

Aspects of Railway Capacity and Occupation Time Estimation

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Abstract: The priority of the EU transport policy in railway sector is to open up the railway market. The objective is to provide railway undertakings with access to the railway network on equal terms. The main problem is determining the infrastructure capacity. A variety of methodologies are used across Europe for the capacity estimation of railway infrastructure. This diversity has forced railway infrastructure managers to seek a new, common methodology. The UIC methodology is an easy way to calculate the capacity consumption. However, there the possibility to expound this methodology in different ways, which can result in different capacity consumptions. There is an advantage to improve this methodology and to set a clear and unified method of occupation time estimation. The fundamental improvement to UIC methodology is the definition of the occupation time by the trains. This paper gives a description of Slovak and UIC methodologies as a basis for a newly developed approach. The new way of estimation of the capacity consumption (occupation time) is based on a graphic approach. The new methodology concerns the estimation of the infrastructure occupation time and is a conceptual framework developed by the authors for an easier evaluation of occupation time in train traffic diagrams. The new methodology makes the UIC methodology more usable and enables more exact results to be obtained from infrastructure capacity examination.

Key words: Methodology for capacity estimation, train traffic diagram, occupation square, occupation rate, buffer time.

1. Introduction

The priority of the EU is to open up the railway market with the deregulation of this sector. The objective is to provide railway undertakings with access to the railway network on equal terms. This access will be determined by infrastructure managers, which has led to a re-evaluation of their capacity. The main problem is determining the capacity, and the second step is to manage the existing capacity.

Across Europe a variety of methodologies is used for the capacity estimation of railway infrastructure. It is possible to classify these methodologies according to analytical, graphical and simulation approaches [1].

The aim of the paper is to characterize the used methodology for capacity estimation in Slovakia, as well another approach developed by the UIC

(International Union of Railways). There are different approaches and different time of edition. This diversity has forced railway infrastructure managers to seek a new, common methodology. The UIC methodology is an easy way to calculate the capacity consumption. However, there the possibility to expound this methodology in different ways, which can result in different capacity consumptions. There is an advantage to improve this methodology and to set a clear and unified method of occupation time estimation [2].

2. Methodology of ŽSR

Railway infrastructure in Slovakia is managed by ŽSR (Železnice Slovenskej Republiky). ŽSR carries out railroad capacity estimation with a methodology based on an analytical or graphical approach, and even on mix of these approaches. The methodology of capacity estimation is introduced in the internal ŽSR Regulation (D 24). By using this the theoretical or practical capacity of railway equipment like track lines,

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stationary development of switches or traffic tracks in stations can be computed.

Railway infrastructure capacity is expressed by the number of the trains, or couplings of trains, which are sustained and regularly manageable on a given track line within a certain time period. In most cases, a 24 h time period is taken, considering the permanent technical and traffic equipment, type of rail vehicles and the method of traffic organization [2].

The capacity is restrained by the element in which capacity is the lowest over the whole complex. When computing the capacity the premise is taken that all trains are running at the same speed (parallel train diagram). If necessary trains running at other speeds are transformed to trains of the same speed by indexes. If we do not consider the true possibilities of the given infrastructure, we can simply estimate the maximum (theoretical) capacity N_{max} which is given by the formula [3, 4]:

$$N_{max} = \frac{T}{t_{obs}} \text{ (number of trains)} \quad (1)$$

where,

T is time window (min);

t_{obs} is average occupation per individual train path (min).

For normal traffic conditions, the so-called practical capacity is used. It is calculated by such quantity of train traffic, which is sustained and regularly manageable for the given technical and traffic track equipment during a specifies time period with consideration of the time needed for the inspections, planned reconstructions and maintenance of the operating equipment and its elements, as well buffering delays and traffic failures.

The ŽSR methodology uses a graphical or analytical approach for capacity estimation, based on determining the boundary inter-stationary section. Here the running time of a typical train is evaluated, as well the time period of the train sequences of a theoretical train diagram. The boundary inter-stationary section is the section containing the longest train sequence period.

The graphical approach is based on the construction of a train traffic diagram. Here all the train paths are sequenced in time order, by considering the railway traffic. If there is space for more trains, they are added to subsequent next train paths. There is a need to respect all the relevant time intervals. The sum of inserted trains in the boundary stationary section indicates the capacity of the track line. Also there is a need to define the occupation time for the planning of train sequences in the boundary inter-stationary section.

