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POSSIBILITIES FOR INTEGRATED TIMETABLES WITHIN THE SERBIAN RAILWAY NETWORK

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Ulf Fischer[1], Simo Mirković[2], Sanjin Milinković[3], Andreas Schöbel[4]

[1]ÖBB Holding AG, Wien, Austria
E-mail: ulf.fischer@oebb.at
[2]Saobraćajni institut CIP, Belgrade, Serbia
[3]Saobraćajni fakultet, Univerzitet u Beogradu, Belgrade, Serbia
[4]Institute for Traffic Engineering, Vienna University of Technology, Wien, Austria

Abstract. *Timetables are key control elements for railways. They determine all costs for operation but also have a great effect on a railway company´s revenue, because the utilization of trains depends largely on travel times and available connections. In this paper, a fully functioning system of so-called integrated timetables within Serbia's present inter-city railway network is developed. A big difference to common timetables lies in the fact that all the lines are served several times a day with a fixed interval of two hours and all the trains serving one junction are connected to all the trains going from there to other directions in a short transfer time. So it is possible to reduce total travel time between several Serbian towns to as much as three hours without major investment for improving the tracks' maximum speed potential. The two-hour-interval has been decided to perform the balancing act between working out ways to increase the attractiveness of the railway networks while making best use of the modest rolling stock and infrastructure which are now available. Going along with renovation of the tracks, it might even be possible to shorten the intervals to one hour, to increase the trains' speed and to integrate local traffic within this system in the future.*

Key Words: *Railway Operation, Integrated Timetable, Passenger Transport, Simulation*

1. INTRODUCTION

The idea of this paper is to develop a system of integrated timetables within the the Serbian Railway network. The focus is placed on Inter-City connections within Serbia as well as links to the surrounding countries. The following conception is based on considerations published in Fischer, 2012 [1] and gives an overview of a possible system of integrated timetables. By introducing an integrated timetable, the overall travel times can be reduced without upgrading the tracks to higher speed that would involve a large amount of investments and years of realization. Together with an adequate number of punctual

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and reliable trains, both the image and the reputation of railways in Serbia can be clearly increased. If this is followed by a renewal of tracks, these ideas can easily be transferred to a new configuration, as they are not an interim solution but a fully working concept.

The main reason for undertaking work on a new conception is the fact that today's railway network in Serbia is in quite a poor state, as Grujić and Bundalo point out [2]. Travel times are long; there are hardly any connections between trains and so the number of passengers is declining [3]. The difficult economic situation of the Republic of Serbia does not enable a high number of investments in the railway lines and so we have set up as our goal to invent a fully working timetable system that can sustainably improve the Serbian Railways and lead to a higher utilisation ratio of the trains without much investment in railway stations, tracks and superstructures.

The solution for this situation will probably be an integrated timetable, as it can be implemented quickly and as it seems affordable. Beck [4] combines these facts in one single sentence: *Entscheidend für den wirtschaftlichen Erfolg oder Misserfolg von Unternehmen des Schienenpersonenverkehrs ist der Fahrplan, durch den Erlöse und Kosten des Unternehmens wesentlich beeinflusst werden*. This means that it is just the timetable which is the central economic key element with an impact on costs and benefits as well as the reputation of a railway company.

The first part of the paper spells out definitions for timetables and especially integrated timetable systems, which are the basis for the following considerations. In the second part, an integrated timetable system for the Serbian Railway network is developed. In the third part, this system is put successfully to test by a railway-operation simulation software and the results of this simulation are discussed. Finally, the paper ends with the presentation of future prospects of the timetable system and its possible effects on the Serbian railways reputation.

2. Integrated Timetables

First of all, some terms related to timetables must be defined. The *clock cycle* means that a certain procedure is regularly repeated after a specified amount of time. Following the timetable, after one train's departure from station A to station B there is a certain intermission before the next train is to leave station A for station B. The *cycle time* t_T is an interval between these two trains [4]. If all the trains along the given route go by this fixed cycle, we can speak about a *clock-faced timetable*.

