RESERVES FOR INCREASING RAILWAY CAPACITY

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ABSTRACT

Reserves for increasing the capacity of railways, among other things, are associated with the possibilities of reducing the length of block sections and reducing the spatial and temporal inter-train interval. The actual length of the block sections, determined by the inter-train interval, is considerably greater than the estimated length required for traffic safety. The similar arrangement of traffic lights leads to an underestimation of the available throughput. To bring the lengths of the block sections into line with the braking distance, it is suggested to consider the movement of trains at the yellow indication of the traffic light without reducing the speed. Reducing the braking distance, the length of the block sections and their number will increase the carrying capacity, especially in the areas of freight traffic. Satellite radionavigation systems that regulate traffic without floor traffic lights and rail chains can help to ensure the minimum required interval between trains.

Keywords: railway, throughput, length of the block-section, braking distance of the train, inter-train interval, arrangement of passing traffic lights, satellite navigation.

Background. *With an acute shortage of the capacity of domestic railways, there are also large reserves, the realization of which is possible without additional capital investments. However, opportunities remain opportunities, as long as the invisible barriers hinder.*

Objective. *The objective of the authors is to consider reserves for railway capacity.*

Methods. *The authors use general scientific and engineering methods, comparative analysis, graph construction, evaluation approach.*

Results.

All-round defense

The maximum permissible speed of freight trains is one of the most important characteristics that determines the carrying capacity of the railway transport. Another no less significant term in the existing formulas for calculating the throughput of a two-track section is the inter-train interval around which a closed circle arises.

On the one hand, according to the calculated interval of passing trains the location of the passing traffic lights on the hauls is determined and the length of the block sections is set [1]. The length of the block sections must be no less than the braking distance with full service and auto stop braking after the train passes a traffic light with a yellow signal with the maximum speed for this track section. On the other hand, the length of the block sections itself determines the possible intensity of train traffic and the throughput capacity of the site.

The problem of a closed circle is that the length of the block sections is set according to the minimum value of the calculated inter-train interval and the maximum permissible speed of the trains, while in fact the situation looks different.

Firstly, there are speed restrictions for trains on the sections because of various reasons. Secondly, it is impossible to provide synchronization of train movement, strict observance of inter-train intervals and the standard travel time. Non-synchronousness is exacerbated by the requirement to move at the yellow light of a traffic light with a limited speed when approaching and departing from a separate point and on long lifts. Thirdly, to stop the train in the most unfavorable conditions, one block-section is sufficient, while with a three-digit auto-blocking, an interval between the trains of at least three block sections (three braking distances) is provided. Fourthly, almost at all sections of the network, the maximum permissible speed of trains is set lower than in the Regulations on Technical Operations (PTE). Fifthly, the widespread oversaturation of the freight areas with trains leads to movement at yellow and red lights of the traffic lights, lowering of the speed and reduction of the required braking distance.

Following «from green to a green light» of the traffic light means that the distance between passing trains is at least three braking distances with full service braking. But this type of braking as a working one is forbidden by job descriptions [2]. When regulating the speed at the distances and stops, braking I or II is applied. In this case, the braking distance increases by 1,5–2. The analysis of the high-speed tapes shows that when the yellow signal is on, the drivers begin the braking of the train in advance. A wide range of speed values largely depends on their qualifications.

The maximum permissible speed of freight trains on the railway network is distributed as follows: up to 40 km/h – 1 %, 40 km/h – 4,9 %, 50 km/h – 1,8 %, 60 km/h – 19,1 %, 70 km/h – 10,2 %, 80 km/h – 62,1 % and 90 km/h – 0,9 % (Pic. 1).

In modern conditions, the implementation of the maximum speed of freight trains in accordance with § 17 PTE [3] can provide an increase in the section speed by at least 10 km/h.

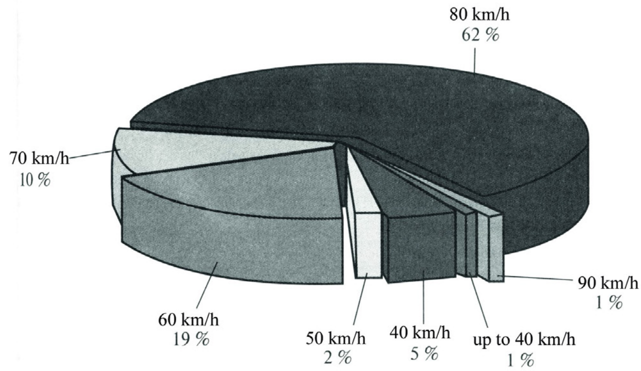
To brake cleverly – to carry fast

Increasing speed and increasing the density of train traffic are obvious reserves of growth in capacity. At the same time, there is a conflict of goals, since increased security and increased capacity often contradict each other.

