# Simulation Model of Belgrade Suburban Passenger Trains Service Using OpenTrack

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*Abstract* – **In this paper, simulation models, created in the OpenTrack simulation tool, were used to compare the proposed timetable with a variant in which all trains from and Lazarevac would be extended to Belgrade Center. This paper aims to analyze the effects of the increasing number of trains on part of Belgrade railway junction from Resnik to Belgrade Center. The results have shown that the section from Dedinje junction to Resnik has more than enough capacity for the increased number of trains. Also, the simulation results show us that when the number of trains increases by 40%, BG trains can operate without or with acceptable delays.**

*Keywords* – **railway, simulation, BG voz, OpenTrack.**

## I. INTRODUCTION

The constant increase of the population in big cities, the separation of the place of living from the workplace, and road traffic congestion led to the need to better organize and improve the public transport system as much as possible.

Planning and organization of public transport is a very important task that contributes to the better connection, integration, and functioning of different parts of the city.

Rail transport, as one of the key modes of public transport, plays a vital role in the development and modernization of the transport system not only on long distances but also in suburban and urban areas. One of the main advantages the suburban rail transport is its possibility of transporting a large number of passengers, independent of weather and time of day from suburban areas to the city center. Among other advantages of suburban rail transport, it is also important to mention that rail transport has a minimum effect on traffic jams, noise, and environmental pollution and destruction.

In many cities, rail transport is the main mode of passenger transport, which offers the best service. Public rail transport can be divided into metro, light railway, suburban lines, or tram systems. However, most of these systems are very expensive, and building them requires huge investments. Because of that we must analyze the rail traffic and create a simulation model which is very important as an input to a process of planning in railways.

Railway simulation is used to generate data on the number of lines, lines capacity, number of traveled passengers, train delays, travel times, and other output parameters. In the last two decades, many authors have used various simulation techniques, methods, programming languages, or specialized software to model railway traffic, like Petri Nets [1], Matlab [2], or software Open Track [3], [4].

## II. OPENTRACK SIMULATION SOFTWARE

The observed problem is solved by simulation. Simulation models are developed using the software package OpenTrack. OpenTrack was developed at the Swiss Federal Institute of Technology's Institute for Transportation Planning and Systems (ETH IVT). OpenTrack is a dynamic rail simulation software for continuous simulations. As such it simulates the behavior of all railway elements (infrastructure network, rolling stock, and timetable), as well as all the processes between them [5].

### A. Input data

The Open track manages input data in three modules: rolling stock (trains), infrastructure, and timetable. The software offers users the possibility to create their own databases. Once data has been entered into the software, it can be used in many different simulation projects.

In this paper, the main infrastructure database consists of the length of the block sections, number, and length of the station tracks and intersections, and location of the signals.

### B. Simulation process

During the simulation, OpenTrack calculates train movements under the constraints of the signaling system and timetable. All trains try to obey the given timetable. Occupied tracks and restrictive signal aspects may impede a train's progress.

OpenTrack uses a mixed continuous/discrete simulation process that allows a time-driven running of all the continuous and discrete processes (of both the vehicles and the safety systems) under the conditions of the integrated dispatching rules. Therefore, parameters including occupied track sections, signal switching times, and restrictive signal states all influence the train performance [3].

OpenTrack is a dynamic rail simulation program, which enables users to run the software in a step-by-step process and monitor results in real-time. This allows users to monitor the simulation in an animation mode so they can easily analyze possible conflicts, occupied tracks, reserved tracks, or signal aspects.

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## C. Output data

One of the major benefits of using an object-oriented language is the great variety of data types, presentation formats, and specifications that are available to the user. After a simulation run, OpenTrack offers some evaluations, and software can analyze and display the resulting data in the form of diagrams, train graphs, occupation diagrams, and statistics [6]. Similarly, users can choose to model the entire network or selected parts, depending on their needs.

## III. MODEL FORMULATION

To provide better services to public transport in Belgrade, following the example of other European cities, the city of Belgrade, in cooperation with the „Železnice Srbije", in 2010. implemented project „City railway - BG voz, new public transport" [7]. Over the past six years, this railway suburban system has been constantly upgraded with the introduction of new and the extension of existing lines.