By the symmetrical clock-faced timetable, all trains go as pairs of aller/retour connections with same travel times for both directions. It is appropriate to choose integer divisors (or multiples) of full hours for the cycle time, as these times are easily appreciable and can be combined with each other. For example, two lines with a one-hour-interval superimposing themselves on a certain section may lead to a half-hour-interval on this section. If the timetables are symmetrical by minute 00, it is possible to calculate the departure time for the return trip, provided the arrival time at the destination is known.

An example for this situation is shown in Figure 1. Here is shown an one-hour-interval (red lines) superposed with a second (blue lines), both symmetrical by minute 00. The trains meet each other every 15 minutes, as well as in the stations of Zürich, Olten and Bern, as the travel time in-between is in both cases 30 minutes.

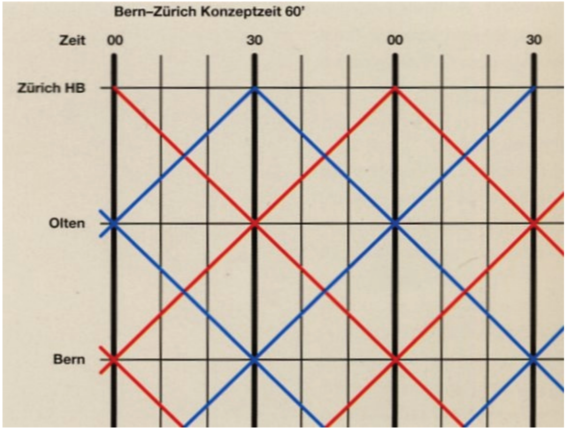

Fig. 1 Extract of a projected timetable on Zürich – Bern route [5]

An *ideal integrated timetable* at last is a symmetrical clock-faced timetable, having all lines in the entire network joined with each other, so that there are feasible connections between the single lines in the junctions. Basic requirements are to have consistent cycle times throughout the network and to make the whole timetable symmetrical by the same minute. The system gains efficiency by including more lines and by offering connections over a longer period of time (best from the early morning to about midnight) [6].

Of course, there are always geographical, economic or operational reasons for which this ideal integrated timetable can not be realized and must be modified. For example, since not all the important junctions are at an appropriate distance apart, not all connections can be put into effect. Also, some lines can not be provided all day long with a short interval and are stretched during the time of low demand, especially in the forenoon or the late evening. Actually, this is more important for regional traffic than for Inter-City-connections.

Two mathematical boundary conditions are essential for integrated timetables, the *edge-* and the *circle-equation*. As trains meet each other after every half cycle time, it is reasonable to choose these places to be junctions (so called *nodes*), as connection times into other directions are short in this case. This is the reason for uniform cycle times throughout the network [6].

Edge-time t_K, that is to say, the time one train needs on the line (edge) between two nodes, including stops in-between as well as half the stopping time at the two nodes, should be half of the cycle time (or multiple): $t_K = n \cdot 0{,}5 \cdot t_T$; $n = 1,2,3\ldots$ The satisfaction of this equation for all the edges in the network is a precondition for an ideal integrated timetable [6].

As already mentioned, the connections between the single lines are also very important. The sum of all the edge times on every route (travel from node A via one or more other nodes back to node A) should be an integer multiple of the cycle time. $\sum t_K = n \cdot t_T$; $n = 1,2,3\ldots$ This condition significantly reduces the possibilities for integrated timetables. Fig. 2 shows frequent parts of networks for which the circle-equation is not satisfied [6].

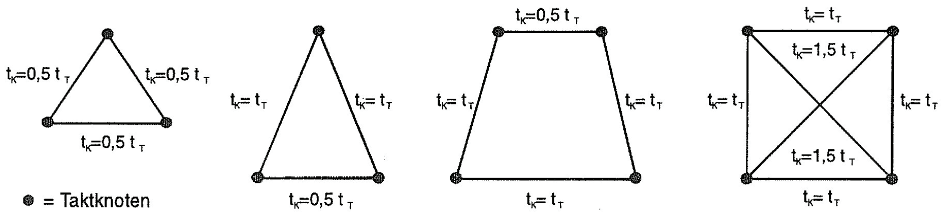

Fig. 2 Examples for networks which are not feasible for integrated timetables [6]

Since it is not easy to change the lengths of the edges (tracks), only changes in the travel times can have effects on the edge times. They can either be reduced (better acceleration, higher speeds) or lengthened (additional stops, reducing speed) to meet the requirements. It is important to note that within an integrated timetable system travel times are not as fast as possible but as fast as necessary [6]. In fact, it is not possible to transfer the whole ideal system into reality.

