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POSSIBILITIES FOR INTEGRATED TIMETABLES WITHIN THE NETWORK OF SERBIAN RAILWAYS

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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. Within this paper, a fully functioning system of so called integrated timetables within Serbia's present inter-city railway network is developed. The big difference to common timetables is, that all lines are served several times daily with a fixed interval of two hours and all trains serving one junction have the ability to be connected to all other directions there within short transfer time. So it is possible to reduce total travel time between several Serbian towns up to three hours without major investment for improving the tracks' maximum speed. The two-hour-interval has been decided to perform the balancing act between working out ways to increase the attractivity of 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.*

Keywords – Railway Operation, Integrated Timetable, Passenger Transport, Simulation.

1. INTRODUCTION

The idea of this paper was to develop a system of integrated timetables within the network of Serbian Railways. The focus is placed on Inter-City connections as well as links to surrounding countries. The following concept is based on considerations published in Fischer, 2012 [1] and gives an overview on a possible system of integrated timetables that can be realized quick and affordable. By introducing an integrated timetable, the total travel times can be reduced without upgrading the tracks to higher speed that involves a large amount of investments and years of realization. Together with an adequate number of punctual and reliable trains, image and signification of railways in Serbia can be clearly increased. If tracks are renewed yet, these ideas can easily be transferred to the new configuration, as they are not an interim solution but a fully working concept.

2. DEVELOPING AN INTEGRATED TIMETABLE

First of all, several terms going with timetables have to be defined: A *clock-faced timetable* is a timetable with constant intervals between the single trains. A *symmetric clock-faced timetable* extends this definition on both directions. And, at last, an *integrated timetable* takes this into account for the entire network made up of junctions (hubs) and lines (so called edges) between them.

Such a timetable can only be realized, if two mathematical boundary conditions are satisfied, the *edge-* and *circle-equations*. The edge-equation requires the travel time between two hubs to be half of the interval or a multiple of that. To fulfill the circle-equation, every ride from one hub through the network back to this one must be a multiple of the

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interval [2].

Of course it is often not possible to realize this *ideal integrated timetable*, as hubs should not only be chosen by mathematical reasons but of their notability (bigger towns, junctions). Then it can be slightly modified so that, for example, in this hub some connections have a longer time for interchange.

The main slogan for the traffic on a network of integrated timetables is “as fast as required” unlike common timetables where it is “as fast as possible”. To provide good connections it might be useful even to stretch travel times on single sections, if this measure leads to better connections. In general is to be said that in this concept, time is much more important than distance.

Another important factor is the design of the hubs. As several lines meet together there, an adequate number of platforms must be provided and trains must not obstruct each other during arrival or departure. By using one platform with two tracks for up to four trains (with intermediate switches), the necessary interchange time can be reduced as people don’t have to change platforms.

For the timetable development itself a top-down-system is essential. After setting lines and hubs, travel times have to be calculated and the lines can be linked. Single lines should be determined by their length and long-distance-lines have a higher priority than regional or local lines as latter are much easier to be linked in. After that, the demand of rolling stock can be estimated and circulation plans can be developed. The last step is to check the plausibility of the concept by examining tracks’ and stations’ capacities, especially on single track sections. Problems found by this evaluation can be solved in a further step of iteration [3].

Two factors are essential for a functioning system of integrated timetables: Reliability and punctuality of the trains. As all lines are well connected, the delay of a single train can cause lots of delays throughout the entire network. So it must be careful proved whether a train has to wait for a delayed connection or not. All in all integrated timetables increase the attractiveness of a railway system more than any other comparable effort.

3. CONCEPT FOR SERBIAN RAILWAY’S NETWORK

As mentioned in chapter two, the first aim was to set the individual lines and connections between them. Based on today’s network of long-distance trains, seven lines were chosen to make up the core of the concept (Table 1). Five of them are domestic ones (although several trains may be extended across the borders) and two are almost exclusively meant for international transport. The domestic ones should get typical local toponyms for marketing reasons and all lines are assigned colour codes. All lines run in a two hour interval, which is the result of the balancing act between working out ways to increase the attractivity of railway networks while making best use of the modest rolling stock and infrastructure which are now available.

