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Horizons of Railway Transport – Determinants of the development of the railway system in the context of the society-wide assessment of investments in railway infrastructure and public passenger transport

Transport Accessibility of Regional Centres as a Tool for Sustainable Mobility

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Abstract

The uneven distribution of the population in the territory has many common denominators. The Czech Republic is no exception, where, in addition to geographical factors, the degree of development of the transport network also plays an important role. There are significant differences in transport accessibility between regions. It must have a good transport infrastructure to make public transport more competitive and sustainable with individual car transport. This paper maps the development of transport networks in the Czech Republic and compares commuting times between the different regional cities of the Czech Republic. Individual car transport, rail transport, and bus transport were chosen as the main transport modes.

Keywords: accessibility; demography; matrix; transport network.

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1. Introduction

The quality of the transport network is a complicated parameter to measure. It can be viewed from many different perspectives, for example, in terms of length, speed, capacity, safety, and cost per use. It is also difficult to compare countries because it is impossible to set up a uniform European framework in terms of regulations and rules for road or rail traffic (Bulíček et al. 2021).

However, national transport policies aim to improve the quality of the entire transport system, either through new linear constructions or by improving the parameters of the current transport network (Bulková et al. 2023). Cempírek et al. (2016) states that the Czech Republic is relatively stagnant in the length of the rail transport network. Still, a substantial amount of funding is allocated to increasing the speed of the quality of the current infrastructure. A whole set of projects for building a high-speed rail network is in preparation. In road transport, attention has long been given to completing the motorway network and constructing bypasses on class I roads. Over the last seven years, the length of the motorway network has been extended by about 110 km, representing less than 10% of the network's total length (Ministry of Transport 2021). The pace of construction is slow, which should be helped by the new linear law. All efforts aim to reduce the time distance between settlements in the country. In this paper, a network of regional cities is chosen as a sample and their inter-temporal accessibility by individual car transport, rail transport, and bus transport is compared.

2. Transport accessibility

One of the parameters that characterize the transport network is the accessibility of the individual vertices. In terms of distance travelled and total network length, the longer the network, the shorter the average route length travelled on such a network. The notional limits are the complete graph at the upper boundary when no more edges can be created that would shorten any distance between vertices, and at the lower border, the skeleton of the graph and the relative position of each vertex in the network (Široký et al. 2021; Tischer et al. 2020).

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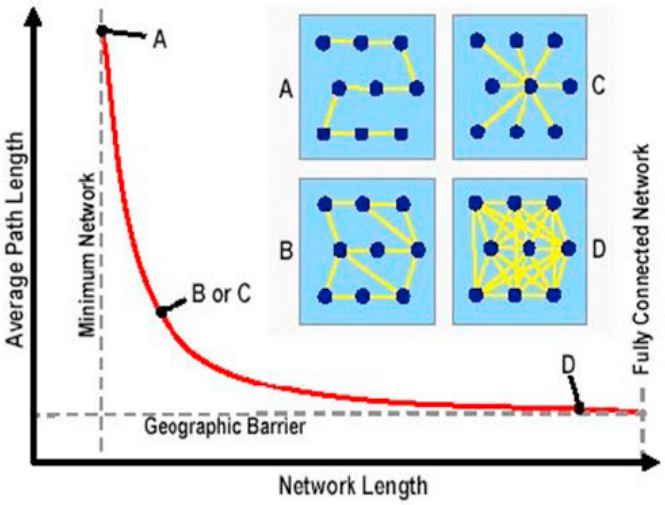

Fig. 1. Topology and connectivity of transport network.

It was customary to express the accessibility of a particular area using lines connecting places of the same temporal (isochrone) or spatial (isochore) distance (Potkány and Krajčírová 2017). However, new research by Fransen et al. (2015) in this area also distinguishes other forms of accessibility, such as:

- IPTN – Index of Public Transport Needs. This includes the needs of different socio-economic groups, age groups, or the location of housing units,
- IPTP – Index of Public Transport Provision – this includes accessibility to social services, hospitals, public administration, shops, etc.,
- IPTG – Index of Public Transport Gaps – is the difference between IPTN and IPTP. Ideally, both indices should be identical.

