ETCS AS A TOOL TO INCREASE THE CAPACITY OF RAILWAY LINE – SIMULATION ASSESSMENT

[1]Petr NACHTIGALL, [1]Erik TISCHER

[1]*University of Pardubice, Pardubice, Czech Republic, EU, petr.nachtigall@upce.cz, erik.tischer@upce.cz*

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Abstract

Simulation software has become an integral part of solving scientific problems. Transport is no exception; therefore, every transport project must be based on a model and simulation. ETCS is a novelty interlocking system of train protection. Its various application levels offer new possibilities for access to train protection. ETCS L2 levels are being built on railway lines in the Czech Republic and the Slovak Republic. This system brings the highest added value in terms of railway transport capacity. This poster deals with the simulation of a fictitious track equipped with ETCS L2 in the OpenTrack software and a comparison of performance indicators with the state-of-the-art.

Keywords: Simulation, ETCS, headway, capacity

1. INTRODUCTION

Current trends in rail transport are forcing infrastructure managers to increase the track capacity. Congested line sections in agglomerations do not allow for further capacity increases by shortening the interval and longer trains are not possible due to the length of the platforms. On the other hand, the European Train Control System (ETCS) is going to be implemented, which transfers responsibility for speed reduction and stopping the train from the driver to this system. However, this can harm the capacity of the lines, as the reliability of such a system must be ensured with almost 100% certainty. This article deals with the simulation of the ETCS with benefits (short block sections) on the capacity of the Czech railway infrastructure.

2. COMPARISON OF THE CONVENTIONAL MODEL AND ETCS IN FOREIGN PROJECTS

The authors investigated the current state-of-the-art of scientific knowledge in the field of ETCS implementation and its impact on a line capacity. For example, the study [1] deals with the implementation of the different ETCS application levels and their impact on the line capacity. The study mainly discusses the L2 and L3 application levels. Based on simulations, the authors assume the potential for increased line capacity when using these systems, assuming higher line speeds (above 200 $km \cdot h^{-1}$) [1]. In another study according to the source [2], which deals with the comparison of the ETCS L2 application level with conventional ATP (Automatic Train Protection) systems, mainly analytical methods are used. Based on analytical calculation methods, the authors conclude that a real capacity increase of 10 % can be achieved on a suburban railway network. A case study is developed for selected suburban lines around London [2]. Another study [3] compares the operation of conventional ATP and the European Railway Traffic Management System (ERTMS) at different ETCS application levels. Here, the increase in rail line capacity is only demonstrated in ETCS application-level L3. For the other application levels, a minimal difference compared to existing systems is observed and a slight degradation of line capacity is allowed depending on the setting of the braking curves [3]. Another study deals with the capacity assessment of the line Zagreb - Rijeka M202 (Croatia), which is part of the TEN-T network. In the study, the traffic organisation was changed to increase the capacity for freight traffic. Simulations in OpenTrack software showed that the reconstruction of the line and the change of traffic organisation would increase the available capacity of the line for freight traffic by approximately 23 %. However, the study does not directly investigate the effect of ETCS, but also the overall reconstruction of the line, which distorts the result [4].

The next study [5,6] focuses on the reconstruction of the line R 201 Zaprešić - Zabok (Croatia). The expected timetable was simulated using OpenTrack software. The study also included an investigation of a suitable train protection system. However, the simulation of the individual scenarios did not demonstrate the benefits of implementing ETCS over a national train protection system. The study assessed the benefits of line reconstruction in terms of increasing the attractiveness of the line and increasing its capacity. However, as in the previous study [4], the direct effect of ETCS on the increase in line capacity was not demonstrated by simulation.

Nicola Coviello's PhD thesis [7] deals directly with the impact of ETCS and train heterogeneity on the practical throughput of single-track lines. The results of the theoretical part of this thesis are then verified on a case study of the Trans-Mongolian Railway. The author establishes an interesting research methodology by first dividing the line into sub-sections, including functional systems such as stations and open-line sections. These sub-sections are then submitted to a practical throughput calculation, using analytical methods. The theoretical results obtained are then submitted to simulation in the RailSys software, for which approximately twenty operational scenarios are built. Each of these scenarios is then submitted, using the multiple simulation technique, to the order of hundreds of replications with randomly varying input delays of trains entering the system. The author found that the practical throughput is mainly affected by the heterogeneity of trains and the number of trains running in a bundle. The impact of ETCS on the capacity of single-track lines was assessed to be quite negligible.

