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THE CAPACITY OF RAILWAY LINES IN CONTEXT OF PRESENT AND FUTURE SITUATION

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1. Introduction

The requirements put on the railway transport system are increased in the consonance with the accelerated speed of life. The railway is in different position from the historical position on the beginning of railway transport operation. It is not possible to suppose that the customers will adjust to strict transport conditions unilaterally promulgated by railway companies as it was possible in the history. Nowadays the railway companies have to adjust to requirements of customers and have to play an active role on the transport market. This fact has also an influence on the capacity of railway lines. The infrastructure parameters are mostly on the same level as in the history, but the access to railway transport has been modified. The modernisation works are naturally made also in the railway transport sector (e.g. new types of interlocking plants, improving of characteristics of railway lines, etc.), but one problem is still remained. The question is the ability of these measurements to respond to changed requirements on the railway transport operation and in the conditions of limited financial sources. There is a close relation between these facts and capacity of railway lines.

The capacity is an important index representing the crucial quantitative relation between railway transport operation and railway infrastructure. The railway capacity estimation is consisted of estimation of line segments and estimation of stations (capacity of transport tracks and station gridirons). The capacity of railway lines is the most important part from the point of view of the present access to railway transport operation.

There are different points of view on the capacity of railway lines, because there are existed various results of the capacity estimations. It is proved that the railway capacity is not depended on the occupation time and on the length and choice of the calculating time period only as it could be said in general.

There are some new factors in the transport technology like the preponderance of passenger transport over the freight transport, improved frequency time schedules, increasing differences between speeds of train categories etc. It is naturally that all of these facts have an influence – also out of the frame of occupancy time caused by train journeys or by permanent manipulations.

2. Valid Methodologies for Estimating of Railway Capacity

There are utilized two methodologies for estimating of capacity of railway lines in the Czech Republic – the methodology "ČD D24" [1] representing the main access and the Codex UIC406 "Capacity" [3]. The professional public allows that there are some problems in both methodologies. There are some activities and attempts for approximation of present methodologies (algorithms) to new conditions in the Czech Republic and also abroad.

2.1 Methodology "ČD D24"

The original version of this methodology [1] was come in the operation on the 1st October 1965 by the former national railway company "ČSD". This methodology is still valid (naturally with respect to later changes) in both countries (the Czech and Slovak Republic).

The capacity of railway line segment is defined as the extent of train transport what is able to be continually and regularly handled on the estimated railway line segment in the specified time period. There is respect to present condition and technical equipment of the line segment as well as to the valid codes for using of technical devices implemented on the line. The capacity is expressed in the form of number of trains per direction usually in the time period of 24 hours. This number of trains has to be dispatched on the line segment in the continuously way.

The maximal (theoretical) capacity n_{max} is capacity of parallel time schedule calculated without regard for reserves.

$$n_{max} = \frac{T}{t_{obs}} \quad [\text{trains/time period}], \qquad (1)$$

where:

n_{max} .... maximal (theoretical) capacity [trains/time period],

T .... calculating time period [min],

t_{obs} .... time standard (technological time) of occupancy of operational device by one train [min].

The **practical capacity *n*** is defined next to it. This type of capacity is estimated with respect to technological times needful for prescribed controls, maintenances, planned reconstructions and general overhauls of operational devices and its parts by that the full using of devices is not allowed (possible). There is also respect to equalizing of delays (guarantying of quality).

$$n = \frac{T - \left(\sum t_{výl} + \sum t_{stál}\right)}{t_{obs} + t_{dod} + t_{ruš}} \quad [\text{trains/time period}], \qquad (2)$$

where:

n .... practical capacity [trains/time period],

T .... calculating time period [min],

$t_{výl}$ .... total time of technical closures [min],

$t_{stál}$ .... total time of permanent manipulations (other in what capacity calculated is) [min],

t_{obs} .... time standard (technological time) of occupancy of operational device by one train [min/train],

t_{dod} .... average additional time of occupancy per train – it is consisted of reserve time for indirect occupation of the infrastructure element caused by occupying of cooperating element and also of reserve for equalizing of delay [min/train],

$t_{ruš}$ .... time of disturbing in collision points [min].

