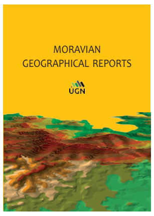

MORAVIAN GEOGRAPHICAL REPORTS

sciendo

Institute of Geonics, The Czech Academy of Sciences
journal homepage: http://www.geonika.cz/mgr.html
doi: 10.2478/mgr-2019-0011

Assessment of territorial benefits and efficiency from the construction of motorway and speed train networks: The Czech case

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Abstract

The Czech Republic has been developing its motorway network since the 1970s, while efforts to upgrade its railway system from the 1990s have been limited to improvements of existing major lines. Only recently has the government decided to construct new "speed connection" rail lines. This article investigates the possible territorial benefits from the future development of planned motorways and of various speed connection railway options. The modelling is based on Huff´s gravity model that calculates the benefits from improved accessibility, to job and service centres for residents of each municipality. The modelling outcomes are used to compare planned motorway development and rail development options with respect to their efficiency, related to the investment and potential numbers of users.

Keywords: *transportation infrastructure; spatial planning; job accessibility; speed rail connections; gravity model; Czech Republic*

Article history: *Received 6 December 2018, Accepted 30 August 2019, Published 30 September 2019*

1. Introduction

1.1 Background

Czech Republic has made reasonable progress in building its motorway network in the last two decades, but the density of motorways remains lower than in neighbouring Germany and Austria, for example. Plans for the construction of new motorways are fixed in spatial plans and, with some delays caused mostly by lengthy procedures of acquiring land and conflicts with nature preservation, they are implemented.

Unlike many European countries which have been developing their national high-speed rail network, contributing in this way to an emerging continental high-speed train system, the development of the Czech rail infrastructure is quite delayed. The Republic inherited a very dense network of railways originating mostly from the 19th century, but their quality and speed are behind contemporary European standards. The most important rail connections to neighbouring metropoles in Austria, Germany, Slovakia and Poland were upgraded in the last twenty years, but maximum speeds on the improved sections do not exceed 160 km.h^{-1} and are often below 100 km.h^{-1}. Improved quality is planned for upgrading other lines from Prague to Bavaria and Upper Austria, but the speed of these upgrades is considerably slower than motorway construction, shifting a larger share of traffic load to the road networks.

Recent experiences with congested motorways, especially in the metropolitan area of Prague and on the main route between Prague and Brno, show that individual car transportation as well as bus service dependent on the same roadways as cars, cannot be effective solutions to ever-increasing transportation needs. On the other hand, even the recent small improvements in rail service on some lines proves that passengers will easily shift from unpredictable driving to reliable, comfortable and comparatively fast rail offerings whenever adequate services are available. Consequently, ridership on the Czech railways has been steadily increasing since 2010 when the company started to run new trains on improved tracks (ČTK, 2018). Nevertheless, a rail system compatible with 21st century technologies and competitive with road and air transport remains an ideal objective, and only recently has such a system gained governmental support which may result in implementation. Nonetheless, doubts about the efficiency of investments in the development of

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high-speed railways in the Czech Republic still occur. The country is rather small, with only the national capital of Prague exceeding one million inhabitants and regional population centres (Brno, Ostrava, Plzeň) with populations between 150 and 350 thousand. Distances between these centres are between 100 and 200 kilometres. Based on existing data, the volumes of international passengers cannot sustain the project economically, even if a partial shift of current air passengers for Frankfurt, Berlin, Vienna, Budapest, etc., is considered. All considered, this situation hardly allows for the development of the virtues of a high-speed rail network as an independent system. Therefore, the Ministry of Transportation abandoned the original idea of separated high-speed railways derived from the French, Spanish or Italian models, in favour of the hybrid system of "speed connections" (RS, rychlá spojení), interconnected with the existing, upgraded standard railway network. This would allow the deviation of some trains from the speed connection line to service smaller cities and their hinterlands along standard railways. The number of passengers may increase significantly with daily and other frequent commuting from smaller places to major centres by trains that will combine their journey on speed and standard rail systems.

Plans for the speed connection network have not been stabilised yet. Corridors of the proposed lines partly follow (recently and currently) improved major standard railway lines, which may make it possible to combine service on uncompleted speed connection sections with these improved standard sections or to use the standard railways to bypass the speed rail during repairs (cf. Šlegr, 2012, pp. 104–108).

1.2 Objectives of the research

Most previous studies in this area have analysed the costs of a new investment in a single road, motorway or railway separately, comparing them to the benefits of saved passenger time and increased revenue from passenger fares and cargo payments. One objective of this research project was to enlarge the benefit assessment – from costs and time savings brought about by alternative plans to considerations of their territorial impact, at least with respect to residences. This aim is represented by the increased attractiveness of residential "source" locations induced by improved access to and from jobs and services in central places ("destination centres"). Improved speed of travel will enlarge the pool of places from which commuters may reach major cities with a wide variety of jobs and services, and this is considered as a major engine for the change in attractiveness of these source places. Additionally, the enlarged coverage of smaller centres connected with new or improved transportation infrastructure, will contribute to overlapping the commuter areas of different centres, increasing individual choices of access to different centres with different jobs and services. These two effects, i.e. an enlarged commuter area to major centres, and the wider variety of accessible smaller centres, create the territorial benefit of the transport infrastructure improvements.