Other scientific sources like Lättman et al. (2016), Hernandez (2018), Blanquart and Koning (2017), and Mugion et al. (2018) provide a different perspective on accessibility. Factors such as distance of stops, number of departures, reliability, punctuality, information system, simplicity, and comfort are included here. These are, therefore, somewhat subjective or harder-to-measure factors. Also, authors like Basagna et al. (2018) and Mononen et al. (2017) look at the impact of public transport accessibility on economic indicators such as average wages or unemployment rates or on health indicators such as BMI or public health.

Thus, it is clear from the available literature, like Dadashpoor and Rostami (2017), that accessibility is comprehensive and has many implications beyond the transport sector into demography, public health, and economics. Thus, changes in transport supply need to be considered from many perspectives, and the beneficiaries of the benefits are often entities other than the customer or the transport operator (Bulíček and Bažant 2020; Hernandez 2018).

3. Accessibility of Regional Centres

One of the possible measures of the quality of the transport network is the mutual accessibility of individual major demographic units, i.e., regional centres. The three most essential transport modes were compared - individual automobile transport (hereafter IAD), rail transport (hereafter ŽD), and bus transport (subsequently AD). For each transport mode, a matrix was created to add the time values of the fastest connection between every two nodes. Thanks to the Economic and Transport Geography course students for their significant help with collecting these values. An extract of this input for AD is given in Table 1.

Table 1. Example of input values.

AD	Brno	České Budějovice	Hradec Králové	Jihlava
Brno		215	165	70
České Budějovice			285	147
Hradec Králové				220

The total number of matrix cells that entered the calculation was 78. This number is the sum of all cells above the main diagonal of the 13×13 matrix. Cells below the main diagonal were not considered because the authors assume the matrix is symmetric along the main diagonal. The total of all the rankings of each cell in the matrices is given in Table 2.

Table 2. The sum of all cell scores in the matrix.

	Suma [min]	Difference from minimum	
		[min]	[%]
ŽD	16,687	5,372	47
AD	18,939	7,624	67
IAD	11,315	0	0

Table 2 shows that in aggregate, ŽD is almost half as slow as IAD, and AD is 20% worse.

4. Results

Based on the knowledge of the distance matrix, the time difference between IAD-ŽD and AD-ŽD was calculated. For this, formulas 1 and 2 were used.

$$t_{ij}^{ŽD} = T_{ij}^{ŽD} - T_{ij}^{IAD} \quad (1)$$

$$t_{ij}^{AD} = T_{ij}^{ŽD} - T_{ij}^{AD} \quad (2)$$

where:

$t_{ij}^{ŽD}$ .....difference between ŽD and IAD [min]

t_{ij}^{AD} .....difference between ŽD and AD [min]

T_{ij}^{AD} .....travel time between nodes *i* and *j* by AD [min]

$T_{ij}^{ŽD}$ .....travel time between nodes *i* and *j* by ŽD [min]

T_{ij}^{IAD} .....travel time between nodes *i* and *j* by IAD [min]

For better clarity, only an example output for comparing AD and ŽD travel times is given in Table 3. Positive values in the matrix indicate that the ŽD is faster than AD or IAD.

Table 3. Example of output values [min].

AD	České Budějovice	Hradec Králové	Olomouc	Ostrava
České Budějovice		36	-13	-58
Hradec Králové			-55	-160
Jihlava				55

4.1. Comparison of ŽD and IAD

Regarding time accessibility, it is not surprising that car transport performs best. At the same time, there are eight combinations of vertices where rail accessibility is better than by car. Half of these pairs are Pardubice and Olomouc, accessible by train but take more than 2 hours to connect by road, compared to 80 minutes by train. Thus, in terms of the difference in journey times, train connections are less successful:

- Pardubice – Olomouc – 47 minutes (38 %),
- Pardubice – Praha – 22 minutes (26 %),
- Pardubice – Zlín – 20 minutes (11 %),
- Praha – Olomouc – 17 minutes (11 %).

