1. Introduction

The graphic train schedule is a key document in railway transportation. It guarantees the train’s safety, fast and comfortable transportation of passengers and goods, efficient use of the rolling stock, all station’s operational consistency, the utilization of the infrastructure capacity and the provision of maintenance for all elements of the railway infrastructure. All graphic train schedules are developed by The National Railway Infrastructure Company through the „Graph Generator” system. The current research shows an approach to creating different variants of graphic train schedules, using the capabilities of MS Excel. The order in which the graphic schedules are developed is thoroughly described.

2. Data

2.1. Data Input

In order to use MS Excel for creating, managing and changing existing GTS, the data for the railways and the locomotives and trains which operate on them is needed.

- Tracks data
  - Section length – the distance between two stations/stops in km;
  - Maximum speed – the maximum speed allowed by the tracks, km/h.
- Locomotive, car and train data
  - Maximum speed – the maximum speed allowed by the locomotives, cars and trains, km/h.
- Dynamic characteristics – data for the positive and negative acceleration of the train in each segment of the route
  - Average acceleration for each speed interval.

2.2. Data throughput

The processing of the input data is done in two separate tables in two separate sheets one for both directions of the route. Each table should contain 48 columns. The number of rows depends on the number of stops/stations.

- Column A – station names, serial number or code.
- Column B – section length, “F”, km – the distance between two stations (given as the distance between a particular station and the previous one).
- Column C – distance travelled, L, km.

For row (station/stop) n:

\[ L_n = \sum_{i=1}^{n} L_{n-i} + L_s \]  

- Example: C12=C11+B12.

- Column D – station position, y. Choose one of two directions as the primary direction – \( y_a = L_a \). For the other (i.e. secondary direction) \( y_b = L_{route} - L_a \), where \( L_{route} \) is the length of the entire route.
- Column E: the maximum speed allowed by the tracks: \( V_s, \) km/h.
- Column F: the maximum speed allowed by the locomotive – \( V_L, \) km/h.

- Columns G, H and I: the maximum speed allowed by each train category: \( V_i, \) km/h. Column G – for fast trains (FsT), col. H – passenger trains (PT), col. I: freight trains (FrT).

- Columns J, K and L: operational speed: \( V_4, \) km/h, for FsT, PT and FrT in each segment. \( V_4 \) is 95% of the lowest of all three; \( V_1, V_2 \) and \( V_5, \) 5% being the safety coefficient.

*the number of train categories is optional; examples will be given with FsT, PT and FrT.

- Columns M, N and O: average positive acceleration (between 0 and \( V_4, a_p, \) m/s²), for FsT, PT and FrT.

- Columns P, Q and R: average negative acceleration (or deceleration) between \( V_4 \) and 0, \( a_n, \) m/s² for FsT, PT and FrT.

- Columns S, T and U: acceleration ratio: \[ k_i = \frac{a_i}{a_y} \] for FsT, PT and FrT.

- Columns V, W and X: distance travelled while accelerating for FsT, PT and FrT: \( S_1, \) km.

 Normally: \[ S_i = \frac{V_n^2 - V_{n+1}^2}{2a_i} \]

In this case: \( S_{ii} = \frac{(V_n)^2}{3.6} \times \frac{1}{2a_y} \times 0.001 \) km.

*If column positions are correct, \( S_{ii} \) for FsT for the first section is in cell VS and equal to \( s = 0.001 \times (SJS/3.6)^2 / 2 * M5)’’

- Columns Y, Z and AA: distance travelled while decelerating for FsT, PT and FrT: \( S_i = \frac{(V_n)^2}{3.6} \times \frac{1}{2a_y} \times 0.001 \) km.

\( S_2 \) for FsT for the first section is in cell Y5 and equal to \( s = 0.001 \times ((SJS/3.6)^2 / 2 * P5)’’

- Columns AB, AC and AD: \( S_{3i} = S_{ii} + S_{2i}, \) km, for FsT, PT and FrT.