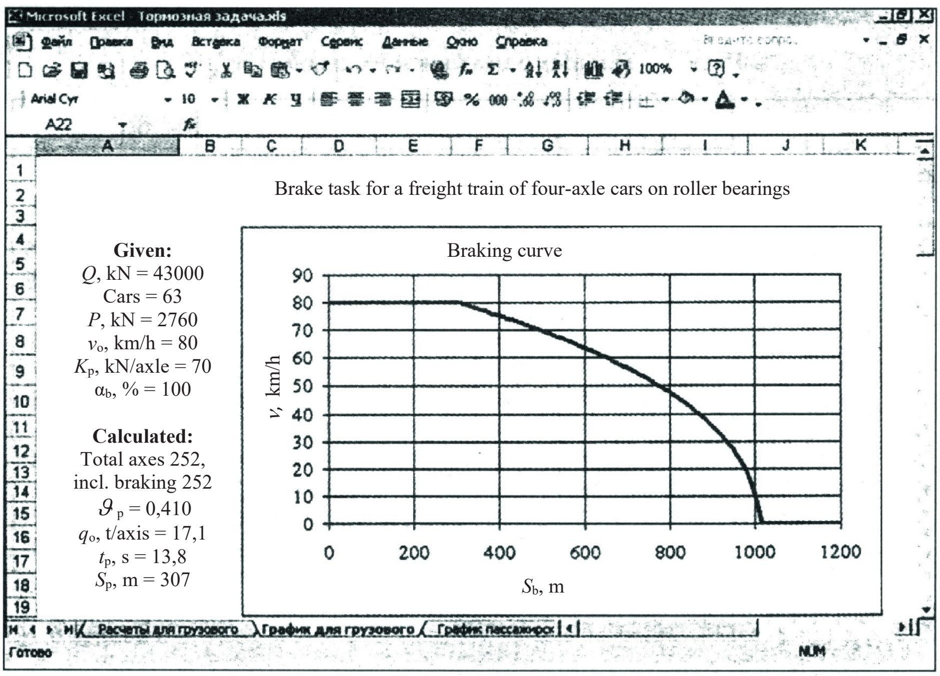
To ensure traffic safety, it is necessary to stop the train in time before the obstacle. This can be achieved by the continuous speed control of the on-board computer, in which the braking problem is solved (Pic. 2). On the one hand, there is a search for braking facilities, providing a reduction in the speed of movement or a complete stop of the train at the required distance. And on the other hand, the distance at which a given train with known braking means can stop or reduce the speed of movement to the desired value is determined.

After turning the crane handle into the braking position, it takes some time before the brake pads come into contact with the wheels. This time interval is called the time of preparation of brakes for action. The path S_p, which the train passes at this moment, is called the preparatory braking distance, and the distance S_d, when it moves with the pressed brake pads, is an actual braking distance. That is, the braking distance S_b consists of the preparatory and the actual:

$$S_b = S_p + S_d. \qquad (1)$$



Pic. 1. Distribution of the maximum permissible speeds of freight trains in the traffic schedule.



Pic. 2. Solving the braking task on a computer.

During the preparation of brakes to operate at a constant speed, the train passes the distance

$$S_P = 1000 \cdot v_o \frac{t_P}{3600} \approx 0,278 \cdot v_o \cdot t_P, \qquad (2)$$

where v_o – train speed at the moment of beginning of braking, km/h; t_p – time for preparing the brakes for action, s.

The time of preparation of brakes to act with automatic brakes for a freight train of 200 axles or less is assumed to be 7 seconds, the length from 200 to 300 axes – 10 seconds and more than 300 axes – 12 seconds. With manual brakes t_p = 60 seconds.

The process of train braking is determined by the length of the braking distance S_b, the initial speed v_o and the final speed v_k, the slope of the track I and the braking means with a design braking coefficient υ_r. The solution of the braking task is reduced to find one of these quantities from the known rest.