As various modes of transportation can contribute to improved accessibility and improved transportation infrastructures can serve various areas of the country, the main task of this research project was to compare the benefit differential from investment options in different transportation modes and lines, rather than to quantify the benefits in absolute terms.

2. Theoretical overview

The attractiveness of a place is an outcome of its qualities as appreciated by its users. In a market economy, such an indicator can be expressed by property (housing, commercial, industrial, etc.) prices that indicate the use value of sites and structures built upon them, as an endogenous relationship because accessibility capitalises as property prices (cf. Osland and Thorsen, 2013). This immediate and simple methodology obviously cannot be used for the assessment of attractiveness in the future. In such cases, an indirect method of modelling can be applied that incorporates opportunities related to the labour market and service centres. The method assesses the change of attractiveness of a place for residents (attributes of the locations of origin) by calculating the time differential for accessing destinations of everyday use, such as jobs and facilities providing services (attributes of the locations of destination). These attributes, together with the friction of distance between origins and destinations, express the fact that an increasing spatial or temporal remoteness of two places implicates declining relations between them (Rodrigue et al., 2017; Huff and Jenks, 1968; Seidenglanz, 2008).

The dependence of an indicator of living place attractiveness on the spatial accessibility of jobs and services derives from trade-off theory (Balchin et al., 1988, pp. 50–52; O´Farrell and Markham, 1975). This theory accounts for the spatial behaviour of households optimising the location of their residence by minimising the total costs for housing and commuting (measured in time and fares) against the quality of housing. Consequently, the spatial accessibility of a place can be defined as the potential that a variety of activities, services and job opportunities could be made available from the place within a certain interval of physical or time distance. Accessibility is strongly tied to the means of mobility available in any area in question (Hanson, 2004). The available modes of transportation strongly affect the settlement pattern. As such, the history of settlement change is closely intertwined with the development of transportation technology, at least from the time when people started to live beyond walking distances from job places during the Industrial Revolution. Adams (1970) has distinguished the walking-horsecar, electric streetcar, automobile and freeway eras. While the speed of transportation means limited the former eras to a local scale only, the automobile era crossed the limits to suburbia, and the freeway era shifted the scale of commuting to a regional tier. Kraft (2012, pp. 3–4) defines three basic types of criteria for the settlement hierarchy: accessibility of the nodes, infrastructure endowment and size-relevant features. The future era of high-speed railways will follow the trend of increasing the spatial scale of commuting but, much more than the freeway era, will result in increased disparities between serviced centres and by-passed areas, as described by Creswell (2010, pp. 24–25).

The development of a new quality transport infrastructure affects the spatial pattern of accessibility in the area, resulting in changes in the time needed to access destinations. Certain authors warn against excessive technological determinism (Coe et al., 2007), however, but it is reasonable to assume that projects for a new or upgraded transport infrastructure will induce changes in the spatial behaviours of both inhabitants and businesses and, consequently, changes in attractiveness within and among particular regions and places.

Transport strategies as means to improve spatial accessibility and, consequently, to enhance regional economies through the improved attractiveness of places, have been studied by Geurs et al. (2010) *inter alia*. Many authors have investigated the spatial effects of improved transportation on house and rent prices at the city or regional level (cf. Grimes and Young, 2013). Normatively, the issue of spatial equity in transport strategies has been raised by Lucas et al. (2016).

The modelling of accessibility and its changes has used several different approaches. Some have used graph theory (Black, 2003; Brinke, 1999). Traffic volumes are determined from the supply side by parameters of the transport infrastructure, but they also rely on the demand raised by individual mobility strategies, preferences and capabilities of persons (Geurs and van Wee, 2004). Condeço-Melhorado et al. (2014) provide a comprehensive survey of modelling applications and methodological issues related to accessibility and spatial interaction.

Methods for accessibility measurement often mix normative and positive approaches, i.e. they establish a general normative measure (derived from empirical research on the behaviours of people) to bridge the gaps in data on the behaviour of individuals (Páez et al., 2012). Gravity models (e.g. Hansen, 1959; Huff, 1963; Wilson, 1967; Ingram, 1971; Reif, 1973; Sen and Smith, 1995; Bruinsma–Rietveld, 1998) represent tools to both appraise present spatial relations and interactions, and to predict their future change. One type of gravity model is the potential model that measures interactions between a single location and every other location (Rodrigue et al., 2017). Gravity (potential) models overcome the absence of empirical data on the future attractiveness of places. For existing attractiveness, they may be validated by comparison with actual property price differentials in various places. Relevant studies dealing with the applications of gravity models were published in international fora by Cochrane (1975), McArthur et al. (2011), Mikkonen and Luoma (1999), Christie (2001), Khadaroo and Seetanah (2008), and Tsekeris and Stathopoulos (2006). With respect to the Czechoslovakian and subsequently Czech research, several authors have elaborated the theoretical level (e.g. Pavlík and Kühnl, 1981; Bezák, 1975), as well as applications of the gravity model in geography or economics (e.g. Hampl, 2005; Maryáš, 1983; Marada et al., 2010).

3. Methodology and data

The methodology in this report uses the body of theoretical work described above. It presumes that public benefits result from building new transport infrastructures, consisting of improved accessibility to centres providing jobs and facilities with higher rank "supra-local" services for residents. The improved accessibility results in a higher attractiveness for the places of residence that are affected by the improved infrastructure.

