wagons for trains with a condensed arrival of wagons. Changes in the power of streams of wagon flows or the norms of the formation plan are sufficient grounds for allocating additional destination assignments when $N•T_{ek} \geq cm$.

The change in the load of marshalling yards due to redistribution of wagons between train destinations occurs since the streams of wagon flows allocated to independent destinations often significantly exceed the minimum value sufficient for this. At the same time, the shorter streams adjacent to them lack an insignificant number of wagons for the expediency of allocation to separate destinations. Therefore, they are combined with even shorter streams, and the wagon flows are additionally processed at adjacent technical stations. If it is necessary to reduce the load of adjacent technical stations, the transit capacity of trains can be increased by redistributing wagons between adjacent streams of wagon flows due to some downscaling of more distant destinations to replenish short streams. In general, the expediency of separating into separate destinations streams of wagon flows, replenished due to a more distant stream that meets condition of sufficiency, is determined by the inequality:

$$\sum_{i=1}^{n}\sum_{j=1}^{l} N_i T_{\text{ek j}} - \sum_{i=1}^{n}\sum_{j=1}^{l} N_i^{\text{lack}} T_{\text{ek j}} >$$
$$> \left[(k-1) + \frac{N_{\text{S}} - \sum_{i=1}^{n} N_i^{\text{lack}}}{N_{\text{S}}}\right] cm, \qquad (5)$$

where N_S – the stream of the wagon flow that satisfies the sufficient condition;

N_i – the volume of the stream i replenished by the wagons of destination N_S;

$T_{ek\,j}$ – resulting or eliminated reduced saving of wagon-hours when wagon flow i transit the station without being processed;

N_i^{lack} – lack of wagons in stream i to meet the sufficient condition;

k – the number of additional train assignments.

For replenishment, streams of wagon flows can be used, initially meeting the sufficient condition, but in which the excess of wagons is less than the shortage in the adjacent stream. This is explained by the fact that the decrease in the far stream of the wagon flow N_1 to replenish the nearer stream for N_2^{lack} in a sufficient condition for profitability of allocating N_1:

$$(N_1 - N_2^{lack})T^{s}_{ek} \ge \left(\frac{N_1 - N_2^{lack}}{N_1}\right) cm$$

equally affects the change in the values of the right and left parts of the inequalities, without changing their ratio.

The sequence of calculations when redistributing sorting operations between technical stations:

1. Those streams of wagon flows are identified that satisfy the sufficient condition and that are allocated to the transit destinations of trains through the station in question.

2. Those streams of wagon flows are identified that satisfy the necessary condition, and which, after replenishment, will be able to pass through the station without processing.

3. From the jets that satisfy the necessary condition, such adjacent streams are distinguished, with which the more distant streams satisfy the sufficient condition.

4. For streams of wagon flows allocated according to step 3, the missing wagons are found to fulfil the sufficient condition.

5. The streams identified at step 4, replenished with the missing number of wagons, are checked for fulfilment of the sufficient condition (5).

Advance modelling of the wagon accumulation process is used as information support for operational redistribution of sorting operations. The rational redistribution of sorting operations contributes to creation of optimal conditions for functioning of sections and stations and increases the transit capacity of wagon flows. It is possible to redistribute the sorting operations between stations in the considered way both when calculating and adjusting the formation plan, and during operational planning of train operations, when difficulties have already arisen or are predicted with processing of wagons at some stations. The time over which sorting operations are reallocated depends on the likely duration of the foreseeable disruption.

CONCLUSIONS

Train formation planning is a key task of operational management of the transportation process. Therefore, replacement of the passive, uncontrolled process of accumulation of wagons for train formation by the dispatching control of train formation makes it possible to eliminate the existing uncertainty and spontaneity in the operational work of railways.

The operational management of train formation allows significantly expanding the list of tasks solved by the train formation plan. In addition to setting the destinations of trains being formed, which is periodically inefficient, organisation of wagon flows is quickly adapted to the real operational situation, the time for complete assembling of trains is regulated in advance in accordance with the provision of trains with locomotives and the «threads» of the train schedule. Initial information is provided to optimise the work of train locomotives; saturation of sections with trains is controlled; the maintenance of wagons at stations is also endured.

The characteristics of optimal conditions for operation of sections and stations are determined. Forecasting the mode of operation of sections and stations makes it possible to create the most effective conditions for train and marshalling operations using train management.

To control the train formation, the measures of dispatching actions are provided, which make it possible to influence and determine the efficiency of the transportation process.

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Information about the author:
Levin, Dmitry Yu., *D.Sc. (Eng), Chief expert of JSC NIIAS, Moscow, Russia, levindu@yandex.ru.*

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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.