- Columns AE, AF and AG: IF-function “NEDRMS” (Not Enough Distance to Reach Maximum Speed) for FsT, PT and FrT.

- DTA – distance travelled while accelerating; DTC – distance travelled while travelling with constant speed; DTD – distance travelled while decelerating.

\[ \text{Fig.1. Accelerating, traveling with constant speed, decelerating} \]
If \( l \) is equal to or greater than \( S_{3i} \), then \( DTA = S_{1} \), \( DTC = l - S_{1} \geq 0 \), \( DTD = S_{2} \). When \( S_{3i} \) is greater than \( l \) the text “NEDRMS” will appear in the cell for that particular row and for that particular train category. Example of IF - operator: 

\[ IF(SB5=AB5," NEDRMS") \]

If \( l \) is equal to or greater than \( S_{3i} \), no text will appear.

- **Columns AH, AI and AJ:** the time it takes a FsT, PT or FrT to travel between stations A and B and not stopping at either of them (transit): \( t_{ii} = \frac{1}{V_{ii}} \cdot 60 \) min. \( DTA=0, DTC=1, DTD=0. \)

- **Columns AK, AL and AM:** the time it takes a FsT, PT or FrT to travel between stations A and B, stopping at each of them:

\[ t_{2i} = \left( \frac{3,6 \cdot 10^{3} \cdot (l - S_{ii})}{V_{ii}} + \frac{V_{ii}}{3,6 \cdot a_{ii}} \right) \cdot \frac{1}{60}, \text{min,} \]

\( DTA = S_{1} \),

\( DTC = l - S_{1} \geq 0 \),

\( DTD = S_{2} \).

\( I_{2} \) for FsT for the first section (cell AK5) is 

\[ =(3600*(SB5-AB5)/JS5/JS5*(3.6*M5)+JS5/JS5*(3.6*P5))/60* \]

- **Columns AN, AO and AP:** the time it takes for a FsT, PT or FrT to travel between the section A and B, stopping only at station B

\[ t_{3i} = \left( \frac{3,6 \cdot 10^{3} \cdot (l - S_{ii})}{V_{ii}} + \frac{V_{ii}}{3,6 \cdot a_{ii}} \right) \cdot \frac{1}{60}, \text{min,} \]

\( DTA = S_{1} = 0, \)

\( DTC = l - S_{1} - S_{2} = l - S_{1} \geq 0, \)

\( DTD = S_{2} = 0. \)

\( I_{3} \) for FsT for the first section is 

\[ =(3600*(SB5-Y5)/JS5/JS5*(3.6*M5)+JS5/JS5*(3.6*P5))/60* \]

- **Columns AQ, AR and AS:** the time it takes a FsT, PT or FrT to travel between stations A and B, and accelerating from (A):  

\[ t_{4i} = \left( V_{ii} \frac{3,6 \cdot 10^{3} \cdot (l - S_{ii})}{V_{ii}} + \frac{3,6 \cdot 10^{3}}{3,6 \cdot a_{ii}} \right) \cdot \frac{1}{60}, \text{min,} \]

\( DTA = S_{1} \),

\( DTC = l - S_{1} - S_{2} = l - S_{1} \geq 0, \)

\( DTD = S_{2} = 0. \)

\( I_{4} \) for FsT for the first section is 

\[ =(3600*(SB5-V5)/JS5/JS5*(3.6*M5)+JS5/JS5*(3.6*P5))/60* \]

- **Columns AT, AU and AV:** the time it takes a FsT, PT or FrT to travel between A and B where there is NEDRMS: \( I_{5} \).

The train travels in the section, reaching \( V \leq V_{4} \).

\( t^{'}: \) The time it takes the train to reach \( V. \)

\( t^{''}: \) The time it takes the train to decelerate from \( V \) to 0km/h.

