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IMPROVEMENT OF SUBURBAN RAILWAY SERVICES BY INFRASTRUCTURE AND TIMETABLE MODIFICATIONS BASED ON SIMULATION MODELLING

Summary. As part of this research, a computer model of the existing bidirectional single-track railway line section between Zagreb Glavni and Turopolje railway stations has been developed, and it has been modified with the aim of developing a new model of the double-track line on this line section, and which in relation to the existing conditions also includes additionally the new stop Donja Lomnica. The purpose of developing the new model of the double-track line is to study the possibility of introducing a new plan of cyclic timetable of the suburban and regional trains that would significantly improve the quality of existing service in railway suburban traffic of the city of Zagreb. The procedure of single-track line model modification has been performed based on simulation of railway operations in the station areas with the aim of improvement of line capacity necessary for introduction of new solution of the cyclic timetable. Within this approach, the solutions for modification of railway infrastructure in stations have been selected which have proven to be the best regarding the achievement of the mentioned purpose. As part of this work, a new solution of cyclic timetable of suburban and regional trains on the new model of the double-track railway line has been proposed by taking into consideration the existing characteristics of traffic of other trains on the observed railway line section, as in Zagreb Glavni railway station which represents the main node in the network. Stability of this cyclic timetable has been tested by the application of three different simulation scenarios. The results of this research have proven that the introduction of the new model of double-track line can enable stable application of the proposed cyclic timetable.

1. INTRODUCTION

The railway line between Zagreb Glavni and Turopolje railway stations is a section of the railway line Zagreb Glavni – Sisak – Novska that has been classified in the category of the railway line for international traffic. On the section from the Zagreb Glavni to Turopolje railway station, which has been marked with black line in Figure 1, there are two additional railway stations Zagreb Klara and Velika Gorica as well as three stops Buzin, Odra and Mraclin. This line section is operated by domestic passenger and freight trains as well as fast passenger trains and freight trains in international traffic.

Due to the continuous growth of the number of population on the south periphery of the city of Zagreb and Velika Gorica and its surrounding towns, and the population's age structure, which consists of 62% of population in the age from 15 to 59 years, representing the potential categories of passengers as part of commutations, as well as because of other advantages of railway transport in relation to travelling by passenger car related to the duration and price of travelling, in case of increase in offer and the quality of suburban transport service on observed line section, there are justified reasons to expect significant growth of its demand [1]. Additionally, this kind of improvement of suburban transport service can be a solution for resolving the existing problem of road traffic jams in this part of Zagreb metropolitan area, and it may affect reduction in passenger travel time loss [2].

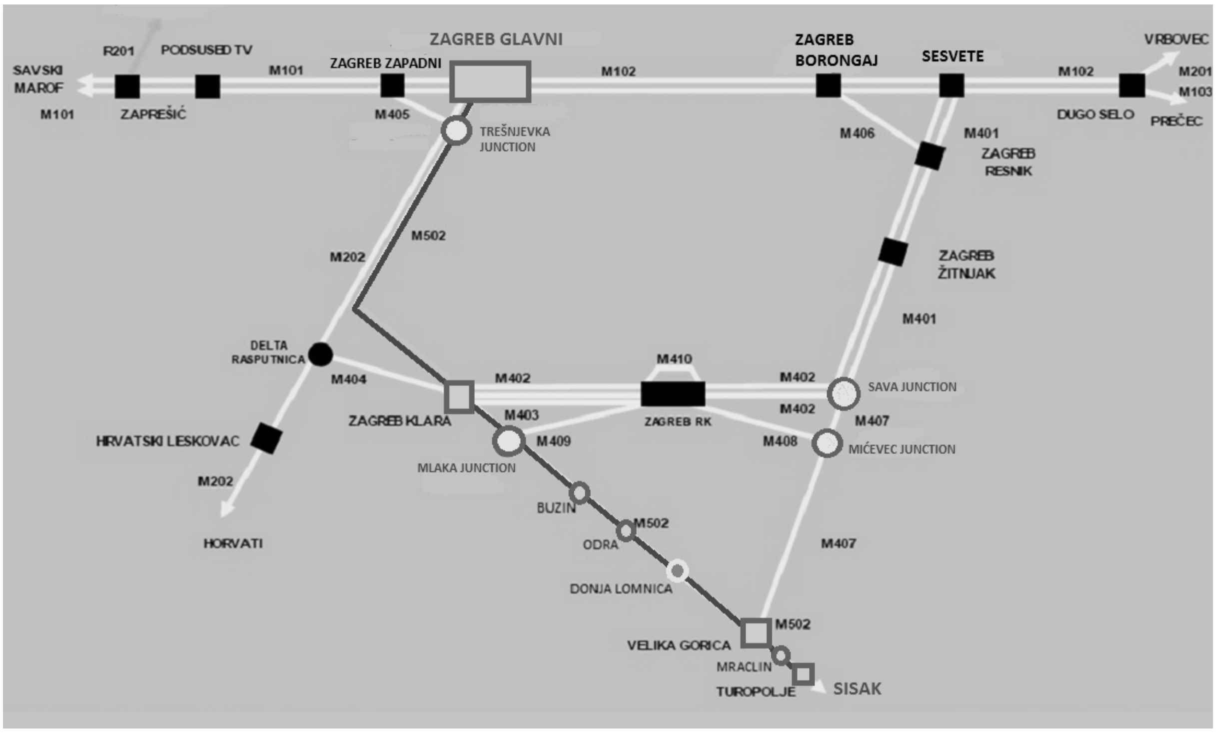

Fig. 1. Scheme of the Zagreb node with respective railway lines

The quality and attractiveness of this transport service could be significantly increased by introducing the cyclic timetable of suburban and regional trains, which would stop on all train stops on the line section between Zagreb Glavni and Turopolje railway stations, with the introduction of a greater number of new paths of suburban trains, which requires an increase of the existing capacity of the railway infrastructure on the observed line section. Additionally, the capacity increasement is also needed for potential introduction of additional freight trains based on the study of the behaviour of passenger trains to better use the time-gap in which freight trains can be introduced without changing the number and timetable of suburban and regional trains [3].