Coefficient of capacity utilizing K_{vp} is defined as ratio of number of regular trains to practical capacity of the line segment or operational device. The value is also able to be presented in percentage.

$$K_{vp} = \frac{N}{n} = \frac{N(t_{obs} + t_{dod} + t_{ruš})}{T - (\sum t_{výl} + \sum t_{stál})} \quad [-], \tag{3}$$

The meaning of symbols is cleared up in upper text.

Occupation degree of operational device (element) S_o is ratio of total occupation time of the operational device (element) by regular train transport to calculating time period without times of closures and permanent manipulations.

$$S_o = \frac{\sum t_{obs}}{T - (\sum t_{výl} + \sum t_{stál})} = \frac{N \cdot t_{obs}}{T - (T_{výl} + T_{stál})} \quad [-], \tag{4}$$

where:

S_o .... occupation degree [-],

T .... calculating time period [min],

t_{obs} .... average time of occupation per train [min],

N .... number of trains (real or supposed) [number of trains],

$t_{výl}$ .... time of planned closures [min],

$t_{stál}$ .... time of permanent operations [min].

It is presupposed in the methodology "ČD D24" that there is some requirement (train) at disposal in the buffer of queuing system at any moment, but it is not wholly valid in present conditions. The characterized system is based on the principle that the trains are waiting and entering the line segment immediately in the moment when the segment becomes free. This principle is able to be characterized as a random system. This way of operation is not appropriate in the present condition with prevailing passenger transport. The passenger trains have to be operated in accurate way and without unnecessary idle time periods because of competition with individual car transport. There is able to found good tendency to implement improve frequency time schedules next to it, but this model of railway transport operation has also very negative impacts on capacity of railway lines. On the other hand improved frequency time schedules are connected with a lot of advantages especially for passengers (departures in the same minute every period; management of connections with minimized time lost etc.).

The additional times of occupation following from the improved frequency time schedules are non-receivable by using of the methodology "ČD D24". These additional times are based in the fact that the trains have to waiting till the departure time prescribed by the time schedule in spite of the fact that the line segment is able to be free, but with not so big time slot for another (e.g. freight) train. The capacity closed in this additional occupation time is irretrievably lost.

The complete elimination of this negative impact is not possible, because there are also a lot of preconditions to be carried out for implementation of improved frequency time schedule (e.g. interaction with other railway lines, requirement on arrival in the specified moment etc.). The coordination of time schedules of regional and long-distance trains is also able to be a complication from this point of view. The extent and requirements of freight transport remain still as a question because the situation will be completely modified in consonance with liberalization of the railway market, but it is able to suppose that it will have a negative impact on capacity too (e.g. requirements on minimizing of travel times and also on specified times of departure and arrival).

Another problem will be coordination of lines using the same infrastructure for minimizing of subsequent frequency by the methodology known as the "Circle of Žilina" [2]. This is seemed as a problem especially in the suburban areas (integrated transport systems) with requirements on close subsequent frequencies between trains.

2.2 Methodology based on Codex UIC406

The modern view on the questions of capacity of railway lines is presented by the Codex UIC406 "Capacity" valid from 1st June 2004 for all UIC members [3]. **The capacity of infrastructure** is defined as serviceable capacity in the frame of timetabling of requirement time slots for trains on the specified segment of infrastructure and in specified time period.

On the other hand it is conceded here that the "capacity" does not exist, because it is also depended on the way of infrastructure utilizing. The number of trains, average speed, stability and heterogeneity of time schedule are named here as the basic parameters influencing the capacity.

As it follows from above mentioned, the capacity estimation is based on the evaluating of the existing time schedule or case study in the case of the proposed railway line segments (in the future).