3. SIMULATION MODEL PREPARATION

For the simulation, the software OpenTrack was used, which is used for the simulation of various types of railway systems. This tool is mainly used for verifying the capacity possibilities of the railway infrastructure or other railway infrastructure, verifying the stability of the proposed timetables, and testing the train's energy consumption. The input data for the creation of the simulation model are infrastructure, vehicles, and timetable data [8].

The construction of the simulation model itself is then carried out in three phases. In the first phase, infrastructure data is fed into the model. The infrastructure (traffic network) is represented by a network graph (nodes and edges). The parameters of individual routes and paths are then entered into the simulation model. In the next step, data on the rolling stock are entered. This includes the name of the traction vehicle, weight, adhesion weight, length, maximum speed, traction power system, traction power, driving and vehicle drag coefficients and the type of train protection used. Subsequently, the train types are inserted using the train editor [8]. To simulate the considered operational concepts, it is also necessary to create a timetable. In this step, the specific train is assigned a number, category, track occupancy method, time position and the corresponding itineraries with their preferential order [9,10,11].

For this research project, it was necessary to build the model in such a way that occurs the use of various types of tracks and train protection. The details and implementation of the different levels of signalling are described in the following chapter.

4. INFRASTRUCTURE

For this research, a fictitious line with a total length of 18.35 km with three intermediate stations and three stops was designed. The track model is designed to form an infinite loop. This created three open-line sections, each containing one stop. The line is double-tracked throughout its length. To eliminate additional unwanted input variables, the track has no slope throughout its length and does not contain any curves. The stations are designed as four tracks. To get as large a variability of outputs as possible, a variant header length is designed at each station. The header lengths range from 300 to 800 metres. The header length affects the size of the block sections and, in conventional operation, the length of the slow speed zone. Switch points and crossovers are used on each header with a variable speed range in the branch line direction from 40 to 80 km·h^{-1}. The stops are placed according to the position of the block signals in the most appropriate place. Then we can observe its influence on the throughput of the block section.

4.1. Conventional (Czech) train protection system (LS)

The used station signalling equipment is an electronic interlocking system, partial technological times are taken from the ESA 44 interlocking system, which is one of the most newly installed interlocking systems on the network of the Infrastructure Manager (Správa železnic, s.o.) The line sections are equipped with a two-way electronic three-character automatic block with five or six sections of 1,000 m in length. The length of the line sections adjacent to the stations is of course dependent on the length of the station head and header and therefore the distance between the departure and block signals. A model of a line equipped for conventional operation is shown in **Figure 1**.

4.2. Operation under the ETCS L2

The used station interlocking plant remains the same, i.e., the electronic interlocking system. In the stations are the signals with the speed signalling system. The modification consists of the fact that the point defining the beginning of the speed restriction given by the main signal is no longer the position of this signal but the position of the limiting infrastructure element (switch). Typically, this is the first diverging turnout with the speed restriction. The individual block sections are no longer divided by block signals. The open line section is divided by fictitious signals of ETCS L2. Those blocks are 400 to 430 metres long and the model of the line equipped by ETCS L2 is shown in **Figure 2**.

Figure 1 Conventional model of the infrastructure

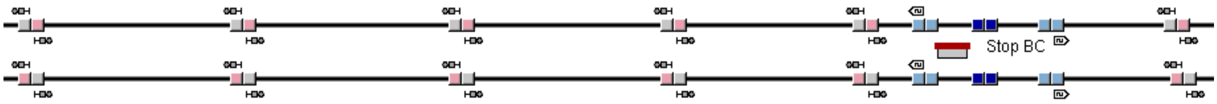

Figure 2 Model of the line equipped by ETCS L2

Another input which was necessary to enter was the parameters of the rolling stock. Five types of trainsets were selected, which represent trains that are common in the Czech Republic. Their most important parameters are shown in **Table 1**.

