CALCULATION OF THE CAPACITY OF SWITCH AREA WITHIN RAILWAY STATIONS WITH THE USE OF SIMULATION METHODS

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ABSTRACT

The paper deals with the research on the capacity of switch area within railway stations using computer simulation. The paper briefly introduces some of the currently used methodologies for the calculation of the capacity of switch area and subsequently introduces the concept of the new method, the basis of which is based on the application of the simulation approach. The simulation approach is particularly useful in view of the fact that it can better reflect the reality of traffic compared to purely analytical approaches. The paper also presents a comparison of results from selected currently used methodologies, results of simulation runs with train delays and results from the newly created methodology.

Keywords: railway station capacity, switch area, simulation,

1. INTRODUCTION

Assessment of railway infrastructure capacity is very important activity that applies both to planning new or reconstructing existing infrastructure, planning and timetabling, and last but not least in the operational management of transport processes.
The capacity of the railway infrastructure is closely related to the economy of operation and to the quality of the realized transport.
The performance and quality of railway transport closely dependents on the capacity of the railway infrastructure on which the transport processes are implemented. Capacity calculations are performed primarily for individual tracks of railway lines and railway stations. For railway stations the calculations are individually performed for station tracks and for individual switch area. This article focuses on the capacity calculations of switch area.

Thoughts about capacity calculations are linked to the entire history of rail transport. First methods were focused mainly on quantitative indicators, such as the number of trains (or technological operations) that can be performed on the given infrastructure in compliance with the rules for operating the transport on the given infrastructure. With increasing traffic density qualitative indicators were also observed in the calculations. While such level of capacity utilization is reached, a gradual reduction in the level of transport quality can be occurred in the case that the range of traffic will be still grown on a particular infrastructure. Individual features of this process can be different for each individual infrastructure element (case) due to different local operation conditions. On the other hand, this principle is valid and a challenge for research in the field of railway capacity estimation.

2. EXISTING APPROACHES TO CALCULATE THE CAPACITY OF THE SWITCH AREA WITHIN RAILWAY STATIONS

Currently, a number of approaches to assess the capacity of switch area are being used. Mostly used are analytical and graphical-analytical methods. In general, within SŽDC (dominant railway infrastructure manager in the Czech Republic) there is primarily used the procedure under the D24 directive (originally the ČSD directive D24) - Assessment of the capacity of railway lines. This directive was approved in 1965 and, at the time of its inception, was a good and progressive methodology for the implementation of capacity calculations. From today's point of view, the directive D24 is morally obsolete and, in many respects, does not reflect the nature of the current operation and does not meet the requirements of the current railway transport. Nevertheless, it provides a large number of output indicators that indicate the capacity of the infrastructure. Currently, efforts are being made to replace it with a new modern methodology.

Such kind of so-called graphical methods can be included among the existing methodologies. Graphical methods are not used too often. This is due in particular to their difficult algorithmization and the consequent increased demands on the experience of the worker who carries out the calculation. This is the way in which the so-called additional trains are inserted into suitable gaps within timetable that is tested. When inserting additional trains, care should be taken to avoid any conflict with the trains already recorded in the timetable. The number and ratio of individual types of trains to be introduced and their characteristics must principally be based on the composition of the tested timetable. Second way of graphical methods utilization is so called compression characterized in following paragraph.

The Codex UIC 406 - Capacity, was established in 2004 under the UIC as a recommendation for a uniform and standardized approach to the calculation of capacity in railway transport, it is dedicated to all members of the UIC. This methodology is based on a compression method. Timeslots of trains in tested timetable are adjusted so as to determine the minimum interval for which the range of traffic in the given timetable can be realized. In this compression the collision-free approach and the original sequence of trains must be maintained. From the value of the minimum possible interval of the occupancy of the infrastructure by the given transport range and the length of the interval in which the calculation took place, a basic indicator of this methodology - occupancy time rate, is evaluated.
The main problem of this method is that the train paths are not able to be moved in reality and existing gaps usually cannot be used with the same effectivity as free gap occurred on the end of compressed timetable. For instance, real gaps between existing train paths can be too short for placement of an additional train, so that the capacity is free, but utilizable.
The individual existing methodologies use a variety of computational procedures and provide a different set of output variables in the area of capacity.