A hierarchical concept is essential for designing integrated timetables. First of all, the existing tracks and stations must be analyzed along with setting up nodes and lines. After calculating travel times, the edge times should be established. While connecting single lines, priority should be given to longer lines with a huge number of connections because shorter lines can easily be integrated into the existing system. In the end, the locomotive diagrams should be worked out and the available tracks and stations capacities should be checked. The system must be optimized in several steps of iteration [6]. For it should always be borne in mind that an integrated timetable makes notable benefits for passengers. It can be adapted to nearly every situation.

3. Developing Integrated Timetables for the Serbian Railway Network

According to section 2, the first step in developing an integrated timetable for Serbia assumes an inspection of the today's tracks and stations as well as the distribution of the big towns. Serbia has five towns with more than 100.000 inhabitants and 13 more with over 50.000 residents. 13 of these 18 are along the tracks that are used by far-distance trains today. So it is quite useful to conceive the lines of the integrated timetable similar to today's lines. Totally, seven lines are developed with five of them serving international connections (Table 1).

Table 1 Projected IC and EC lines

Line Name	Route
IC 1 Vojvodina	Beograd – Novi Sad – Subotica (– Budapest)
IC 2 Morava	Beograd – Lapovo – Niš (– Sofia / Skopje)
IC 3 Zlatibor	Beograd – Valjevo – Užice (– Podgorica)
IC 4 Raška	Stalać – Kraljevo – Požega – Užice
IC 5 Šumadija	Lapovo – Kragujevac – Kraljevo
EuroCity	Beograd – Sr. Mitrovica – Vinkovci – Zagreb
EuroCity	Beograd – Pančevo – Vršac - Timişoara

These seven lines can make up the basis of an integrated timetable in Serbia. With additional regional connections, four more big towns, especially in the north of the country, can be reached. There are also important tourist spots like the spas of Vranje and Vrnjačka Banja or the skiing resort of Zlatibor situated along these lines as well as border crossings to all the neighboring countries.

It does not seem useful to create two categories of long distance trains with different numbers of intermediate stops as travel speeds are quite low and so additional stops do not lead to a big increase in travel times. Intermediate stops are chosen as they are in today's timetable [7].

Between Belgrade and Lapovo, there exist two single-track sections via Mladenovac and via Mala Krsna. The first is used for southbound trains, whereas the second is used by trains going to Belgrade. With these sections included, about 90% of the track length between Belgrade and Niš are double-tracked. The line from Belgrade to the Croatian border has two tracks, too, but the rest of the network is only single-tracked.

As mentioned at the beginning, the concept should work without major investments in new tracks and without increasing track speeds. Only three small projects should be mentioned which are essential for a better quality of this concept:

- Beograd Centar station is being finished at the moment. The old Central Station is in a very poor state and certainly could not handle a higher number of trains. Travel speeds on the old station's tracks are also very low, so Beograd Centar must be finished before this timetable can be introduced.
- The line Kraljevo – Vrnjačka Banja – Stalać is closed at the moment. This line should be reopened to introduce IC line 4. Otherwise, IC lines 4 and 5 would have to be added to a single line Užice – Kraljevo – Lapovo. But in this case there would not be proper connections towards Niš.
- Between Subotica and Novi Sad, near the station of Mali Iđoš, a 2-3 km long double-track section should be built to allow train crossings without slowing down.

In the following Fig. 3, the whole projected network is shown on a map of today's railway network. Every intermediate stop for the long-distance trains is shown here, with the possible extensions of IC lines 1, 2 and 3 marked by dashed lines. Regional connections are also shown.

