**Rationing of Intermediate Intervals of Freight Trans Movement**

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**Abstract.** The main objective of the work is to regulate the headway intervals of freight trains movement on three-aspect block sections, taking into account random factors affecting the process. To achieve this goal, analytical analysis, tabular methods, and mathematical modeling were used. The study analyzed the time norms required to reach the block signals for cases with unrestricted and restricted block section lengths (2.6 km), considering the set and permissible speeds for freight trains on the section. Random factors influencing speed restrictions in the initial block section during train movement were identified. A mathematical model was developed to regulate the time taken to travel the distances to the block signals (i), (i+1), and (i+2) based on the time affected by random factors. The developed mathematical model allows for ensuring train movement safety by analyzing the time spent by freight trains to cover the distance to the block signals in the initial block section at the set speed due to repair works.

**Keywords:** Regulation, interval, train movement, modeling, block section, railway section, throughput capacity

**INTRODUCTION**

The main task of railway transport is to safely and efficiently deliver cargo and passengers to their destinations in the shortest possible time [1, 2]. In this regard, it is important to properly regulate the time intervals when trains travel the distance from point A to point B.

In regulation, constant factors such as the technical equipment of railway sections, the technical condition of rolling stock, and the management system are taken into account. However, factors that exert random effects during train operations are not considered [2, 3]. These include issues such as poor communication among employees of enterprises operating within the same technological system, lack or inaccuracy of information, and various hidden time losses in the work process [2, 3, 4] (such as the incompetence of train dispatchers or engineers, delays in maintaining regulatory documents, employees' indifferent attitude toward their work, failure to give timely orders on warnings, incorrect indication of parameters at places where repairs are being conducted, etc.). In this regard, it is advisable to develop a new approach to the regulation of interval times for freight train movements, which determines the main budget indicators of railway transport.

**METHODS**

Many scientists at different times have conducted research in the field of increasing the capacity of railway sections, regulating, reducing, and standardizing the interval times between trains [5, 6, 7]. However, these works have not sufficiently studied the impact of random factors that lead to an increase in the time standards spent during train operations. In particular, in the research [7, 8, 9] the schematic representation of train movements in three-signal block sections on railway sections equipped with automatic blocking systems is shown (Figure 1).



**FIGURE 1.** The scheme of the intermediate interval for freight trains at a three-character block section of the section equipped with automatic blocking

At the same time (Fig. 1) the author determined the length of block sections for freight trains weighing 6,500 tons and 1,05 km long [10]

(1)

|  |  |
| --- | --- |
| here | interval time of the initial three-character block section, minutes; |
|  | train length, *km*. |
|  | the set speed of freight trains on the stages, *km/h*. |

According to the technical usage rules [12], the distance limit between block sections of a section equipped with automatic blocking is set at 2,6 km. The author has studied the changes in interval times for freight trains in cases where the length of block sections is limited according to [12] (limited) and in cases where it exceeds that length (unlimited (see Figure 2).

**FIGURE 2.** Graph of the dependence of the duration of movement of trains on the three-character block section lengths at a speed of 70 km/h

According to the analysis results, it was determined that at the block section length limit of 2,6 km, the interval time for freight trains is equal to 0 in 7,5 minutes. Thus, it can be seen that the interval time for freight trains with equal initial block section lengths at the crossing is appropriate for sending trains from the station with a duration of 8 minutes. The time for freight trains to cover the initial (*i*) block section length until the passing signal is determined by the following expression [10, 11].

(2)

The times spent by the freight train to cover the distances to the passing signals of the block sections (*i*+1) and (*i*+2) (see Figure 1) are determined by the following expressions [11].

(3)

(4)

|  |  |
| --- | --- |
| here | the braking distance for freight trains is from v to vper km; |
|  | the allowed speed until the yellow light of the passing signal at the crossing is accepted as 50 km/h [14]. |

The requirement to consider the braking time [14] must be taken into account when calculating the distance covered by the train to the passing signal (*i*+2) according to expression (4). Therefore, the time spent to cover the distance to the passing signal (*i*+2) is determined by the following expression [10].