3.1 Accessibility

The gravity potential was applied for the modelling of accessibility, assessing benefit differentials for various options of infrastructure improvements. The accessibility from a source place (the origin location of commuting) is represented by a matrix of potential interactions with all destination centres (the targets of commuting) within the area of potential access. The resulting changed attractiveness is quantified with differentials of the units of benefit from changed accessibility.

3.2 Identification of commuting sources and destinations

The source places/locations from which residents commute to centres are represented by all communities/municipalities. As the size of the "source" communities/municipalities is usually small (an average Czech community/municipality as an administrative unit, including the 1.25 million residents of Prague, accounts for about 1,630 inhabitants, with a median of 380 inhabitants), this provides enough detailed information for the national size of this survey. The relevant census data on population and commuters were attached to the GIS reference points of the municipalities. This approach is reasonable for small towns and villages (which prevail among Czech municipalities), but in large cities it tends to underestimate real time accessibility as the model does not calculate local transport within the cities. On the other hand, the willingness to commute to large cities distorts the distance decay functions by acceptance of longer commuting times, as well as a variety of other factors influencing the willingness to commute among different age groups, gender, and particularly the education status of commuters (cf. Johansson et al., 2002; Heldt Cassel et al., 2013).

The selection of destination centres in the Czech Republic followed the commuter-based regionalisation of the Czech Republic (Mulíček et al., 2011; Sýkora and Mulíček, 2009; Sýkora and Mulíček, 2012) that resulted in the determination of the micro-regional job centres. The micro-regional job centres and their relevant catchment areas were established using data on job commuting: the catchment areas had to have at least 1,000 occupied job places and had to be the primary destination for commuters from at least one of the municipalities in the commuting area. A total of 260 micro-regional job centres were identified for 2001 (Sýkora and Mulíček, 2009). For the needs of this project the original methodology was reworked by updating the data using the Census of 2011, resulting in 234 micro-regional job centres.

To depict cross-border relationships, foreign destination centres were considered if they were located at distances of up to about 100 kilometres by road or rail from the Czech border, and with a population minimum at 50,000 inhabitants. In addition, to assess the impact of the construction of motorways and the speed connection rail lines, Central European metropolises of international importance situated at a greater distance (than 100 km from the border) were incorporated in the model, namely Budapest, Frankfurt (M), Leipzig, Stuttgart, Berlin, Cologne and Düsseldorf. For these cases, the calculation of the benefit from time savings was not confined by the distance decay curve.

For the calculation of commuting time, the model considered as destination reference points, the railway / bus station or point on the road communications nearest to the reference point of the relevant central municipality.

The significance of the destination job and service centres was defined using the indicator of "centre comprehensive size" ("komplexní velikost" (KV): Hampl et al., 2005; Kraft and Vančura, 2009). The "centre comprehensive size" is calculated as one-third of the (sum of the share of the centre in question with respect to the national population PLUS a doubled share of the centre in question with respect to national jobs), multiplied by 10,000:

$$KV = \frac{\frac{POP_C}{POP_{CR}} + 2 \times \frac{OPM_C}{OPM_{CR}}}{3} \times 10{,}000$$

where POP_C = population of the centre, POP_{CR} = population of the Czech Republic, OPM_C = occupied job places in the centre, and OPM_{CR} = occupied job places of the Czech Republic.

For the centres outside of the Czech Republic, where the data on occupied job places were not available, a regression function based on their population size was used for determination of their comprehensive sizes. The function derives from the relationship between population and job size in Czech centres, which is demonstrated in Figure 1.

3.3 Distance decay

The concept of distance decay is useful for modelling the effects on accessibility through an improvement in transport infrastructure and, as a result, attractiveness of the territory (Wheeler and Muller, 1981; Spiekermann and Wegener, 2007; Tse et al., 2003; Hanly and Dargay, 2003; van Wee, 2001; Rouwendal, 1999). The distance decay function depicts how increasing time distances between places decrease the volume of interactions between them:

$$\textit{Distance decay}(t) = (1 - \Phi[(t(x) - \mu) / \sigma])$$

where t = travel time, $\Phi[(t(x) - \mu)/\sigma]$ = distribution function of the normal distribution N (μ, σ^2), μ = median and σ = standard variation/deviation.

For Czech conditions, Novotný et al. (2008) and later Novotný (2011) elaborated the concept of distance decay for daily commuting, based on his own detailed research on commuting behaviours in Central Bohemia and with reference to national census data (see Fig. 2).

For some routes, the distance decay function will be affected by other physical, social and technological factors in addition to the friction of distance effects. It can be also modified for individual social groups of commuters and by different objectives or purposes (variety of job positions, various grades of education facilities, hierarchical position of services and health care, etc.). The overall country-wide scale and the long time period in which the expected projects as well as the changes imposed by them will occur, however, makes the use of the general decay curve calculated by Novotný (2011) acceptable. The country-wide scale, where only relations between individual centres are studied, also makes it acceptable to ignore the time-distance relations within urban areas, which obviously may be different in various cases of cities and urban areas. The final model will not follow the recommendation of Johansson et al. (2002) to split the accessibility measure into parts on three different spatial levels.