After setting these lines, travel times for every section are calculated according to Serbian Railways' official timetable for 2012 [7]. Acceleration is set at 0,3 m/s^2, braking with 0,6 m/s^2. Intermediate stops should usually take two minutes but are longer in case of changing the engine or the travel direction. Time recovery margins are added according to UIC leaflet 451-1 [8].

As mentioned at the beginning, a two-hour-interval is chosen for all seven lines to perform the balancing act between working out ways to increase the attractiveness of railway networks while making best use of the modest rolling stock and infrastructure which are now available. The trains may run in the period from 6h to 22h, which creates as many as six to nine daily connections between all nodes. International trains and night trains can easily be integrated into this concept.

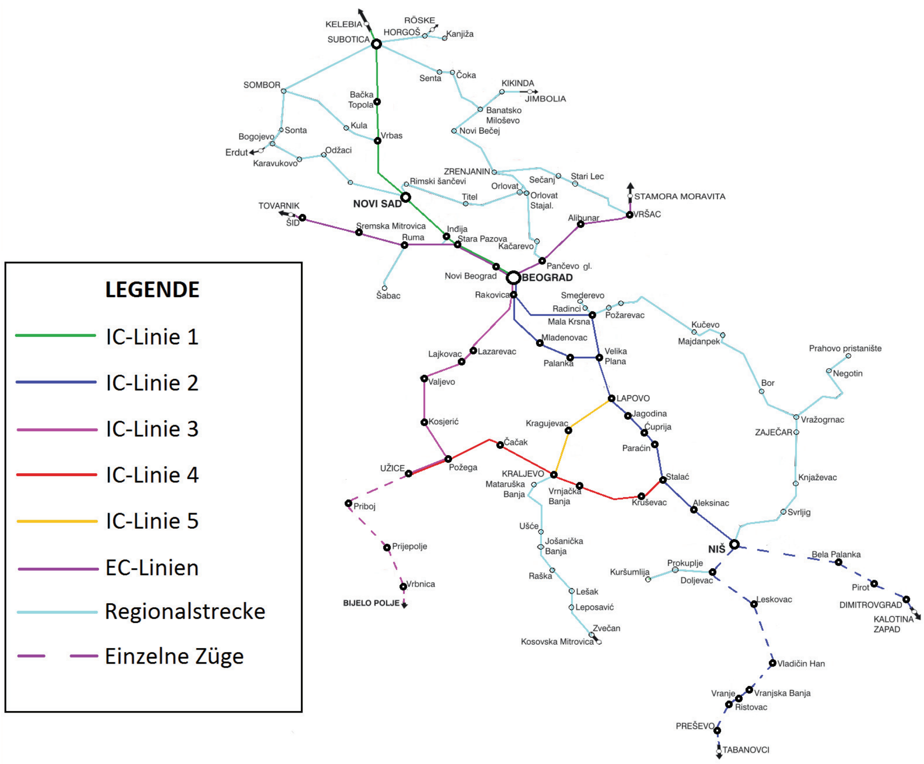

Fig. 3 Serbian Railway Network with seven IC- and EC-lines

The following Fig. 4 shows an overview on the seven lines with travel times and possible connections. The numbers next to the towns are arrival (directly next to the station) and departure (with a space between station and number) minutes for every line. Even numbers stand for even hours and italic numbers for odd hours according to the two-hour-interval. Intermediate stops without possibilities of changing trains do not have their arrival and departing times marked nor are the times for regional connections shown so as not to have the figure overloaded.

The timetables allow short transfer times (about 5-15 minutes) to change trains in all directions at nearly all stations. Only two connections cannot be integrated, i.e. the one from Lapovo to Stalać at Kraljevo and the one from Romania to Croatia and Subotica at Beograd Centar. In the following section, all three important connection types are described in detail. The figures show the single nodes with transfer times between arrival and departure at every station, given in minutes.

The most important station is, of course, Beograd Centar with five lines going together. As the connection with Romania is not as important as the other lines, the best thing to do seems to be working out short transfer times from Croatia and Subotica to the south of Serbia. As the station is quite large, transfer times should not be less than ten minutes. With a block time of five minutes it is possible to get all transfer times into a time frame of ten to 20 minutes. Fig. 5 gives an overview on that situation.

