Methods for calculating and analyzing the capacity of a railway line with mixed traffic

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Abstract. This paper considers methods of determining the capacity of railway lines with mixed traffic. This issue is relevant, since the calculation with the help of standard analytical formulas often does not correspond to the actual existing capacity of the railway line. In connection with this circumstance, the paper considers the method of calculating the capacity of the railway line using simulation modeling, the results of which are closer to the real values of the available capacity.

1 Introduction

The problem of this study is the way to calculate the capacity of railway lines with mixed traffic. Mixed traffic is the organization of traffic on the railway line, when there is a movement of trains of different categories on one polygon. Since this paper considers the Moscow - St. Petersburg railroad, mixed traffic refers to high-speed and long-distance trains. This line also carries commuter trains, but in order to optimize the simulation model, they will not be taken into account.

In the process of mixed traffic there are inevitably numerous overtaking by trains of faster high-speed categories of trains of slower categories. This in turn reduces the number of trains that can be passed on the railway line. In addition, the timetable provides for technological windows - breaks in traffic, during which the railway infrastructure is serviced [1]. These aspects affect the value of the available capacity of the railway line, which is determined mainly by analytical calculations using standard formulas that give errors relative to actual values, as they do not take into account all aspects of the passage of trains. The relevance of the article lies in the application of simulation modeling, which makes it possible to take into account these aspects. The subsequent correction of analytical formulas by introducing the coefficient of simulation modeling is a scientific novelty.

2 Literature Review

A similar issue was considered in an article published in the second issue of 2021 of the journal "Railway Transport" by well-known experts A.F. Borodin, G.G. Gorbunov, A.Yu. Sokolov, A. E. Smirnov, I. R. Gurgenidze, S. V. Kalinin and A. P. Kozlovsky. They reviewed the issue of rational use of station capacity and its increase through the introduction of

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interval control of train traffic. The article provides a classification of interval train control systems. The paper also provides a scheme of a simulation model that simulates the work of a railway station and allows you to build models of train schedules. However, there is no analysis of analytical formulas in the work [2].

The issue of simulation modeling of railway traffic was also considered in many foreign publications [3-11].

3 The Order of Building a Simulation Model

The simulation model is built using the AnyLogic software package. Most of the blocks in the model belong to the railway library, but some of them are taken from the library of simulation processes. First of all, we build a railroad polygon, using the railroad track, and then we mark the separate points on it with points. We take milliseconds as the unit of model time, and we find the route speed of the train relative to the train schedule given in Table 1. Its equivalent route speed is recalculated through the coefficient of model speed, and in relation to it determine the sectional speeds of long-distance trains. We do the length of the polygon is 17.75 m, as due to the peculiarities of the program complex to build a polygon model length equivalent to the real distance is not possible [12]. We build the simulation model for even and odd directions separately. We find the length of polygon between intermediate railway stations according to [13], [14], [15], [16].

We start the block part of the simulation model with the trainSource block of the railway library. We apply the block selectOutput of the simulation library to separate the processes. As an example, consider the assignment of the Peregrine train number 752a, running from Moscow to St. Petersburg for 3 hours and 30 minutes. We apply the trainMoveTo block from the railway library to move the train to our desired point. At the end of the simulated process we use the trainDispose block from the railway library. To analyze the statistics of the trains’ running time, use the timeMeasureStart and timeMeasureEnd blocks of the Process Modeling Library between the selectOutput and trainMoveTo blocks, respectively, and between trainMoveTo and trainDispose. Finally, we add a histogram and specify timeMeasureEnd as the data source. If it is necessary to simulate a stop at an intermediate station, specify the necessary point on the railroad track in the trainMoveTo block, and then use the delay block, where in the delay time field we enter a value based on 5 milliseconds = 1 minute of standby. Similarly, we build all the appointments of high-speed and long-distance trains for each direction separately. Connect the blocks with connector connector.

Allocate the simulated threads manually to their destinations. In order to implement this operation, we introduce a variable trainSizeWithLoco with an integer value (int), which we change in the editbox field by writing the integer value manually. Then in each block of selectOutput we use the allocation by condition, which we then write as a function

\[
\text{entity.size()} == j,
\]

if j – value from 1 to n; n – number of appointments.

We will collect statistics on the time of trains after analyzing the analytical formulas on the basis of histogram data.