By the analytical approach is total occupation time calculated as a conjunction of the number of corresponding trains and the particular occupation time periods. Next, an average infrastructure occupation per individual train path as well as the buffer time per train path is calculated, and so an effective (practical) capacity of the track line section is estimated as follows [2, 4]:

$$n = \frac{T - (T_{vytl} + T_{stal})}{t_{obs} + t_{medz}^{poz}} \text{ (train paths per time window)} \quad (2)$$

where,

n is practical capacity (train paths per day);

T is time window (min);

T_{vytl} is supplement for maintenance (min);

T_{stal} is fixed occupation (min);

t_{obs} is average occupation per individual train path (min);

t_{medz}^{poz} is buffer time per individual train path according to the ŽSR methodology (min).

On double track lines, the capacity is calculated separately for each track (direction). There is possibility to calculate the capacity for a pre-constructed timetable as well for a proposed timetable. In this case statistical methods are used and the prospective occupation times calculated.

The key question is how to estimate the occupation time. Average occupation times per train in principle consist of the travel time in the boundary section and the operation intervals time. Average occupation times for a single track line are defined as half the

train period time (Fig. 1). The train period time is Ref. [4]:

$$T_{per} = t_r^N + \tau_A + t_r^P + \tau_B \quad (\text{number of trains}) \quad (3)$$

where,

t_r^N is travel time in even direction;

t_r^P is travel time in odd direction;

τ_A is stationary operating interval at station A;

τ_B is stationary operating interval at station B.

In the case of double track lines the occupation time is defined as a train sequence interval (Fig. 2).

The train sequence interval (headway) is the shortest time between the departure (run through) of the first train from the station (or diverging junction) and the departure (run through) of the second train from the same station (or diverging junction) on the same track line in the same open line in compliance with the regular running times and prescribed dwell times of the trains. The train sequence interval is determined up to the nearest station where overtaking is possible, or diverging junction where one of the trains can run along a diverging line. The train sequence interval consists of the travel time and running follow-up interval (time segment from arrival of first train at the front of the station to the departure of the second train from the back of the station on the same track line). If the track line is equipped with an automatic block, the train sequence interval is estimated as a running time in three blocks.

The length of the train sequence interval depends on Ref. [5]:

- the type of the block and interlocking system;
- the speed and length of the trains;
- the length of stations, the number and length of block sections in the inter-stationary sections;
- specified work technology for incoming train and for train dispatch.

Operating interval is the shortest time interval between the arrival, through running or departure of two trains in order to meet the conditions for their safe operation. Operating interval standards are defined

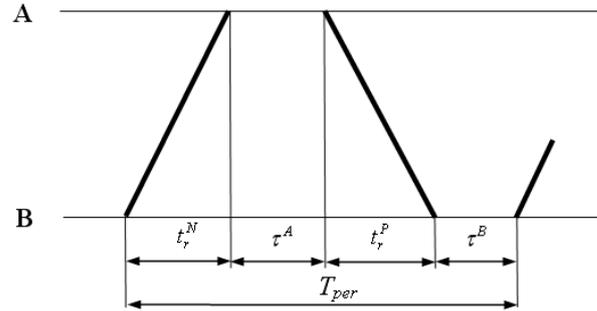


Fig. 1 Train period time [2].

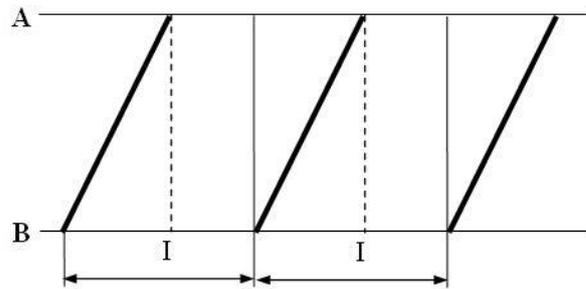


Fig. 2 Train sequence interval [2].

separately for each station and for each direction of adjunct tracks in cases where the simultaneous running of such trains is not allowed. Depending on collision points, the operating intervals are divided into station intervals and tracks intervals. The following are considered [5]:

(1) Station operating intervals:

- interval of sequential entries;
- interval of sequential entry and departure;
- interval of sequential departure and entry;
- interval of sequential departures.

(2) Track operating intervals:

- running follow-up interval;
- opposite running interval.

