

INNOVATIVE APPROACH TO DETERMINING RAILWAY LINE CAPACITY

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The contribution deals with critical assessment of used analytical and graphic-analytical methods for determining the lines capacity and of problems connected to the capacity formulation. Negative outcomes from executed case studies force us to investigate new approaches, which would result in more accurate capacity determination. Simulation models appear to be an appropriate tool allowing the investigation of the capacity of transport infrastructure in the interaction with the range of traffic. In case of incongruity between the transport infrastructure and the range of traffic operation, the implementation of various arrangements including the economical assessment can be simulated by means of scenarios. At the end of the paper a short list of the experience with the application of simulation modelling on particular lines in the Czech Republic is presented.

Key words: capacity, railway transport, infrastructure, simulation modeling

1 Introduction

In railway transport determining line capacity is of crucial importance. It is the interaction between the range and organization of the transportation process (TP) and the range of transport infrastructure (TI). The knowledge of capacity is especially important when creating the timetable, which represents the key tool for basic and operational control not only of TP.

The development of the matter of determining line capacity has been long and rather complicated. Starting with simple thoughts, it has in successive steps progressed to a longstanding use of analytical and graphic-analytical methods of solution, which are based on deterministic concept of transport. Nowadays, an effective tool for investigating the capacity is represented by transport models and especially simulation models. Such models are capable of taking- in the interaction between the range of TP and the range of TI upon any given input in terms of the traffic organization together with respecting required level of quality. Naturally, the complexity of conditions requires adequate methods, means and tools to be used for capacity determination. Also the economical assessment of the arrangements aiming at providing commensurate quality is considered to be very important. In this paper we would like to present the frame of one of partial results obtained within institutional programme “Theory of Transport Systems” solved at

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2 Analysis of analytical and graphic-analytical methods

There are two methodologies of calculating the capacity currently utilised in the conditions of the Czech Republic, i.e.:

- Railway Infrastructure Administration (SŽDC) (CD - Czech Railways) methodology D24 [1] representing the main approach,
- International Union of Railways (UIC) Leaflet 406 on capacity [2].

Expert public generally admit that both the methods have their imperfections and internal and external effort to draw computing algorithms closer to new reality and new situation can be noticed.

2.1 SŽDC (ČD) D24 Methodology

This methodology is rather old. Since 1st October 1965, its original version has been in force and utilized without any significant changes. It contains the definitions of capacity, maximum (theoretical) capacity, practical capacity, capacity consumption coefficient, the level of occupation, capacity supplement as well as relevant analytical relations is presented there.

Methodology [1] supposes that in the storage of input requirements for the system of bulk service (which is one of the descriptions of a track unit) there is always a requirement (i. e. train) available. However, this has nothing to do with current situation, when passenger traffic prevails significantly. Such an assumption would mean that the running - through trains would be stopped in the stations because of the occupation of the track unit and they would enter it incidentally at the moment when the when the unit is available, or on the other hand, the departure times in TT would be set up according to the limiting consecutive interval, and thus they would not meet present requirements for the quality of periodical TT, or they would not even meet the passengers' demand. The trend in passenger traffic is just the opposite.

In order to be able to compete especially with individual motor traffic, passenger trains must be operated with maximal punctuality and without useless idle time. A positive trend of the last period appears to be the application of periodical TT (both, regular – interval and/or interval ones), which provides the passengers with many indisputable advantages (from departures at the same minute of the hour to solutions of changes in the nodes of the regular-interval TT). Such organization of rail operation, though, decreases the capacity. At the same time, this decrease is not recognizable within the used methodology, as there exist certain time periods, where the track unit is available, still the consecutive train must 'wait' for its departure time as set in periodical TT. Such time and thus the capacity get lost irrecoverably.

2.2 Methodology UIC 406

A newer approach to the issue is in UIC Leaflet 406 on capacity, which came into force on 1st June 2004. [2]. TI capacity is defined there as available capacity within the allocation of required train paths on a segment of TI in a certain time window.