Nowadays, in Belgrade suburban rail service operates four lines which operate from: Batajnica to Ovča (line 1), Resnik to Ovča (line 2), Belgrade Center to Mladenovac, and a new line from Belgrade Center to Lazarevac. On this line, some of the trains are planned to overlap existing service between Belgrade Center and Resnik while others terminate in Resnik with possible connections to Ovča – Resnik trains. The total number of trains that operate on this line is 12.

In this paper we create two different models: the first model considers the current state and provided number of trains and rail traffic organizations. The second model considers the abolition of all trains from Resnik to Lazarevac and running new 34 trains from Lazarevac to Dedinje junction. This state gives an opportunity in the traffic planning process, whether trains will run to Ovča or Belgrade Center. In the newly built timetable, trains on line 4 run every hour without conflicts with other trains on the observed section from Resnik to the Dedinje junction (Belgrade Center).

Both models were created using current data with some approximations and 2019/2020 timetable. The total number of trains in the first model is 187 and 209 trains in the second model. The total number of trains in both models (variant 1 and variant 2 represent models) are given in Table 1 [8].

TABLE I
TOTAL NUMBER OF TRAINS IN BOTH VARIANTS

| Train Category | Line detail | | V1 | V2 |
|---|---|---|---|---|
| Freight train | Domestic & international trains | | 98 | 98 |
| Passenger | Domestic & international trains | | 38 | 38 |
| BG voz | line 1 | Ovča - Batajnica | 0 | 0 |
| | line 2 | Resnik - Ovča | 29 | 33 |
| | line 3 | BG Centar - Mladenovac | 6 | 6 |
| | line 4 | BG Centar - Lazarevac | 2 | 34 |
| | | Ovča - Lazarevac | 4 | 0 |
| | | Resnik - Lazarevac | 6 | 0 |

Some dead-end tracks were not included in the model, and train speeds were used from the current timetable. The graphic representation of both models is the same and is shown in figure 1.
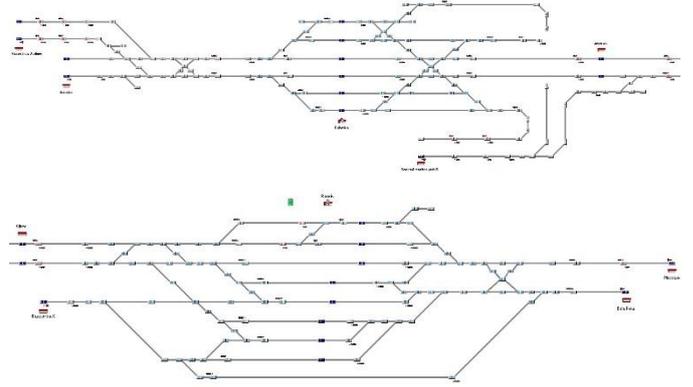


Fig. 1. Stations Rakovica and Resnik in OpenTrack models

The motivation for this paper is the need to analyze the effects of the new timetable and the increasing number of trains on part of the Belgrade railway junction from Resnik to Belgrade Center. This provides an answer to the question of whether there are delays and unscheduled stops of trains, and what is the length of delays. This paper aims to analyze occupations of tracks in stations Rakovica and Resnik in both variants.

## IV. SIMULATION RESULTS AND DISCUSSION

There are many output files that OpenTrack generates during simulation. Some files contain global information about the whole simulation while others contain information about a particular train, station, or track section [5].

In that case, the purpose of these models was to give us an answer to the question can BG trains operate without delays when the number of trains was increased by 40%? For this comparison four criteria were used: average delays per train, number of trains with late arrivals and departures at stations, stop the train at the main signal, and station track occupation. All information was obtained from files OT_Messages.txt, OT_Delay.delavg, and OT_OccStatistics.txt.

OT_Messages.txt is an output file that includes all warnings and normal messages which appear during simulation. Warnings include late arrivals, departures and stops at stations and signals for each train, and the duration of these conflicts. Also from this file, we can which course changed priority. Average train delays for all trains in a model can be seen from OT_Delay.delavg. Station occupations by tracks in stations can be seen from OT_OccStatistics.txt.

## A. Number of stopped trains at signals

In regular operating conditions when all trains are running on time, stoppings in front of the entrance or exit are not planned. If these events occur, they unnecessarily prolong traveling times and decrease traffic flow. The first simulation

results show the total number of stopped trains in front of the signal in station Rakovica and Resnik (Table 2).