The individual existing methodologies use a variety of computational procedures and provide a different set of output indicators in the area of railway capacity. One of the basic output values which is common to most analytical (analytical-graphical methods) values, is the indicator occupancy time rate.

The proposal for a new methodology for the calculation of switch area capacity was carried out in the framework of the expert study which dealt with the calculation of railway station capacity focusing both – switch areas and station tracks. The contracting authority of this study was SŽDC. During the preparation of the new methodology for station capacity calculation, some existing methodologies have been thoroughly tested. Within the project, a comparison of selected output indicators, which these different methodologies provide, was made. The testing was carried out on selected railway stations and was carried out on a large set of different transport scenarios that represented different characteristics and different intensities of traffic.

Outputs of currently used indicators (e.g. occupancy time rate) mainly provide quantitative view on switch area assessment whether it is still more important to check qualitative aspects nowadays due to increasing volume of traffic and sometimes due to relative invariable extent of infrastructure (long-term investments).

3. APPLYING NEW APPROACHES IN CALCULATING THE CAPACITY OF SWITCH AREA WITHIN RAILWAY STATIONS

The new methodology combines the analytical calculation method with the simulation calculation when the mesoscopic level of detail is applied within the simulation section. Main aim to provide the new approach is to add qualitative aspect of capacity assessment of infrastructure because this aspect is not included in traditional assessment.
The analytical part is the calculation of station intervals, which are a necessary part of the calculation. These intervals represent headway times between 2 subsequent technology operations (e.g. train drives).
New methodology for switch area capacity estimation is supposed to simplify those using abstractions of number of station tracks in terms of facilitating the calculation of these intervals.
Already in 1974 prof. Schwanhäußer came up with a probable approach to calculate secondary train delays, which was innovated in 1998 [Schwanhäußer]. This was also an analytical approach that did not reflect a concrete timetable, leading to inaccurate conclusions in assessing secondary delays and other statistical indicators. However, the approach based on the evaluation of secondary delays is so inspirational and objectivizing that there is an attempt to follow it.
Just replacing this analytical part with the simulation part is intended to eliminate such inaccuracies, even at the cost of having to enter specific timeslots of considered trains. It also includes generating random aspects - train delays with the appropriate probability distribution and parameterization.

Using simulation allows to assess infrastructure with indicator focused on secondary delay (increment of possible primary delay of train at estimated part of railway infrastructure) which significantly reflects on the infrastructure possibilities to handle the amount of traffic and secondary delay also indicates quality of the infrastructure. Other indicator that was suggested and can help with assessment of quality of railway infrastructure is average length of queue (how many trains in average have to wait to be able to use switch area or part of switch area).
Advantages of this approach are: indicators of quality are provided; all needed details (timetable, train priorities, parameters of delays etc.) are taken into account as well.
Disadvantages of this approach are: only the switch area that is assessed is evaluated. So in case more switch areas in the station and all of them should be assessed, it must be done separately, but this limitation occurred also in the most of used state-of-art analytical approaches, so

that this disadvantage can be seen as acceptable. Another disadvantage is that tracks in railway station or on connected railway lines are not included in the assessment. Potential conflicts on these tracks are not considered. Switch areas are evaluated in an 'isolated' way also from the operational point of view. On the other hand, operational limitations (possible capacity problems) of neighbouring infrastructure are not related to the switch area capacity itself. There is not united opinion if switch area capacity should be evaluated in isolated or complex point of view.

4. CALCULATIONS AND COMPARSION OF OLDER METHODOLOGIES WITH THE NEW METHODOLOGY

Within the project, comparative calculations were performed using selected existing methodologies (see Chapter 2). Additionally, the disadvantages and limitations of the methodologies used were identified and a new methodology has been proposed (see Chapter 3). Comparative calculations were performed using the newly proposed methodology.

Within this chapter the basic output indicators of the mentioned methodologies will be presented and the results will be presented for selected examples of the switch area capacity calculation.

Three different railway stations were examined within the project. These stations differed in both their size and topology. These were the stations Zdice, Lysá nad Labem and Praha hl.n. Zdice railway station is a simple station on a double-track railway line with one branch single-track line.

Lysá nad Labem is a railway junction of busy lines. There is a higher rate of train crossing from one line to another. Station Praha hl.n. is an example of a large node with high traffic (it is primarily about passenger transport). Stations Lysá nad Labem and Praha hl.n. were chosen for the relatively complicated topological layout of switch areas.