In the analytical integration of the equation of motion of the train, the entire range of velocity variation from initial to final is divided into intervals. For each of the intervals in accordance with expression

$$\frac{dv}{dt} = 2\left(f_k - w_k\right) \text{ km/h·min}$$

the distance which the train passes is found. The total value of the actual braking distance

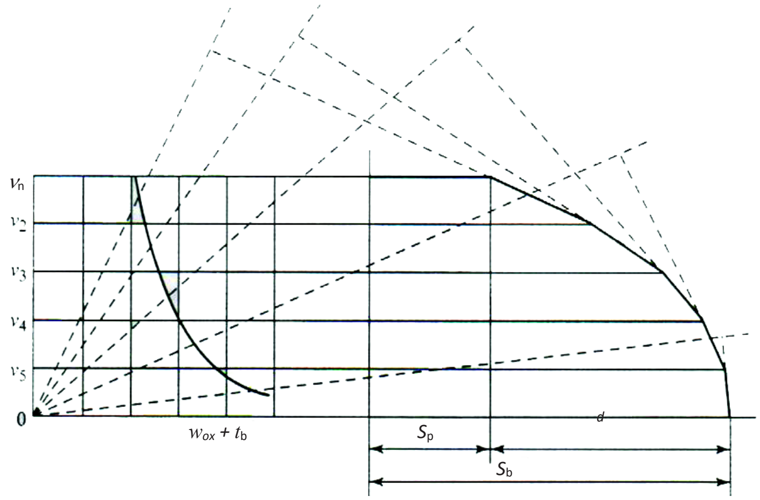
$$S_D = \sum \frac{500\left(v_{ki}^2 - v_{ki}^2\right)}{\zeta r_{avi}}, \text{ m}$$

where v_{ni}, v_{ki} – values of the initial and final speeds of the train at the i-th interval, km/h; r_{avi} – average value of the specific resultant forces applied to the train on the i-th speed change interval, N/kN.

The average value of the specific resultant forces applied to the train on the i-th interval of the speed change is determined in accordance with the formula

$$r_i = -\frac{Pw_0^{'}\left(v_{avi}\right) + Qw_0^{''}\left(v_{avi}\right)}{P+Q} - b_t\left(v_{avi}\right) - i_i. \qquad (3)$$

To graphically determine the length of the braking distance in rectangular coordinates (Pic. 3), a diagram



Pic. 3. Graphical method for determining the braking distance of a train.

of the decelerating forces for the braking mode is constructed and a distance equal to the brake preparation distance S_p calculated in accordance with the expression (2) is plotted along the abscissa axis.

At the speed of the beginning of braking, v_n a horizontal line is made, corresponding to a constant speed within the brake preparation distance. Then, the entire range of speed changes from v_n to zero is divided into intervals of no more than 10 km/h and a speed curve from the coordinate of the end of the brake preparation distance to the point at which the speed value becomes equal to 0 is plotted by the Lipets method. The distance S_t is the required stopping distance, and accordingly the length of the block-section.

Thus, the maximum permissible speed affects the throughput through the running speed and the length of the block sections. This dependence can be expressed by the formula

$$n = \frac{Tv}{60S}, \qquad (4)$$

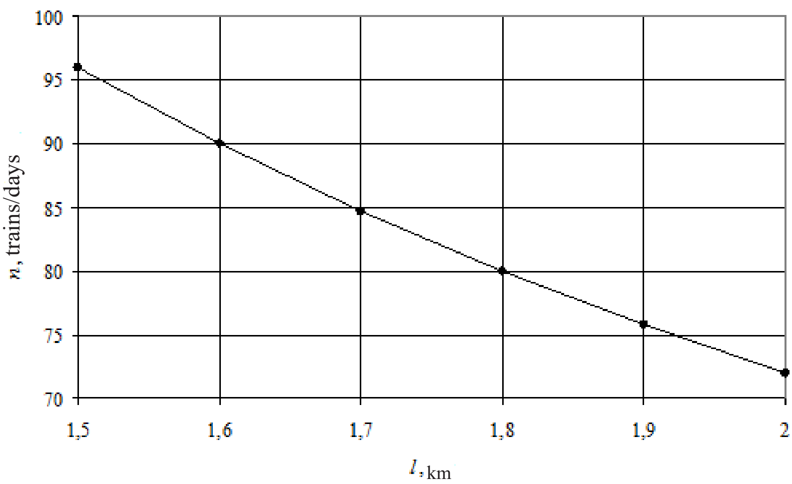
where T – period of time for which the throughput is determined, min; v – speed of trains; S –space interval between trains, km, with automatic blocking is equal to the length of three block sections.