Table 1 Parameters of used trainsets

Train category	Engine	V_{max}	Length [m]	Weight [t]
Express freight train (Nex)	TRAXX F 140 MS	120 km·h^{-1}	600	1,000
Through freight train (Pn)	ČD Cargo 363.5	80 km·h^{-1}	600	1,800
Passenger train (Os)	471	140 km·h^{-1}	80	155
Fast train (R)	661	160 km·h^{-1}	132	170
Intercity (Ex)	680	200 km·h^{-1}	185	385

5. METHODOLOGY OF HOW TO COMPARE THE CONVENTIONAL MODEL AND ETCS L2

To compare the output parameters of the model, it was necessary to define which of these characteristics would be monitored and compared with each other. The authors decided to monitor the difference in the achieved headway time. The value of the headway time is determined according to Formula 1 as the maximum of the three headway sub-values (the headway for the next operating post, the headway for the rear operating point and the headway for the section). The sub-value for the line is then again determined as the maximum of the values for each block section. The value of the headway time is very important for the calculation of the line capacity, and throughput and for the construction of a stable timetable.

$$M = \max(M_Z, M_P, M_T) \qquad [1]$$

where:

M= final headway (min)

M_Z = sub-headway for the rear operating point (min)

M_P = sub-headway for the next operating post (min)

M_T = sub-headway for the section (min)

A tool in OpenTrack software called the Headway calculator was used to determine the value of the final headway time (**Figure 3**). This tool allows for determining the headway for any pair of trains. Using the multiple simulation methods, different values of the consecutive headway are tested, and the resulting value is determined using the half-interval method. The important condition is that the path of the first train must not influence the path of the second train. In certain cases, it may conditionally influence it, which is not desirable in this model [12,13,14,15].

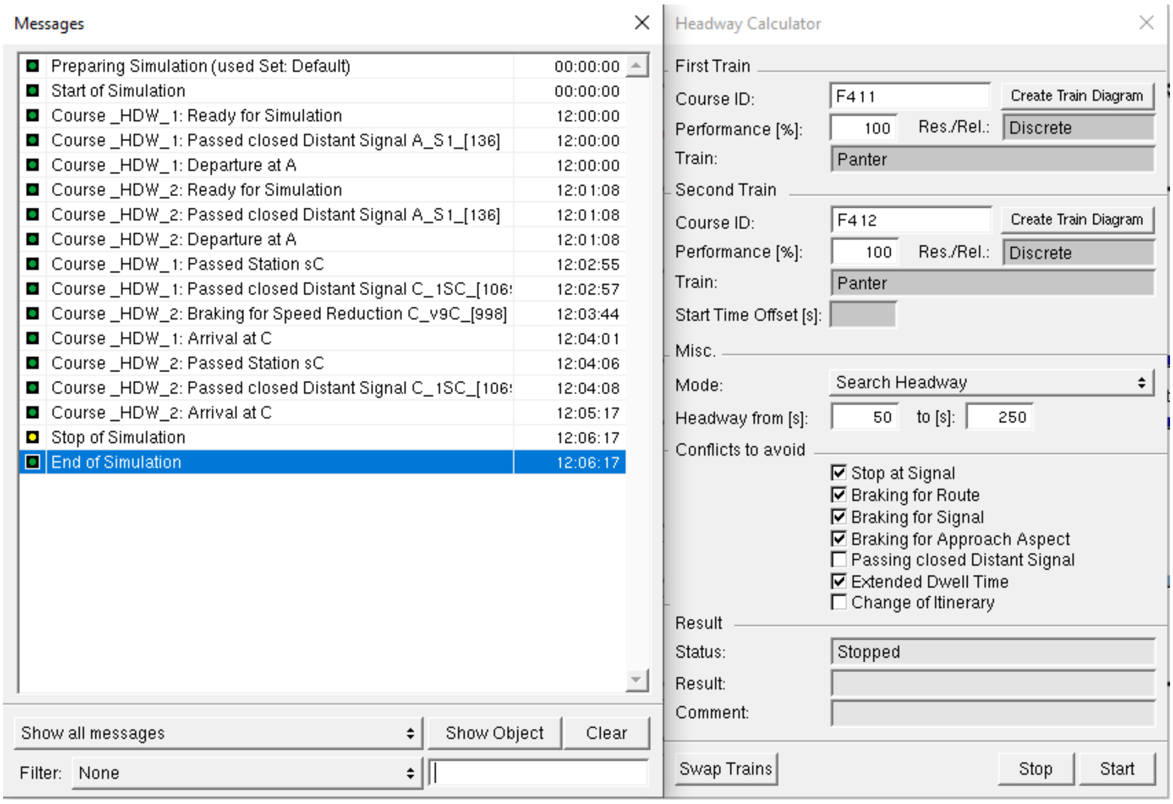

Figure 3 Headway calculator in OpenTrack

For correctly determined headway time, it was necessary to exclude those pairs of trains that cannot occur in normal operating situations. For these reasons, rules were defined to determine the behaviour of the defined pairs of trains. The defined train sequence is based on the infrastructure manager regulation SŽDC D1 [16]. Defined behaviour for individual train types is as follows in the bullets.