For each of these stations, several traffic scenarios were created. These scenarios are differing both in intensity and type of traffic. The current and future planned (able to be occurred with high probability) scenarios of traffic are also included. Other scenarios are hypothetic, but representing legitimate kinds of traffic situation (e.g. increased volume of suburban transport, situation with freight transport in dominant role etc.).

The corresponding calculations were made for all the created scenarios by the above-mentioned methodologies for all switch areas at all stations (2switch areas at each station).

The disadvantages of the existing methods (especially SŽDC D24 methodology) were considered in designing the new methodology. Existing methods have certain insufficient aspects, such as: the need to divide the switch area into elements (groups of switches) for the purpose of calculating, to determine probably time of inaccessibility of infrastructure due to occupation of collective elements by other trains (e.g. going in other direction), missing incorporation of the fact, that train routes are cancelled stepwise (how the individual switches are becoming unoccupied behind a train), difficult interpretation of the resultant value of occupancy time rate in practice and more.

The new methodology was designed with respect to elimination the above shortcomings.

Each of these methodologies provides a set of output indicators. These indicators determine the quantitative and qualitative relationship between the traffic intensity and the range and capabilities of the given transport infrastructure. Most of the output indicators are not directly comparable to the indicators of other methods.

The D24 methodology provides many output parameters. Basic indicators include the occupancy time rate,

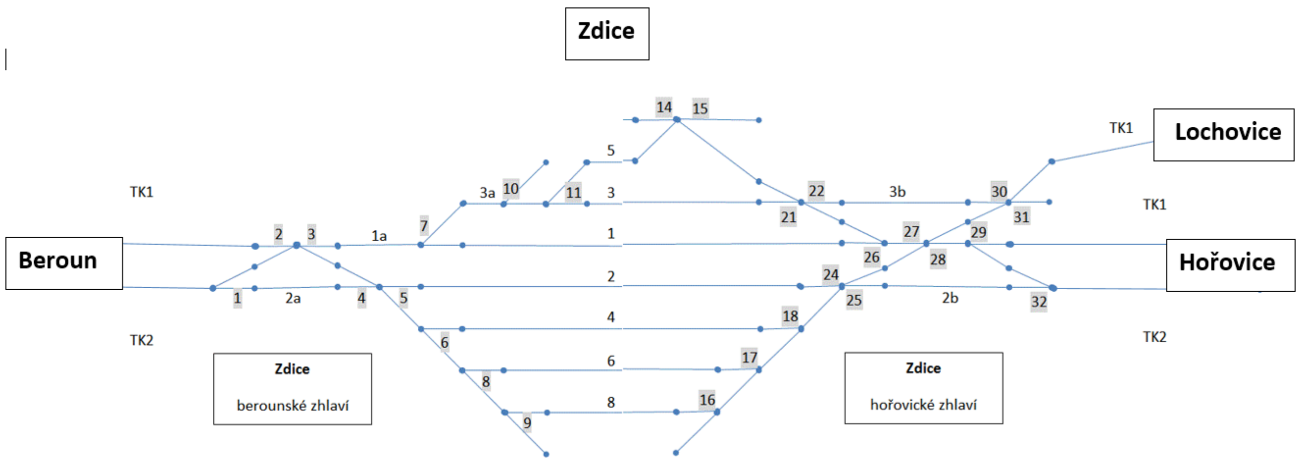

Figure 1 – Schematic layout of Zdice station

capacity, capacity utilization, gap (between operation and average reserve time related to one operation. The UIC406 methodology provides occupancy time rate, number of trains in concatenation, concatenation rate and list of concatenation trains for the given switch area.

Newly proposed methodology, based on the mesoscopic simulation of separated operation of a switch area, provides primarily qualitative indicators secondary delay and average queue length. Secondary delay is defined as increment of delay connected to examined part of infrastructure – switch area (incl. possible waiting in front of this switch area).

Calculation for the chosen transport scenario for the switch area in direction of Hořovice at the railway station Zdice was selected as an example to be presented.

Schematic layout of Zdice railway station and its connection to the adjacent railway stations are shown in Figure 1. The station consists of two switch areas and 8 station tracks, which can be used for train movements or stay (dwelling of trains).

One of the station tracks is dead-end track and is only available from the direction Hořovice and Lochovice. Other main tracks are accessible from all external lines.