Table 1. Projected Inter-City lines

Name	Route
IC1 Vojvodina	Beograd – Novi Sad – Subotica
IC2 Morava	Beograd – Lapovo – Niš
IC3 Zlatibor	Beograd – Požega – Užice
IC4 Raška	Stalać – Kraljevo – Užice
IC5 Šumadija	Lapovo – Kragujevac – Kraljevo
EuroCity	Beograd – Sr. Mitrovica – Zagreb
EuroCity	Beograd – Vršac – Timişoara

IC-Lines 1 and 2 as well as the Eurocity connection with Croatia are today’s core of the network with serving four of Serbia’s five biggest towns (Beograd, Novi Sad, Niš and Subotica) and being part of the European Corridor X. IC-Line 3 is part of the important connections with Montenegro’s port of Bar. The IC-Lines 4 and 5 are set up to establish proper connections around the junction of Kraljevo and require special consideration.

The first idea was to establish a direct connection Beograd – Kraljevo via Lapovo but this wasn’t considered well because according to the boundary conditions mentioned in chapter two, short transfer times would not be possible within this configuration. So it was decided to establish a connection Stalać – Požega (extended directly to Užice) with good connections to Beograd at Požega, as well Niš and Beograd at Stalać (Fig.1). To explain the time format in this figure, x and y stand for even and odd hours. The single numbers are minutes for interchanging trains. As the timetable is symmetrical, these times are valid for both directions.

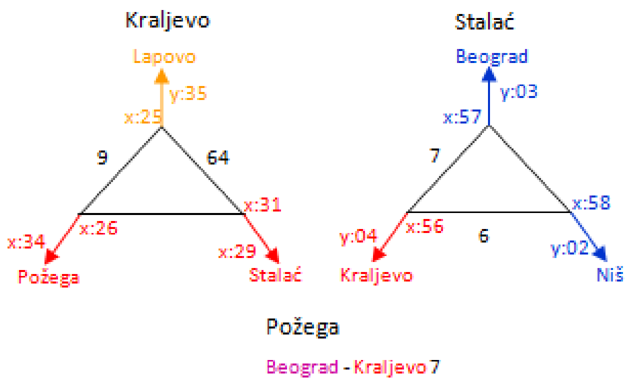

Fig.1. Examples for interchanges at several hubs

The remaining gap between Lapovo and Kraljevo is filled by an additional IC-Line tendering proper connections to nearly all other directions and providing a larger number of intermediate stops. Tough the lack of a direct connection, the total travel time from Čačak and Kraljevo to Beograd via Požega (PO) can be significantly reduced in comparison to the direct route via Lapovo (LA). This is one of the biggest efforts of an integrated timetable (Table 2).

Table 2. Comparison of selected travel times

Connection	via PO	via LA
Beograd – Kraljevo	3h 47min	4h 15min
Beograd – Čačak	3h 20min	4h 45min
Beograd – Vr. Banja	4h 19min	4h 50min

The network is completed by the second EuroCity line linking Beograd with Timişoara in Romania also serving some important towns in Vojvodina like Pančevo. An overview of these seven lines and some regional lines that might be linked in is shown in Fig.2. The same time format is used as in Fig.1.

All intermediate stops are shown in Fig.2. It turned out to be useful to introduce only one category of fast trains as, caused by the low speed in the entire network, additional stops take not so much time. To avoid additional stops for crossing, southbound trains on IC-Line 2 run via Mladenovac as trains heading towards Beograd serve Mala Krsna.

For calculating travel times of the trains, timetable documents of ŽS were used [4]. So it came out that the travel times between two stations are almost the same like in today's timetables. All travel times were calculated with one class 441 locomotive and up to eight carriages. Intermediate stops take mostly two minutes time, unless engine or direction are changed. Recovery margins recommended by the UIC in leaflet 451-1 [5] were specified.

As mentioned in chapter one, the goal was to develop a fully functioning system on today's infrastructure. Nevertheless, some investments have to be made to provide a reliable supply, but they are locally restricted. The two biggest projects are the refurbishments of the tracks between Kraljevo and Stalać, where there is no traffic at the moment and the completion of Beograd Centar railway station. This is necessary to guarantee the shorter travel times in comparison to the route via Beograd's main station. A small but effective measure is also to build a double track section with a length of two kilometres at Mali Iđoš to enable crossing trains without an additional stop (Fig.2).