The estimation is provided by similar methods as in the methodology "ČD D24". There are two ways of estimation in the Codex UIC406 – graphical and analytical. The graphical method is based in compression of trains with the time distance required by the operational intervals. The analytical method is based on the formulas (5) and (6).

$$k = A + B + C + D \quad [\text{min}], \tag{5}$$

where:

k .... the utilized (occupied) time [min],

A .... infrastructure restrictions [min],

B .... time of gaps [min],

C .... reserve for single-tracked lines [min],

D .... time reserve for maintenance [min].

$$K = \frac{k \cdot 100}{U} \quad [\%], \tag{6}$$

where:

K .... utilizing of capacity [%],

U .... calculating time period [min].

The difference between methods based on Codex UIC406 and ČD D24 is that these values calculated within the Codex UIC406 are necessary to compare with defined standard value depended on the type of estimated railway line segment. There are a lot of other parameters with an impact on capacity, e.g. operating reliability of infrastructure and rolling stock, the interdependences between estimated segment and connected segments, the quality level required by railway companies (e.g. cancelling of service in the case of delay), variance of travel times, number of trains per hour, the length of estimated line segment and the possibilities for train crossing and overtaking. The values mentioned in the ***Tab. 1*** are informative only because of above mentioned reasons.

Tab. 1 *Informative Values of Capacity Utilizing on Specified Types of Railway Lines*

Type of Line	Utilizing of Capacity		Note
	Traffic Peak	Whole Day	
Special suburban transport	85 %	70 %	High degree of capacity utilizing is allowed because of possible cancelling of services
Special high speed line	75 %	60 %	
Lines with mixed traffic	75 %	60 %	It is able to be higher in the case of low number of trains (fewer trains than 5 per hour) with high heterogeneity.

Source: [3]

If is the resulting value from previous calculations lower than the values mentioned in the table, it is able to suppose that there is a capacity reserve on the estimated railway line segment, but it is necessary to be demonstrated by another steps of infrastructure analysis. This process is based on the attempt to insert required trains (with typical characteristics) into examined time schedule. It is necessary to do it in iterative way till the standard value of capacity utilizing will be exceeded or till the inserting of any other train will be not possible.

The capacity is influenced by many factors as was been mentioned above. Some of them are able to be quantified in mathematical way, some of them not (questions of improved frequency time schedules). One of the factors able to be quantified is increasing difference between travel times of "fast" and "slow" trains on the selected segments of railway line. This factor is able to be represented in the form of subsequent interval for specified combination of trains [4].

On the other hand some problems are occurred by quantification of capacity reserve. The universal type of trains (usually with characteristics of "Pn" trains) was inserted into the time schedule by utilizing of former methods. The capacity reserve was judged from this value, but it is not suitable in present conditions because the difference between technical characteristics of train types is rising. The solution is based in attempt to insert the required train (trains) into the real time schedule in "ad hoc" way. The situation is also depended on the sequence of existed and inserted trains.

2.3 Assessment of Methodologies

The basic accesses to estimation of capacity of railway lines with utilizing of methodologies "ČD D24" and "Codex UIC406" have been mentioned in previous parts of the paper. These methodologies are often indispensable e.g. for special form of operation without the time schedule (in the case of crisis situation) or for the first judgment of solved line segment without the utilizing of advanced software tools and without knowledge of detail parameters and characteristics of the solved line.

There is not existed unified, general and verifiable method for estimation of capacity of railway lines as follows from above mentioned facts. The general formula for estimating of capacity (usable also out of the railway sector) is included in the methodology "ČD D24". On the other hand there are existed some problems connected with implementation of improved frequency time schedules in the form of indirect occupation of the infrastructure. There is existed the occupation time when the line segment is free, but it is not able to be used by train because the train has to wait on the time guaranteed by this improved frequency time schedule and no other train is able to use this infrastructure because the time slot is not so long.

There is also the problem of rising variance of train speed especially in the suburban transport. It can be mathematically quantified as subsequent interval between trains also depended on combination of train types. On the other hand there is occurred a problem of quantifying of free capacity (reserve) of line in consonance with variance of subsequent intervals and different requirements on time slots for each type of train.

