The rational connection coefficient calculation with different train structures

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Abstract. Nowadays, the development of the country's economy causes an increase in the volume of transportation. To develop them, the railway must continuously master transportation capacity through gradual development. Essential limitations of investment expenditures for the development of the railway provided that the volumes of transportation are fully fulfilled have put the railway in search of modern solutions. The increase in carrying capacity and capacity based on the complex strengthening of railway sections and technical means will ensure balanced development of the growth in traffic volume. Railway, block train, single train, cash throughput, required bandwidth.

1. Introduction

Thus, the railway is on the threshold of stage-by-stage development in the development of freight flows. New innovative technologies applied in the transport process require substantial capital investments in the development of road transport capacity. The least expensive is to solve the problem by increasing the weight of the train significantly. In this way, the railways are mainly increasing their capacity. However, the lack of a comprehensive approach to the solution of the problem and coordination of its implementation will cause significant organizational difficulties in the operational work. It will be a source of technological disturbances, especially at railway junctions in the future.

2. Economy-mathematical model for calculation of rational connection coefficient and problem statement

The organization of the joint passage of single, twin and block trains for the development of the given load flow can be carried out at their different ratio determined by \( \alpha_{\text{twin}} \) connection coefficient. The higher this ratio, i.e. the higher the share of flow allowed in block trains, the smaller the size of the movement and the higher all performance indicators. However, as \( \alpha_{\text{twin}} \) increases, so does the capital investment in elongation of the tracks at separate points to arrange the crossing of block trains with each other. Conversely, if cargo traffic is carried mainly in single trains, the capital investment will be minimal, although the performance of the line will be the worst.

Practice and calculations show that the organization of the circulation of block trains on single-track lines can be most fully used to increase the throughput and carrying capacity in the presence of appropriate lengths of tracks for crossing and overtaking trains.
On single-track lines efficiency of the organization of block trains are reached basically at the expense of release of locomotive brigades and sections of locomotives, decrease in the number of stops of cargo trains under overtaking and crossing, decrease in capital expenses for travelling development of stations and building of the second main ways (construction of the second ways is remote).

Introduction of block trains causes certain changes in the system of operation of railway sections. Particularly, the standards of station intervals and the time for a change of locomotive crews are increasing. At stations where a block train is formed or disassembled, time for connection and disconnection operations must be provided. Besides, block trains with setting locomotives in the head and tail of the train are limited in length and weight, which is due to the reliability of the car brakes and coupling devices.

Thus, the definition of spheres of profitability of the organization of movement of block trains with various factors of connection as a means of strengthening of throughput capacity of single-track lines represents a technical and economic problem.

Considering driving of block trains as a certain stage of increase in throughput capacity, allowing to allocate capital investments to the construction of the second main ways, it is possible to define at known characteristics of a line and cargo traffic, the rational factor of connection. For the decision of this problem, we will consider schemes of development of throughput capacity with various variants of the passage of block trains. In each variant of throughput amplification, the connection coefficient varies from 0.1 to 1.0. For each variant of stage throughput amplification there can be certain total reduced costs.

The physical controlled system is a line, the state of which is characterized by a vector, the coordinates of which are the length of the Iext station tracks and the connection coefficient αtwin.

Let's give each of all possible on the line a serial number n=1, 2, 3,...,|S| and indicate the parameters corresponding to this stage, as follows

\[ l_{ext1}, l_{ext2}, ..., l_{ext|S|}, \alpha_{twin1}, \alpha_{twin2}, ..., \alpha_{twin|S|}, \]

The measure of station tracks extension is carried out in terms of \( t_1, t_2, ..., t_{|S|-1} \). Thus, the control parameters are vectors: line parameters

\[ X = \{l_{ext1}, l_{ext2}, ..., l_{ext|S|}, \alpha_{twin1}, \alpha_{twin2}, ..., \alpha_{twin|S|}\}, \]

and parameter change deadlines.

\[ T = \{t_1, t_2, ..., t_{|S|-1}\}, \]

Changing the control parameters of the line requires one-time capital expenditures, which depend on the parameters vector

\[ K_k = K_k \{l_{ext1}, l_{ext2}, ..., l_{ext|S|}, \alpha_{twin1}, \alpha_{twin2}, ..., \alpha_{twin|S|}\}, \]

and the given annual transportation costs depend on the value of parameters characterizing the technical equipment and the lifetime of the line.

\[ E_k = E_k \{l_{ext1}, l_{ext2}, ..., l_{ext|S|}, \alpha_{twin1}, \alpha_{twin2}, ..., \alpha_{twin|S|}\}. \]
The task is to choose such values of control parameters \( X \) and period of their change \( T \), at which the total reduced costs would be minimal, i.e. at any scheme of line development \( X^*, T^* \) are determined.