The station is connected to three lines. The line Beroun-Zdice includes 2 tracks that are connected to the station tracks via the "Beroun's switch area". Both double track line Zdice-Hořovice and single track branch line Zdice-Lochovice are connected to the station via the "Hořovice-Lochovice's switch area".

The sample transport scenario is based on the current timetable. Due to the fact that the station is able to realize higher traffic, additional trains (long-distance, regional and freight) have been added to the timetable. These additional trains have been added to examine the capabilities of individual methodologies in a situation approaching capacity limits. In such cases, accurate results are very important. Adding of additional trains was an attempt to create a real expansion of existing traffic. The realistic procedure has been chosen with regard to application in practice.

Within this scenario, in addition to standard train paths, one independent locomotive shunting movement was realized. It is the withdrawal of locomotive from the train number 7803 and its shunting movement on the opposite side of the train. This shunting movement isn't shown in the timetable in Figure 2 for obvious reasons.

Calculations were performed at the reference interval of 120 minutes between 8:00 and 10:00.

The following trains and shunting movement were included in the calculation for the given period: 60003, 60100, 753, 752, Lc_7803, 60004, 7950, 7802, 60011, 1241, 60010, 7801, 60005, 60002, 7903. Trains 754 and 755 are not used in the calculation because they are trains running on train paths 750 and 751 shifted by 120 minutes. For the same reason, a pair of trains 7903/7904 is omitted from the calculation. Timetable of this transport scenario is shown in Figure 2.

Shifting of solved time period is recommended in the case, when this shifting will allow consider all trains as complete (if some of trains is intersecting a border of solved time period, e.g. 8:00 or 10:00). Naturally, the defined length (120 min) must be preserved. The results can be interpreted in easier and more accurate way than when some train intersecting the border must be considered only by part of its occupation time. On the other hand, in the cases of rush operation this situation can be inevitable. Due to this fact above mentioned modifications (omissions of same trains) are made.

The running time used in the calculations are not determined directly according to regulation (SŽDC V7)

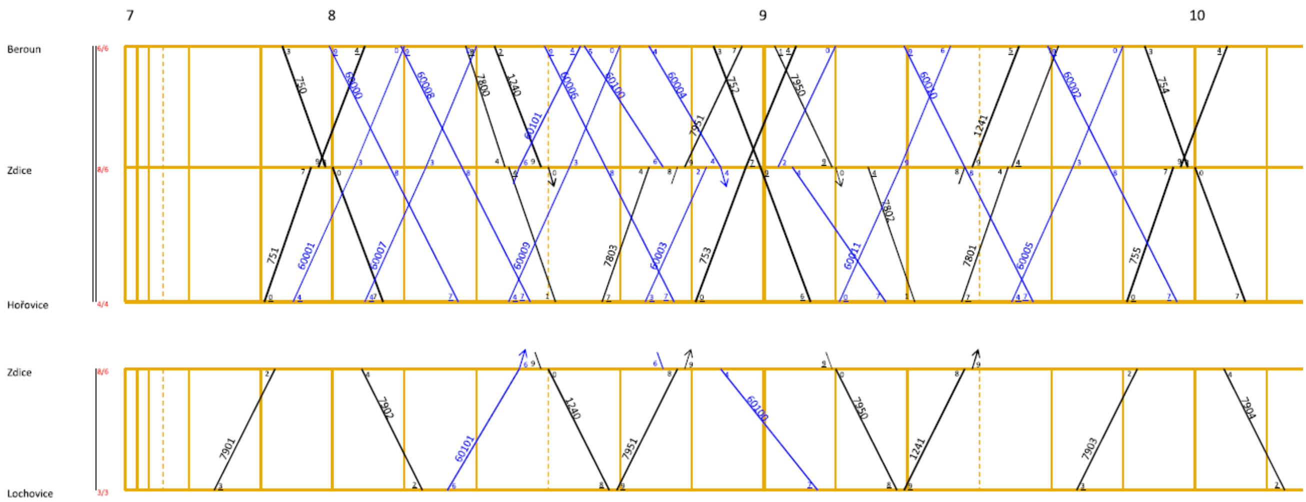

Figure 2 - Timetable

ISBN 978-88-97999-85-0; Affenzeller, Bruzzone, Jiménez, Longo and Piera Eds.

as the sum of theoretical running time and the corresponding layover time (a part add to running time due to reliability reasons). Running times are taken from the simulation model created within the project. The simulation model follows the above principles. Also, other input data, such as time of occupancy, are taken from the outputs of the simulation model, which is determined in accordance with applicable regulations (SŽDC D24, SŽDC 104).