This would make it possible for the passengers in suburban traffic to have more frequent and more uniform departures of trains as well as more stable and robust timetable with less influence of unexpected traffic disturbances on punctuality of trains due to higher rate of time supplements in scheduled running times and trains headways [4, 5], which is especially important for the efficiency of freight trains traffic [6].

Changing the topology of a railway network can greatly affect its capacity, where railway infrastructure can be altered in a multitude of different ways to change theoretical capacity. This approach is often used for removing physical bottlenecks in the current railway system and to help in capacity planning activities [7]. The planning process in public transportation consists of several consecutive planning phases starting from network design, usually followed by line planning, timetabling and vehicle and crew scheduling [8]. According to this, the aim of this research is to determine whether and with which measures related to the modification of the existing infrastructure and timetable there is the possibility of introducing cyclic timetable of suburban trains in a cycle of 15 minutes in the period of peak traffic load with the purpose of attracting commuters to shift from road transport to suburban rail services. In our case, it is important here to take into consideration the existing characteristics of traffic of other trains on the observed railway line section, as in Zagreb Glavni railway station, which represents the main node in the network of railway lines for suburban traffic of the City of Zagreb, with more than 400 departures of various categories of trains in one day. For this purpose, a simulation model of the existing railway system on concerned line section and its continuation to Sisak railway station has to be modelled as well as all the remaining railway lines in the railway network of Zagreb node, which is shown in Figure 1.

2. DEVELOPMENT OF A SIMULATION MODEL OF DOUBLE-TRACK RAILWAY LINE ON THE RELATION BETWEEN ZAGREB GLAVNI AND TUROPOLJE RAILWAY STATION WITH A NEW STOP DONJA LOMNICA

For the development of the simulation model for the needs of this work, a computer program OpenTrack was used, which enables the development of micro-simulation models of railway systems. This kind of microscopic simulation model can be used for simulation of railway operations based on user-defined train, infrastructure, and timetable databases [9].

To be able to simulate traffic on the observed rail section in relation to the rest of the rail network of the Zagreb node for the needs of this research, first the model of the current state of railway lines in the Zagreb node, Figure 1, has been developed. As part of this, the simulation model of railway line on the relation Zagreb Glavni – Sisak, which includes the observed section between Zagreb Glavni and Turopolje railway station, has been developed.

As part of this model, the data about the existing condition of the railway infrastructure, rolling stock and annual timetable for period 2016/2017 for the observed line section have been used. With the help of the model of the current state of the railway line on the section Zagreb Glavni – Turopolje, applying the UIC 406 method for the assessment of railway infrastructure capacity, its throughput capacity according to the 2016/2017 timetable has been studied. The critical interstation distance on the observed railway line section is the distance between the railway stations Velika Gorica and Turopolje. Its capacity is 110 trains per day and 12 trains during the peak load in the period from 6 to 9 a.m. According to the current timetable for the year 2016/17 during the day there are 36 passenger and 22 cargo trains operating on this line. Based on the traffic simulation on the made model of the current single-track railway line, it has been determined that the timetable parameters obtained by simulation fully agree with the parameters of the planned timetable (Figure 2). Thus, it has been proven that the created model of the railway system that encompasses the models of railway infrastructure and trains corresponds to a sufficient extent to the actual state of this system.

Regarding the infrastructure parameters and the current characteristics of the traffic during the peak period on the observed section of the railway line, simulation results show that it is not possible to organize stable cyclic timetable of the suburban and regional passenger trains in a cycle shorter than one hour, so in the existing timetable of regional passenger trains there is a cycle of approximately one hour. The main problem for developing the cyclic timetable on the observed railway line with a cycle shorter than one hour is the timetable of other trains, mainly by international cargo trains.

With the aim of developing a proposal of a new cyclic timetable of trains in a cycle of 15 minutes in the peak traffic periods, and in a cycle of 30 minutes in the off-peak traffic load, a new model of a double-track railway line on the section from Zagreb Glavni to Turopolje has been developed. This approach is based on the fact that diverse high-quality timetable variants have also a key role in the design of tomorrow's railway infrastructure and in reliable stability and capacity analysis leading to efficient and sound railway networks [10]. As part of developing a new proposal of the double-track railway line in the railway station areas of the stations Zagreb Glavni, Zagreb Klara, Velika Gorica and Turopolje, certain changes in the infrastructure have been made to modify these railway stations for the traffic of trains along the double-track line. The proposed method used for single-track line model modification is based on simulation of the railway operations in the station areas. This method implies iterations of simulation processes with the aim of improvement of capacity in station area which is necessary for introduction of appropriate solution of cyclic timetable of suburban and regional trains on the line section between Zagreb Glavni and Turopolje railway stations. In this method, the solutions have been selected that have proven to be the best regarding the achievement of the mentioned purpose. Furthermore, the model of the current opened single-track railway line has been modified into a double-track railway line without any changes in the location of block signals, railway-road crossings and existing stops. Here, a change of the maximally allowed speed of the trains on the open railway line, but in accordance with Croatian regulations related to train braking and sight distances, has been made regarding the needs of creating a cyclic timetable that is to be achieved as part of this research. Additionally, in the model, a new stop Donja Lomnica has been introduced that would cover an area with more than 2,500 citizens who live in the town Donja Lomnica and the surrounding area.