The present situation in the operation of railway transport demands fundamental changes in capacity calculations and essential modifications in methodologies for estimating of capacity of railway lines. Information capability of present methodologies is limited in the frame of present requirements on railway transport and on complex estimation of all phenomenons connected with railway.

3. Case Studies

The consideration about capacity of railway lines with all characterized problems is illustrated in study way on some segments of railway lines in agglomeration of Brno. The main aim of the case studies is first of all to point out the urgency of utilizing of simulations for complex evaluation of these questions.

3.1 Line Segment "Brno-Maloměřice – Kuřim"

The line segment "Brno-Maloměřice – Kuřim" is part of the national railway line with meaning for international transport (TEN-T). This segment is also utilized for suburban regional transport of Brno. The improve frequency time schedule is implemented by the long-distance trains with frequency of 120 min and also by the regional trains with frequency from 20 till 30 min. The segment is occupied by 102 regular and 16 irregular trains in even direction and by 109 regular and 19 irregular trains in odd direction. The results of capacity calculations made on the Jan Perner Transport Faculty are mentioned in the following Tab. 2. All numbers are for the time schedule 2007/2008.

***Tab. 2** Capacity of the line segment "Brno-Maloměřice – Kuřim"*

Line Segment (sub-segment)	Index	Brno – Kuřim (Even Direction)	Kuřim – Brno (Odd Direction)
Brno-Maloměřice – Brno-Královo Pole	$\sum t_{obs}$ [min]	541.5	471
	t_{obs} [min]	4.88	4.44
	S_o [-]	0.399	0.353
Brno-Královo Pole – Kuřim	$\sum t_{obs}$ [min]	525.5	528.5
	t_{obs} [min]	4.73	5.03
	S_o [-]	0.396	0.407

Source: Authors, based on [5].

The results are able to be verified by the data rendered by the infrastructure manager (Railway Infrastructure Administration, state organisation). These data are accessible for the line segment "Brno-Královo Pole – Kuřim" only, but the results calculated by the "Codex UIC406" are also mentioned in the following Tab. 3.

Line Segment	Methodology	Index	Brno – Kuřim (Even Direction)	Kuřim – Brno (Odd Direction)
Brno-Královo Pole - Kuřim	ČD D24	*n* [trains]	170	170
		Reserve [free train slots]	74	73
		t_{obs} [min]	5.06	5.08
		S_o [-]	0.35	0.36
		K_{vp} [%]	56	57
	Codex UIC 406	*n* [trains]	162	162
		K [%]	59	60

Source: Railway Infrastructure Administration, state organisation [6].

The same foundation of both mentioned methodologies (ČD D24, Codex UIC406) is illustrated by the ***Tab. 3*** – the results are reconcilable and very close one to another.

It is necessary to judge the results gained by the "Codex UIC406" from the point of view of the values mentioned in the Tab. 1. The informative value of capacity utilizing (*K*) for the line segments with special suburban transport is 60 %. For that reason it is able to declare this railway line segment as fully employed without capacity reserve [3].

This fact is in correspondence with the pieces of knowledge of the workers responsible for planning of transport on this line, because the broadening of transport on this line segment is very problematic from the capacity point of view.

The negative impact of the improved frequency time schedules on the capacity is also proved by this case study, because this type of railway operation is implemented by preponderance of regional and long-distance passenger trains. The mathematical expression of these negative effects remains as the question, because also the results calculated by the "Codex UIC406" and judged by values mentioned in the Tab. 1 (also originally published in [3]) are informative only.

3.2 The Line Segment "Tišnov – Nedvědice – Žďár nad Sázavou"

There are solved two segments on this railway line, Tišnov – Nedvědice with the length of 15.4 km and the segment Bystřice nad Pernštejnem – Nové Město na Moravě with length of 16.3 km. This railway line is able to be characterized as single tracked and local dispatched from each station by train dispatchers after the regulation ČD D2. The line is equipped by the semiautomatic line interlocking. The values of capacity for both line segments are mentioned in the following ***Tab. 4***.