- Ride in the next operation post
    - The pair of trains are formed by the trains of the same category. In that case, the first train is running at the track speed and the second is running to the passing track (reduced speed).
    - The pair of trains are formed by the first train of a higher category and the second train of a lower category. In that case, the first train is running at the track speed and the second is running to the passing track (reduced speed).
    - The pair of trains are formed by the first train of the lower category and the second train of the higher category. In that case, the first train is running to the passing track (reduced speed) and it is passed by the second train which is running at the track speed.
    - The pair of trains are formed by the first train (passenger) and the second is the goods train. In that case, the first train is running at the track speed and the second one is passing at a reduced speed over the passing track.
- Ride in the rear operating point – the first train departing always from the main track and the second one from the passing track (standstill) regardless of the train category.

Furthermore, a uniform stopping and time of train stop policy have been set for passenger trains. All trains of category R and Os stop at stations A, B and C. Their time of a train stop is 60 seconds. Only trains of category Os stop at stops with a time of a train stop of 30 seconds.

6. SIMULATION OF THE HEADWAY AND EVALUATION OF THE RESULTS

Model validation was performed on the prepared infrastructure model. The results of the test simulation were compared with the analytical calculation according to infrastructure manager regulation SŽDC SM 124 [12] and SŽDC 104 [17] with a deviation of only 1.33 % [18]. Subsequently, the main simulation was carried out to determine the values of the headway time for each pair of trains. Each of the train pairs was simulated separately, on all open line sections in two variants (arrival to the front operation post and departure from the rear operating point). First, conventional operation in LS mode was simulated, followed by operation in ETCS L2 mode. The resulting values of the arrival headways were compared with the values of the departing headways, and the maximum of these values was selected to determine the resulting headway. **Table 2** shows the resulting values in seconds corresponding to the maximum of each pair of elements for the open line section between Station A and Station B in the direct direction. The columns marked AB contain the values for the conventional operation, the columns marked ETCS contain the values for ETCS L2 operation.

Table 2 Results of the headway calculator after maximization for the section A - B

Section A - B											
		First train									
		Nex		Pn		Os		R		Ex	
		AB	ETCS	AB	ETCS	AB	ETCS	AB	ETCS	AB	ETCS
Second train	Nex	83	68	229	209	151	134	89	74	43	33
	Pn	57	56	98	82	80	61	65	65	28	28
	Os	70	56	156	128	138	133	65	65	28	28
	R	164	137	246	226	196	148	73	69	28	28
	Ex	226	199	308	288	258	210	182	151	62	53

The calculated values were further compared with each other. The graph in **Figure 4** shows the average values of the headway for individual open-line sections. The graph shows that the deployment of ETCS L2 improved the values of the headway in all open-line sections. The key benefit of ETCS L2 operation can also be derived from the simulation process and its results. The biggest observed benefit is the change in the position of the speed restriction reference point, where the value of the interval of gradual arrivals (arrival interval) is reduced.