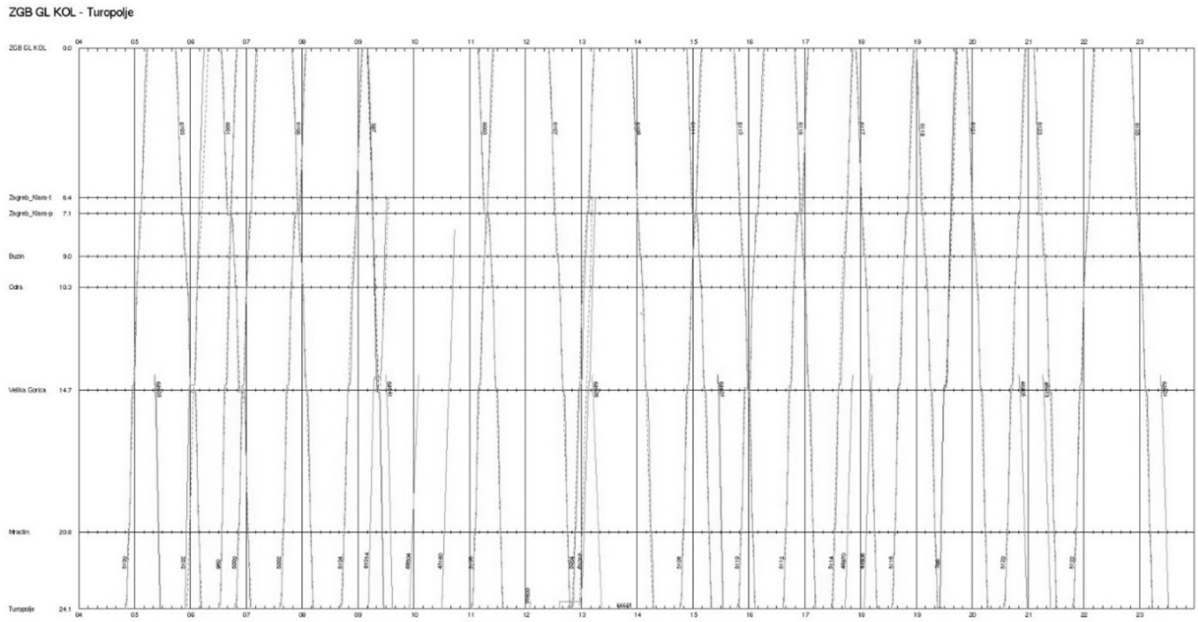

Fig. 2. Timetable graph for 2016/2017 for the line section Zagreb Glavni – Turopolje obtained by simulation in the OpenTrack program

2.1. Proposal of infrastructural changes and modelling of the station area of the Zagreb Glavni railway station

At the railway station Zagreb Glavni the changes have been made on the extension of the first and second track westwards, as shown in Figure 3. Along with the single-track railway line to the Zagreb Klara station, a new track has been modelled that enters the station Zagreb Glavni parallel with the track of the existing single-track railway line, which is marked in red in Figure 1.

To realise such track connection, it was necessary to build in five switches, namely switches number: 9a, 6c, 5c, 5ab, 5e that are located next to the switches No. 7, 6, 5, 4 in order to realise the track connection with tracks VD - 1, S1, S2, S3, S4, S5 and thus enable undisturbed entry and departure of trains into the railway station from the direction of Zagreb Zapadni and Zagreb Klara railway stations and thus maintain adequate capacity of the station Zagreb Glavni. Thereby new train routes have been created and some of existing train routes have been modified regarding the flank protection elements. These changes in the model of the existing condition of the station Zagreb Glavni are presented in Figure 3.

2.2. Proposal of changes and modelling of the station area of the Zagreb Klara railway station

At the railway station Zagreb Klara in order to construct the second track in the passenger part or the station, the 13th track was redesigned into the main through track, and in order to realise the track connection, switches 1a, 2a, 2b, 4a and 4b in direction of the Velika Gorica station were built-in. In the cargo part of the station Zagreb Klara, the fourth track was redesigned into the main through track, and switches 9a, 21a, 21b, 21c, 21d, 20a and 20b were built-in, as presented in Figure 4.

2.3. Modelling and changes in the station area of the Velika Gorica railway station

At the Velika Gorica railway station, changes have been made on the third track that has become the main through track for the second track of the new model of the double-track railway line, and a passenger platform has been constructed along the second and third tracks. In the extension of the third track towards the Turopolje station, two switches numbers 1a and 3a were built-in in order to realise the track connection with the first and second track, switch 11a because of the separation of the industrial track and switch 9a from which the line continues to Zagreb Žitnjak railway station, all of which is presented in Figure 5.

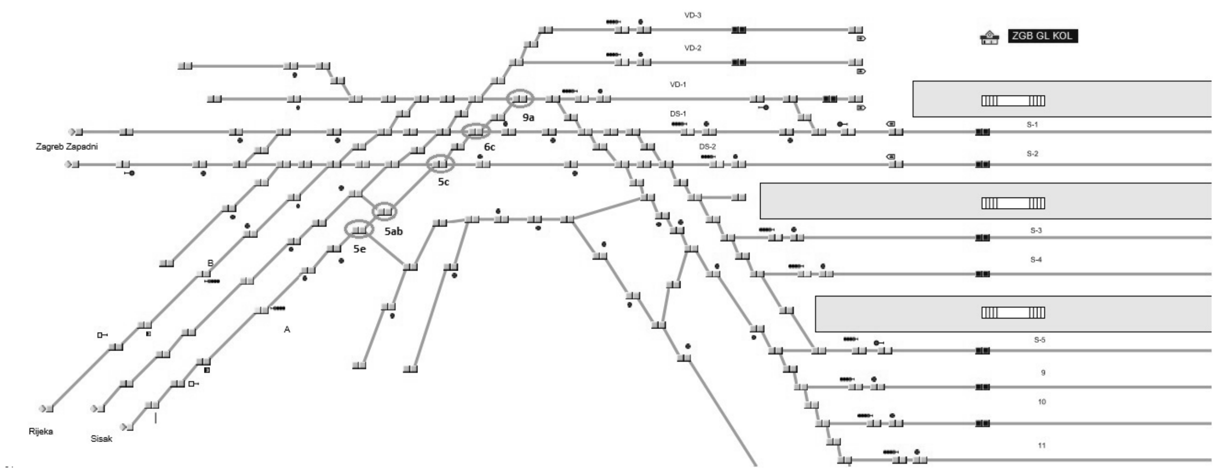

Fig. 3. Changes in the model of the current condition of the Zagreb Glavni railway station infrastructure