3.4 Attractiveness of a place

The attractiveness of a place is calculated as a sum of the accessibilities to destination centres within the time distance relevant for commuting, reduced by distance decay:

$$\textit{Attractiveness of the place}_i = \sum_{j=1}^{n} (KV_j \times \textit{distance decay}[t_{ij}])$$

where KV = centre comprehensive size, i = the municipality for which the probability of selection as a destination centre is calculated, j = commuting destination centre, n = total number of destination centres, including the centre j and t = travel time.

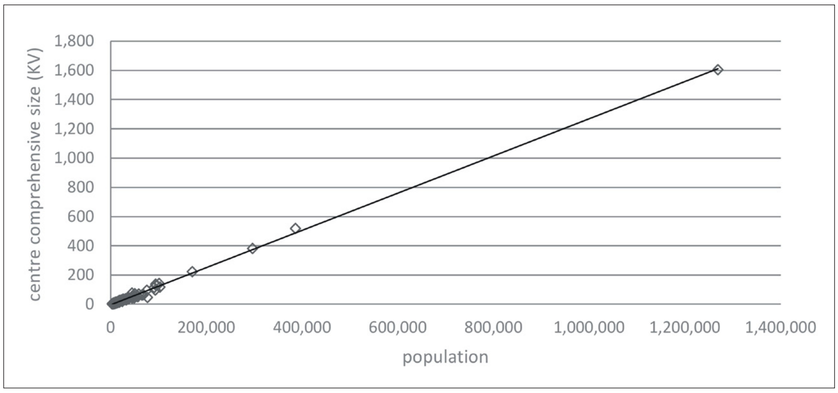

Fig. 1: Regression function for population and comprehensive size (KV) of Czech job centres: y = 0.0013(population) – 2.7826; R^2 = 0.9972. Source: authors' calculations*

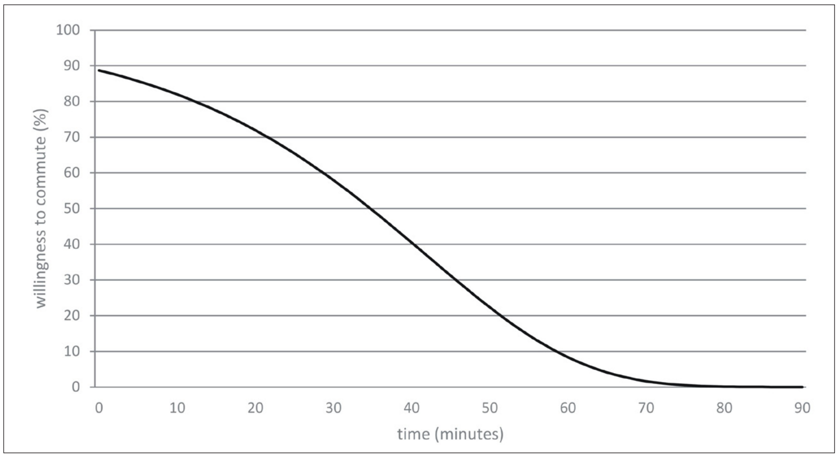

Fig. 2: The distance decay curve. Sources: Novotný et al., 2008; Novotný, 2011

The result of the calculation indicates the (change of) attractiveness of a place. It is a dimensionless quantity that expresses the effect of the change in transport on spatial accessibility of all destination centres in question. The better the accessibility of the territory, related both to the accessibility of transport infrastructure and the time accessibility of the accessible target centres, the higher the attractiveness of the territory in question.

3.5 Calibrated benefits

Calibrated benefit is calculated for each municipality. The calibrated benefits are attached to the source places of municipalities as well as destination centres, and the KV of the destination centres makes calibration. Benefits for larger territorial units up to the whole country equate to the sum of calibrated benefits of all municipalities within the territory in question.

$$\textbf{Calibrated benefit} = \frac{((\textbf{Attr.perspective} - \textbf{Attr.existing}) \times \textbf{population})}{\mathbf{10{,}000}}$$

$$\textbf{benefit} = \sum \textbf{calibrated benefits}$$

where Attr. perspective = attractiveness of the place after the accessibility has been improved, Attr. existing = attractiveness of the place before the accessibility has been improved and population = population affected by the improved accessibility.

The calibrated benefit quantified by the units of benefit can be calculated also for individual demographic and socio-economic groups, such as age groups, educational levels, etc. In such a case, the population data in the formula above should be replaced with the population of the relevant group.

The outcome of the benefit calculation is a value expressed as "units of benefit", of dimensionless quantity, that reflects the effects of the changing accessibility of centres on the spatial pattern of attractiveness. The unit of benefit value allows for the comparison of the benefits among various options of transportation infrastructure.

For destination centres as job and service providers, the model considers the demand for jobs and services, *ceteris paribus*, constant within the national territory, and thus it neglects any possible secondary effects of emerging new jobs and services at more attractive centres, without their compensation by reduction elsewhere. As such, with respect to jobs and services the model is zero-sum based.