TABLE II
NUMBER OF STOPPED TRAINS AT SIGNALS

| Station | Train type | V1 | | | V2 | | |
|---|---|---|---|---|---|---|---|
| | | Exit | Entrance | Σ | Exit | Entrance | Σ |
| Resnik | BG train | 12 | 3 | 15 | 19 | 3 | 22 |
| Resnik | Other | 21 | 8 | 29 | 23 | 15 | 38 |
| Rakovica | BG train | 1 | 2 | 3 | 1 | 3 | 4 |
| Rakovica | Other | 1 | 2 | 4 | 2 | 4 | 6 |
| Total | | 35 | 15 | 50 | 45 | 25 | 70 |

As we can see from table 2 the total number of stopped trains is increased from 50 in the first and 70 in the second model. On the other hand, there is a small increase in stopping the BG trains at the signal. All trains mostly stopped at some of the exit signals in station Resnik.

### B. Late arrivals and departures at stations

The number of BG trains with late arrivals at stations Rakovica and Resnik in both models is shown in table 3. Also, this table consists of arrivals of all trains in models and their delays.

TABLE III
NUMBER OF TRAINS WITH LATE ARRIVALS AND THEIR DELAYS

| Station | All trains | Total delays (min) | Average delays per train (min) | BG trains | Total delays of BG trains (min) | Average delays per BG train (min) |
|---|---|---|---|---|---|---|
| Variant 1 | | | | | | |
| Rakovica | 69 | 118.48 | 1.72 | 28 | 53.25 | 1.90 |
| Resnik | 40 | 706.83 | 17.67 | 6 | 19.32 | 3.22 |
| Variant 2 | | | | | | |
| Rakovica | 85 | 199.95 | 2.35 | 44 | 114.08 | 2.59 |
| Resnik | 50 | 759.20 | 15.18 | 13 | 46.73 | 3.59 |

As can be seen from Table 3 the number of trains with late arrivals at stations increased in variant 2. In variant one, the current state showed better results in total delays in stations and average delays per train. If we notice that in the second model the number of trains is increased by more the 40%, these delays

are meaningless and acceptable. More trains later arrived in Resnik than in Rakovica. Compared to the total number of trains the BG trains have very small delays when arriving in stations. Other trains have a very big total and average delays. That delays can cause timetable disturbances, especially if BG voz runs on every hour or less in the future.

The number of BG trains with late departures at stations Rakovica and Resnik in both models is shown in table 4. Also, this table consists of departures of all trains in models and their delays.

TABLE IV
NUMBER OF TRAINS WITH LATE DEPARTURES AND THEIR DELAYS

| Station | All trains | Total delays (min) | Average delays per train (min) | BG trains | Total delays of BG trains (min) | Average delays per BG train (min) |
|---|---|---|---|---|---|---|
| Variant 1 | | | | | | |
| Rakovica | 24 | 63.37 | 2.64 | 10 | 33.43 | 3.34 |
| Resnik | 25 | 81.35 | 3.25 | 10 | 50.75 | 5.08 |
| Variant 2 | | | | | | |
| Rakovica | 32 | 142.65 | 4.46 | 15 | 74.67 | 4.98 |
| Resnik | 43 | 179.85 | 4.18 | 25 | 117.93 | 4.72 |

Results show that the number of trains with late departures at stations is larger for variant 2 than for variant 1. Compared to the total number of trains BG trains have a lot less average delays in both models and these delays are similar in both stations.

### C. Average delays per train

By analyzing the obtained results for both models it can be seen that a lot of trains traffic on time or ahead the time in model two, compared to model one. It is noticeable that for increasing the total number of trains, from 53 to 71 BG trains, the average delay decreased. This is especially pronounced for line 4 from Belgrade Center to Lazarevac. The total average delay per train in both models is less than two minutes and train 7116 had a maximum delay of 10 minutes. If the number of freight and local passenger trains operates according to the current timetable the second model with an increased number of BG trains can be considered as a possible solution. Figure 2 shows the average delays per train in both models.