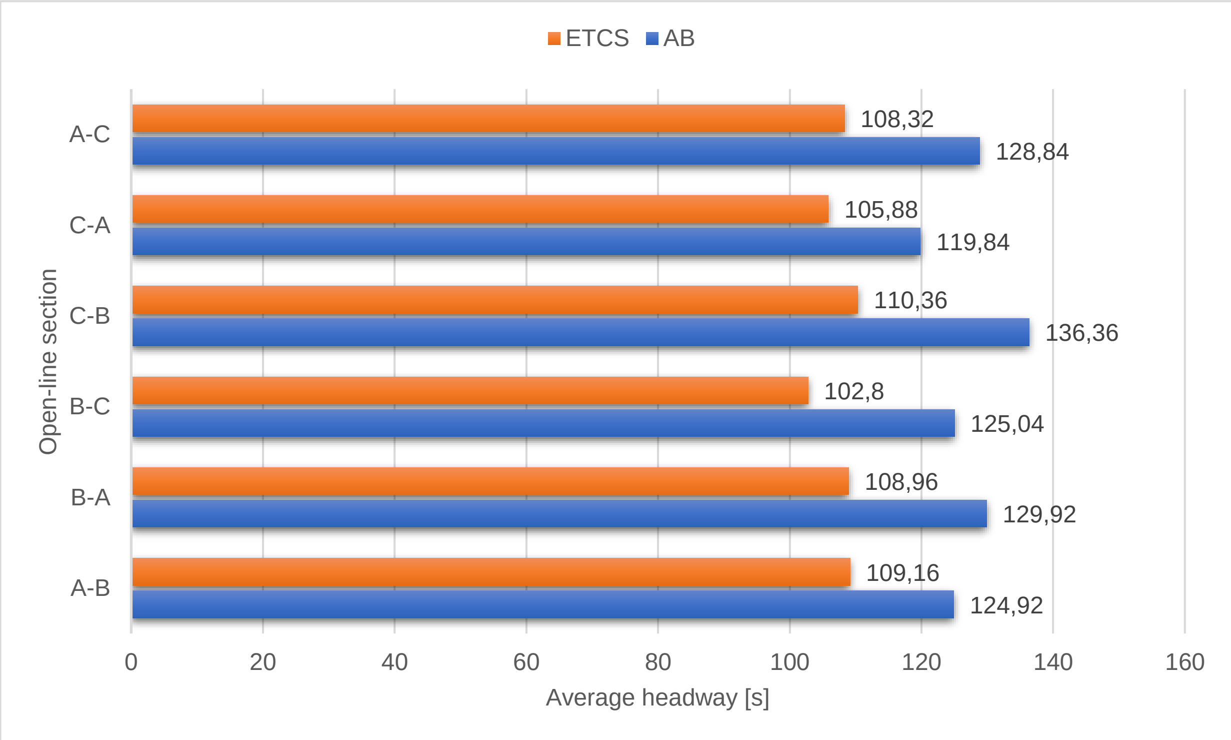

Figure 4 Comparison of the average headway for each open line section

Table 3 further provides a percentage comparison of the values for the simulated open-line sections. An important conclusion is that the average improvement in the value of the headway is 19.1 %. This value confirms the benefits of ETCS L2 with benefits.

Table 3 Comparison of the values for the headway

Section	[s]	[%]
A-B	-15.76	11.39
B-A	-20.96	25.44
B-C	-22.24	21.86
C-B	-26.00	22.97
C-A	-20.52	15.82
A-C	-13.96	11.19

7. CONCLUSION

The research conducted by the authors for this article is loosely related to their previous research in ATC system simulation. The results obtained show that they confirm the benefits reported in the literature review by applying the ETCS L2 with benefits. The increase of the line capacity by reducing the headway is evident.

The results obtained are of course valid for the proposed model of the research infrastructure and are not of general validity. It always depends on the configuration of the infrastructure and the chosen parameters. The authors aimed to demonstrate the level of effectiveness of ETCS L2 with benefits on a general line equipped with an autoblock. The simulation results show an improvement of 19.1% in the resulting value of the headway.

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REFERENCES

[1] EMERY, D. Enhanced ETCS_L2/L3 train control system. NING, B., ed. *Advanced Train Control Systems.* [online]. WIT Press, 2010, 2010-06-29, pp. 113-122. [cit. 2021-8-22]. *WIT Transactions on State of the Art in Science and Engineering*. ISBN 978-1-84564-494-9. Available from: https://doi.org/10.2495/978-1-84564-494-9/13.

[2] BARTER, W. A. M. ERTMS Level 2: effect on capacity compared with “best practice” conventional signalling. NING, B., ed. *Advanced Train Control Systems* [online]. WIT Press, 2010, 2010-06-29, pp. 103-112. [cit. 2021-8-22]. WIT Transactions on State of the Art in Science and Engineering. ISBN 978-1-84564-494-9. Available from: https://doi.org/10.2495/978-1-84564-494-9/12.

[3] LANDEX, Alex a Lars Wittrup, JENSE. Infrastructure Capacity in the ERTMS Signaling System. In: *Conference: RailNorrköping 2019, 8th International Conference on Railway Operations Modelling and Analysis (ICROMA)* [online]. Norrköping (Švédsko): ICROMA, 2019 [cit. 2021-8-22]. Available from: https://www.researchgate.net/publication/334836397_Infrastructure_Capacity_in_the_ERTMS_Signaling_System/link/5d42f6d892851cd04699a7c7/download.