\( S^{'}: \) The distance travelled, while accelerating for \( t^{'} \) minutes.

\( S^{''}: \) The distance travelled, while decelerating for \( t^{''} \) minutes.

\( DTA = S^{'} < S_{1}, \quad DTC = l - S^{'} = S^{''} = 0, \quad DTD = S^{''} < S_{1}. \)

\[ k_{i} = \frac{a_{ii}}{a_{ii}} = \frac{t_{ii}^{'} = S_{ii}}{t_{ii} = S_{ii}} = \frac{t_{ii}^{'} = S_{ii}}{S_{ii}^{'}}. \]

\[ I_{5} = \frac{a_{ii} \cdot V_{ii}^{2}}{2} + \frac{a_{ii} \cdot V_{ii}^{2}}{2} + \frac{k_{ii} \cdot a_{ii} \cdot t_{ii}^{2}}{2} \]

\[ t_{ii}^{'} = \frac{2 \cdot l_{ii} \cdot k_{ii}}{(k_{ii} + 1) \cdot a_{ii}}, t_{ii}^{''} = \frac{2 \cdot l_{ii} \cdot k_{ii}}{(k_{ii} + 1) \cdot a_{ii}}. \]

In Excel it is calculated as 

\[ t_{ii} = \sqrt{\frac{2 \cdot 10^{3} \cdot (k_{ii} + 1) \cdot l_{ii}}{3,6 \cdot 10^{3} \cdot k_{ii} \cdot a_{ii}}} \]

\( t_{5} \) for FsT for the first section is 

\[ =\sqrt{\text{IF}((S5+1)*SB5/(MS5*SS5*1.8))} \]

\[ = \text{only valid when there is NEDRMS.} \]

3. **Graphic environment**

3.1. **Station (y) parameters**

The chart chosen for the GTS is Chart>standart type>XY(satter)> Scatter with data points connected by lines. Select two random adjacent empty cells for the data range. Click Next, remove the legend and Finish the chart, fig.2.

![Fig.2. Chart for the GTS](chart.png)

Click on the chart object and then right-click on the actual chart – Format Plot Area. Area=none. Right-click on the vertical axis (y) and press Format Axis>Scale,

Minimum = 0;

Maximum = (the length of the entire route).

*Examples will be given with a 205.2km route*.

Click on the horizontal (x) axis and press Format Axis>Scale, 

Minimum = 0; maximum = 24; Right click>chart options>axes. Remove Value Y axis and Value X axis. From gridlines – no Y gridlines.

In a new sheet create a table:

<table>
<thead>
<tr>
<th>STATION</th>
<th>0</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>station name 1</td>
<td>( y_{1} )</td>
<td>( y_{1} )</td>
</tr>
<tr>
<td>station name 2</td>
<td>( y_{2} )</td>
<td>( y_{2} )</td>
</tr>
<tr>
<td>station name (n-1)</td>
<td>( y_{n-1} )</td>
<td>( y_{n-1} )</td>
</tr>
<tr>
<td>station name n</td>
<td>( y_{n} )</td>
<td>( y_{n} )</td>
</tr>
</tbody>
</table>
Station name 1: contains the name (=‘cell name’) of the first station. \( y_1 \): the position of the first station, see input data, column
D. \( y_A =205.2 \) (route length) - A is the first station. \( y_n =0 \) (last station).