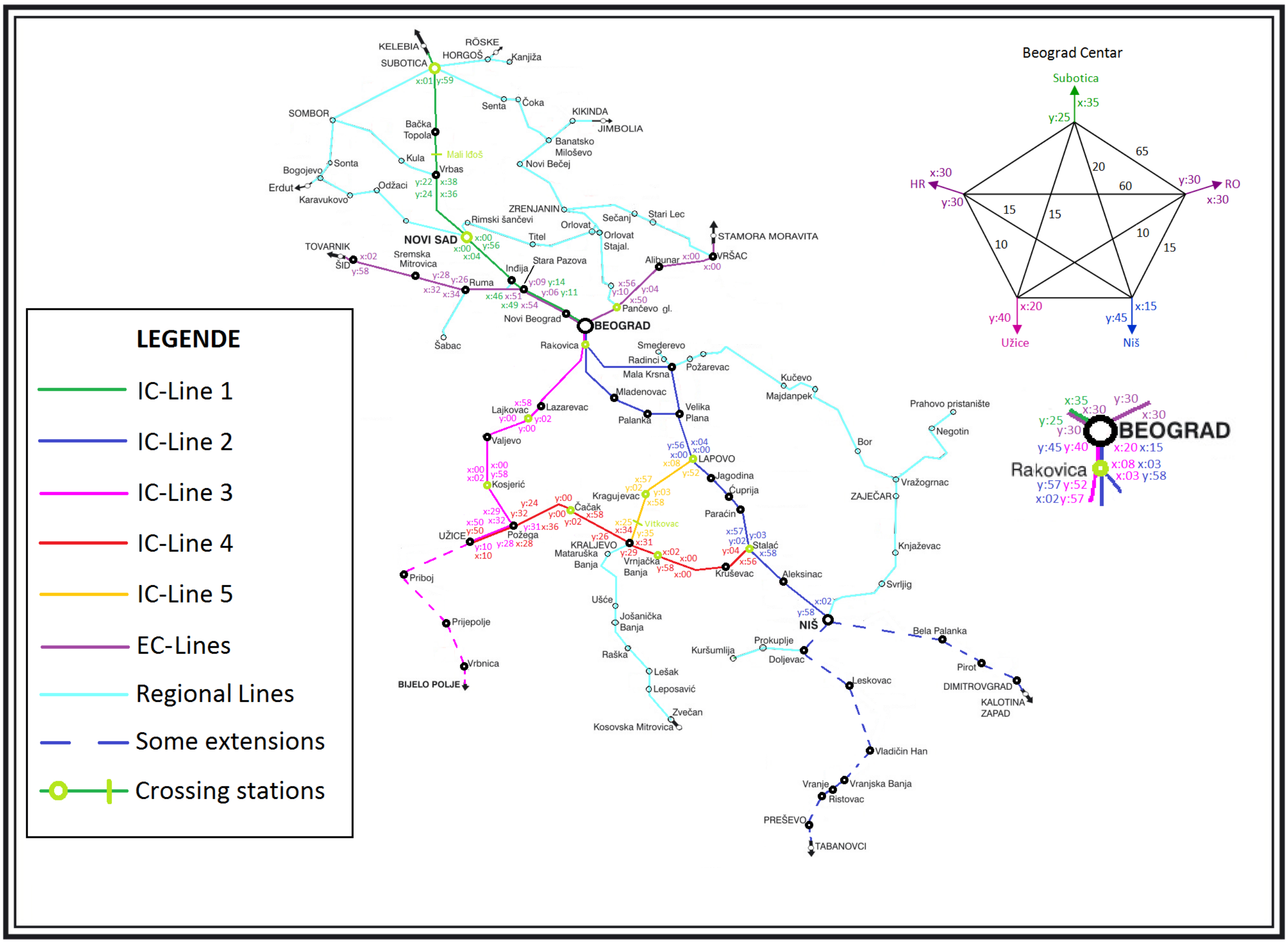

Fig.2. Overview on all seven lines with intermediate stops, travel times and possible regional connections

4. VERIFICATION OF THE RESULTS BY USING A SIMULATION PROGRAM

The manually calculated results from chapter three underwent verification with OpenTrack, a simulation program for railway systems developed at ETH Zurich. By using this tool it is possible to simulate different operation conditions on railway networks e.g. regular timetables, impacts of delays or occupancy of tracks and stations. After running the simulation, the results can be used for the next step of iteration to optimize the timetable.