Non-identical intervals

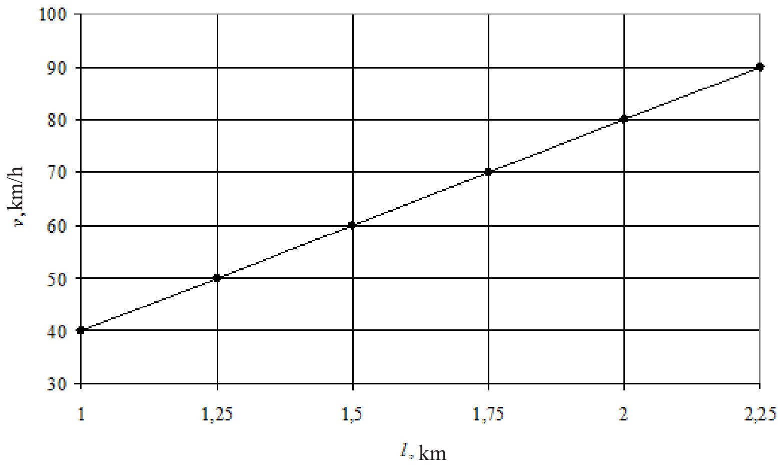
In practice, the length of the block sections, determined by the inter-train interval, is considerably longer than the length sufficient to ensure the safety of train traffic [5]. This arrangement of traffic lights leads to an underestimation of the available capacity of the sections (Pic. 4). But the existing automatic blocking design does not allow to quickly change the arrangement of track lights based on a real braking distance [6]. The need for this can be seen from the graph in Pic. 5, which shows how changing the maximum allowed train speed should change the length of the block sections. This option, however, is possible only in the near future with the use of satellite navigation, when the use of track lights and rail chains will terminate [5].

A reasonable reduction in the length of block sections with a three-digit auto-lock allows to reduce the inter-train interval (Pic. 6).

With automatic blocking, the movement of the trains «under the green to the green light of the traffic light» is accepted, i.e. the maximum permissible speed and minimum inter-train interval should ensure that trains only follow the green indication of traffic lights [8]. This is ensured by the spatial (S) and temporary (I) intervals between trains:



Pic. 4. The relationship between the average length of the block-sections and the available throughput of the site.



Pic. 5. Change in the average length of the block sections, depending on the maximum permissible train speed for maintaining the available throughput capacity of the site.

$S = Z \cdot l_{bl} + l_p$;
$I = Z \cdot l_{bl} + l_p \cdot \upsilon_h$,
where l_{bl} – length of the block-section; l_p – length of the train; v_h – running speed of the train.

The nonidentity of the spatial (S) and temporal (I) intervals is caused by the unequal plan and the longitudinal profile of the track and the different speed of the trains. The minimum and maximum values of the spatial and temporal intervals in the sections may differ by 2–3 times (Pic. 7).

The nonidentity of the temporary (I) intervals, apart from the above reasons, can be caused by the limitations of the speed of the trains, their acceleration when starting from the site, slowing down at stops and testing the auto brake in the first two block sections (after the traffic light). The increase in the range of time interval distribution is also associated with the parallel laying of the «thread» of the traffic schedule for freight, suburban and passenger trains (Pic. 8).