An example of such a table in MS Excel:

<table>
<thead>
<tr>
<th>STATION NAME</th>
<th>0</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sf</td>
<td>205.2</td>
<td>205.2</td>
</tr>
<tr>
<td>Zf</td>
<td>202.5</td>
<td>202.5</td>
</tr>
<tr>
<td>Gb</td>
<td>195.1</td>
<td>195.1</td>
</tr>
<tr>
<td>Vl</td>
<td>187.0</td>
<td>187.0</td>
</tr>
<tr>
<td>Do</td>
<td>181.3</td>
<td>181.3</td>
</tr>
<tr>
<td>Das</td>
<td>179.6</td>
<td>179.6</td>
</tr>
<tr>
<td>Mtl</td>
<td>178.6</td>
<td>178.6</td>
</tr>
<tr>
<td>Prr</td>
<td>175.3</td>
<td>175.3</td>
</tr>
<tr>
<td>Prr</td>
<td>172.5</td>
<td>172.5</td>
</tr>
<tr>
<td>Kra</td>
<td>170.5</td>
<td>170.5</td>
</tr>
</tbody>
</table>

Go to the chart, right click>series>name – =‘cell name’ which contains the station name, code or number
x values – the adjacent cells of the table, containing 0 and 24 (the same for each series) y values – the adjacent cells of the tables, containing \( y_1 \) and \( y_A \).

This will result in a horizontal line that runs through the entire width of the chart (from 0 to 24h). Repeat this process for each station, always using 0 and 24 as x-axis parameters. For each station-series right click>patterns: select a black line with no markers, thick for stations, thin for stops. From Data labels>Label contains select series name and y value, fig.3.

Optional – add two more series, both with all of the station’s positions as y-axis parameters, and a column with respective number of cells, each equal to 0 for the first series and 24 for the second series as x-axis parameters. Go to the chart, right click>data series>data labels - remove labels. Go to Patterns: select a thick, black line and choose a marker. Do this for both series: it illustrates where the stations/stops are on the y-scale.

3.2 Time scale

From chart options>gridlines select Value (X) axis – minor gridlines. Then by right clicking on a vertical gridline select format gridlines>scale: minimum – should already be 0; Maximum – should already be 24; Major unit – 1 - will display major gridline every hour; Minor unit – 0.1667 (1/6=0.1(6)) – will display minor gridline every 10 minutes. From chart options>axes: select value (X) axis. The blank graphic environment is shown on fig.4.

4. Trains

4.1 Adding trains

In a new sheet create two tables: one for each direction. Example sheet name: GTS. The number columns is equal to \( 19 + 2(N_{FsT} + N_{PT} + N_{FrT}) \), where N is the number of FsT/PT/FrT. Examples will be given with 15 FsT, 15 PT and 15 FrT travelling in each direction (45 trains per direction). The first row(s) should contain the necessary indications (user’s choice). Each table contains 4 subtables. 1st subtable: contains only one column with the station’s positions, relevant to all categories. 2nd subtable – 5 columns, containing \( l_1, l_2, l_3, l_4 \) and \( l_5 \) for the first category (FsT). Also in the 2nd subtable – a column, containing the stop durations, leave it empty for now. The next two columns (also in the 2nd subtable) are designated for the first FsT (ex.5601) – 8th column contains its x-axis value (time value) and 9th contains the duration of all the stops that are unique to 5601. The next two columns (10th and 11th, part of 2nd subtable) are for the second FsT in this direction (ex. FsT 5603) etc. The 2nd subtable ends with the last FsT. For each category there should be 6 columns (for \( l_1, l_2, l_3, l_4, l_5 \) and stop durations) and again two columns for each train. The cells containing \( l_1, l_2, l_3, l_4 \) and \( l_5 \) should be a function of the particular cell (=‘cell name’) from the previous sheet, which would ease any future manipulation.