4 Order of Analysis of Analytical Formulas

Let's analyze the standard formula for determining the available capacity [1]. It has the following form:
Let's analyze the standard formula for determining the available capacity \[ N_{max} = \frac{(1440-t_{tech})}{t_p}, \alpha_n, \] (1)

if \( t_{tech} \) – daily time budget for infrastructure maintenance and repair;
\( t_p \) – design interval between trains;
\( \alpha_n \) – coefficient of reliability of infrastructure and rolling stock, we take equal to 0.96 [1];

The inter-train interval of formula (1) is determined by formula 2: [1]

\[
I_p = \frac{0.5L_{t1}+L_{bl1}+L_{bl2}+0.5L_{t2}}{v_{av}16.7} + t_s;
\]

Where \( L_{t1}, L_{t2} \) – the length, respectively, of the train ahead and behind;
\( L_{bl} \) - the distance the second train travels in the time it takes for the driver to perceive the signal of the short-range traffic light;
\( L_{bl1}, L_{bl2} \) – the length of the first and second, respectively, block sections relative to the train ahead;
\( v_{av} \) - average speed of trains along block sections;
\( t_s \) - the time to perceive changes in the traffic light, we take equal to 0.05 min.

Using simulation modeling we find the value of the calculated intertrain interval \( I_r \), by changing the average speed indicator. To obtain this value, we use the schedule of passenger and fast trains between Moscow-Passazhirskaya and St. Petersburg-Gravny stations for January 14, 2022. This date is chosen as the most optimal in terms of transport resistance. Table 1 below shows the movement of trains between these stations [17].

### Table 1.
Schedule of high-speed and passenger trains between Moscow-Passazhirskaya-Kazanskaya and St. Petersburg-Gravny stations.

<table>
<thead>
<tr>
<th>№ train</th>
<th>Departure</th>
<th>Arrival</th>
<th>№ train</th>
<th>Departure</th>
<th>Arrival</th>
</tr>
</thead>
<tbody>
<tr>
<td>030</td>
<td>00:15</td>
<td>10:13</td>
<td>119</td>
<td>00:12</td>
<td>09:52</td>
</tr>
<tr>
<td>020</td>
<td>00:20</td>
<td>08:59</td>
<td>711</td>
<td>00:20</td>
<td>05:50</td>
</tr>
<tr>
<td>016</td>
<td>00:41</td>
<td>09:13</td>
<td>159</td>
<td>02:04</td>
<td>10:16</td>
</tr>
<tr>
<td>082</td>
<td>02:03</td>
<td>10:35</td>
<td>751</td>
<td>05:30</td>
<td>09:00</td>
</tr>
<tr>
<td>090</td>
<td>02:38</td>
<td>12:07</td>
<td>755</td>
<td>06:40</td>
<td>10:43</td>
</tr>
<tr>
<td>752</td>
<td>05:45</td>
<td>09:15</td>
<td>757</td>
<td>06:50</td>
<td>10:52</td>
</tr>
<tr>
<td>756</td>
<td>06:50</td>
<td>10:45</td>
<td>759</td>
<td>09:00</td>
<td>12:58</td>
</tr>
<tr>
<td>758</td>
<td>07:00</td>
<td>11:04</td>
<td>761</td>
<td>09:10</td>
<td>13:05</td>
</tr>
<tr>
<td>760*</td>
<td>09:20</td>
<td>13:20</td>
<td>171</td>
<td>12:11</td>
<td>23:18</td>
</tr>
<tr>
<td>762</td>
<td>09:40</td>
<td>13:32</td>
<td>767</td>
<td>13:00</td>
<td>17:00</td>
</tr>
<tr>
<td>172c</td>
<td>11:26</td>
<td>21:05</td>
<td>769</td>
<td>13:10</td>
<td>17:10</td>
</tr>
<tr>
<td>714</td>
<td>14:40</td>
<td>20:00</td>
<td>737</td>
<td>13:52</td>
<td>19:39</td>
</tr>
<tr>
<td>726</td>
<td>15:21</td>
<td>22:20</td>
<td>771</td>
<td>15:00</td>
<td>18:55</td>
</tr>
<tr>
<td>772</td>
<td>15:30</td>
<td>19:25</td>
<td>773</td>
<td>15:10</td>
<td>19:05</td>
</tr>
<tr>
<td>774</td>
<td>15:40</td>
<td>19:25</td>
<td>725</td>
<td>15:16</td>
<td>21:58</td>
</tr>
<tr>
<td>776</td>
<td>17:30</td>
<td>21:15</td>
<td>775</td>
<td>17:00</td>
<td>20:57</td>
</tr>
<tr>
<td>778</td>
<td>17:40</td>
<td>21:35</td>
<td>777</td>
<td>17:10</td>
<td>21:05</td>
</tr>
<tr>
<td>160</td>
<td>18:45</td>
<td>02:02</td>
<td>779</td>
<td>19:00</td>
<td>22:58</td>
</tr>
<tr>
<td>780</td>
<td>19:30</td>
<td>23:25</td>
<td>781</td>
<td>19:10</td>
<td>23:13</td>
</tr>
<tr>
<td>136c</td>
<td>19:35</td>
<td>05:01</td>
<td>081</td>
<td>20:04</td>
<td>04:35</td>
</tr>
<tr>
<td>782</td>
<td>19:40</td>
<td>23:44</td>
<td>089</td>
<td>20:32</td>
<td>04:53</td>
</tr>
<tr>
<td>132</td>
<td>22:00</td>
<td>07:19</td>
<td>783</td>
<td>20:50</td>
<td>00:35</td>
</tr>
</tbody>
</table>