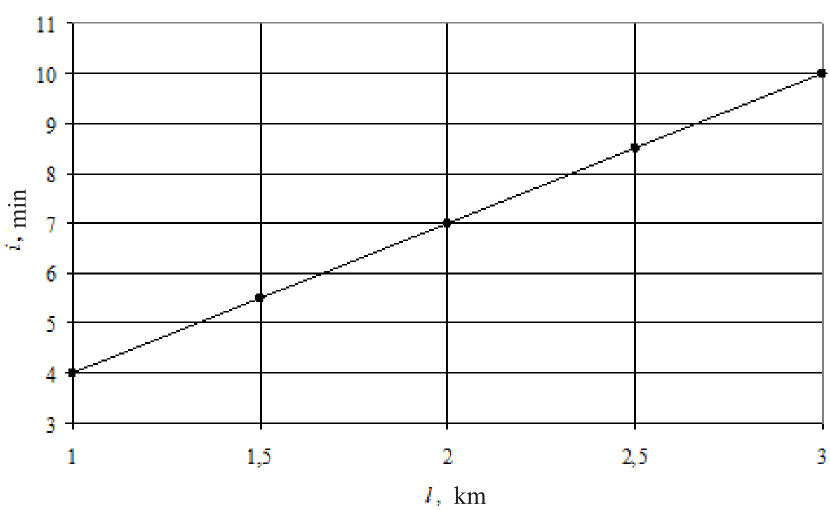
With three-digit automatic blocking, the following trains are delineated at the same time by at least three block sections, proceeding from this and taking into account the calculated inter-train interval with which the trains move at the established speed, they choose the places of installation of passing traffic lights on the hauls. The length of the block sections must be no less than the stopping distance with full service and automatic braking after the train passes a traffic light with a yellow signal with the maximum speed realized at the given place of the track. It is assumed that the train is provided with a minimum brake pressing in accordance with the current regulations [4].

Braking curve and direct control

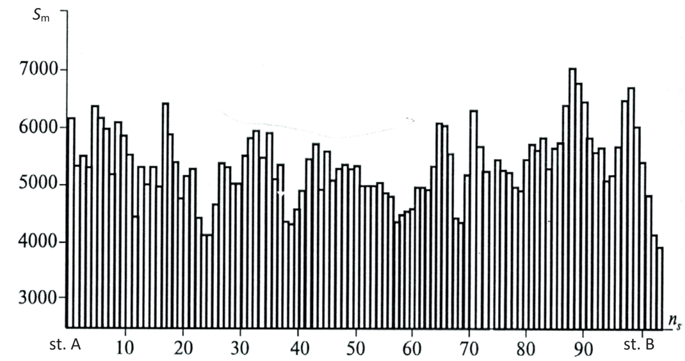
Arrangement of passing traffic lights to ensure minimal delineation of trains by three braking distances in real train operation is subject to the influence of various additional factors and does not allow realizing the estimated throughput. Therefore, on the network, the length of the block sections, determined by the inter-train interval, is considerably longer than the length required for the safe movement of trains (Pic. 9).

Among the additional factors affecting the length of the block sections, there are non-synchronism of train traffic, over-graphic speed limits, differences in the passing of stations (with or without a stop, traffic along the main or lateral tracks), etc.

With strict observance of the distance between the passing traffic lights equal to the braking distance, the non-synchronism of train traffic and the presence



Pic. 6. Influence of the lengths of block sections on the inter-train interval.



Pic. 7. Spatial intervals between trains on the section when following on the green indications of traffic lights.

of speed limits will result in the trains following the alternating readings of the green and yellow signals. To maintain the maximum permissible speed in these conditions, it is possible to use a four-digit auto-lock or a three-digit auto-lock, but a four-digit ALSN. Both these decisions, with the current restriction of the speed of trains to the yellow traffic light, will cause an increase in the inter-train interval and a reduction in available throughput.

To bring the lengths of the block sections into line with the braking distance for the non-synchronous movement of trains and the presence of speed limits, it is advisable to consider the movement of trains at the yellow indication of the traffic light without reducing the speed. It is possible because the yellow light of the traffic light protects an in-front free block section, whose length is not less than the braking distance, and this is enough to stop the train, which is at the maximum permissible speed. Why to reduce the speed of the train immediately after the passage of the green light? The train must pass the block-section between the green and yellow lights at the most probable speed. Moreover, the existing automatic brake control systems provide: measuring the actual speed of the train and comparing it with the permissible traffic conditions; measuring the efficiency of train brakes; giving the driver warning signals about the need to turn on the brakes to reduce the speed, etc.

Automatic brake control systems are divided into auto stops and automatic control systems. Auto stop is a set of devices on the locomotive, designed to automatically stop the train before the prohibiting traffic light signal in the event of loss of vigilance by the driver. The automatic control system, in contrast to the auto-stop, performs the aiming service braking before the prohibitions of traffic lights and the speed limits. Such systems effectively prevent the passage of traffic lights with a prohibitory indication, and there is no need to limit the speed of the train before the yellow traffic light. Unreasonable decrease in speed significantly worsens the capacity of the railways.