In the case of an interval of sequential entry and departure where the second train runs on the same track line on which the first arrived, we call this a crossing interval.

The value of the operating interval depends on:

- technical equipment and the method of station interlocking and signaling;
- type of attendance and security of switches and signals;

- traffic operation;
- railway station layout, the length of arrival tracks, the deployment of signals, the length of switches area, the location of the operating control point;
- gradient proportions of block sections close to the operating control point, braking distance and the distance of the entry signals from the nearest switch;
- the type, length, speed and load of train;
- whether the second train at the station stops or runs through;
- organization of work resulting from technological processes and local conditions.

Most of the operating intervals are composed of two time components:

- permanent (station) handling (t_s);
- dynamic components (t_d).

Permanent handling includes the operations to ensure the safe arrival, departure or passing through of a train. This includes the determination of the clearance for the train route, switching of the turnouts and signals, the service or activity of interlocking or telephone reporting. The dynamic component is related to the running train and depends on the distance over which the train runs at entry, departure or passing as well as

on its speed.

3. UIC Methodology

According to UIC Code 406, the capacity of the railway infrastructure is the total number of possible train paths within a defined time window when considering the actual path combination or known developments respectively, and the infrastructure manager's own assumptions in nodes, individual lines or part of the network, with market-oriented quality [7].

This methodology is based on the graphical compression of train paths within defined compression sections to determine the consumption time on the section. This compression considers the minimum headways, which depend on the signalling system and train characteristics (Figs. 3 and 4).

The capacity consumption is characterized by the value of infrastructure occupation (% of the time-window). UIC Code 406 gives typical values corresponding to the type of track (Table 1). If the infrastructure occupation is higher or equal to this certain typical value, the analyzed line section should be considered a congested infrastructure, and no further additional train paths can be added to the timetable. If

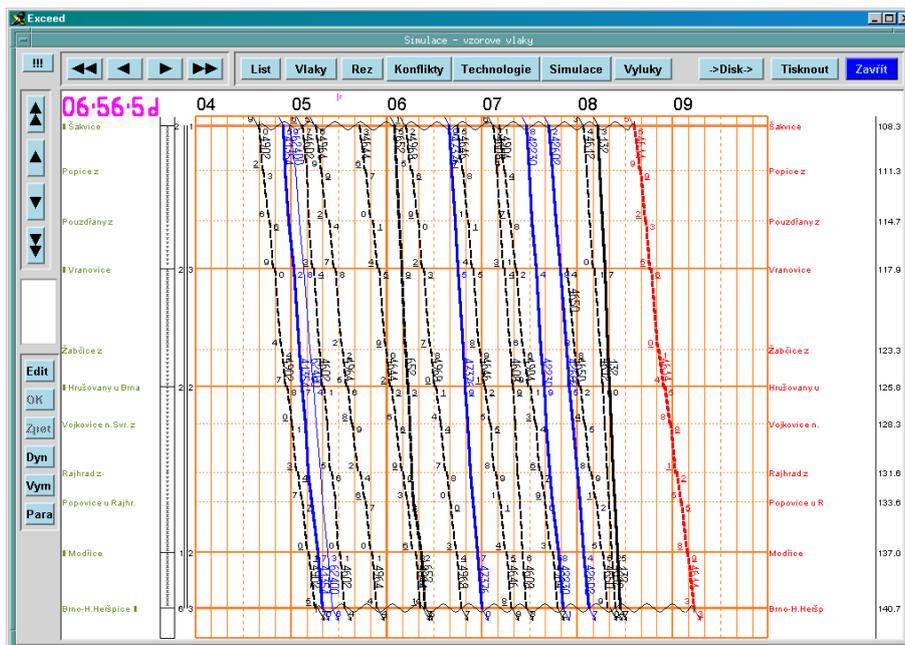


Fig. 3 Train traffic diagram—trains on double track line [6].