The train configuration was worked out more in detail, so travel times were calculated with following train compositions: IC-Line 1 and EC to Zagreb with ŽS 441.7 and six carriages; EC to Timişoara with ŽS 661 and five carriages, IC-Lines 2/3 with ŽS 461 and up to nine carriages and for the remaining two lines, diesel multiple units ŽS 712 were taken in account because of the request to change the direction quickly at Stalać, Lapovo and Požega. Of course, trains can be made up with a lower number of carriages or the class 712 DMUs can be substituted by newer class 711.

The simulation run showed that the elaborated timetable concept is fully working. Small delays up to ten minutes could easily be made up between two hubs and along the line from Lapovo to Beograd, that is especially susceptible for delays, even 15 minutes can be obtained, which is essential to guarantee all connections at Beograd Centar station (Fig.2).

Experiments with higher delays showed that connecting trains should not wait longer than five to ten minutes, as otherwise they would carry on the delay to the next hub. So dispositions done by the dispatchers at the single hubs belong to the most important tasks.

Not part of the simulation was an investigation of the track capacity, because the exact location of signals and blocks was not known. As Fig.3 for the example of the line Beograd – Novi Sad – Subotica and an interval of two hours shows, there seem to be enough slots available for regional and freight trains. Within this figure, recovery margins can be made out by comparing the ideal (black) with the real (purple) lines.

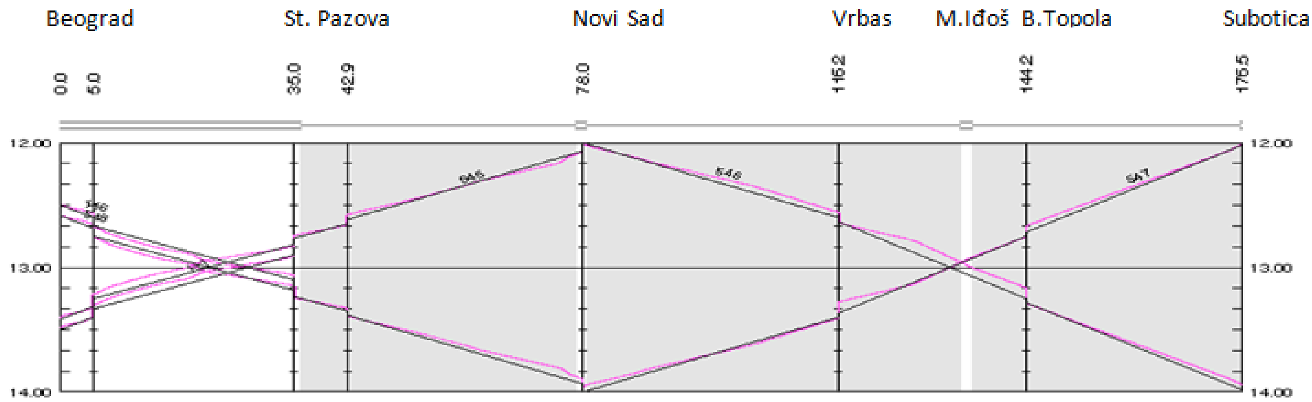

Fig.3. Timetable extract for Beograd – Subotica from 12:00 to 14:00 with IC and EC trains (OpenTrack)

5. CONCLUSIONS

The introduction of an integrated timetable on Serbia's railway network could be the first step to improve the situation of passenger transport in the country. As indicated in chapter four, the profitable freight traffic is not affected from the improvements in passenger traffic, as the tracks seem to have sufficient capacity to handle today's freight traffic.

The next step might be to adapt regional lines to fit into the timetable system. At hubs like Subotica, Novi Sad or Niš, the interchange time should be low and connecting trains should easily being reached on foot. Regional traffic on main lines should be adapted to the times of IC trains, so that there is also a good connection between faster and slower trains. After that, the target of an integrated timetable throughout the network is realized.

The third goal might be to modernize the tracks as well as the rolling stock. With rising of the actual speed limits, travel times can further be reduced. When the whole Corridor X is improved to a speed limit of 160 km/h, travel times of about two hours between Beograd and Niš and about 1 hour 30 from Beograd to Subotica will be possible.

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