3.6 Spatial equity of the benefit distribution

The 'equity of benefits' distribution from increased accessibility among various individuals and social groups is often discussed (Manderscheid, 2009). Obviously, with new infrastructures that serve only certain hubs and bypass other areas, a gap between the accessibility of the serviced areas and those bypassed will emerge. In practice, this issue is rarely raised in evaluations of transportation projects, as they often do not explicitly consider social and spatial equity (Keeling, 2008). Lucas et al. (2015) recommend the use of the Gini index as a scale-independent measure for equity of accessibility. The use of this method is quite frequent for assessment of various inequalities in benefit distribution: for spatial distribution issues, see Murray and Davis (2001), Delbosc and Currie (2011), Welch and Mishra (2013). The coefficient expresses the ratio of the area between the area under the line of equality and the calculated Lorenz curve (area A) with the total area under the line of equality (area A + B). The Gini Coefficient can be expressed by the equation: G = A / (A + B) (e.g. Rodrigue et al., 2017). In our case, the graph-based method using the Lorenz curve and the Gini index was used in order to assess the spatial equity of the commuters' benefits from improved rail infrastructure – and to compare it with motorway construction.

3.7 Investment costs

To compare the effectiveness of the model options, the relation between the relevant costs must be complemented by the relations with their benefits. The costs side was reduced to only the infrastructure investment, without considering subsequent running and maintenance costs.

This simplification provides only a 'rough' estimate, but it is made reasonable by the fact that the purpose of the analysis was just to identify the benefit differentials between the model options, which will probably compensate for the errors under any options. As detailed budgets of source data on investment costs are missing for prospective projects, which are mostly at the preliminary stage, the general price standards were used.

The investment costs for roads and motorways were calculated from the price standards of ŘSD (2013). They distinguish the costs for motorways, speed roads (recently renamed as 2nd class motorways), national 1st class roads, 2nd class roads, etc.

The investment costs for rail construction and improvements were calculated from the general price standards for rail investments by Robeš and Zeman (2003). These standards classify the investment costs to new single-track and double-track railways, electrified and non-electrified, and they also rate the upgrading of existing railways and construction of additional track to existing railways. The costs for station improvements were added to the general cost by a coefficient.

For both the road and rail construction costs, additional costs for tunnels and bridges were not considered. This is reasoned by approximately the same share of these constructions per 100 kms in the options, which would eliminate the costs in the differential.

4. Model options and relevant travel times

The assessment model was structured into road and rail sections, with levels of development in the rail sections, and with options related to currently discussed variants of the routing.

4.1 Road transport section

The road transport section of the model follows the policy of motorway construction and the improving of existing main road arteries that is generally accepted and fixed in spatial plans. There are some alternative partial sections of routing but their eventual choice will not affect significantly the change of travel times when the project is completed. As such, the part of the model related to road transport dealt only with the initial (2017) state and final situation as designed in plans and projects (ŘSD, 2016).

Network data OpenStreetMap was used to calculate road distances. OpenStreetMap data was selected based on an up-to-date network dataset with cross-border links to foreign centres. The use of OpenStreetMap for network analysis was evaluated with respect to the completeness and accuracy of data for network analysis (Graser et al., 2015; Brovelli et al., 2017). The information on projects for upgraded roads and new motorways was made available by the Road and Motorway Directorate (Ředitelství silnic a dálnic, ŘSD). Sections of the network were adjusted by the tools of GIS: Split Lines at Points, Snap, etc.

For calculating time distance by individual cars, a model speed was attached to each road section, following the outcomes of the research by Hudeček (2010). To include the physical factors of the friction of distance, the category of road, the number of lanes and the longitudinal tilt were accounted for. The model speed was also reduced for sections passing through built-up areas.

Customised data OpenStreetMap was used also for bus service. From the road network, only those sections used by regular bus service were considered. Bus routes were obtained from the national information system on timetables using the comprehensive set of localised public transport stops. The average travel speed of buses was modified from the individual car transport with respect to the delay in the intermediate stops by a coefficient of 0.5 for local feeder buses, which was validated on various routes. The new plans for road infrastructure improvement are depicted in Figure 3.

4.2 Rail transport section

The modelling for rail transport was more complex. Three levels of rail infrastructure development were used as a basis for the model options. Level A consisted in upgrading of major lines by their straightening and building second tracks for presently single-track lines. It implies both the completion of the currently executed projects and the new projects purported by the Ministry of Transportation. The level B adds new speed connection lines to level A. It splits into five alternative options, The B1 option is based on corridors for the speed connection lines and further improvements on existing rail infrastructure as they are anchored in spatial planning documents for regions (namely Development Principles [Zásady územního rozvoje], ZÚR). The other options (B2 to B5) assess alternatives to some of the corridors and they also bring additional new ideas of speed connections studied by the Management of Railway Infrastructure (Správa železniční dopravní cesty, SŽDC) by order of the Ministry of Transportation (SŽDC, 2010; SŽDC, 2014). Level C adds some projects that have been studied as a long-term vision: it was also elaborated in alternative options (C1, C2).

The maps ArcČR500 and OpenStreetMap provided the geographic data on the rail network. The location of stations was kindly provided by the CEDA company, Ltd. Typical travel times from timetables were considered for each section of railway for the calculation of time distance. The data were received from machine-readable timetables developed by the CHAPS Company. In the next step, a specialised GTFS (General Transit Feed Specification) file was created, which consisted of several text files. The received model travel times were tested on a pilot area of the Prague integrated transport system, which covers a great deal of the commuter area of Prague.