The first row is used for indications (optional, user’s choice). From the row sidebar select each row that contains a station position except the ones that contain the first two stations. Holding Ctrl press on each row one by one and then right click>insert. These new empty rows will from here on be referred to as secondary rows. Starting from the first empty cell (which should be below the second station position) make all empty cells equal to the one above them. All columns of the secondary rows are empty except the first column – enter the value of the mandatory (minimum) stop durations. The other rows (from here on to be referred to as primary rows) contain the station positions \( l_1, l_2, l_3, l_4, l_5 \) for FsT, PT and FrT. To add FsT 5601 go the row that contains the first station position and the first of the two columns, designated for 5601 (should be H2). Enter the departure time value (x-axis) for 5601 in the decimal numeric system (ex. the decimal value of “quarter after 10 PM” is 22.25). Do not enter anything in the column to the right as this is the first station.
Depending on the type of travel choose \( t_1, t_2, t_3, t_4 \) or \( t_5 \). If for example the train stops at the next station (excluding NEDRMS-cases), then the train’s \( x \) (time) value in the second station should be \( H_3 = H_2 + C_3/60 \) (\( C_3 \) contains \( t_2 \) for the first section).

\[ H_4 \] should be \( \sim H_3 + SG_4/60 + 14/60 \), \( G_4 \) being the cell on the left, containing the mandatory (minimum) stop durations for all trains of this category and \( I_4 \) on the right containing the stop durations unique to 5601 (extra stop durations). Choose whether to use \( t_1, t_2, t_3, t_4 \) or \( t_5 \) for each section. The formula in each cell in the secondary rows is the same \( H_n = H_{n-1} + SG_n/60 + I_n/60 \). See fig. 5.

To create a new train simply copy the first column from 5601 (containing the \( x \)-values, not the extra stop durations) and paste it onto 5603. \( J_2 \) is now equal to \( H_2 \) and both trains have identical \( x \)-values. Enter new values for \( J_2 \) and then the extra stop durations for 5603. Do the same for all FsT. Repeat this process for PT and FrT. Repeat this process for the other direction.

To add 5601 to the chart right click on it and choose data>series>add. Name: =H1, \( x \) values – all \( x \) values, ex. =sheet name’$A$2:$A$99. If FsT 5601, 5603, 5605 etc. all depart and arrive in the same stations the selected \( y \) -values interval is the same.

Go to the chart, right click on the 5601 series and format data series. For all train categories do not show \( x \) values, \( y \) values. Enter new values for \( J_2 \) onto 5603. is now equal to \( H_3 \). Cell \( G_4 \) being the cell on the left, containing the numerical value of each of their \( x \) -value cells that do not exist, the numerical value of each of their \( x \) -value cells that do not exist. And example can be seen on fig. 4.

**NOTE**: a chart in MS Excel can support up to 255 series. This limits the number of trains \( N_{\text{trains}} \) the user can add \( N_{\text{trains}} = 255 - 2 - N_{\text{stations}} \).

The current example is for a route with 50 stations/stops, which means 203 trains for both directions.

Optional – for each series go to format data series>data labels and select series name. This would indicate the \( x \)-value on each of its data points. Where necessary you can delete any particular label by clicking on the exact data point and format data point>data labels - unselect series name.

### 4.2. Conflict-finder

Create a new sheet (example name “conflict-primary”). There are two types of conflicts:

- a conflict between two trains travelling in the same direction at the same time. Select the minimum amount of time \( t_{\text{min}} \) between two trains in a random cell. Cell \( K1 \) is used for that purpose in the example - \( f_{(K1)} = 4/60 = 0.0666[\text{min}] \)
- a conflict between two trains, travelling at the same time in the same section in different (opposite) directions. Only relevant in single-track sections of the route. Example – one train is travelling from station A to station B and a second train is travelling from B to A. A-B is a single-track section. \( t_{\text{min}} \) - single-track section safety time. The second train is allowed to depart from B (heading towards A) only \( t_{\text{min}} \) minutes after the first train arrives at B. In the example \( t_{\text{min}} \) is given in cell AD1:

\[ f_{(AD1)} = 2/60 = 0.033[\text{min}] \]

**EXAMPLE:**
15 FsT, 15 PT and 15 FrT travelling in each direction (total – 90 trains). Number of stations/stops – 50, therefore the number of train positions, relevant to the train’s \( x \)-values, is 2.50-2=98. The sheet must contain 45 tables, one for each train (45 per direction). Each table consists of 4 subtables, each 98 rows by 45 columns. Therefore each table is 98 rows by 180 columns plus extra columns for indications or sums (user’s choice).