Logically, a country that does not have high-speed transport cannot achieve high numbers in this respect in the number of vertices that can be reached faster by ŽD than by IAD. On the other hand, travel speed and transfer times are not the only aspects to consider when evaluating transport systems. Others may be comfort, accident rate, weather, the possibility of working on the train or refreshing oneself during the journey. Everyone's perception is different, so the authors conducted a significance-level analysis. In the first step, another matrix was created according to formula 3, which shows by what percentage the journey of the ŽD is longer than the journey of the IAD.

$$t_{ij}^{\%} = \frac{T_{ij}^{ŽD} - T_{ij}^{IAD}}{T_{ij}^{IAD}} \cdot 100 \quad (3)$$

An example of this resulting matrix is shown in Table 4, and each number thus expresses the percentage by which the IAD route is preferable to the ŽD route.

Table 4. Example of output values [%].

AD	České Budějovice	Hradec Králové	Olomouc	Ostrava
České Budějovice		91	60	53
Hradec Králové			-8	3
Jihlava				97

It has already been mentioned that each passenger's perception of the value of time differs, so the authors have compiled Table 5, which shows significance levels from 0% to 60%. Based on this, the number of cells satisfying the condition that ŽD is preferable to IAD increases.

Table 5. Significance level [%].

Significance level	Nr. of cells	% of cells	Significance level	Nr. of cells	% of cells
0%	8	10.3	35%	32	41.0
5%	11	14.1	40%	34	43.6
10%	15	19.2	45%	36	46.2
15%	20	25.6	50%	40	51.3
20%	23	29.5	55%	45	57.7
25%	24	30.8	60%	49	62.8
30%	28	35.9			

It is clear from Table 5 that even with a 30% reduction in the quality parameter time, the increase in the benefit of rail transport is only 35%. This is better illustrated in Figure 2.

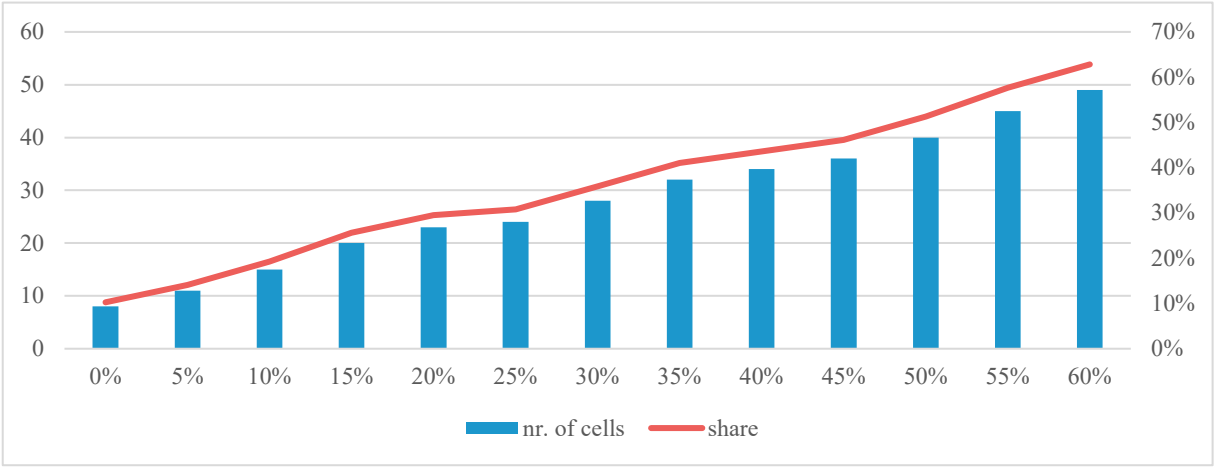

Fig. 2. Change of share of ŽD by the level of significance.

From this point of view, the ŽD does not offer quality competition to the IAD on many routes. However, the railway network development plans presented by the Ministry of Transport of the Czech Republic in 2011 may change this situation. The construction of new high-speed lines will significantly reduce travel times between the main centres of the Czech Republic. Figure 3 shows this planned (ideal) situation. Unfortunately, the vision of the Ministry of Transport of the Czech Republic that this situation will be a reality in 2020 has not been fulfilled. However, in the document of Správa železnic (2019), it is written that a new law on linear construction has now been approved, and the construction of high-speed lines is moving from the planning to the implementation phase.