The results of the capacity calculation using D24 directive

The first step in the capacity calculation of the switch area is the assembling of "Overview of trains movement through the switch area". The second step is the assembling "Train path dependency table". The last step is to calculate the values of the capacity indicators for the given switch area. The resulting indicators are shown in the following table.

k_p	Ratio of trains in all operations	0.96
$N_ú$	Capacity [operation]	60.643 (60)
N	Capacity [train]	58.217 (58)
K_{vp}	Capacity utilization	0.487
S_o	Occupancy time rate	0.333
z	Average reserve time related to one operation [min]	2.759
t_{mez}	Gap between operation [min]	0.599

The results of the capacity calculation using UIC406 methodology

An own proprietary software tool was used to calculate using the UIC406 methodology. The input data for the calculation are data on the individual trains and occupation times of the individual elements of the switch area. Based on these input data, an overview of the occupancy of switches is created. Next, using the compression method, the total occupation time of the switch area is determined

Total occupation time after compression [hh:mm:ss]		00:35:34
Occupancy time rate		0.296
Number of trains in concatenation		18
Concatenation rate [%]		62.1
Concatenation trains	751, 60001, 60007, 60101, 1240, 60009, 7803, 7951, 60003, 60100, 753, Lc_7803, 7950, 7802, 60011, 1241, 7801, 60005	

The results of the capacity calculation using the Z-SIM method

For the Z-SIM method, the results from the mesoscopic simulation of separated operation of a switch area are presented. The presented results represent an average of 100 simulation replications.

Input delay – sum [min]	240,202
Input delay – average per train [min]	8.283
Secondary delay – sum [min]	9.656
Secondary delay – average per train [min]	0.333
Average queue length [number of trains]	0.080
Ratio of waiting [%]	18.20

5. CONCLUSIONS

Result of investigations it is still recommended to use currently used key indicator - occupancy time rate. This indicator allows to objectively assess the use of transport infrastructure over time due to its formulation as a ratio between a sum of time occupation and total length of calculation time period. The indicator allows you to take into account the different occupation times arising for each operation as well as the expression for only a part of the transport infrastructure.

The project compares two analytical methods SŽDC D24 and UIC 406 that provide similar results.The key indicator of both methodologies is the occupancy time rate, so it is possible to compare its values achieved in individual scenarios. Comparison of the individual scenarios for stations Zdice, Lysá nad Labem and Praha hl.n. was evaluated, after excluding extreme cases, an average deviation of 6.5%. It can be said that the results achieved by both methodologies are comparable.

It is assumed that along with the increasing occupancy time rate, the sum of secondary train delays in the Z-SIM method will increase. The results of the comparison are depicted in Figure 3. It can be seen from this figure that higher-grade switch areas are generally more prone to unfairness in the form of average secondary delays per train.

However, the relationship between the secondary delay and the occupancy time rate is not completely tight (ie. that each specific value of the occupancy time rate would exactly correspond to the specific delay value). Relationship between the two variables is a framework. This confirms that it is necessary to address not only the occupancy time rate as a quantifier but also the above-mentioned indicator, reflecting other aspects of switch area and the operation affecting quality. At the same time, it underlines the necessity of a comprehensive perception of capacity in the context of multiple indicators, not as a single aggregate variable.