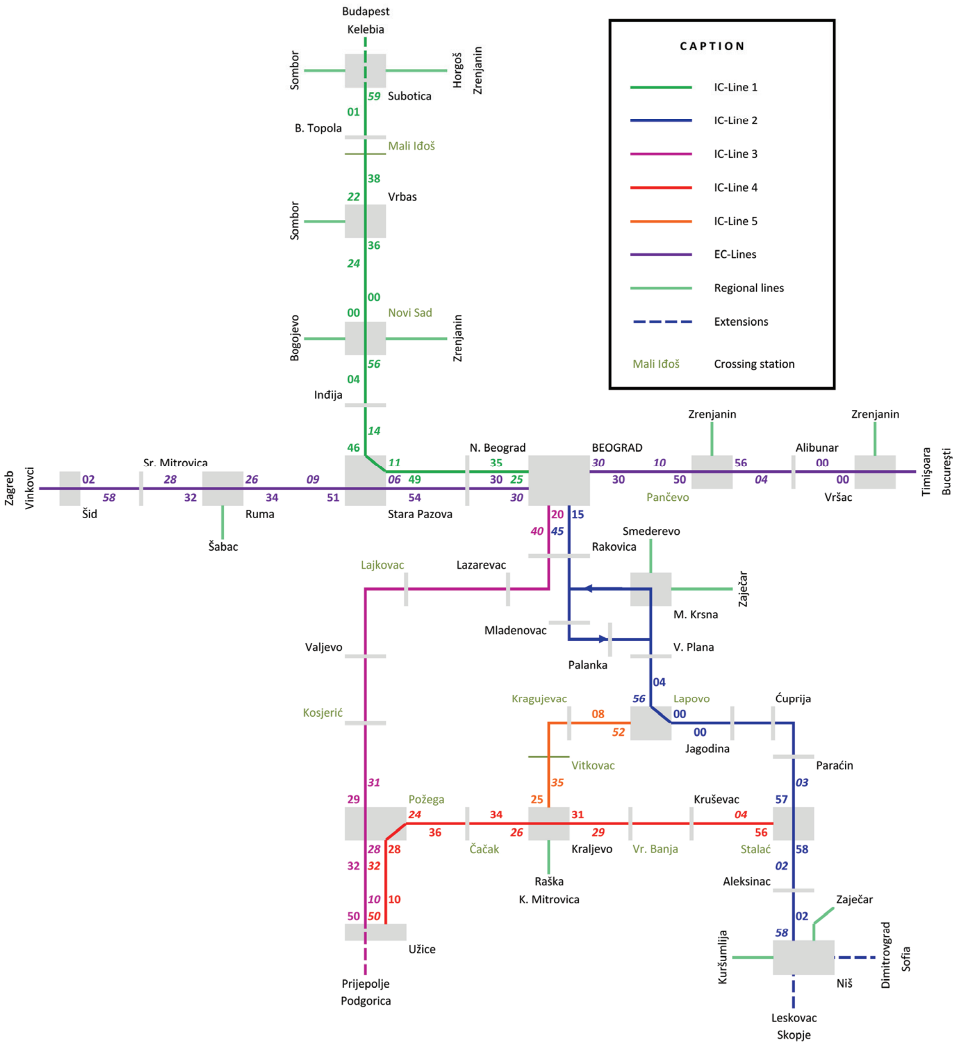

Fig. 4 Overview on the seven IC- and EC-lines with travel times and connections

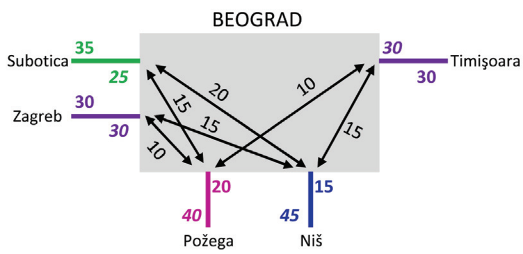

Fig. 5 Overview on the connection and transfer situation at Beograd Centar station

The second type of stations are Lapovo, Stalać and Kraljevo, where one line passes through and a second one starts or ends there. Here a short transfer time from the terminating line in both other directions should be possible. As an example, Fig. 6 shows the situation at Lapovo, where IC line 2 passes through while IC line 5 begins.