(5)

|  |  |
| --- | --- |
| here | braking time for trains during the period from x to y, in minutes. |

The time taken for the train to cover the distance to the passing signal (*i*+2) while decelerating from the allowed speed to 20 km/h [14] is determined by the following expression [10, 11].

(6)

|  |  |
| --- | --- |
| here | stopping distance of trains (at speeds from to ), *km*; |
|  | block-section to the border, km. |

The time of movement of the train (*i*+2) to the pedestrian traffic light when braking at a speed from 20 km/h to 0 km/ h is determined by the expression [10]

(7)

|  |  |
| --- | --- |
| here | train braking time (when exceeding the speed limit up to 20 km/h) |
|  | the stopping distance of trains (at speeds from 20 km/h to 0) [13], *km*. |

**RESULTS AND DISCUSSION**

Initially, the random influencing factor, namely speed-limiting warnings, was taken into account in the normalization of the interval times for freight trains (see Figure 3).



**FIGURE 3.** The movement scheme of freight trains in a three-symbol block section of a track equipped with automatic blocking, where the speed of movement is limited

A mathematical model has been developed for regulating the intervals of freight trains, taking into account random factors affecting the distances covered by trains up to the signals of block section (*i*), (*i*+1), and (*i*+2).

For the development of the mathematical model for regulating the intervals of freight trains, the following conditional symbols have been accepted:

|  |  |
| --- | --- |
| here: | the length of the area where repair work is being carried out, in *km*; |
|  | the speed of the train in the area where repair work is being carried out, in *km/h*; |
|  | the time taken for the train to traverse the area where repair work is being carried out, in *minutes*; |
|  | the time taken for the train to reach the (*i*) passing signal, considering the warning given in the initial block section, in *minutes*; |
|  | the time taken for the train to reach the (*i*+1) passing signal, considering the warning given in the initial block section, in *minutes*; |
|  | the time taken for the train to reach the (i+2) passing signal, assuming an unlimited length of the block section, in *minutes*; |
|  | the time taken for the train to reach the (*i*+2) passing signal, assuming a limited length of the block section, in *minutes*; |
|  | the time for the train to decelerate to the given warning point, in *minutes*; |
|  | the time for the trains to accelerate after the given warning point, in *minutes*; |
|  | the deceleration of the trains up to the given warning point, |
|  | the acceleration of the trains after the given warning point, |
|  | the length of the deceleration zone for the trains up to the given warning point, in meters, *m*; |
|  | the length of the acceleration zone for the trains after the given warning point, in meters, *m*. |

Considering random influencing factors, the following conditions have been established for the mathematical model of regulating freight train intervals:

The simplified forms of expressions (2) and (3) with mathematical laws are as follows

(8)

(9)

As a result, it is proposed to determine the time norms for trains to traverse the distances to the (i), (i+1), and (i+2) passing signals in both unlimited and limited block section lengths   
(2,6 km) using the following expressions (10) to (13).

(10)

(11)

(12)

(13)

In this case, the time spent by the train to traverse the area where repair work is being carried out is determined by the following expression

(14)

The time for the train to decelerate and accelerate to the given warning point is determined by the following expressions

(15)

(16)

The deceleration and acceleration of the train to the given warning point are determined by the following expressions

(17)

(18)

Taking into account random influencing factors, the mathematical model for regulating the time taken by freight trains to traverse the distances to the (i) and (i+1) passing signals has been developed in the form of the following expressions:

(19)

(20)

In traversing the distance to the (i) and (i+1) passing signals, the values of the distance to the (i+2) passing signal are determined through expressions (12) and (13), taking into account the parameters of expressions (19) and (20).

The results obtained from the mathematical model of the method for regulating the minimum interval times to the (*i*), (*i*+1), and (*i*+2) passing signals when the speed of freight trains is limited to 25 km/h in the initial block section are presented in Tables 3 and 4.