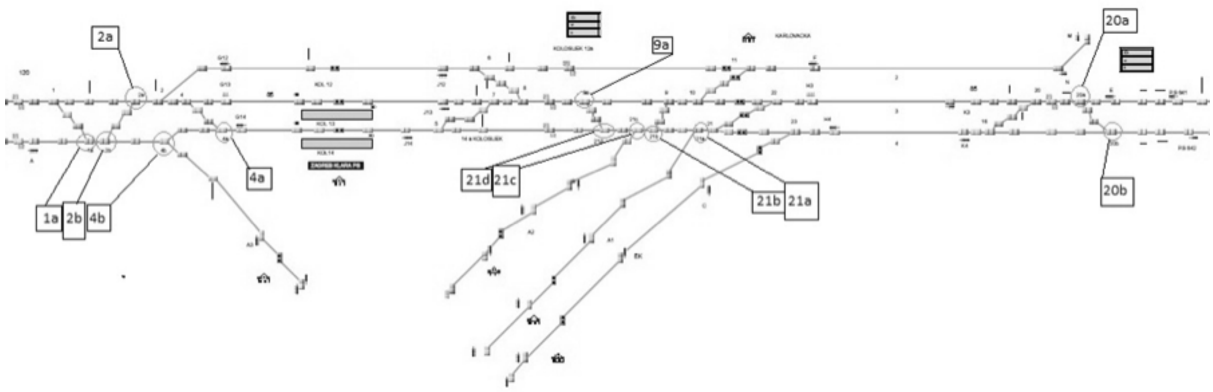

Fig. 4. Changes at the Zagreb Klara station

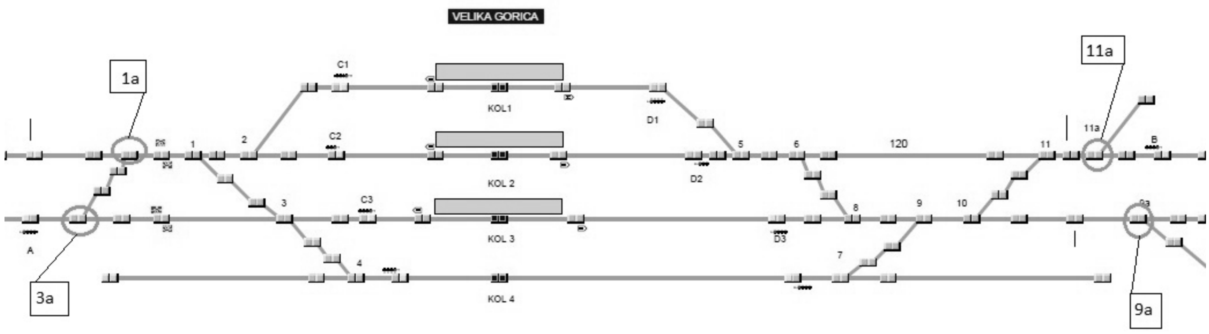

Fig. 5. Changes at the Velika Gorica railway station

2.4. Modelling and changes at the station area of the Turopolje railway station

At the Turopolje railway station, the second track of the double-track railway line is extended to the second track of the railway station. One switch No. 8a, a platform between the first and the second track has been built-in, as well as the exit signals on the first track. All this is presented in Figure 6.

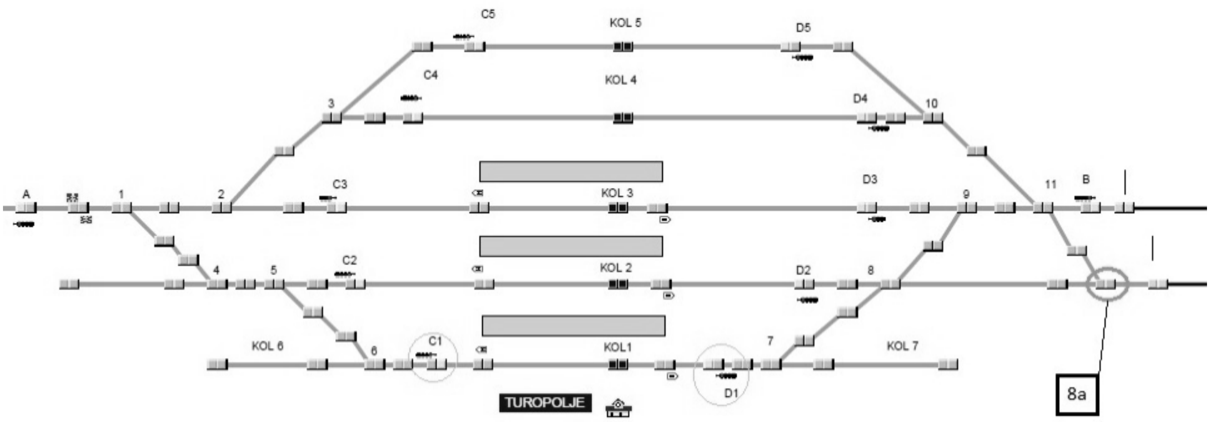

Fig. 6. Changes at the Turopolje railway station

2.5. Upgrade of the model through introduction of the new stop Donja Lomnica

On the railway line Zagreb Glavni – Turopolje, there were three stops:

- stops Buzin and Odra that are located between the Zagreb Klara station and the Velika Gorica railway station (Figure 7), and
- stop Mraclin between the stations Velika Gorica and Turopolje.