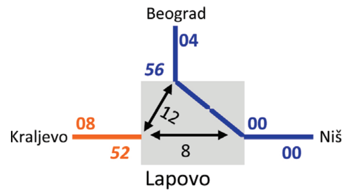

Fig. 6 Overview on the connection and transfer situation at Lapovo station

Stara Pazova and Požega typify the last type of station. Here two lines come from one direction and split up. Within towns like that a short transfer time around the corner should be possible. As an example, Fig. 7 shows the situation at Požega, where IC lines 3 and 4 split up and give a 7-minute-connection from Belgrade to Kraljevo and Stalać.

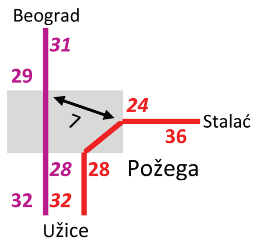

Fig. 7 Overview on the connection and transfer situation at Požega station

As mentioned before, proper connections can be created in all six important nodes throughout the network. In case of delay, the dispatcher has the task to decide whether a connection can be guaranteed or must be given up. By using the UIC-based recovery margins (see above) and some additional extra times, a delay of more than 20 minutes can be made up between Niš an Belgrade, so that all connections can be guaranteed. In case of larger delays, one or more connections must be given up or otherwise the whole system would collapse.

Table 2 gives an overview on possible time reductions with this concept of integrated timetables compared with today's situation with no integration at all. Of course, on most of these connections using trains is not common today because of the large interchanging times. Also, the number of connections available every day is given in brackets for both possibilities.

Table 2 Examples of time reduction by introducing integrated timetables

Connection From – To	Travel time today [7]	Travel time with i.t.
Novi Sad – Niš	ca. 6:30-8:00 (3 times/day)	5:54 (7 times/day)
Novi Sad – Užice	ca. 6:00-7:30 (7)	4:49 (8)
Subotica – Kraljevo	ca. 9:30-12:00 (2)	7:25 (4)
Subotica – Valjevo	ca. 7:00-9:30 (7)	5:18 (8)
Kragujevac – Užice	ca. 5:00-7:00 (3)	2:48 (6)
Čačak – Niš	ca. 8:00 (2)	2:57 (7)

All in all, a significant improvement in city-to-city connections that are not on a direct line can be made with an integrated timetable concept. It opens up new business segments for the Serbian Railways and will lead to an increased use of trains in comparison to far-distance buses. It is the basis on which railways can successfully compete with buses.

4. Verifying the Results with Simulation Software

All travel times, transfer times as well as acceleration and braking effects are first calculated by hand. Later on, a computer software for railway operations is used to check.

The *Brockhaus* dictionary defines simulation as the *recreation or simplification of physical, technical, biological or economic processes by mathematical models close to reality but cheaper, easier or more harmless than the original* (translated from [9]). So, the railway simulation is a simplified recreation of tracks, stations and trains by mathematical methods.

With the computer-based simulation, the recreation of reality is done by software. After entering the required input data, the computer program is able to calculate all operational processes and then supply information on them as well as warnings and possible errors. Applying this information, the timetable can be improved step by step with an iteration.

For the simulation of the integrated timetable on the Serbia Railway network, the software *OpenTrack* developed at Swiss ETH Zurich is used. It is easy to learn but quite a powerful software solution for simulating all aspects of railway operation. The software is developed by former student Daniel Hürlimann in his diploma thesis, later improved by other students and employees of the university and is today marketed by his own enterprise [10].

The mathematical basis for the software is a numerical solution of the motion equation $s = s_0 + \int v\, dt$ that is used to calculate acceleration and constant speed of the single trains; so, it leads to a time-distance-diagram. Braking is calculated by fixed deceleration factors as the braking of a train cannot be described by a single formula. All the trains within the system are required to fulfill their motion equations and so the timetable system is worked out for a given period of time.