Tab. 4 Capacity of Railway Line Segments "Tišnov – Nedvědice" and "Bystřice nad Pernštejnem – Nové Město na Moravě"

Line Segment	Methodology	Index	T = 1440 min	T = reduced*
Tišnov – Nedvědice	ČD D24	n [trains]	34	27
		Free Train Slots	3	-4
		t_{obs} [min]	27.29	
		S_o [-]	0.60	0.75
		K_{vp} [%]	91	115
	Codex UIC406	n [trains]	30	24
		K [%]	103	129
Bystřice nad Pernštejnem – Nové Město na Moravě	ČD D24	n [trains]	34	25
		Free Train Slots	6	-3
		t_{obs} [min]	27.61	
		S_o [-]	0.54	0.73
		K_{vp} [%]	82	112
	Codex UIC406	n [trains]	31	22
		K [%]	90	127

* Reduced calculating time period (for the time of day with operation of passenger transport): Tišnov – Nedvědice 1155 min; Bystřice n. P. – Nové Město n. M. 1055 min.

Source: Railway Infrastructure Administration, state organisation [6].

The value of capacity utilizing K_{vp} overruns 100 % in some cases here. There is able to be found a precondition that the railway line will suffer by operational problems, but the real situation is contrary and the service is possible to be characterized as reliable. There is an evident discrepancy between calculated preconditions and reality of operation. It is proved by this fact that there are some imperfections in both used methodologies for capacity estimation (ČD D24 and Codex UIC406).

On the other hand there is a space for simulations based on repeating of random experiments, because this type of methods is suitable for discovering of local specifics causing breaking of theoretical preconditions.

4. Capacity of Suburban Railway Lines and High Speed Trains

It is also needful to remind the high speed trains in the context of suburban railway lines. The conventional transport infrastructure is used often by the high speed trains, because building of new infrastructure (railway lines) is able to be problematic in the urban areas. The problem of speed variance is escalated by these new high speed trains in spite of the fact that the speed is naturally limited on these line segments.

The work [7] elaborated on the Jan Perner Transport Faculty is focused on the capacity of the railway line segment "Praha-Běchovice – Kolín" with suburban regional transport and with implementation of high speed trains using conventional infrastructure. The implementation of high speed railway transport is in the Czech Republic in distant future, but it is necessary to make plans now for preventing of possible mistakes by making of investments in the railway infrastructure sector. On the other hand the complex view on the questions of capacity in the frame of railway line with highly developed suburban and high-speed as well as long-distance and freight transport is put in this work.

The line segment is able to be characterized as segment with rush long-distance passenger transport incl. trains "SC Pendolino". The regional transport is incorporated into the Prague suburban railway transport system named "Esko" as the line No. S1 and also in the Prague Integrated Transport.

There are operated 76 odd trains (Praha – Kolín) and 81 even trains (Kolín – Praha) per day in the frame of long-distance passenger trains. In the segment of suburban transport there are 38 odd and 37 even trains with the improved frequency 60 min and in the line segment Praha – Český Brod in the time period 4 AM – 9 PM with frequency of 30 min.

The freight transport is very significant as well. There are 39 odd trains and 43 even trains (irregular trains included). The capacity has been examined in two line segments Kolín – Velim (double-tracked line) and Český Brod – Úvaly (3-tracked line) with respect of different technical and technological characteristics of both segments. Some capacity indices are mentioned in the following ***Tab. 5***.

***Tab. 5** Capacity of Railway Line "Kolín – Praha"*

Line Segment	Index	Track		
		1 (odd)	0 (middle)	2 (even)
Kolín - Velim	$\sum t_{obs}$ [min]	556.01	-	610.49
	t_{obs} [min]	4.03	-	4.27
	S_o [-]	0.42	-	0.46
Český Brod - Úvaly	$\sum t_{obs}$ [min]	447.37	258,60	509,45
	t_{obs} [min]	3.36	5.75	3.56
	S_o [-]	0.33	0.19	0.38

Source: [8]

The calculated values of occupation degree S_o are situated under the lower border of zone of sufficient utilizing 0.5 – 0.67 [1].