In the proposed model, the new stop Donja Lomnica is located between the stop Odra and the Velika Gorica railway station at km 412+250 with the platform length of 150 m. The stop Donja Lomnica is named after the settlement near which it has been located, and the purpose of constructing this stop is the large population of this place and its surrounding area that has about 2500 people and a relatively big distance of about 4 kilometres from the centre of Donja Lomnica to the stop Odra, as well as to the Velika Gorica railway station.

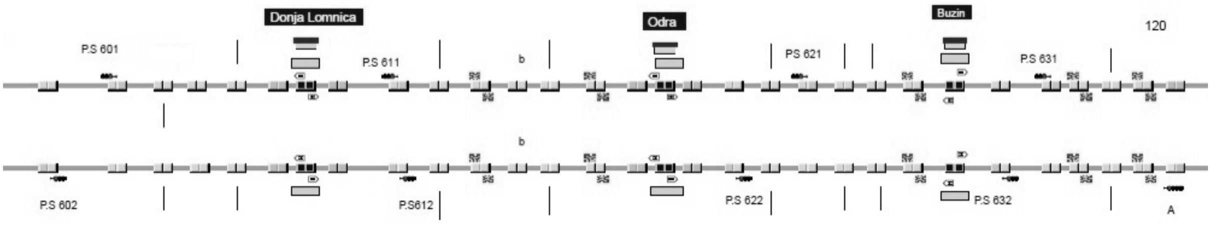

Fig. 7. The position of proposed new stop Donja Lomnica in the graphic interface of new computer model of the double-track railway line

3. SIMULATION ANALYSIS OF THE CYCLIC TIMETABLE ON DOUBLE-TRACK RAILWAY LINE ZAGREB GLAVNI – TUROPOLJE

To increase the quality of the transportation service on the relation between Zagreb Glavni and Turopolje railway station, it is very important to provide the users with a stable timetable as well as with more frequent departures of trains during peak traffic loads. It is assumed that the upgrade of the model of the existing railway line in terms of constructing a double-track line should enable the formation of an adequate cyclic timetable of the suburban and regional trains on that railway line section, which opens up the possibility of introducing additional train paths in peak traffic periods and to shorten the train running times, i.e. travelling times.

The very important advantage of the cyclic timetable is that it allows customers to plan journeys more precisely, without necessarily having access to a complicated timetable document which leads to better spread of load on coaches and better utilisation of available rolling stock, as well as to the integration between rail and other modes of transport [11].

In order to investigate whether the proposed changes of the railway infrastructure can enable the introduction of a stable cyclic timetable, a timetable of the suburban and regional trains has been created in a cycle of 15 minutes in the peak traffic load period presented in Figure 9. This timetable also takes into consideration the existing characteristics of the traffic of other trains on the considered railway line section.

For the needs of testing the stability of the proposed cyclic timetable, three different scenarios for the simulation analysis of the stability of the cyclic timetable have been designed, by applying the developed computer model of the railway lines in the Zagreb node, as well as a new double-track line on the relation Zagreb Glavni – Turopolje.

All three scenarios for the simulation of the suburban and regional train traffic have used the model of the newer version of electric multiple unit (EMU) of the series HŽ 6112. In this way, in combination with the increase of the highest permitted speed on certain sections of the open line, there is significant reduction of the travelling time of the suburban and regional trains on the observed section in relation to the implementation of the older series of the electric multiple units HŽ 6111.

Apart from having a smaller possibility of acceleration, the maximal speed of the EMU of the series HŽ 6111 is 120 km/h, whereas the maximal speed of the EMU of series HŽ 6112 is 160 km/h. This reduction of the running time on the observed line section speaks in favour of the introduction of a new stop Donja Lomnica into the timetable, which is why the total travelling time of suburban trains on the observed relation of the line that stops at this stop is prolonged by the amount that is smaller than the achieved reduction of the travelling time due to the correction of the maximum speed on the line and application of EMUs of series HŽ 6112.

Figure 8 presents the comparison between speed, acceleration and track resistance profiles of EMUs HŽ 6112 (grey line) and HŽ 6111 (black line) on the line section between railway stations Zagreb Glavni and Turopolje.

In the simulation process, the program OpenTrack uses generally accepted formulas for simulation of train movements. The frictional behaviour between wheel and rail in a speed-dependent manner (Friction Coefficient μ) is calculated by Curtius and Kniffler formula as follows:

$$\mu=\frac{2.1\ \text{m/s}}{v+12{,}2\ \text{m/s}}+0{,}1611 \quad (1)$$

Respectively, for simulation of train dynamics, Strahl's formula for locomotives, Sauthoff's formula for passenger wagons and an improved Strahl's formula (for freight wagons) were used [12].

3.1. The first scenario for simulation analysis of the cyclic timetable stability

Within this scenario, the realisation of the proposed cyclic timetable has been simulated, without the influence of additional disturbances on the railway traffic flow. This is the way of checking whether the timetable plan is feasible, i.e., it is determined whether there are any unwanted conflicts between trains in the timetable in case when there are no other disturbances in traffic. As part of this scenario, the train departures from the Zagreb Glavni and Turopolje stations are organized in time intervals of one hour, half an hour, and in the peak traffic load 15 minutes, respectively:

- 04:00 - 05:00 – trains running in the time interval of 1 hour
- 05:00 - 06:00 - trains running in the time interval of 30 minutes
- 06:00 - 09:00 - trains running in the time interval of 15 minutes
- 09:00 - 14:00 - trains running in the time interval of 30 minutes
- 14:00 - 17:00 - trains running in the time interval of 15 minutes
- 17:00 - 21:00 - trains running in the time interval of 30 minutes
- 21:00 - 00:00 - trains running in the time interval of 1 hour

Trains operating on the relation between stations Zagreb Glavni and Sisak operate on average every hour. They are integrated in the cyclic timetable and they operate from Zagreb Glavni in the following times:

- 05:00 - 09:00 every full hour;
- 09:00 - 13:00 every two hours;
- 14:00 - 17:00 every full hour;
- 19:00 - 23:00 every two hours.