1st subtable – contains the copied (or referred-to cells =’sheet name’, ‘cell name’) \( x \)-values of all trains in the primary direction.

2nd subtable – first IF-operator – finds conflicts between trains, travelling in the same direction. In the example the first row of the table is the 7th row of the sheet (previous rows used for indications \( t_{\text{min}} \) and \( t_{\text{min}} \)). Cell AT7 (AT-46th column) contains the first IF-operator: \( =IF(SA7=0; IF(ABS(SA7-AT7)>SK1; "", 1)) \). When the formula is dragged across the entire 2nd subtable “1” will appear in each cell where there is a conflict. AT7:104 compares the first FsT to itself, so is therefore deleted. The same should be done in each table – AT7:104, AU110:207, AV213:310 etc. should be deleted (AT-47th, AU - 48th, AV - 49th...) so as not to count each train’s numerical (fictional) conflict with itself. In the current example each table has 5 rows, containing indications and 1 empty row between each two tables. Designate a cell to sum up all cells from the 2nd subtable of each table (ex. =SUM(AD7:CL104)). After copying the formulas for each train (45 tables – should be around 4600 rows) sum up all those designated cells and divide the value by 2 – the result is the number of conflicts between trains, travelling in the primary direction. 

#conflict} *the first part of the function \( IF(SA7=0) \) is used to separate and exclude the non-existing trains. If there are two columns for trains that do not exist, the numerical value of each of their \( x \)-value cells for every section will be 0. Then, according to the formula, the interval between them would be 0 (0-0<\( t_{\text{min}} \)). The first part of the IF-formula weeds out the blanks so as not to report fictional/non-existing conflicts (conflicts between two trains, both of which does not exist). And example can be seen on fig. 4. – the segment shows parts of the first conflict-finders (2nd subtable) for the first and second FsT, travelling in the primary direction.
3rd subtable (columns 91:135) enter the copied x-values (or referred-to cells =‘sheet name’, ‘cell name’) of all trains travelling in the secondary direction.

Create/add a column before them and fill it with the numbers 1, 2, 3…98 (delete column after inverting), then select the entire subtable and invert it using the sort descending (Z-A) Excel-function. The upside down subtable gives the x-axis (time) values of all trains travelling in the secondary direction but relevant to the positions of the primary direction, not their own (x-values positions inverted to match the y-values positions of the primary direction).

4th subtable (last 45 columns – 136:180) – contains the second IF-operator, which finds conflicts between trains, travelling in different (opposite) directions in the same section at the same time. In the example t_min is given in cell AD1. Each (of all 45) table compares the 1st, 2nd etc. train from the primary direction with each train, travelling in the secondary direction. Example: “=IF($A7=0,” “IF(ABS($A110-B102)>$SK1,” ”, 1))” – the operator compares the first x-axis (time) value for the first FsT. In cell C2 enter “=B2*$A2”, where $A2 (constant column) is the first position, travelled distance, km, travelling speed, km/h, operational letters. Repeat the process for each table.

The operational parameters are the statistical characteristics of each train’s (or category’s) work. Create two new sheets – OP-prim and OP-sec for the primary and secondary direction (both directions have 98 positions). The primary direction will be used as an example. The table has 91 columns – (15.2+15.2+15.2+1).

Row 1 is used for indications. Copy the 98 position values to column A, starting from the second row. Columns B and C are for the first FsT, columns D and E are for the second FsT etc. The positions (column A) are relevant to all categories. In cell B2 enter “=IF(‘GTS’!H2>0,” “IF(ABS(SA7-CMT7)>SAD51,” ”, 1))”. The second IF-operator is only relevant to single-track sections of the route; delete the appropriate cells if there are two or more tracks.