It is admitted there that capacity as such does not exist because it depends on the way the TI is utilized. The basic parameters, on which capacity depends, are number of trains, average speed, timetable stability and heterogeneity. The relation between them is illustrated in Fig 1. There is one axis for each parameter drawn from a unique origin. A chord representing capacity then links together the values of

each parameter. Capacity numerical value itself is represented with the length of the chord, which is the result of more criteria analysis.

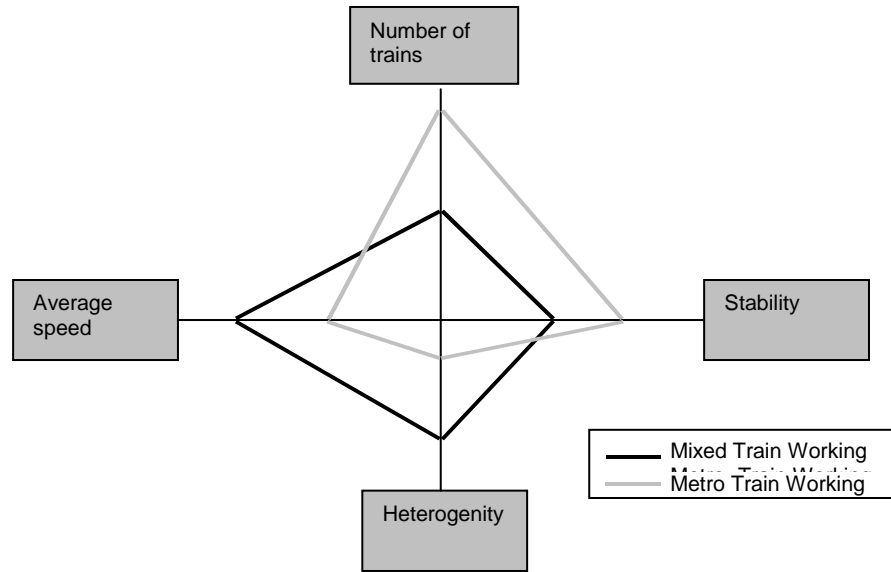


Figure 1: The capacity balance according to UIC Leaflet 406 [2].

The above mentioned facts indicate that capacity determination is based on assessment of existing TT; in case of assessing future line it depends on assessment of a case study.

The examination of the capacity itself using [2] is executed through similar methods as when using methodology [1], i.e. through a graphical method and calculation. The graphical method lies in compression of designed paths on a time window related to operational intervals.

The UIC numeric method is based on the following relations (1) and (2):

$$k = A + B + C + D \text{ [min]} \tag{1}$$

- Where: *k* total consumption time [min],
A infrastructure occupation [min],
B buffer time [min],
C supplement for single track lines [min],
D supplements for maintenance [min].

$$K = \frac{k \cdot 100}{U} [\%] \tag{2}$$

- Where: *K* capacity consumption [%],
U time window [min].

Compared to methodology [1], the difference appears to be the need to compare the results of the calculations according to formulas (1) and (2) to a certain typical value corresponding to the type of track. However, not even these values can be determined exactly. There is a number of parameters which can influence them, e.g. reliability of TI and vehicles, interdependency of the examined line section and the neighbouring sections, the level of quality required by carriers (e.g. contract for the option of cancellation

of a delayed service), margin on journey time, number of trains per hour, the length of the line section, particular options of crossings and overtaking on this line section. Thus the values in diagram 1 are only approximate.

Diagram 1 Guideline figures of capacity consumption on particular types of line

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 utilisation
Dedicated high-speed line	75 %	60 %	
Mixed-traffic lines	75 %	60 %	K can be higher when number of trains is low (smaller than 5 per hour)

Source: [2]

Provided that the numerical values in the above mentioned calculations are lower than the values in the table, we can assume the existence of available capacity, however this must be proved through follow up steps in TI analysis. This iterative procedure lies in the attempt to insert required tracks with their typical characteristics into the examined TT. When the insertion is successful, the procedure has to be iterated to the point when the guideline standard value of capacity consumption is exceeded (reached) and/ or another additional track cannot be inserted.

2.3 Problems related to capacity definition

Capacity is influenced by a number of factors. They are more or less mathematically quantifiable, compared to the problem of periodical TT, where one of the specialties of transportation – unstorability - comes out plainly.