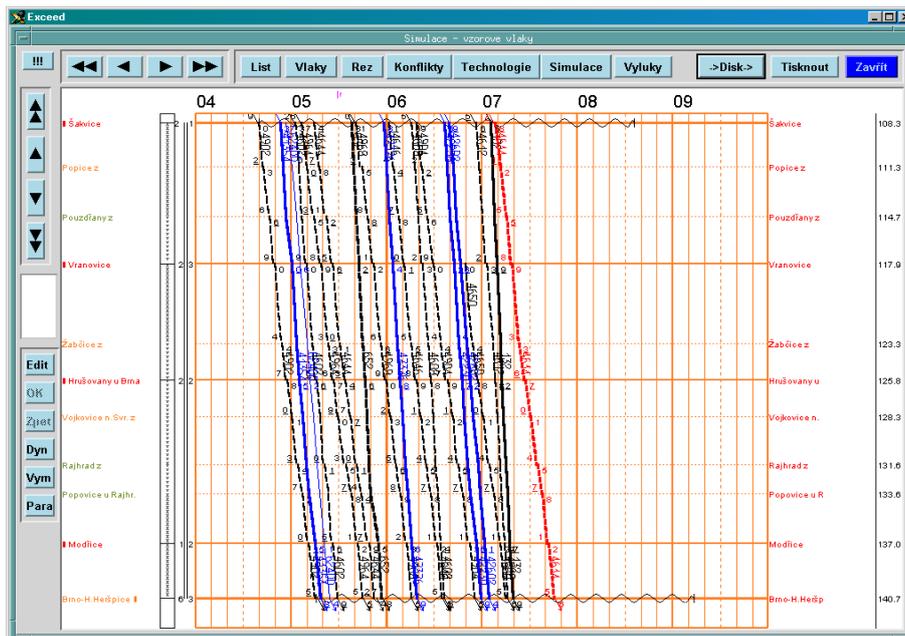


Fig. 4 Train traffic diagram—trains after compression according UIC Code 406 [6].

the occupation is lower than the typical value the capacity analysis must be further developed, and this procedure can be repeated until the infrastructure occupation reaches the congestion level.

This methodology is sufficient for the estimation of time occupation on double tracked lines [2].

The formula for determining the capacity consumption according to UIC Code 406 is Ref. [7]:

$$k = A + B + C + D \quad (\text{min}) \quad (4)$$

where,

k is total consumption time (min);

A is infrastructure occupation (min);

B is buffer time (min);

C is supplement for single-track lines (min);

D is supplement for maintenance (min).

The capacity consumption is defined as:

$$K = \frac{k}{U} \cdot 100 \quad (\%) \quad (5)$$

where,

K is capacity consumption (%);

U is chosen time window (min).

The imperfections in the UIC methodology for consumption estimation are [2]:

- It does not exactly define the track section for capacity investigation;
- The occupation time after compression is only vaguely defined, it is not clear whether the occupation time is calculated for the first or last station on the track section, the occupation time calculation is different in case unparallel train paths;
- It does not exactly define the capacity utilization on single-track lines. The supplement “C” for single-track lines does not say more about solving the capacity of single-track lines.

Proposal of the new methodology for the occupation time estimation.

Table 1 Recommended limits of consume capacity in UIC Code 406 [8].

Type of line	Peak hour	Daily period	Comment
Dedicated suburban passenger traffic	85%	70%	The possibility to cancel some services allows for high levels of capacity utilization
Dedicated high-speed line	75%	60%	-
Mixed-traffic line	75%	60%	Can be higher when number of trains is low (less than 5 per hour) with strong heterogeneity

A new approach to evaluate occupation time (consumption time) is proposed in accordance with UIC Code 406. This methodology proposed by the authors does not require the consumption procedure and use of the simulation procedures. The new approach is also based on a graphical methodology. The assembled train diagram defines the occupation surface (the so-called occupation squares), which is done by consideration of the distance and time in the train traffic diagram [2]. The share of all the occupation surfaces on the total surface of the train diagram graphic (time window) identifies the occupation rate (capacity consumption). The proposed formula for the occupation rate is:

$$S_V = \frac{\sum_{i=1}^n S_{obsi} + \sum_{j=1}^m S_{PVj}}{S_T} \cdot 100 \quad (\%) \quad (6)$$

where,

$\sum S_{obsi}$ is a sum of the occupation squares in the block sections (travel time);

$\sum S_{PV}$ is a sum of the occupation squares by track time intervals and station time intervals (in the case of one-way traffic these are the train sequence intervals, in the case of a single-track line these are crossing intervals and stepwise arrival intervals);

S_T is square of the time window (peak hour or all day);

I is $1..n$, where n is the number of occupation squares of the block section;

j is $1..m$, where m is the number of occupation squares of the operation time intervals (in the station and block sections).

The value of the occupation rate expresses the utilization of the infrastructure capacity, considering the necessary occupation times in percent.