3
Calculations can be made with complication of the modeling cycle and inclusion of calculations by the methods outlined, for example, in papers [18-20]. Taking into account the time of departure and arrival of trains and intermediate stops, we find the value of the average route speed of the train on each of the sections of the polygon by the following formula 3.

\[ V_m = \frac{L_r \cdot 1000}{t_m \cdot 3600} \]  

(3)

where \( L_r \) – the length of the Moscow-St. Petersburg railroad range, assumed to be 645.5 km; 
\( t_m \) – travel time,

In order to translate the obtained velocity into the scale of the simulation model, we calculate the coefficient of model velocity. The formula for it is presented below.

\[ K_{vm} = \frac{L_r \cdot 1000 \cdot t_m \cdot 60}{36 \cdot 366} \]  

(4)

\[ K_{vm} = \frac{645.5 \cdot 1000 \cdot 3.5 \cdot 60}{36 \cdot 366} = 2181.97 = 2182 \]  

(5)

Below is an example of calculating the average route speed of a Sapsan train number 752a, running from Moscow to St. Petersburg without intermediate stops.

\[ V_m = \frac{645.5 \cdot 1000}{3.5 \cdot 3600} = 51.23 \text{ m/c} \]

\[ V_{mm} = 51.23 \cdot 2182 = 111784 \text{ m/c}. \]

The values of acceleration and deceleration speeds are 3 m/s² and 2 m/s², respectively. We translate them into the model velocity:

\[ V_{acc} = 3 \cdot 2182 = 6546 \text{ m/c2}, \]

\[ V_{decs} = 2 \cdot 2182 = 4364 \text{ m/c2}. \]

Next, we will automate the calculations. Figure 3 below shows the calculation of the model velocity in the software package Maple.

Next, it is necessary to check the found coefficient by means of simulation modeling. To do this, we run the simulation model and use the histogram to determine the traversal time.

As a result, we see that the simulated time corresponds to the actual time in minutes, so the coefficient is defined correctly.

After determining the value of the average route speed, we calculate the minimum intertrain interval between "Sapsan":

\[ I_p = \frac{0.5 \cdot 250 \cdot 4500 + 4500 + 0.5 \cdot 250}{51.23 \cdot 60} + 0.05 = 2.73 \text{ min} \]
To achieve a decrease in the value of the inter-train interval and increase the available capacity, we optimize this expression using the target function 6.

\[
F = \frac{0.5 \cdot L_{\text{f1t}} + L_{\text{b1t}} + L_{\text{b2t}} + 0.5 \cdot L_{\text{f2t}}}{V_{\text{ave}} \cdot 60} + t_b \rightarrow \min; \quad V_{\text{ave}} > 0
\] (6)

In the process of optimization we change the values of the lengths of trains and the average route speed, we use the length of block sections as restrictions.

In this case, we assume that the number of cars in the train should be at least 10, and the length of block sections - at least 3900 m (the braking distance of "Sapsan" at a speed of 250 km/h). The maximum speed is determined relative to the established for a particular section of the railway line, we take equal to the maximum on the section Okulovka - Malaya Vishera 70 m/s.

As a result of optimization, we achieve a reduction in the value of the minimum interval:

\[
l_{\text{opt}} = \frac{0.5 \cdot 250 + 3900 + 3900 + 0.5 \cdot 250}{70 \cdot 60} + 0.05 = 2.24 \text{ min}
\]

5 Conclusion

The results of modeling train traffic and analysis of the standard formulas for determining throughput capacity obtained in this study make it possible to significantly increase the accuracy of calculations, as well as to optimize measures to improve it, as according to the block diagram shown in Figure 7, there is an opportunity to reduce the inter-train intervals and thereby increase the available throughput capacity. These measures will make it possible to increase the number of trains and speed up their movement along the section, which in turn will lead to the improvement of passenger service.

Reference


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