From mathematical point of view the figure of the number of trains in a certain period is fully predicative only in case of a homogeneous TT and providing that trains can be dispatched to the interstationary line segment in the consecutive period without dwelling [3]. Though in the real railway traffic, a homogeneous TT occurs rarely, usually in the conditions of closed transport systems (for instance special underground line, in some segments of tramway lines or specific railway lines, e.g. certain regional lines without freight traffic.)

In the majority of cases the matter of heterogeneous TT must be taken into account. Problems are caused by the fact that on a particular line there is more than one type of train with the same type of tractive and connecting vehicles operated. In practice, differences can be observed (passenger traffic trains, freight traffic trains, trains made of tractive vehicle and a set of hauled vehicles, motor unit etc.) Different tractive characteristics of single trains cause different running times or more precisely different occupation times and increasing level of the difference between the running times of the slowest and the fastest train on a given track unit.

Such a problem is computationally solved by constructing a TT congested to the maximum, when certain universal train routes are inserted in it and real but not yet used capacity is eventually assessed from their number [3]. Regarding rather varied characteristics of single train routes the argumentativeness of this way obtained results seems to be less valid and the procedure must be executed ad hoc according

to the type of the train, which should be incorporated. Also the sequence of the inserted train and the existing trains must be taken into account.

The problem escalates with the growing variation span of the speed of particular trains. (Fig. 2).

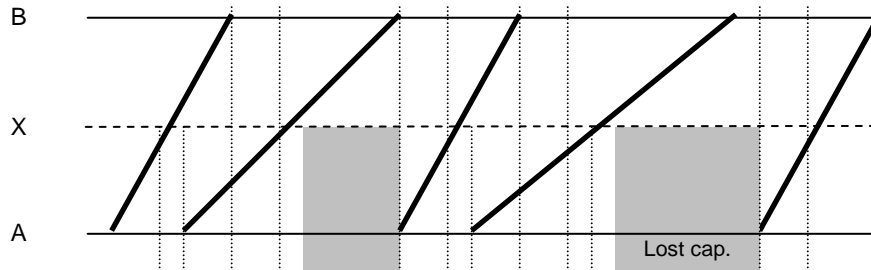


Figure 2: Negative impact of heterogeneous speed trains on the railway line capacity.
 Source: authors

This lost capacity is (in relation to theoretical capacity of interstationary section) are mathematically quantifiable through limiting consecutive interval for given train sequence. The extent of the loss depends on the sequence of particular trains and their speeds. The problem stands as follows: how the capacity should be formulated from an overall point of view, for example for the period of 1440 minutes, or with the number of trains insertable into the TT is defined.

The application of periodical TTs cause indirect occupation of TI due to the dependency of separate trains departures on the period of TT, which was mentioned in chapter 1.1. In fact, not the entire period for calculation can be utilized.

Due to the time period, when the train waits for the departure given by the period of TT, there occurs a time gap, which is not available for occupation of this element of TI with another operation (another train running). Thus it can be considered a lost capacity. The trouble lies in this type of lost capacity's formulation and calculation within the general calculation of capacity. See Fig. 3.

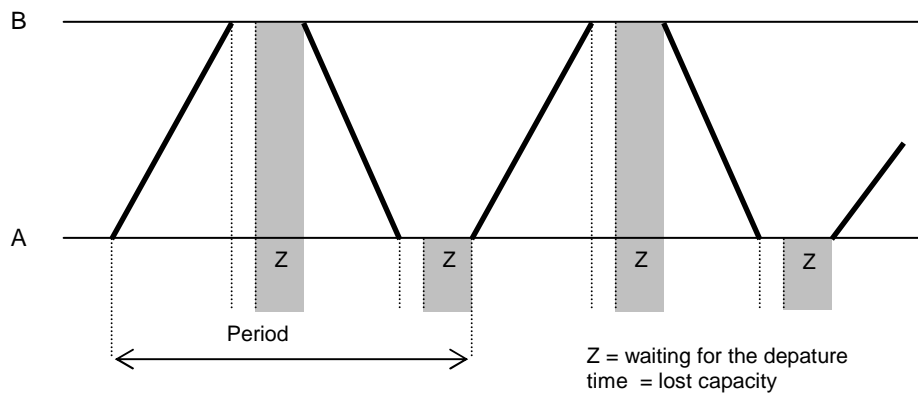


Figure 3: Negative impact on capacity caused by waiting for the departure time as set by the period of TT.
 Source: authors