The square of the time window is carried out as the conjunction of the analyzed track section length and time window in the graphical timetable (Fig. 5).

The occupation square in the block section S_{obsi} is defined by the conjunction of the length of the block section and the travel time in this section (Fig. 6).

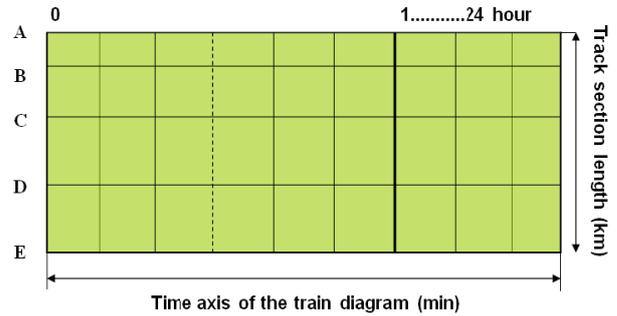


Fig. 5 Square of the time window (all days) S_T of the analyzed track section.

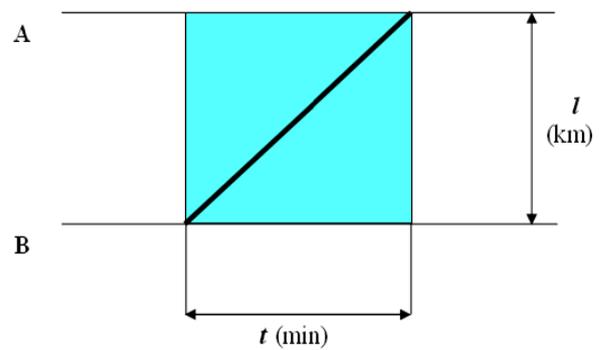


Fig. 6 Occupation square S_{obsi} in the block section.

The occupation squares of the track time intervals and station time intervals S_{PV} are designed for several variants according to different track safety devices and train control system. The squares were defined in compliance with the view of the of ŽSR methodology for the graphical interpretation of the following train intervals. There is a similar definition common in Western Europe—an average buffer time between two trains should not be much less than the average minimum line headway [9]. In principle, the occupation square is determined by the conjunction of the operation time interval (in a station or block section) and the distance between stations or block signals.

Occupation squares representing the track intervals are estimated in the following:

- (1) Cases when an inter-stationary section is at the same time one block section (not divided into more block sections)—see Fig. 7;
- (2) Cases when an inter-stationary section is divided into sections of a few blocks using block

signals (the signals are operated by staff)—see Fig. 8;

(3) Cases when an inter-stationary section is divided into block sections using block signals (with automatic control). There is need to calculate the occupation squares for different situations resulting trains sequences:

- Both have equal running times (accrued from the axiom that the trains run at a distance of three block sections). If the length of the block sections are $l_1, l_2, l_3, \dots, l_n$ and the running times of the train in the block sections are $t_1, t_2, t_3, \dots, t_n$ the formula for the occupation square is (Fig. 9):

$$S_{PV} = 2 \cdot (l_1 \cdot t_1 + l_2 \cdot t_2 + l_3 \cdot t_3 + \dots + l_n \cdot t_n) \quad (7)$$

- The first train is faster than the second train (accrued from the axiom that the trains runs at a distance of two block sections). In this case, the square surface of the time interval is represented by the sum of the squares (see Fig. 10):

$$S_{PV} = l_1 \cdot t_1 + l_2 \cdot t_2 + l_3 \cdot t_3 + \dots + l_n \cdot t_n \quad (8)$$

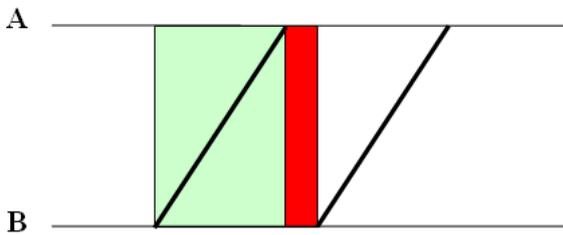


Fig. 7 Occupation square of track time intervals S_{PV} —a simple inter-stationary section.