Increasing the efficiency of the automatic brake control system can be facilitated by the use of speed control curves during braking (Pic. 3), which are built on the basis of information on the parameters of the train (braking coefficient, braking mode, train length, etc.), track parameters (longitudinal profile, coupling conditions, etc.) and target safety parameters for different modes.

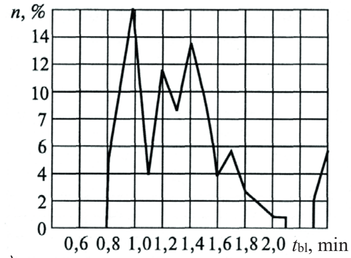
The speed control curve for emergency braking provides a guaranteed deceleration. Calculation of deceleration in this case takes into account only safely operating braking systems. The curve always ends at the place of controlled stop.

The service braking curve controls the deceleration, which is calculated taking into account the braking systems, not all of which are safe. This deceleration is longer than guaranteed during emergency braking. The curve ends at the obstacle. When the values of this curve are exceeded, full service braking is activated.

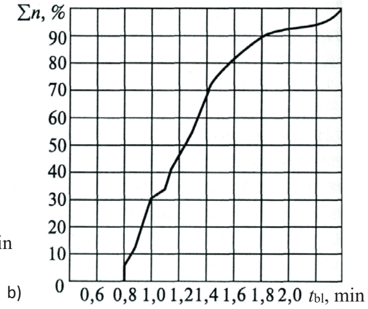
The control curves of speed during braking can be both in the memory of a personal computer, and can be calculated promptly during the trip.

The displayed speed control curve indicates to the driver the timing of the traction and brake activation. The IP point on the curve informs the driver that he is approaching the place where it is necessary to start braking the train.

Observance of the calculated braking distance can significantly shorten the length of the block sections and increase the capacity of the lines.

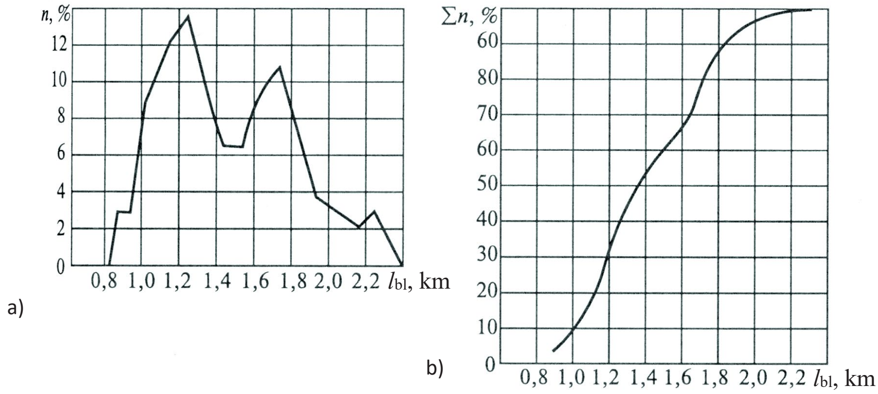


a)



b)

Pic. 8. Differential (a) and integral (b) time distribution curves of trains on one of the sections.



Pic. 9. Differential (a) and integral (b) curves for distribution of the lengths of block sections on one of the sections.

Conclusions.

1. It should be taken into account that the existing requirement to reduce the speed of trains before the yellow and red readings of traffic lights allows reducing the braking distance and the length of the block sections.

2. On the sections of railways, the maximum permissible speed is set at a level lower than that stipulated in the PTE, and a large number of train speed limits are applied, which reduces the length of the block sections.

3. The actual length of the block sections is often considerably larger than the estimated length, which unreasonably increases the inter-drive interval and reduces the throughput of the sections.

4. To stop the train under the most unfavorable conditions, one stopping distance is sufficient, which makes it unnecessary for the train to move «from green to green» indication of the traffic light and maintain the distance between the trains at a minimum of three block sections (three brake sections).

5. Reduction of the braking distance, the length of the block sections and their number makes it possible, without large investments, to increase the carrying capacity, especially of the freight intensive areas.

6. To ensure the minimum required interval between trains will be possible with the use of satellite radio navigation systems which will help to regulate the movement of trains without floor lights and rail chains.

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Article received 06.06.2018, accepted 21.08.2018.