Trains arriving from the Sisak railway station operate at equal time intervals as the trains on Turopolje – Zagreb Glavni relation, but in the presented departure times (as e.g. in station Zagreb Glavni) in the Turopolje station, they are included into the cyclic timetable of the suburban traffic on the relation from Turopolje to Zagreb Glavni.

At the Zagreb Glavni railway station, all the trains towards Turopolje and Sisak depart from the 3rd platform 4th track, and the trains from Turopolje arrive to the 3rd platform 5th track. Therefore, in the technological process of the Zagreb Glavni railway station operation, it was necessary to correct the times of arrivals and departures of trains in the amount of 2 – 4 minutes for the relation Dugo Selo – Zagreb Glavni – Savski Marof (see in Fig. 1) in order to avoid the disturbance of the cyclic timetable.

The running time on the relation Zagreb Glavni – Turopolje in both directions is 24 minutes, and the permitted speed on the section between railway stations Zagreb Glavni and Velika Gorica is 120 km/h, and from Velika Gorica to Turopolje station it is 140 km/h. The total number of passenger trains that run on the relation of the Zagreb Glavni – Turopolje in the proposed new cyclic timetable is 98, and out of these, there are 27 that continue travelling towards Sisak.

The results of railway traffic simulation according to the first scenario for the analysis of the new cyclic timetable (Figure 9) prove that the timetable plan on the proposed model of the double-track railway line is feasible, i.e., it has been determined that there are no undesirable conflicts between trains in the timetable in case when there are no traffic disturbances.

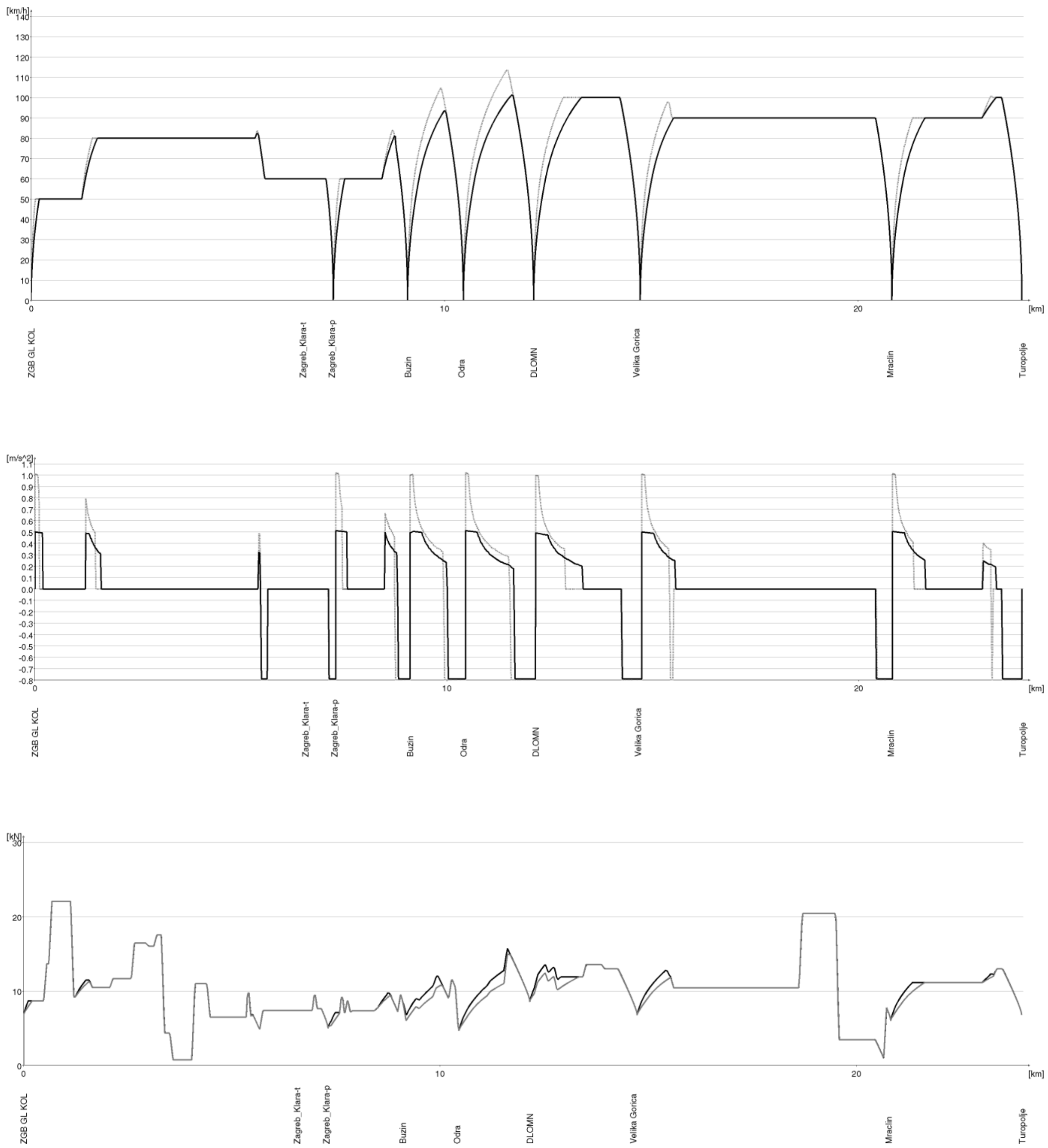

Fig. 8. Comparison of speed, acceleration and track resistance profiles for EMUs HŽ 6112 (grey line) and HŽ 6111 (black line)