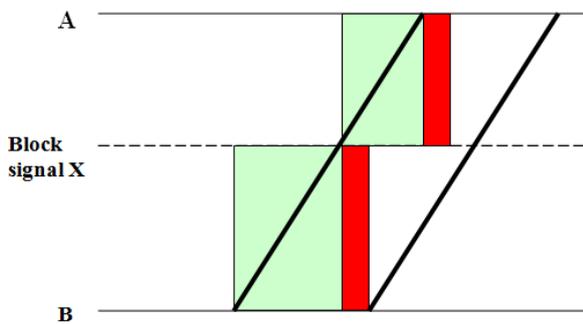


Fig. 8 Occupation squares of track time intervals S_{PV} —inter-stationary section divided into block sections.

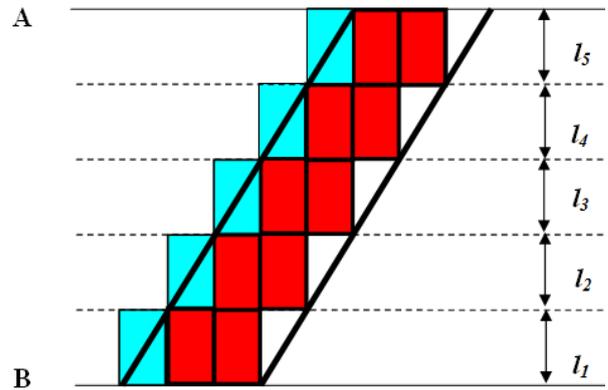


Fig. 9 Occupation squares of track time intervals S_{PV} —an inter-stationary section is divided into block sections (automatic signals)—equally running trains.

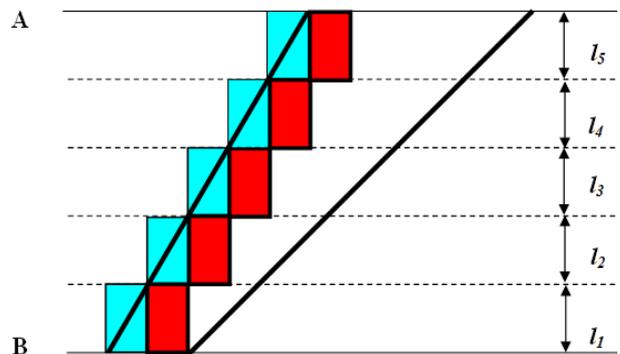


Fig. 10 Occupation squares of track time intervals S_{PV} —an inter-stationary section is divided into block sections (automatic signals)—the first train is faster than the second.

- The first train is slower than the second train (the first train must enter the next station, the second may run at a distance of three block sections). The square surface of the occupation time is represented by the sum of the squares (Fig. 11):

$$S_{PV} = \sum_2^n (l_{n-1} + l_{n-2}) \cdot t_n + l_n \cdot t_n \quad (9)$$

The detailed estimation of the occupation squares is evident from Figs. 9-12.

The formula for the occupation rate in Eq. (6) is the same for single track as well as for double-track line conditions. In the case of trains crossing in the station, the sum of the occupation squares is estimated in a different way. It is necessary to set the station time intervals (crossing intervals, stepwise arrival intervals, stepwise departure intervals, stepwise arrival-departure

interval) according to the ŽSR methodology. Occupation squares are calculated as a conjunction of this station interval and the distance to the relevant block section (Fig. 12). If the trains follow each other, it is necessary to estimate the occupation time as in the case of a double track line.

The inspection of the occupation time according to the new methodology consists of the following steps [2]:

(1) The estimation of the infrastructure occupation rate—Eq. (6);

(2) If the infrastructure occupation rate is higher or equal to a typical value (Table 1) the infrastructure is congested, whereas if the rate is lower than the typical value go to Step 3;

(3) The capacity analysis should be developed further by adding additional train paths typical for the examined time window and track line, until the typical value is reached (Table 1);

(4) Estimate the infrastructure capacity as a percentage of the infrastructure occupation rate Eq. (6).

This proposed methodology for estimating the infrastructure capacity is usable by common supporting timetabling software tools with a graphical capability. The incorporation of occupation square imaging in common software [10-12] is not difficult from a software creation view. The software will fulfill the task of the calculation of the squares in the graphical train diagram (time-table).

4. Case Study

The authors of the methodology conducted case studies for the verification of proposed methodology in terms of real timetabling conditions [2, 4]. Capacity estimation was made using the software ZONA-CP-VT, which uses ŽSR for timetable construction. This software is eligible for the application of the new methodology, and only minor software modification ID required to perform the drawing of the occupation squares in the train traffic diagram.