Similarly, create a new sheet and 45 tables for the trains, travelling in the secondary direction. 3rd and 4th subtables not needed, since all trains from both directions have already been compared to all trains from the opposite direction in the previous sheet. The tables from this sheet are used to search for conflicts between two trains, both travelling in the secondary direction.

### 5. Operational parameters

The operational parameters are the statistical characteristics of each train’s (or category’s) work. Create two new sheets – OP-prim and OP-sec for the primary and secondary direction (both directions have 98 positions). The primary direction will be used as an example. The table has 91 columns – (15.2+15.2+1).

Row 1 is used for indications. Copy the 98 position values to column A, starting from the second row. Columns B and C are for the first FsT, columns D and E are for the second FsT etc. The positions (column A) are relevant to all categories. In cell B2 enter “=IF(‘GTS’!H2>0,” “IF(ABS(SA7-CMT7)>SAD51,” ”, 1))”. The second IF-operator is only relevant to single-track sections of the route; delete the appropriate cells if there are two or more tracks.

Similarly, create a new sheet and 45 tables for the trains, travelling in the secondary direction. 3rd and 4th subtables not needed, since all trains from both directions have already been compared to all trains from the opposite direction in the previous sheet. The tables from this sheet are used to search for conflicts between two trains, both travelling in the secondary direction.
H2:H99 contain all possible x-axis (time) values for the 1st FsT. In cell B101 enter “=MAX(G$2:G$99)”. Cells B100 and B101 give the staring time and end time, no matter which station the train departs from or arrives at.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>positions</td>
<td>5601</td>
<td>5603</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>205.2</td>
<td>1</td>
<td>205.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>202.5</td>
<td>1</td>
<td>202.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>202.5</td>
<td>1</td>
<td>202.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>195.1</td>
<td>1</td>
<td>195.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>B2=IF(G$1&gt;0,“1”,“0”)</td>
<td>1</td>
<td>195.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>B3=IF(G$1&gt;0,“1”,“0”)</td>
<td>0</td>
<td>187</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
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**Fig. 9. Operational parameters train-table**

In cell B102 enter “=(SUM(GTS!$G$2:$G$99)+SUM(GTS!I2:I99))*C101”, where $G$52:G$99 in GTS-sheet are all the mandatory stop durations, relevant for all FsT and I2:99 are all the stops, unique to the 1st train. Cell C101 will be explained later. In cell B103 enter “=B101-B100+0.0000000001” which gives the user the duration of the travel. The number 0.0000000001 will be explained later. In cell B105 enter “=MIN(C2:C99)” which are in the same sheet (OP-prim). In cell B106 enter “=MAX(C2:C99)”. These two cells give the user the position of the first and last station along the route of the route (prim). In cell B108 enter “=B107/B103” which will give the user the travelling speed (counting all stops). The number 0.0000000001 will be explained later. In cell B109 enter “=IF(B100>0,”1”,“0”)” and drag the formula all the way to cell B119.

**Fig. 10. Operational parameters, summary (statistics)**

Copy the entire table and paste it to the right twice – once for PT and once for FrT. It is however necessary to change the stops time formula (in the case of all FsT it’s the “$G$52:G$99” part of the formula). Then copy the entire sheet and paste it in sheet OP-sec. The only things that must be changed are the x-axis values – they are a reference to primary direction values on the GTS sheet, change them to the secondary direction values. Also, change the mandatory y stops in the formulas. Repeat the process for the secondary direction.

### 6. Conclusion

The system enables quick and easy development of graphic train schedules in a MS Excel environment. It can be used for:

- Educational purposes in the theory of graphic schedules,
- As a method for planning and forecast in preliminary studies,
- For researching and tracing routes,
- Graphic schedule variants development,
- As a conflict monitoring system,
- For the evaluation of different route’s operational indicators,
- For developing preliminary projects on train and locomotive coordination and passenger compositions.

### References