Eliminating this negative effect is not possible in full, for the creation of integrated periodical TT itself requires implementing a number of other criteria, which make it unattainable (for instance, the interaction with other line section, departure times requirements, etc.). The situation is also enhanced with periodical TT used in long-distance passenger traffic. Also substantial future changes in freight traffic, where with new carriers oncoming, a competition for trains of freight traffic lines with minimum running times and other requirements regarding their time positioning can be expected and are in question.

Moreover, on shared line segments of certain lines, the solution of coordination of train line TTs on shared through “Žilina circle” method can be expected [3]. This requirement is logical, still it represents another attack on capacity consumption of a line section.

Another important problem appears to be determining the capacity of tracks with platform in the nodes of integrated regular- interval TT. Provided the coordination of the lines in the node is implemented, which is presumable in case of regular-interval integrated TT in order to minimize time loss at changing, a lot of lines coming from different directions must encounter there at the same moment. Thus it is necessary to have in the node as many available tracks with the platform as many trains are supposed to meet in the node. These tracks then stay unoccupied until another moment of coordinated encounter of the trains occurs. In general formula with the ratio of occupation time and computation time, there are low values of occupation obtained.

From this point of view and using methodology [1], the deducted number of tracks with platform can be smaller than necessary for performing the operation according to regular-interval TT, for the need of simultaneous arrival of all trains is not taken into account in calculations.

The interaction between the range of organization of TP and the range of TI is of crucial importance. Insufficient range of TI causes problems in operation and the quality of provided service within the TP just as the carriers' (customers') demand for them. On the other hand, in case the TI is over designed, the redundant TI causes expenses (for example, equipment checks, maintenance, staff costs). These costs represent a loss for TI manager and can have a negative impact of the economical situation in the operation of the line. Thus there is a natural necessity to optimize the interrelation of these factors and capacity is one of the criteria when assessing this relation. Moreover, the solution of the problem is complicated with long-term recovery of the investment in DI as well as practical unfamiliarity with actual range of TP in future, which-unfortunately- many times prevails.

The analysis of case studies [6] when using methodologies [1] and [2] supported the need of change of the approach and methods when determining the capacity and other parameters. Frequently, the elicited values were under the limit of effective utilization of equipment and thus they established the image of possible capacity reserve, which does not exist in real system. In other cases, high values of parameters indicated the impossibility to insert new trains, while the opposite proved true. Eventual alterations (for example, the deduction of indirect occupation, caused by adhering to regular-interval TT, from calculation period) are not generally specified and thus not included in the methodologies and they must be executed individually being accountable to personal responsibility of the operational controller. This contradiction and problematical alterations lead to the decision to implement simulation modelling.

3 Utilization of Transport Modelling for Calculating TI Capacity

Determining DI capacity is an example of possible usage of transport modelling method. For examination of the interaction between TP and TI, it appears effective to use the method of simulation models.

The principle of simulation methods is multiple iteration of independent random experiments and assumptions of actual behaviour of a system with respect to the comparison of separate partial results of this kind of assessment. Using the railway technology register of terms it can be described as examination

of main characteristics of the system by means of the study of performed TTs in the course of changing inputs. In this case, these TTs were performed only in the virtual conditions of the model. As in the railway transport the dependency on the factual conditions seems to be on the increase (train sequence, periodical TT), the possibility to use simulation not only for evaluation of the suggested TT's stability, but for evaluation of capacity itself must be taken into account [4].

In practise, not only the parameter specification of one version of a TT is dealt there, but the comparison of several TT versions. Eventually, the off- set in the values of output parameters, which depend on the changes of input parameters, enable us to observe the responsiveness of the changes of the system behaviour in relation to the input parameters. For instance, the changes of the system characteristics in relation to the change in number of inserted trains or the changes after the application of periodical TT (and their interval) can be observed this way and many this others. Through this the calculation turns into a heuristic algorithm rather deviated from the optimal solution, though. Nevertheless, demands on calculations are lower and provided results, which take into consideration more input parameters, are supposed to have higher predicative value than the results calculated according to methodologies [1] a [2].