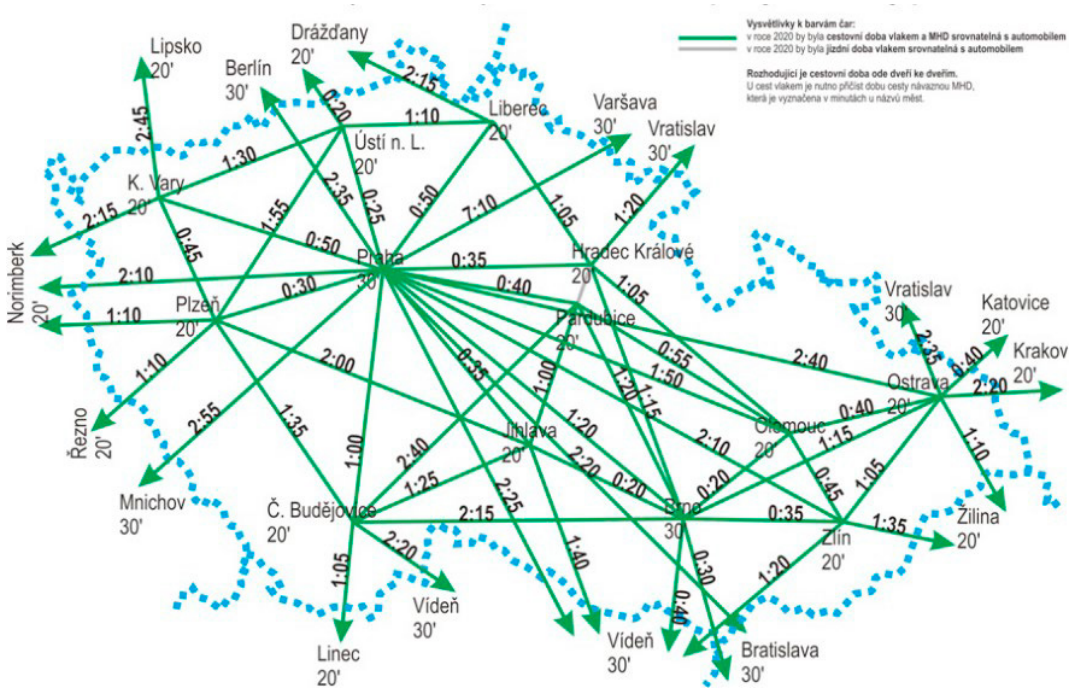

Fig. 3. Map of planned journey times (Ministry of Transport 2011).

Therefore, the paper's authors created the same ŽD table for the target state and made a comparison with the IAD. Table 6 shows the numbers and percentages of cells that satisfy the condition that ŽD is preferable to IAD. For studying the significance level, the opposite procedure to that of Table 5 was used, i.e., ŽD was disadvantaged relative to IAD. This can simulate the passenger's need to travel to the nearest railway station or junction.

Table 6. Significance level [%].

Significance level	Nr. of cells	% of cells	Significance level	Nr. of cells	% of cells
0 %	77	98.7	-35 %	42	53.8
-5 %	76	97.4	-40 %	31	39.7
-10 %	73	93.6	-45 %	24	30.8
-15 %	71	91.0	-50 %	18	23.1
-20 %	67	85.9	-55 %	10	12.8
-25 %	63	80.9	-60 %	3	3.8
-30 %	53	67.9			

Table 6 shows that even with a 25% deterioration in the time value of the ŽD, more than 80% of the cells are still preferable to IAD. Then comes a steep decline at the next stage, and the 50% value is less than a quarter. This is comparable to Cheng and Chen (2015). This is better shown in Figure 4, where the drop between the -25% and -35% levels is noticeable.