The annual total reduced costs can be provided as a criterion function \[3\].

\[
F_s^*(X^*, T^*) = \min_{x \in X, t \in T} \left[ \sum_{s \in S} \left( K_s^x + \sum_{t=t_{s-1}+1}^{t_s} E_s^x (X, t) \right) \right]^{(1+\Delta)^T}.
\]

where \( S \) – a set of bandwidth development stages;
\( T \) – a set of permissible startup times for the actions;
\( X \) – a set of allowable values of parameters and \( I^{t_{ini}}_{ini} \alpha_{twin}^{i} \).

Definition of the rational connection coefficient is reduced to a search of a minimum of total expenses by the formula \(1\) at various values of the connection coefficient for the whole period starting from the first year of operation of the single-track line up to laying of the second tracks, and the most distant period of their construction \( T_{max} \).

In case of a constant freight flow, the introduction of block trains requires the determination, without considering the efficiency of the removal of capital costs for the construction of the second main track, the minimum possible value (in terms of capacity) of the coefficient of connection of trains. The total comparative annual transportation costs shown above are defined as follows

\[
E_{fre} = KE_n + E_{fre} + \mathcal{O},
\]

As far as: \( 0 \leq \alpha_{cdv} \leq 1; l^0_{ct} \leq I_{ext} \leq 2 l^0_{st} \)

where \( K \) is the capital cost of lengthening station tracks, rub/km;
\( E_n \) – normative efficiency coefficient of capital investments, \( E_n = 0.12 \)
\( E_{fre} \) – the given transportation costs, rub/km;
\( E \) – maintenance costs of permanent devices, rub/km;

To solve this problem, calculations were made for different conditions of the line operation at different variants depending on the doubling factor, at the given cargo flow. Calculations have shown that driving block trains under certain conditions allow reducing costs associated with the movement of trains, as the district speed increases and the number of stops decreases.

The greatest value of the site speed will have at the connection coefficient 0.5-0.7 (Figure 1.). The fairness of this conclusion is proved by the fact that 20-30% of single trains with the following composition are not subject to connection: wagons with people, with an oversized cargo of the third degree and more, with discharge cargo of the fourteenth degree and more, rolling stock requiring speed limitation or special conditions \[7\].

The results obtained allow to conclude that under certain conditions, the passing of block trains can be used as a means of reducing transportation costs even when there is no need in terms of capacity.

In the conditions of growing cargo traffic, it is necessary to determine the variable connection coefficient by years, i.e. the minimum possible under the conditions of the line capacity.

The minimum possible connection factor is determined from the condition of

\[
\alpha_{twin} = \frac{N_{cash}^{\sin} - N_{req}^{\sin}}{N_{cash}^{\sin}}
\]

where \( N_{cash}^{\sin} \) – there's cash throughput in single trains;
$N_{req}^{\sin}$ – the required bandwidth of the section, in single trains.

At the organization of movement of block trains, it will be necessary for crossings, overtaking corresponding elongated tracks. The number of elongated tracks depends on the number of stops of block trains at separate intermediate points and can be set according to the method [1-6]. The number of tracks at the stations of formation and disbanding depends on the employment of receiving and dispatching tracks at the pre-set station from the moment of appearance of the first single train to the departure of block-train and can be determined by the recommendations [8-11].

The values included in the formula (6) change depending on the connection factor. The task of finding a rational connection coefficient in the organization of block-train movement was solved by the method of determining the total costs for an equal period for variants with different lengths of station tracks and with different connection coefficient.

Figure 2 shows the dependences of the connection coefficient of economically expedient $\alpha_{\text{twin}}^r$ and minimum required under the conditions of the line capacity $\alpha_{\text{nul}}^r$. As can be seen from the dependences, at the omission of block trains, the growth rate of freight flow does not have a significant effect. So, at the length of station tracks $L_{st}^{\sin} = 850, 1050, 1250, 1500$ m and $L_{st}^{\text{twin}} = 1700$ m, at the increase of cargo traffic from $H_p = 18 \times 10^6$ t per year to $H_p = 37 \times 10^6$ t per year it increases only on 0,3.

Figure 1. Dependence of train connection coefficients on traffic volume.
Thus, the growth of cargo flow does not have a significant impact on the value of rational connection coefficient.

As the research mentioned above results have shown, it is more economically advantageous to drive block trains than to drive single trains. Under these conditions, it is necessary to organize block-trains even if this is not caused by the need for capacity. A rational connection factor has been found when block-trains are used as a capacity enhancement measure, provided that the connected and passenger trains are placed evenly on the schedule within 24 hours.

The given results of calculations in the Table 1 confirm the made conclusions that starting from the cargo traffic \( G_p = 37 \times 10^6 \) t per year it is necessary to put into circulation block trains for maintenance of the set sizes of movement.