The travel times for the future new or upgraded rail lines were received from relevant projects and studies that had been elaborated for the Ministry of Transport and the SŽDC). Figure 4 depicts the levels of rail infrastructure improvement and alternative options within the levels.

5. Results: Assessment of model options

The results of the modelling identify those places with an uneven increase of attractiveness, as a starting point for the assessment of benefit for territorial units as well as for the whole country, and to aid in reasoning with respect to efficiencies of alternatives.

5.1 Road transport

The existing pattern of motorways results in central Bohemia as the most attractive area, followed by the three-pole chain of Brno, central Moravia and Ostrava regions in Moravia. This is caused by the concentration of motorways as well as high density populations in these regions. The planned new motorways will connect less populated regions to these central areas. As such, they will strengthen the attractiveness of the Prague metropolitan area and, to a lesser extent, other metropolitan areas, but the low

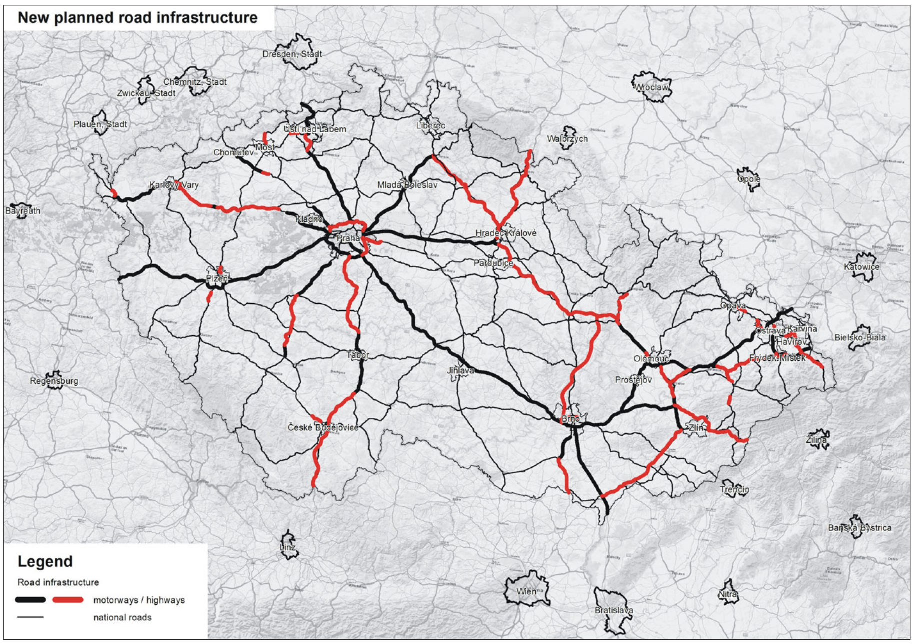

Fig. 3: Existing and new planned road infrastructure
Sources: ŘSD, 2013; ŘSD, 2016

population density in the newly serviced areas will make the total increase of benefit from their improved accessibility much less than the already accomplished benefits from the motorways currently in service.

The benefit from increased attractiveness with improved accessibility covers almost all the territory of the country, but, in the case of about 60% of it, the increase is below 2,500 units of benefit compared to the present values for central Bohemia, reaching between 1 and 1.7 million units (see Fig. 5). The average unitary increase of benefit related to 1 km of a new motorway is 2,518 units, and the estimated increase in the attractiveness index from CZK 1 million investment (prices as of 2017) will result in 16.36 units. This is much less compared to the previous increases in benefits created by the construction of the already existing network of motorways since the 1970s: The increase in existing accessibility compared to the accessibility before the first motorway had been opened is registered as much as 12,886 units of benefit per 1 km of motorway, with a 64.43 units increase in the attractiveness index from CZK 1 million investment (prices as of 2017). Such a comparison of future benefits from the planned to the already existing motorways suggests that the law of diminishing marginal utility strongly applies.

5.2 Rail transport

At present, the low speed of trains on existing railways limits the competitiveness of rail transportation only to the immediate hinterlands of some major job centres, mostly where trains can reach the city centre from suburban stations more quickly than road transport that is affected by traffic congestion. As such, current rail transport can contribute to the attractiveness of places by time