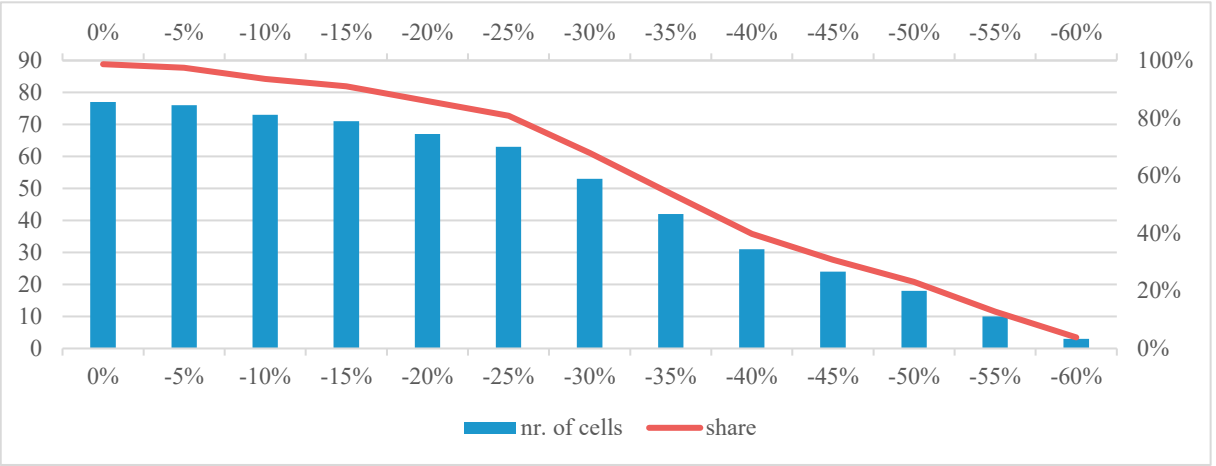

Fig. 4. Change of the IAD share by the level of significance.

The construction of the high-speed network will thus significantly impact the competitiveness of ŽD and the dimensioning of transport terminals. It is necessary not to underestimate this issue. In particular, the lack of attention to the dimensioning of P+R and public transport capacity that will be directed to new high-speed terminals is very inappropriate. That is mentioned by Mugion et al. (2018), Abramović et al. (2020) and Gašparík et al. (2018). Investment in high-speed transport is a long-term priority for our country, but it should not be forgotten that ŽD must be seen in the context of the whole transport process, as mentioned in Nachtigall et al. (2020) and Gašparík et al. (2017).

4.2. Comparison of ŽD and AD

The second pair compared was ŽD and AD. Comparing the two matrices calculated according to formula 2, a 60:40 ratio favouring ŽD emerges. In total minutes, the ŽD is then 2,252 minutes faster. Table 7 compares the totals of all the differences in travel time for each node. These are also supplemented by the number of nodes where the ŽD is faster than AD.

Table 7. Compare journey times ŽD-AD.

Node	Number of negative values	Total value for each node [min]
Ústí nad Labem	12	-1,260
Ostrava	9	-1,112
Pardubice	10	-958
Olomouc	9	-629
Plzeň	8	-605
České Budějovice	9	-424
Zlín	7	-252
Hradec Králové	8	-245
Praha	6	-144
Jihlava	5	186
Karlovy Vary	5	197
Liberec	4	197
Brno	2	545

The authors also performed a correlation analysis of the two columns from Table 7. As a result, these two columns have a significant inverse relationship. Specifically, the value of the correlation coefficient is -0.947. Table 7 further shows that the highest comparative advantage is again for the vertices that appeared in Section 4.1 due to the absence of the D35 motorway. Regarding the number of negative values, the highest-ranked vertices are Ústí nad Labem and Pardubice.

The analysis shows that AD does not pose a threat to the development of the railway, either in terms of travel time or in terms of transport capacity. On the contrary, the role of AD can be expected to decrease with the further modernization of the rail network.

5. Conclusions

Increasing the quality parameters of the railway network has traditionally been one of the pillars of the state transport policy. It is mentioned by Abramović et al. (2017) and Rotger and Nielsen (2015). This is no different in the case of the Czech Republic, where the main priorities are constructing high-speed lines, the European Train Control System (ETCS), and increasing the capacity of lines in conurbations. Here, the authors focused on the accessibility of significant vertices in the Czech Republic, which for this paper were regional centres. Travel times between all pairs of nodes for IAD, ŽD, and AD were compared. Furthermore, the theoretical travel times expected in the Czech Republic after completing all major rail projects were considered based on the predictions of the Ministry of Transport of the Czech Republic. The result shows that ŽD has a vast potential to take over a significant part of IAD's current traffic. Here, sufficient attention must be paid to the correct dimensioning of connecting projects and services such as interchange car parks, internal terminal facilities, and connections to conventional long-distance and suburban transport.

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