[4] LJUBAJ, Ivica, Tomislav Josip MLINARIĆ, Tomislav LEŽAIĆ, Martin STARČEVIĆ, J. GAŠPARIK, J. ČAMAJ, J. MAŠEK a V. ZITRICKÝ. The Possibility of Capacity Increase on the Modernised and Electrified Railway Line R201 along the Zaprešić – Zabok Section. *MATEC Web of Conferences* [online]. 2018, vol. 235. [cit. 2021-8-22]. ISSN 2261-236X. Available from: https://doi.org/10.1051/matecconf/201823500009.

[5] LJUBAJ, Ivica, Tomislav Josip MLINARIĆ a Dino RADONJIĆ. Proposed Solutions for Increasing the Capacity of the Mediterranean Corridor on Section Zagreb - Rijeka. *Procedia Engineering* [online]. 2017, vol. 192, pp. 545-550. [cit. 2021-8-22]. ISSN 18777058. Available from: https://doi.org/10.1016/j.proeng.2017.06.094.

[6] LJUBAJ, I., MIKULČIĆ, M., MLINARIĆ, T. J. Possibility of Increasing the Railway Capacity of the R106 Regional Line by Using a Simulation Tool. *Transport Research Procedia*. 2020, vol. 44, pp. 179-144. Available from: https://doi.org/10.1016/j.trpro.2020.02.020.

[7] COVIELLO, Nicola. *The influence of ETCS and traffic composition on daily capacity of single track lines.* [online]. Torino, 2013. [cit. 2021-8-22]. Disertační práce. Politecnico di Torino. Vedoucí práce Bruno Dalla Chiara. Available from: https://www.kth.se/polopoly_fs/1.491066.1550157236!/X13_019_report.pdf.

[8] HUERLIMANN, D., NASH, AB. *Manual of opentrack - simulation of railway networks*. Version 1.9. OpenTrack Railway Technology Ltd. and ETH Zurich, Zurich, Switzerland, 2017.

[9] MOLKOVÁ, T. a kol. *Kapacita železničních tratí*. Pardubice: Univerzita Pardubice, 2010, 150 p. ISBN 978-80-7395-317-1.

[10] INSAF, S., GHAZEL, M., EL-MILOUDI, EL-KOURSI. Formal modeling of a new On-board Train integrity System ETCS Compliant, 2021, ESREL 2021. Available from: https://doi.org/10.3850/978-981-18-2016-8_290-cd.

[11] VOJTEK, M., KENDRA, M., ZITRICKÝ, V. and ŠIROKÝ, J. "Mathematical approaches for improving the efficiency of railway transport." *Open Engineering*. 2020, vol. 10, no. 1, pp. 57-63. Available from: https://doi.org/10.1515/eng-2020-0008.

[12] Směrnice SŽDC SM 124 – Zjišťování kapacity dráhy, účinnost od 7. 6. 2019.

[13] UIC Kodex 406 – Kapacita. UIC International Union of Railways, Paris, 1. vyd., 2004.

[14] ŠIROKÝ, J., NACHTIGALL, P., TISCHER, E., GAŠPARÍK, J. Simulation of Railway Lines with a Simplified Interlocking System. *Sustainability.* 2021, vol. 13, 1394. Available from: https://doi.org/10.3390/su13031394.

[15] SIPUŠ, D., ABRAMOVIĆ, B. The Possibility of Using Public Transport In Rural Area. *Procedia Engineering*. 2017, vol. 192, pp. 788-793. Available from: https://doi.org/10.1016/j.proeng.2017.06.136.

[16] Předpis SŽDC D1 – Dopravní a návěstní předpis, účinnost od 1. 7. 2013

[17] Směrnice SŽDC 104 – Provozní intervaly a následná mezidobí, účinnost od 1. 10 2013.

[18] TISCHER, Erik, NACHTIGALL, Petr and ŠIROKÝ, Jaromír. "The use of simulation modelling for determining the capacity of railway lines in the Czech conditions" *Open Engineering*. 2020, vol. 10, no. 1, pp. 224-231. Available from: https://doi.org/10.1515/eng-2020-0026.