For the case study a single track line section of

Zbehy-Leopoldov with mixed traffic was chosen. The results obtained are introduced in the following.

During the whole daytime window (1,440 min) 47 regular train paths are inserted in the train diagram.

The results for the outgoing state obtained in Step 1 according to the proposed methodology are shown in Table 2 as the outgoing number of train paths (see also the portion of the train diagram showing the occupation squares in Fig. 13). The occupation rate is 33.3%, thus the capacity consumption does not reach the typical value for mixed traffic lines of 60% (see Table 1—outgoing number of train paths).

In accordance with Step 3, additional train paths were inserted in the train diagram. The additional train paths are typical for the section examined, in this case, they were regional passenger trains and running freight trains (Fig. 14). These paths must be inserted throughout the whole track section inspected until the

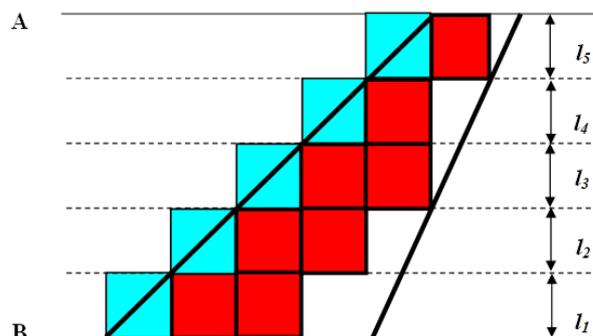


Fig. 11 Occupation squares of track time intervals S_{PV} —an inter-stationary section is divided into block sections (automatic signals)—the first train slower than the second.

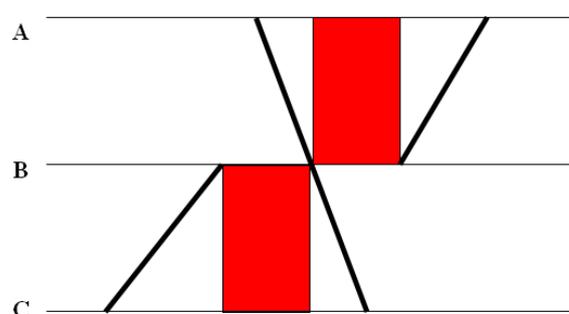


Fig. 12 Occupation squares of the station time intervals (one track line—bidirectional traffic).

Table 2 The obtained results of the case study.

Indicator	Outgoing number of train paths	Final number of train paths
Number of regular train paths in the train diagram	47	47
Number of additional train paths	0	32
Total number of trains	47	79
Sum of the occupation squares $\sum_{i=1}^n S_{obsi} + \sum_{j=1}^m S_{PVj}$ (min·km)	11,508.75	20,194.05
Square of the daytime window S_T (min·km)	34,560	34,560
Capacity consumption (%)	33.3	58.43

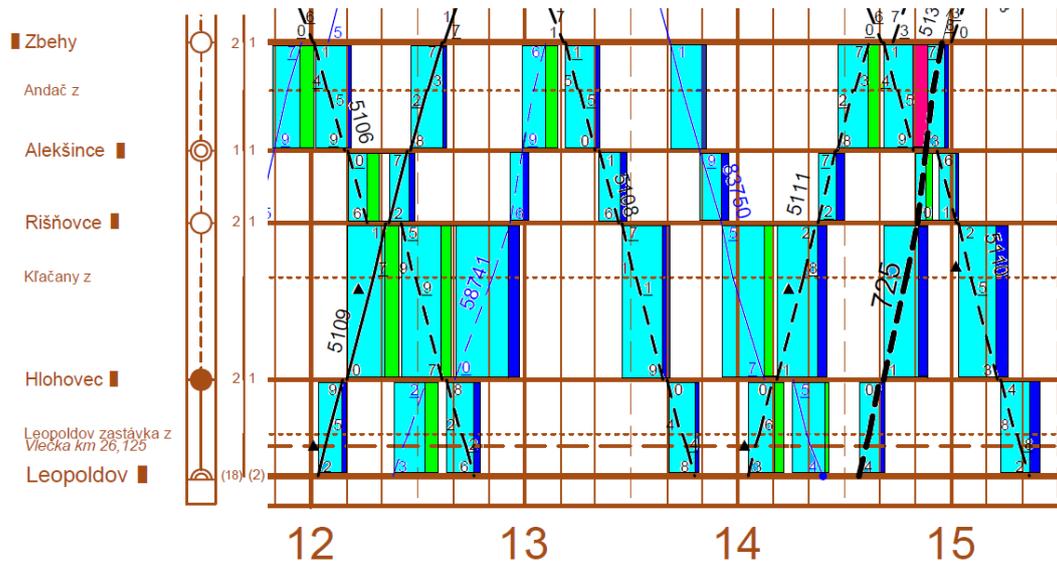


Fig. 13 Occupation squares in a portion of the train traffic diagram—with no additional train paths [2].