The simulation is based on a node-edge model with nodes denoting all points in the network, where basis information like speed, curve radius, etc. changes. Nodes also include the places of signals, switches or stations. These nodes are connected by edges which represent the tracks with their significant information (speed, inclination, radius etc.). So, the input data is made up of all nodes and edges throughout the network as well as engines, trains and a possible timetable.

As described above, the program calculates all the train routes by their timetable and the parameters of the edges and so it is able to determine travel times with arrivals and departures at every station in the network. This calculation process is interactive, which means that the user is able to take part in the simulation like a dispatcher. He can, for example, block single tracks, force a train to wait for another in delay and so forth. The simulation program is both discrete (signals, switches) and continuous (moving of trains).

Output data can be expressed in different diagrams (time-distance, speed-distance, acceleration, braking, energy, …), graphical timetables with delays and other information, track and station occupancy diagrams and different statistics on rolling stock, delays and energy. Most data is given as a text file and can be imported in calculating or drawing program. Fig. 8 gives an overview of the process of the simulation software and all types of input and output data.

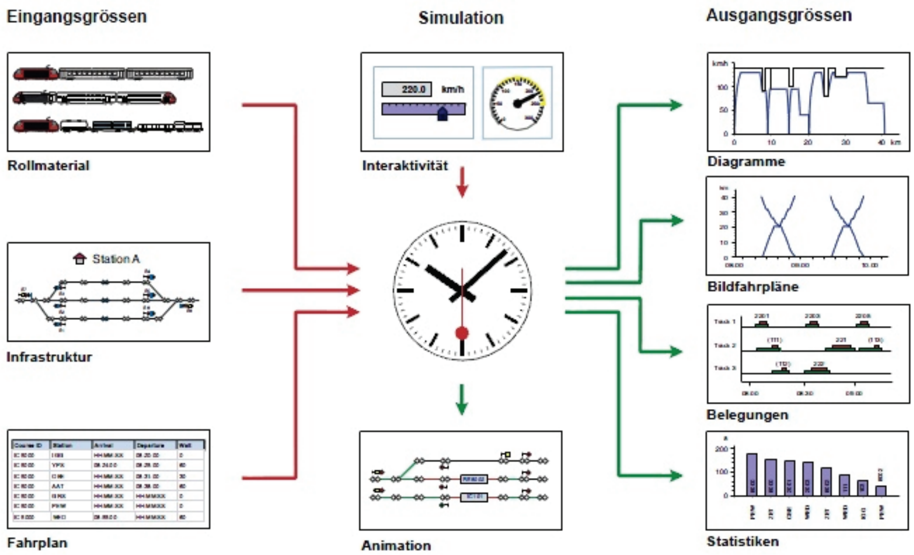

Fig. 8 Processes and data used by the software OpenTrack [10]

To check the suggested timetable concept, it is necessary to build up the Serbian network within the simulation software. To keep it clearly arranged, only tracks and stations that are necessary for calculating and operation are created. All other tracks, additional stations and signals are not taken into consideration. So, Belgrade's Centar station was modeled only with five tracks and all other stations with only one, two or three, although they have far more tracks in reality, but such a wealth of details is not necessary for the simulation. Block signals are not taken into account either, only on the section Rakovica – Beograd – Stara Pazova, where two fast trains go after each other within a short amount of time. That is the reason why an analysis of capacity is not made in this paper. So, only the network shown in Fig. 3 and without the regional lines is modeled.

All tracks are modeled with their allowed speed and real length. The nodes are described as so-called *double-point-nodes*, so one single node always has the information of the neighboring edge. For better view the distance between neighboring nodes is not rendered true to scale. Fig. 9 shows as an example of the section between Novi Beograd and Novi Sad with the junction at Stara Pazova.