### D. Track occupations in Resnik and Rakovica

The last output from the OpenTrack simulation shows a total number of occupations and trains per hour on every station track in Resnik and Rakovica. The station track in Rakovica starts from the second to seventh track in the current infrastructure project. The results are shown in Table 5.
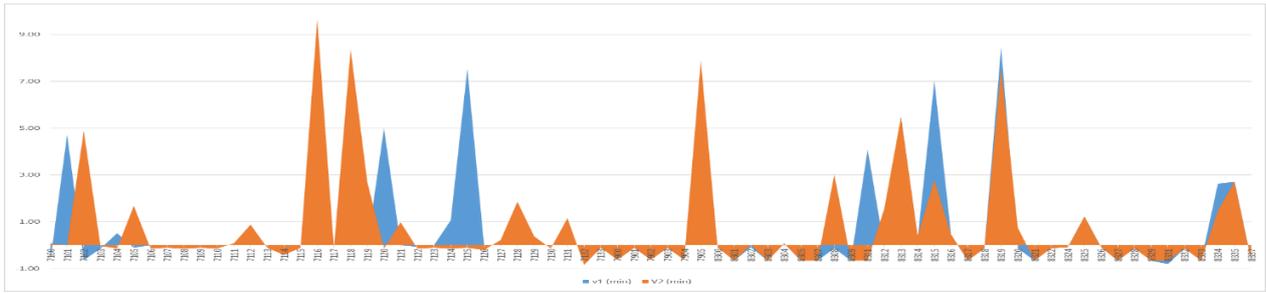
Fig. 2. Average delays per train in both variants

Track eight from station Resnik and track two from station Rakovica are not included because there is no train on these tracks during the simulation.

TABLE V
STATION TRACK OCCUPATIONS IN RESNIK AND RAKOVICA

| Track/ Station | Number of Occupations | | Avg. Trains per Hour | | Max. Trains per Hour | |
|---|---|---|---|---|---|---|
| | **V1** | **V2** | **V1** | **V2** | **V1** | **V2** |
| T1 Res | 33 | 34 | 1.38 | 1.42 | 6 | 6 |
| T2 Res | 39 | 51 | 1.63 | 2.13 | 4 | 6 |
| T3 Res | 58 | 59 | 2.42 | 2.46 | 6 | 6 |
| T4 Res | 13 | 19 | 0.54 | 0.79 | 2 | 3 |
| T5 Res | 33 | 35 | 1.38 | 1.46 | 4 | 4 |
| T6 Res | 6 | 7 | 0.25 | 0.29 | 2 | 2 |
| T7 Res | 3 | 2 | 0.13 | 0.08 | 2 | 2 |
| T3 Rak | 10 | 10 | 0.42 | 0.42 | 2 | 2 |
| T4 Rak | 49 | 63 | 2.04 | 2.63 | 6 | 7 |
| T5 Rak | 33 | 51 | 2.21 | 2.13 | 6 | 6 |
| T6 Rak | 7 | 23 | 0.29 | 0.96 | 2 | 4 |
| T7 Rak | 2 | 2 | 0.08 | 0.08 | 1 | 1 |

Table 5 shows that the most occupied track are T2, T3, and T5 in station Resnik and T4 and T5 in station Rakovica. Also, there is no significant occupation increase for most station tracks, and for some tracks we have more max trains and bigger average trains per hour which is a good output parameter. Resnik track occupation in peak period in model 2 is given in figure 3.
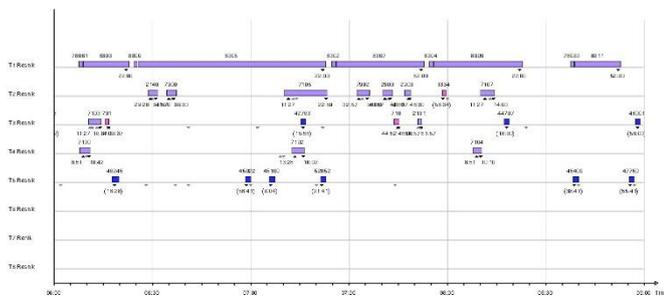


Fig. 3. Resnik tracks occupations in peak period

## V. CONCLUSION

As the results show there is no significant increase in the number and duration of delays when suburban trains from Lazarevac are extended to Belgrade Centar and their number increased. Most of the delays occurred in Resnik which is understandable since Resnik has a limited capacity for parallel movements but also due to the ending of double track. Nevertheless, results show that the section from Dedinje junction to Resnik has more than enough capacity for an increased number of trains. Further increase in a number of trains to Lazarevac would require more detailed analysis and simulation of complete single-track line to Lazarevac.

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