**TABLE 3.** The results of the time norms obtained from the mathematical model for the case where the speed of freight trains is up to 25 km/h in a certain part of the initial block section and the block section length is unlimited

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  | planned movement | movement with a brake |
| 6,0 | 2,0 | 2,4 | 4,0 | 4,1 | 4,1 |
| 6,5 | 2,2 | 2,6 | 4,3 | 4,5 | 4,5 |
| 7,0 | 2,4 | 2,7 | 4,6 | 4,8 | 4,8 |
| 7,5 | 2,6 | 2,8 | 4,9 | 5,1 | 5,1 |
| 8,0 | 2,8 | 3,0 | 5,2 | 5,4 | 5,4 |
| 8,5 | 3,0 | 3,1 | 5,6 | 5,7 | 5,7 |
| 9,0 | 3,2 | 3,3 | 5,9 | 6,0 | 6,0 |
| 9,5 | 3,3 | 3,7 | 6,3 | 6,5 | 6,5 |
| 10,0 | 3,5 | 3,8 | 6,7 | 6,8 | 6,8 |
| 10,5 | 3,7 | 3,9 | 7,0 | 7,1 | 7,1 |
| 11,0 | 3,9 | 4,1 | 7,3 | 7,4 | 7,4 |

**TABLE 4.** The results of the time norms obtained from the mathematical model for the case where the speed of freight trains is up to 25 km/h in a certain part of the initial block section and the block section length is limited to 2,6 km

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  | planned movement | movement with a brake |
| 6,0 | 2 | 2,4 | 4,0 | 4,1 | 4,1 |
| 6,5 | 2,2 | 2,6 | 4,3 | 4,5 | 4,5 |
| 7,0 | 2,4 | 2,7 | 4,6 | 4,8 | 4,8 |
| 7,5 | 2,6 | 2,8 | 4,9 | 5,1 | 5,1 |
| 8,0 | 2,6 | 3,5 | 5,6 | 5,7 | 5,7 |
| 8,5 | 2,6 | 4,2 | 6,2 | 6,4 | 6,4 |
| 9,0 | 2,6 | 4,8 | 6,9 | 7,0 | 7,1 |
| 9,5 | 2,6 | 5,5 | 7,5 | 7,7 | 7,7 |
| 10,0 | 2,6 | 6,1 | 8,2 | 8,3 | 8,4 |
| 10,5 | 2,6 | 6,8 | 8,9 | 9,0 | 9,0 |
| 11,0 | 2,6 | 7,4 | 9,5 | 9,7 | 9,7 |

A comparative analysis of the results obtained using the mathematical model (Tables 3 and 4) was carried out. According to the analysis results, the time norms and for the distances covered by freight trains to the passing signals can increase (as shown in Tables 1 and 2) using the developed mathematical model. Based on these results, the intervals for dispatching freight trains from the station to the section, the schedule times, and the section's throughput capacity values will change.

To cover the distance to the (i+3) passing signal in the section, if both the yellow and red lights of the locomotive signal are illuminated at the same time [14], the train's speed must be reduced to 20 km/h, and the train must stop in front of the first passing signal in the opposite direction. Therefore, the time norms for covering the distance to the (i+3) passing signal were not determined, as the time norms are lower than the speed values specified for warnings about random influencing factors on the trains in the initial block section.

**CONCLUSIONS**

It has been proven that the values of the established intervals for freight trains increase due to random influencing factors in the block sections of the section equipped with automatic blocking.

When regulating the interval times for freight train movement, it is appropriate to consider the parameter values of and .

The mathematical model developed, taking into account random influencing factors in the three-signal initial block section, provides the following capabilities when regulating freight train interval times:

regulating freight train intervals based on the established, permitted, and specified speed values in sections of the railway;

improving the level of safety for freight train movement by considering the time norms for random influencing factors that limit speed in the three-signal block section;

analyzing the time norms for covering the distances to the (*i*), (*i*+1), and (*i*+2) passing signals in both unlimited and limited (2,6 km) cases of three-signal block section lengths, based on random influencing factors;

determining the capacity of sections in a three-signal block section equipped with automatic blocking, taking into account the values of random influencing factors.

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