When simulating the interaction between TP and TI, the dimension of the range of TI [4] can be done in advance (expansion and reduction). This influence can be determined by a wide range of technological indicators raising from the model or calculated from the model outputs, such as the level of occupation of a given element of TI, executed plans of technological processes, executed TTs etc. Thanks to these data it is possible to assess benefits and losses brought by executing the examined arrangement on TI more comprehensively.

Provided a complex study of line segment should be done, it is necessary to create a few variant simulation scenarios with different range of TI, or if appropriate with different variants of TT (when the requirements for TT are not preliminary specified). The required range of TI is then determined according to the technological characteristics of each scenario as well as to the comparison of the scenarios to each other).

Moreover, it is necessary to define the outputs for evaluating capacity. It cannot be assumed that the value calculated as number of trains in a time period will be sufficient. In an indirect way methodology [2] implies that such numeric value is not obtainable with a sufficient level of accuracy, because all above mentioned existing problems would remain to interfere and thus it would stay a generalized value. High level of predictive ability could be found in the set of capacity values with their hypothesis/anticipation or the specification of output parameters responsiveness to the changes of inputs (preferably in the form of a mathematic function).

Only a complex assessment of the situation on a particular TI based on the examination of several input criteria could be considered a credible capacity evaluation, which meets existing requirements.

At the same time, present way of this evaluation, for example according to [1], is still applicable for primary and - in comparison to simulation – quick assessment of the situation (on an appropriate level of accuracy), or as a partial calculation within eventual simulation procedure.

4 Application of Simulation Model

SW product Opentrack, version 1.5.2 was used by the researchers of the institutional project for modelling on six selected lines of three different groups.

The analysis was focus especially on speed coefficient β_u , which was adapted by the solvers and which - compared to the original coefficient- does not contain stays of trains caused by transportation, for they represent productive time of transport operation. In total 400 train lines taken from TT 2008/09 were examined.

On the examined lines (with the exception of line Brno-Přerov, which is supposed to be led in a new route in future), there were two operational scenarios utilized for the simulation. The first scenario was identical with TT 2008/09; it was also used for validation of the accuracy of the model results in relation to the actual state. The second scenario dealt with perspective range of TP. The base for the specification of this range was especially project [5]. In case of line Brno – Přerov, which is supposed to run in a new route, a scenario for only prospective TT was modelled.

In prospective scenarios (TT), a system of periodical TT was implemented within the TP organization, by means of which the impact of this kind of TP organization on TI capacity could be observed. Moreover, application of TP organization of this kind fully corresponds to the majority of plans and intentions concerning railway transport in CR.

When assessing operational scenarios there were used – besides β_u – not only standard quantitative coefficients, but also newly designed quantitative coefficients and economic indicators, i. e.:

- coefficient of elimination of primary delays K_{vz} representing the ratio of primary delay to total time necessary to settlement of the delay in relation to the numeric value of dwell time z (expressing the stability of TT as its level of quality),
- variant range of TI,
- general economical indicators in relation to the kind of suggested arrangement, organizational and/or investment arrangement for facilitating the required range of TP.

More detailed outputs of the simulation are available at the Department of Technology and Operational Control. The solution has fully proved the accuracy of previous theoretical assumptions in this field as well as the benefits of using simulation models when dealing with the issue of determining capacity on new, higher quality level.

5 Conclusion

Approaches to the determination of TI capacity have been changing in time, as new technical possibilities open for the railway transport and also in compliance with changing approach to the railway transport in general.

Owing to growing competition on transportation market and growing financial demands for not only TI construction but also TI operation, determination of capacity is considered to be a complex and crucial issue. Regarding also new trends in the organization of transport, a simple determination of capacity by number of trains in a particular period appears to be insufficient. Thus it is necessary to apply the possibility to assess the capacity characteristics of DI by means of simulation models as their development facilitates and simplifies such assessments.

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