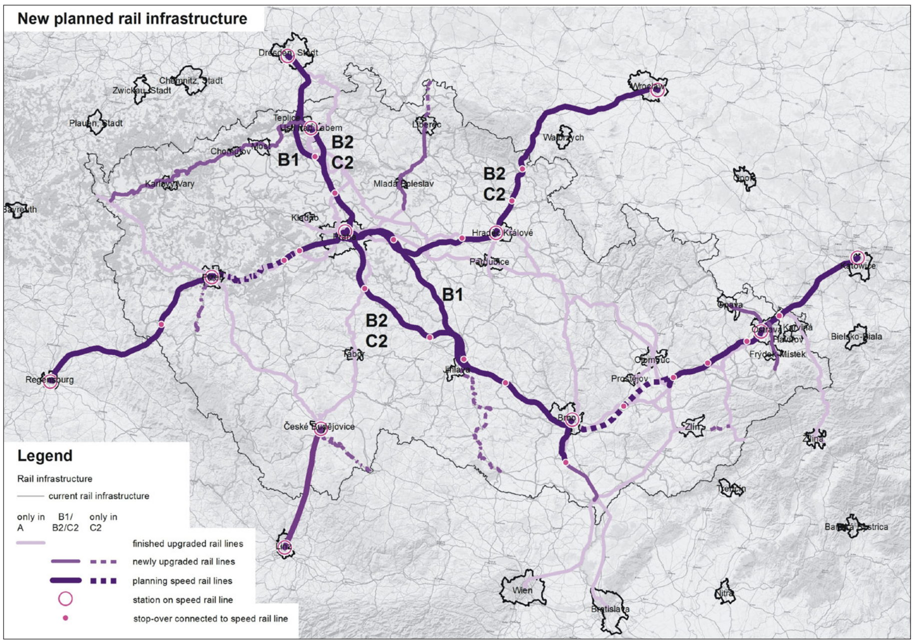

Fig. 4: Existing and new planned rail infrastructure
Sources: ŘSD, 2013; ŘSD, 2016

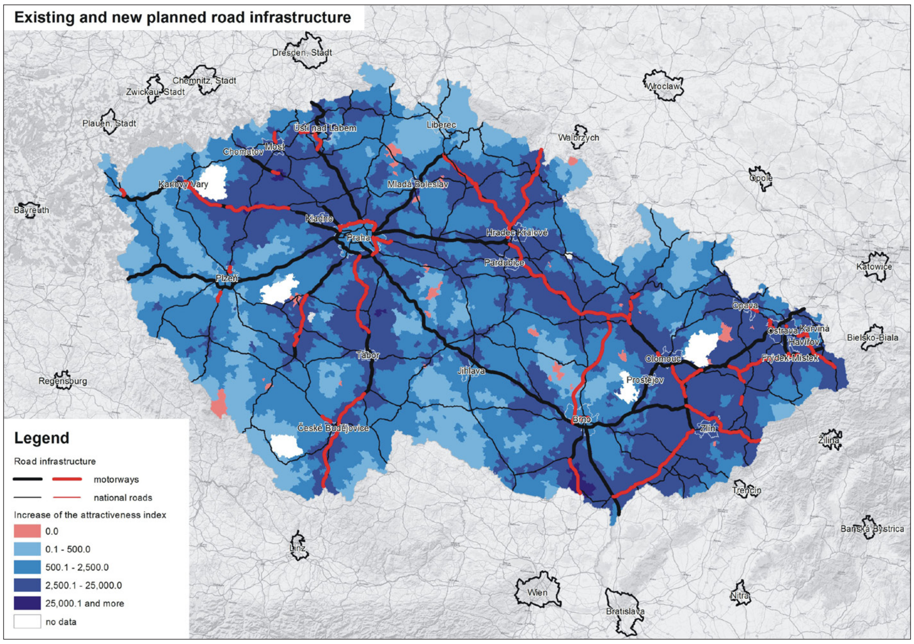

Fig. 5: Territorial benefits from the new planned road infrastructure
Sources: data by ŘSD 2013, 2016; authors' calculations

accessibility only in exceptional cases. The attractiveness induced by rail transportation is currently highest in Prague with its immediate hinterlands (smaller metropolitan area), with values of 1 to 1.7 million units of benefit, while the values for the Brno and Ostrava metropolitan areas do not exceed 50,000. The spread of attractiveness is much less than in the case of motorways.

The model has shown that the larger centres situated on hubs of upgraded or new speed railways will profit from an increased pool of places within commuting time distance, and suburbanites will enjoy time savings to reach the centre.

The level A plan for rail transport improvement (upgrading of major lines) will improve rail accessibility along the upgraded lines, but it will not contribute much to the competitiveness of the rail system with road transport. The improved accessibility will contribute to the attractiveness of the affected centres by an increased choice of jobs and facilities offered by various centres on the line, but it may also undermine the functionality of smaller centres as providers of services and jobs due to the competition of larger and stronger centres, which will become easier to access.

The network of upgraded railways is rather sparse and the increase in speed on them is too small to affect larger parts of the country in significant ways. The model shows that it is only about 70% of the country's territory that is affected at all: i.e. with an increase in benefit above 500 units. Only about 10% of the territory demonstrates a significant increase – above 2,500 units. Large areas remain without improvement: namely the sparsely populated regions of Vysočina centred in Jihlava; North-Western Bohemia; the borderland areas of Silesia and the Bohemian Forest; as well as the urbanised region of Liberec with adjacent north-eastern Bohemia (see Fig. 6).

While territorial benefits will be unevenly distributed, the level A rail improvements will bring considerable total unitary increase of rail accessibility related to the extent and efficiency of the investment. The average benefit from 1 km of upgraded railway is 3,473 units, compared to 2,518 units in the case of finalising motorway plans. The benefits for increased attractiveness related to a CZK 1 million investment registers as 34.43 units, i.e. more than twice the benefits from the planned new motorways.

The benefits from the level B network of rail speed connection will be concentrated in the immediate surroundings of the serviced centres made accessible for commuting. The total increase of accessibility compared to the increase achieved by level A will be smaller than in all the studied alternative options, partly owing to a lesser frequency of the places served along the line.

Option B1 builds upon the projects anchored in regional spatial planning documents. Its positive effects cover the largest territory among the level B options, but it is less effective in the speed connection corridors as it counts on less by-pass stop-overs (Fig. 7). On the other hand, the B1 option is relatively less costly among the level B options, as it offers reasonably high total increase of benefit and its formal feasibility is supported by planning.