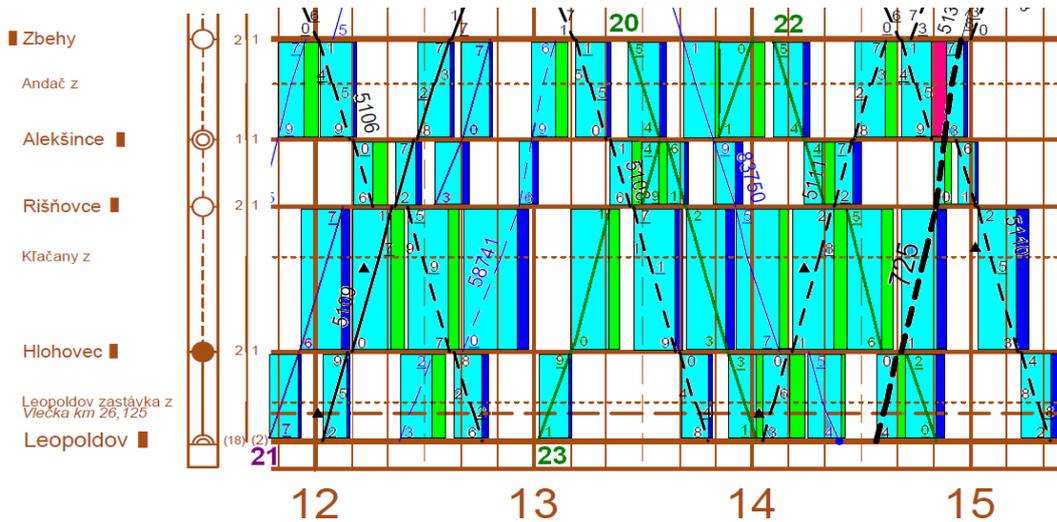


Fig. 14 Occupation squares in a portion of the train traffic diagram—with additional train paths [2].

occupation rate reaches the typical value of 60 %. The result in this case is 32 additional train paths over the 24 h time window. The capacity consumption is 58.43%

and the capacity of the track section is 79 trains per day (see Table 2—final number of train paths).

This result was compared with the current analytical

methodology of ŽSR. ŽSR introduces the capacity for this track section of Zbehy-Leopoldov in the internal document—in the list of ascertained capacities (the so-called booklet of capacities)—as 74 trains per day.

The estimation of the time occupation according to the UIC methodology was not conducted because the UIC methodology gives no satisfactory results for single track lines. There is also a problem in executing the graphical compression of the opposing running train paths, and thus the comparison would not be useful.

5. Conclusions

The disadvantages of UIC methodology should be overcome by the appropriate definition of the simulation investigation running. It is applicable to use some of the methods from the ŽSR methodology regarding time occupation estimation. The fundamental improvement to UIC methodology is the definition of the occupation time by the train paths in the time window, which will be calculated by common simulation software. That is important for the estimation of the unused (free) capacity from compulsory indicators published by the infrastructure manager. The pivotal action of the capacity estimation is to define the required quality of train traffic within the timetable.

The new methodology presented for occupation time estimation based on a graphical approach makes the UIC methodology more usable and enables more exact results to be obtained from infrastructure capacity examination. In common, software tools used for timetabling and capacity inspection it is necessary to add a function for the analysis of occupation squares.

The proposed methodology is not a substitute for simulation techniques that give better results for the capacity because such procedures consider the exact combination of trains, as well delays. It is easy to adapt it to the conditions of other train traffic diagrams used in Western Europe, as well as to other timetabling software (in Germany, Austria, etc.). The authors

examined this adaptation for the situation of Slovak railways. It is possible to integrate this methodology into UIC Code 406, and adapt the unified methodology for all infrastructure managers for capacity estimation.

The paper should be an impulse to begin a wider discussion within the expert community about the new methodology introduced by the authors.

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