There have been elaborated three operational scenarios of future transport development for appraisal of stage in the future (year 2020).

The growth of number of trains in all segments of transport has been taken in account in all scenarios. The high speed trains "Praha – Brno" have been also included with improved frequency time schedule (60 min). The difference between all scenarios is based in different infrastructure extent only.

The operation of regional suburban transport with improved frequency 15 min (in consonance with intention of the "Esko" system) with utilizing of modernized infrastructure in present extent is proposed in the first scenario. As follows from the model situation, it is not possible to elaborate this type of time schedule thank to the limited capacity.

The elaboration of time schedule for the second scenario is possible, but with reduction of frequency in the suburban transport to 30 min.

The construction of fourth track in the segment "Praha – Poříčany" has been examined in the third scenario. The segregation of suburban transport is seen as the aim of this construction. The time schedule without any limitations and with frequency of suburban trains 15 min and also with additional high speed trains is possible in this case. The values of capacity indices are mentioned in the following ***Tab. 6***.

Tab. 6 Capacity in Estimated Line Segments

Scenario	Index	Kolín – Velim, Track		Český Brod – Úvaly, Track		
		2 (even)	1 (odd)	2 (even)	0 (middle)	1 (odd)
Scenario 2	$\sum t_{obs}$ [min]	623.20	501.10	450.90	265.34	483.80
	t_{obs} [min]	3.94	3.28	3.07	6.47	3.41
	N [trains/day]	158	153	147	41	142
Scenario 3	$\sum t_{obs}$ [min]	-	-	312.80	-	334.60
	t_{obs} [min]	-	-	2.41	-	2.66
	N [trains/day]	-	-	130	-	126

Source: [8]

Information about capacity impact of technical and organisational measurements is given by the Tab. 6 and also by the above mentioned text. It is confirmed that it is necessary to well consider all possible operational scenarios and its impact as a crucial step also in context of economics [9].

5. Conclusion

As follows from the analysis of present stage of capacity estimation it is necessary to utilize computer simulation with possibility of creating of variant scenarios for future development. Thanks to common data basis in computer supported simulation it is able to be relative user-friendly to create and examine more variants also with respect to side conditions. It is able to be an effective tool for estimation of capacity of railway lines. In general – the results will be as exact as the number of examined scenarios will be high.

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Resumé

KAPACITA ŽELEZNIČNÍCH TRATÍ V SOUČASNOSTI A BUDOUCNOSTI

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Příspěvek se zabývá aktuální problematikou stanovování propustnosti železničních tratí. Jsou zde zmíněny základní principy výpočetních metodik. Situace je také ilustrována na případových studiích. Vzpomenuty jsou i možné kapacitní efekty vzniklé při případném zavedení vysokorychlostních vlaků, stejně jako problematika propustnosti příměstských úseků.

Summary

THE CAPACITY OF RAILWAY LINES IN CONTEXT OF PRESENT AND FUTURE SITUATION

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The paper deals with actual question of estimation of capacity of railway lines. The basic principles of state-of-art methodologies are also mentioned in the paper. The situation is illustrated on the case studies. The possible capacity effects of implementation of high speed trains are also mentioned as well as the questions of capacity of sburban line segments.

Zusammenfassung

DIE KAPAZITÄT VON EISENBAHNSTRECKEN IN DER GLEICHZEITIGKEIT UND IN DER FOLGEZEIT

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Der Artikel geschäftigt sich mit der Problematik der Kapazität von den Eisenbahnstrecken. Die Hauptprinzipen von gegenwärtigen Methodiken für die Kapazitätsbemessung sind auch charakteriziert in dem Artikel. Die Situation ist also illustriert auf die Fallstudien. Die Möglichkeit von der Implementation des Hochgeschwindigkeitbetriebes ist auch erwähnt als auch die Problematik von Kapazität der Vorstadtstrecken.