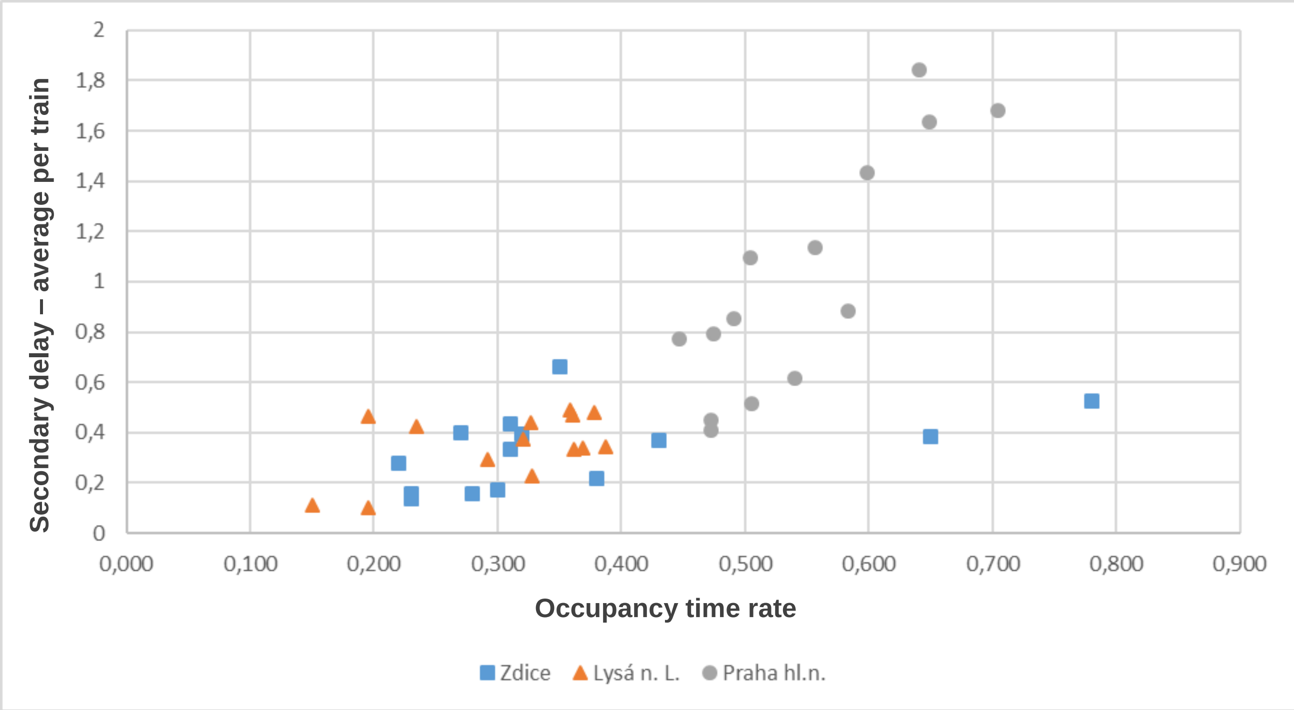

Figure 3 – Dependency between occupancy time rate and average delay time

On the other hand, this also raises the question of whether the average delay per train is indicative. Authors also recommend to take into account values of the secondary delays for individual trains, as the distribution of secondary delays between individual trains can be a key issue. Acceptable average value may be subject to absolutely unsatisfactory values for some of trains, and if time and organizational options allow it, authors recommend to present results in a more detailed breakdown.

From the quality point of view, it is recommended to use mesoscopic simulation of separated operation of a switch area. The value of secondary delay is able to characterize the operation quality of estimated switch area. If this value is too high, it is obvious that switch area is a cause of delays due to a lack of capacity or due to an inappropriate allocation of possible free capacity as well.

On the other hand, it is not necessary to eliminate this delay strictly to value of zero, because such volume of secondary delays (e.g. delay able to be eliminated by other layover times in time schedule) can be accepted. It is necessary to consider all results (values of capacity indicator) in a complex point of view with an effort to discover possible capacity bottlenecks and to prevent their occurrence.

Final conclusion is that mesoscopic simulation can improve the possibilities of switch area capacity estimation. It can also contribute to combined estimation of quantity and quality. This can lead to a complex point of view on capacity estimation of switch area.

Complexity of results also can be improved by ‘additional’ application of microscopic simulation for detail estimation as well. This will be necessary for the case of complicated arguable cases with the results that are close to limits.

REFERENCES

SŽDC (ČSD) D24 – Předpisy pro zjišťování propustnosti železničních tratí, účinnost od 1. 10. 1965.

UIC Code 406 – Capacity. UIC International Union of Railways, Paris, 2004.

DANĚK J., VONKA J.: Dopravní provoz železnic. Bratislava: Alfa, 1988.

Schwanhäußer, W.: Stuttgart 21 – Ergänzende betriebliche Untersuchungen, Teil III“, Leistungsverhalten und Bemessung des geplanten Stuttgarter Hauptbahnhofes und seiner Zulaufstrecken, RWTH Aachen, 1997.

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