In \( H_p = 36,10^6 \) t per year, when driving block trains, the connection coefficients \( \alpha^{\text{twin}}_r \) and \( \alpha^{\text{twin}}_p \) are equal. After this load flow, it is not possible to apply a rational connection coefficient \( \alpha^{\text{twin}}_r \), since the \( \alpha^{\text{twin}}_p \) coefficient required under capacity conditions is higher.

Note:
1. If \( N_{\text{cash}}^{\text{sin}} > N_{\text{req}}^{\text{sin}} \), the section provides single train pass, \( \Delta N – \) positive;
2. If \( N_{\text{cash}}^{\text{sin}} < N_{\text{req}}^{\text{sin}} \), the block-trains are to be passed at the section, \( \Delta N – \) negative.

**Table 1.** Values of the minimum required train coupling ratio by line capacity.

| \( G_p \) million tonnes per year | \( N_{\text{cash}}^{\text{sin}} \) train set | \( N_{\text{req}}^{\text{sin}} \) trains per day | \( \Delta N \) | \( \alpha^{\text{min}}_p \) |
|-------------------------------|-----------------|------------------|-------------|----------------|
| The length of station transhipment routes \( l_{\text{st}}^{\text{sin}} = 850 \) m |
| 19 | 28.0 | 19.02 | 8.98 | — |
| 20 | 28.0 | 20.02 | 7.98 | — |
| 22 | 27.0 | 22.02 | 4.97 | — |
| 30 | 23.0 | 30.04 | -7.04 | 0.31 |
| 34 | 21.0 | 34.05 | -13.05 | 0.62 |
| 36 | 19.0 | 36.05 | -17.05 | 0.80 |
| 37 | 18.0 | 37.05 | -19.05 | 1.00 |
| The length of station transhipment routes \( l_{\text{st}}^{\text{sin}} = 1050 \) m |
| 19 | 28.0 | 15.20 | 12.8 | — |
| 20 | 28.0 | 16.0 | 12.0 | — |
| 22 | 27.0 | 17.6 | 9.4 | — |
| 30 | 23.0 | 24.0 | -1.0 | 0.04 |
| 34 | 21.0 | 27.0 | -6.0 | 0.29 |
| 36 | 20.0 | 28.8 | -8.8 | 0.44 |
| 37 | 19.0 | 29.5 | -10.5 | 0.55 |
| The length of station transhipment routes \( l_{\text{st}}^{\text{sin}} = 1250 \) m |
| 19 | 28.0 | 12.7 | 15.3 | — |
| 20 | 28.0 | 13.4 | 14.6 | — |
| 22 | 27.0 | 14.69 | 12.3 | — |
The length of station transhipment routes $l_{st} = 1500 \text{m}$

|   |   |   |   |   |
|---|---|---|---|---|
| 30 | 23.0 | 20.03 | 2.9 | — |
| 34 | 20.0 | 22.70 | -2.7 | 0.14 |
| 36 | 19.0 | 24.03 | -5.03 | 0.20 |
| 37 | 18.0 | 24.70 | -6.70 | 0.37 |

3. Conclusion
The organization of block-trains movement on the railway lines allows freeing up sections of locomotives and reducing the number of locomotive brigades in train work, increasing the section speed of freight trains, as well as reducing capital costs for track development of the station and construction of additional main tracks:

1. As researches show, with an increase in the coefficient of connection of trains from 0.1 to 0.7, the number of stops decreases, and from 0.7 to 1.0 – the number of stops increases. As a result, the section speed of trains at the connection coefficient 0.1 - 0.7 increases by 50-52%, and at 0.7 - 1.0 – decreases by 8-10%.

2. At the joint passage of single and block trains despite the reduction in the number of stops, with an increase in $\alpha_{\text{twin}}$ the mechanical operation of locomotives on the traction falling on the I train increases. The reason for this is that as $\alpha_{\text{twin}}$ increases, the average mass of trains also increases.

3. Changes in the coefficient of connection of trains have a significant impact on the operated fleet of locomotives. For example, an increase in $\alpha_{\text{twin}}$ from 0.1 to 0.7 leads to a reduction in the operated fleet, and an increase in $\alpha_{\text{twin}}$ from 0.7 to 1.0 leads to an increase in the fleet.

4. Under conditions of the joint passage of single and block trains, the change in $\alpha_{\text{twin}}$ does not affect the downtime of cars under accumulation. At the same time, with an increase in the connection coefficient of simple trains at pre-carriage stations waiting for connection decreases.

5. The rational connection factor is set at a minimum of the reduced costs, which include freight and operating costs as well as capital costs for the extension of station tracks. Calculations have shown that the rational train coupling ratio varies between 0.5-0.7 depending on line conditions and is independent of the traffic volume.

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