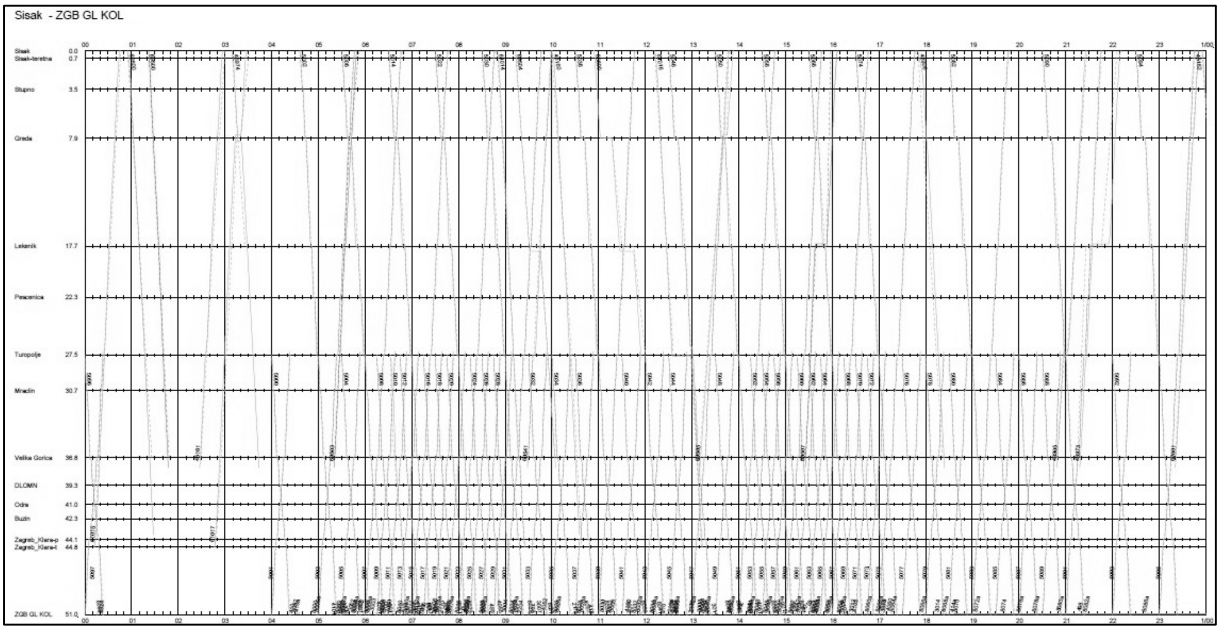

Fig. 9. Graph of the proposed timetable on relation Zagreb Glavni – Turopolje – Sisak

3.2. The second scenario for the analysis of the cyclic timetable stability

The second scenario for the analysis of the cyclic timetable stability simulates the railway traffic under the conditions of temporary works on the line with speed limit of 40 km/h towards Turopolje – Zagreb Glavni, from the stop Mraclin located at km 403+700 to entry signal into the Velika Gorica station at km 409+210.

Results of the analysis show that the speed limit has resulted in the delay of trains 5000, 5002, 5004, 5006, 5008, 5010, 5012, 5014, 5016, 5018, 5020, 5022, 5024, 5026, 5028, 5030, 5032, 5034, 5036, 5038, 5040, 5042, 5044, 5046, 5048, 5050, 5052, 5054, 5056, 5058, 5060, 5062, 5064, 5066, 5068, 5070, 5072, 5074, 5076, 5078, 5080, 5082, 5084, 5086, 5088, 5090, 5092, 5094, and 5096.

At the station Velika Gorica, the trains are about 5 minutes late in departure and in arrival. At the Zagreb Klara station, they are about 4 minutes late in arrival, and at railway station Zagreb Glavni, they are about 3 minutes late in arrival. For instance, train 5024 was late in arrival to the Velika Gorica station and in departure 5 minutes and 10 seconds, whereas in departure from the stop Donja Lomnica it was 4 minutes and 41 seconds late, Odra 4 minutes and 49 seconds and Buzin 4 minutes and 39 seconds.

For the Zagreb Klara station, the train has a delay in arrival and departure of 4 minutes and 28 seconds. The mentioned delays of the train have not influenced in any more significant way the operation of traffic of other trains in the rail network of the Zagreb node nor the traffic of other trains in the network of railway lines of the Zagreb node. The obtained simulation results have shown that the temporary works on the railway line and speed limitation have not influenced larger delays than the presented ones.

3.3. The third scenario for the analysis of cyclic timetable stability

The third scenario for the analysis of the cyclic timetable simulated the failure on the rail-road crossing Buzin at km 405+908, Figure 10. The failure at rail-road crossing lasted from 08:00 - 12:00 sati. Regarding the existing regulations about railway traffic safety in the Republic of Croatia, in this period the trains must necessarily stop before the rail-road crossing, and when all road vehicles leave the crossing area, only then can the trains start to accelerate. As part of the simulation process, the trains waited at the crossing for 10 seconds.

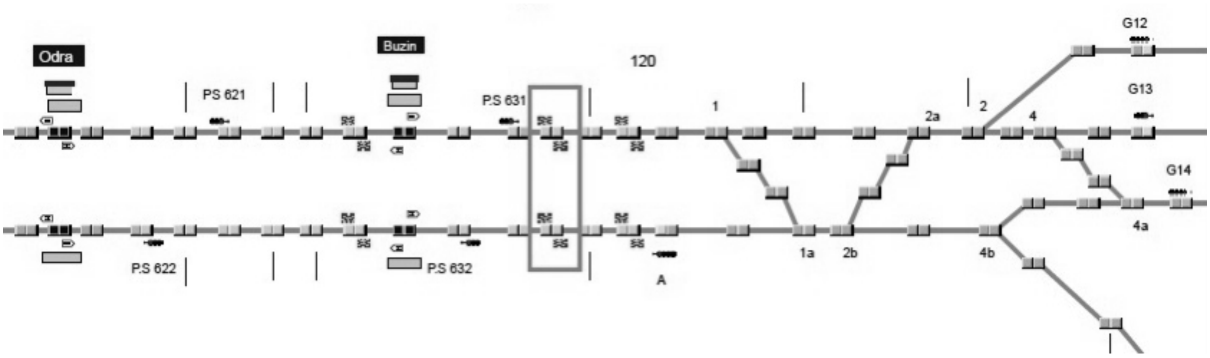

Fig. 10. Location of the rail-road crossing Buzin

The results of the simulation analysis show that a failure at the rail-road crossing Buzin would result in delays of the following trains:

- No. 5022 - arrives in the railway station Zagreb Glavni with a delay of 6 minutes
- No. 5023 - arrives in the railway station Sisak with a delay of 5 minute
- No. 5024 - arrives in the railway station Zagreb with a delay of 6 minutes
- No. 5025 - arrives in the railway station Turopolje with a delay of 6 minutes
- No. 5026 - arrives in the railway station Zagreb Glavni with a delay of 6 minutes
- No. 5027 - arrives in the railway station Turopolje with a delay of 6 minutes
- No. 5028 - arrives in the railway station Zagreb Glavni with a delay of 6 minutes
- No. 5029 - arrives in the railway station Turopolje with a delay of 6 minutes
- No. 5030 - arrives in the railway station Zagreb Glavni with a delay of 6 minutes
- No. 5031 - arrives in the railway station Sisak with a delay of 5 minute
- No. 5032 - arrives in the railway station Zagreb Glavni with a delay of 6 minutes
- No. 5033 - arrives in the railway station Turopolje with a delay of 6 minutes
- No. 5034 - arrives in the railway station Zagreb Glavni with a delay of 6 minutes

Figure 11 shows the relation of the planned and realized timetable for the regional train 5030 which runs on the relation of Sisak – Turopolje – Zagreb Glavni.

Course ID	Station	Arrival		Departure		Use	Dwell	Stop	Delta Load	Distr.
5030	Sisak	HH:MM:SS	HH:MM:SS	08:30:00	08:30:00	✓	0		0.000	
5030	Sisak-teretna	HH:MM:SS	HH:MM:SS	HH:MM:SS	08:31:08	✓	0		0.000	
5030	Stupno	HH:MM:SS	08:33:35	08:34:00	08:34:05	✓	30	✓	0.000	
5030	Greda	08:38:00	08:37:07	08:42:00	08:42:24	✓	0	✓	0.000	
5030	Lekenik	HH:MM:SS	08:48:36	08:51:00	08:51:00	✓	30	✓	0.000	
5030	Pescenica	HH:MM:SS	08:53:58	08:55:00	08:55:00	✓	30	✓	0.000	
5030	Turopolje	08:59:00	08:58:19	09:00:00	09:00:00	✓	0	✓	0.000	
5030	Mraclin	09:02:00	09:02:20	09:03:00	09:03:00	✓	0	✓	0.000	
5030	Velika Gorica	09:07:00	09:12:10	09:08:00	09:13:10	✓	60	✓	0.000	
5030	DLOMN	HH:MM:SS	09:15:11	09:11:00	09:15:41	✓	30	✓	0.000	
5030	Odra	HH:MM:SS	09:17:19	09:13:00	09:17:49	✓	30	✓	0.000	
5030	Buzin	HH:MM:SS	09:19:09	09:15:00	09:19:39	✓	30	✓	0.000	
5030	Zagreb_Klara-p	09:17:00	09:28:59	09:18:00	09:29:59	✓	60	✓	0.000	
5030	Zagreb_Klara-t	HH:MM:SS	HH:MM:SS	HH:MM:SS	09:30:40	✓	0		0.000	
5030	ZGB GL KOL	HH:MM:SS	HH:MM:SS	09:24:00	09:35:10	✓	0		0.000	

Fig. 11. Results of the realisation of the timetable for train No. 5030

The resulting timetable graph due to the failure on the rail-road crossing is presented in Figure 13.

With the analysis of the influence of the mentioned train delays, it has been determined that these delays would not affect the continuation of propagation of consequent delays or cancellations of other trains that operate in the network of railway lines of Zagreb node.

CONCLUSION

In first part of this research, a computer model of the existing railway lines in the network of the Zagreb railway node has been made. To introduce a new timetable solution for improvement of the existing suburban transport service, the current single-track bidirectional railway line on the section Zagreb Glavni – Turopolje has been modified into a double-track line, implementing the measures for the modification of railway infrastructure elements that allow optimal railway operations within the railway station areas. In the model, the new stop Donja Lomnica has been included, which would cover an area of more than 2,500 inhabitants who live in this town and the surrounding area.

To improve the transport service, a proposal of a new timetable has been developed, and it means introduction of the cyclic timetable of regional and suburban trains on that railway section. As part of this proposal of the timetable, the trains in the period of peak traffic load from 6 to 9 and from 14 to 17 were planned in a cycle of 15 minutes, whereas in off-peak period the trains have been planned in a cycle of 30 minutes. Such proposal of the timetable would enable the introduction of additional train paths in the peak traffic load, thus significantly improving the quality of the transport service for the inhabitants (commuters) of the south part of the city of Zagreb, city of Velika Gorica and its surroundings. Moreover, the model includes all the different series of electrical engines and electric multiple units (EMUs) for the traction of regional and suburban trains replaced by the electrical multiple unit of series HŽ 6112. This enabled shortening of running times i.e. travelling times of these trains, and thus also the possibility of constructing the proposed timetable with the introduction of the new stop Donja Lomnica.

The proposed timetable has been tested for stability by the application of three different simulation scenarios. The obtained simulation results show that the resulting delay of trains due to most common disturbances in traffic would not have any significant negative effect on the implementation of the planned timetable regarding the cancellation of train services or expansion of the consequential (secondary) delay in the network. Also, the simulation results have proven that the introduction of the second track, apart from the reduction of train travelling times, with greater throughput capacity of the line in relation to the current one has enabled also stable application of the proposed cyclic timetable of the suburban trains that offers the users higher quality of the suburban transport service.

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