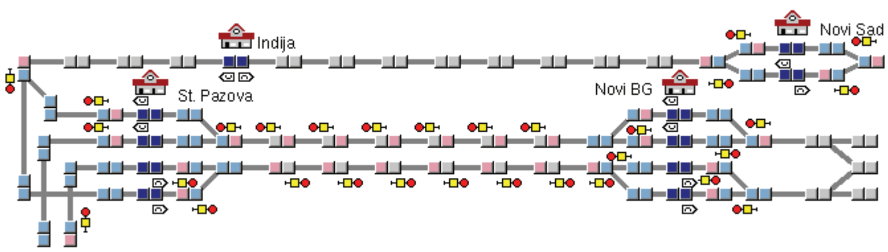

Fig. 9 Example of nodes and edges in the OpenTrack topology

The original engines (ŽS classes 444, 461 and 661) are put in with their characteristic engine diagrams and technical data as well as cars. For the simulation, all trains are made up of one locomotive and 5-7 passenger cars. Class 444 is used in Vojvodina, class 461 to Užice and Niš and class 661 (diesel) for the EC train to Romania as that line is not electrified.

After data input, we can start the simulation process. It shows that the calculated travel times are realistic and that all the connections can be achieved as projected (in terms of infrastructure and operation). Time recovery margins are enough to meet the UIC requirements [8] and all the trains are able to make up for 15 to 25 minutes delay along their entire route. Especially in front of bigger nodes and on single track sections with train crossings, bigger time recovery margins are planned.

5. Conclusions and Future Outlook

This paper has presented a full-fledged working concept of integrated timetables for far-distance passenger transport within today's Serbian Railway network. This concept can be put into action quickly and without major investments in infrastructure and rolling stock.

Comparing to the present situation, three times of train kilometers would be provided and overall travel times could be reduced up to 40%. Of course, more money has to be spent on operating of all the trains but it is clear that also profits would increase immediately. Studies from Switzerland, where an integrated timetable was introduced in 1982, have showed an enormous increase of passenger kilometers [11]. As the potential for public transport in Serbia is high (lots of people today go by far-distance buses), the Serbian Railways should be able to change the modal split by introducing an integrated timetable with shorter travel times on distances not covered without changing trains.

If this systems proves to be successful, it can be extended to regional connections as well. In a further step, it can be combined with investments in the infrastructure, so that all travel times are shortened. But it is important to repeat that this investment is not necessary for the implementation of the timetable improvement.

To conclude, it must be said that Serbia's high potential of railway services is not used in a proper way today and has to be improved. An integrated timetable system with good and short connections and a huge number of available trains can be the first step to establish a glorious future for the Serbian Railways.

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MOGUĆNOSTI ZA STVARANJE OBJEDINJENOG REDA VOŽNJE NA MREŽI PRUGA ŽELEZNICA SRBIJE

Ulf Fischer, Simo Mirković, Sanjin Milinković, Andreas Schöbel

Redovi vožnje su ključni elementi za upravljanje železnicom.Njima se određuju svi troškovi saobraćaja, ali imaju i veliki uticaj na poslovanje železničkih kompanija zato što iskorišćenje vozova zavisi od vremena putovanja i ostvarivih veza. U ovom radu prikazan je potpuno primenjiv objedinjeni red vožnje za inter-siti vozove na postojećoj mreži pruga Železnica Srbije. Velika razlika u odnosu na uobičajne redove vožnje je da se sve linije koriste svakodnevno nekoliko puta sa polascima na svaka dva sata. Svi vozovi u jednom čvoru mogu biti povezani sa drugim pravcima u okviru kratkog vremena promene voza. Tako je moguće skratiti ukupno vreme putovanja između nekoliko gradova u Srbiji, čak i do 3 sata, bez većih investicija za povećanje maksimalne brzine na prugama. Polasci na svaka dva sata su izabrani da bi se uskladile težnje za povećavanjem interesovanja za putovanja železnicom i najbolja moguća iskoristivost malog broja vozila i postojeće infrastrukture. Uporedo sa obnavljanjem koloseka možda bi čak bilo moguće ostvariti polaske na svakih sat vremena, da se poveća brzina vozova i da se u budućnosti i lokalni saobraćaj objedini u ovaj sistem.

Ključne reči: *železnički saobraćaj, objedinjeni red vožnje, prevoz putnika, simulacija*