Option B2 is based on servicing the smaller centres by the speed connection railways (see Fig. 8). This option offers the highest increase in benefit, but it is, at the same time, more demanding in terms of investment costs.

Level C of rail network improvement presents long-term visions that provide full coverage of major centres with speed connection services. In the wider context of Central Europe, the Czech speed connection lines will fully support the relations Berlin–Vienna/Budapest; Munich–Warsaw; Vienna/Bratislava/Prague–Brno–Warsaw; Berlin–Linz–Adria. Additionally, new or improved existing "standard" lines linking some smaller centres to the speed connection lines will be planned. The results of the model assessment reveal the great potentials of speed rail connections, provided the travel speed on them reaches about 300 km.h^{-1}.

The alternative options C1 and C2 explore the effects of the variant connections Prague–Wroclaw via Hradec Králové or Liberec (Fig. 9). The assessment of their total territorial benefits proved that the difference between them is insignificant (but, of course, the spatial distribution of the benefit follows the alternative lines).

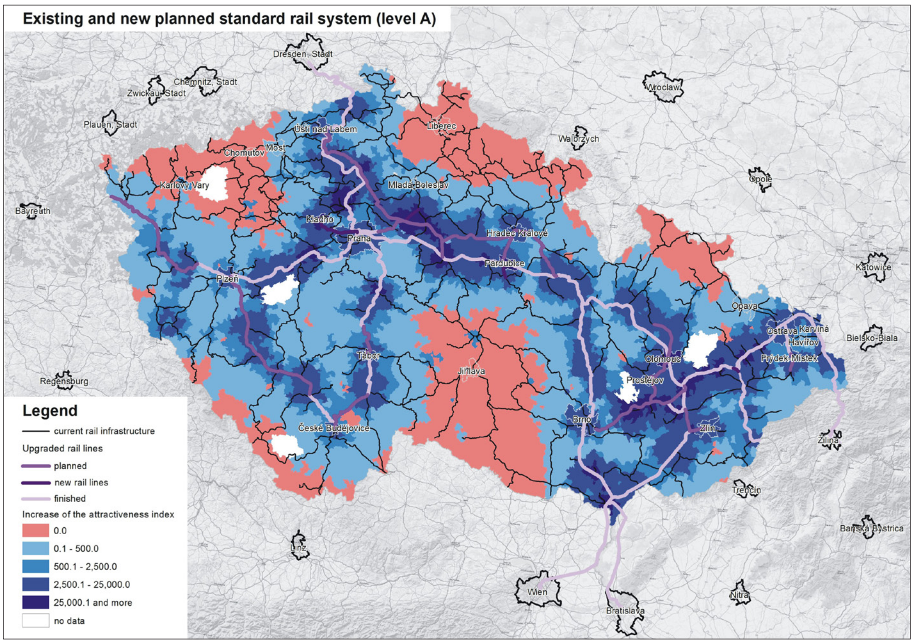

Fig. 6: Territorial benefit from the new planned rail infrastructure, level A
Sources: data by SŽDC, 2012; SŽDC, 2014; Šlegr, 2012; authors' calculations

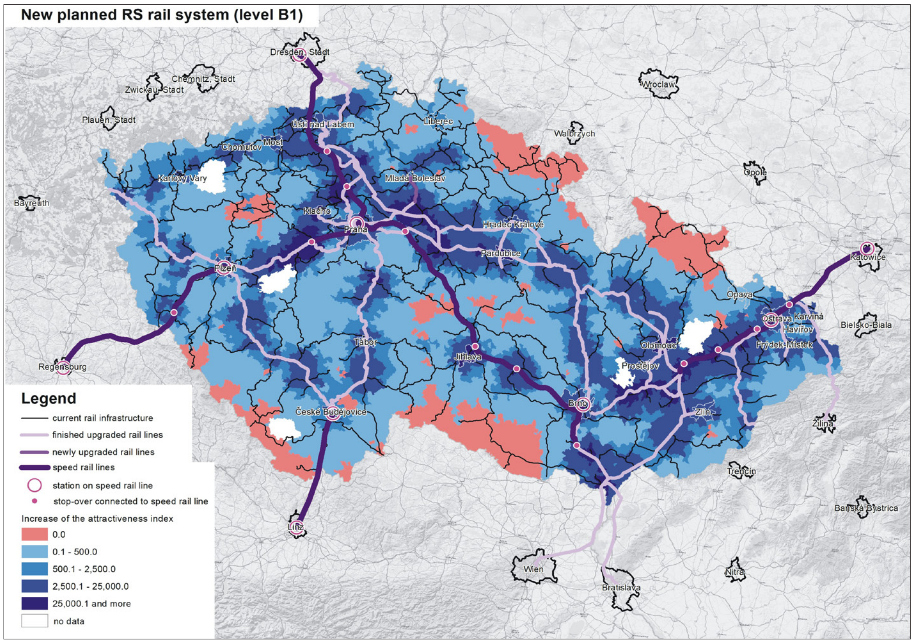

Fig. 7: Territorial benefit from the new planned rail infrastructure, option B1
Sources: data by SŽDC, 2012; SŽDC, 2014; Šlegr, 2012; authors' calculations

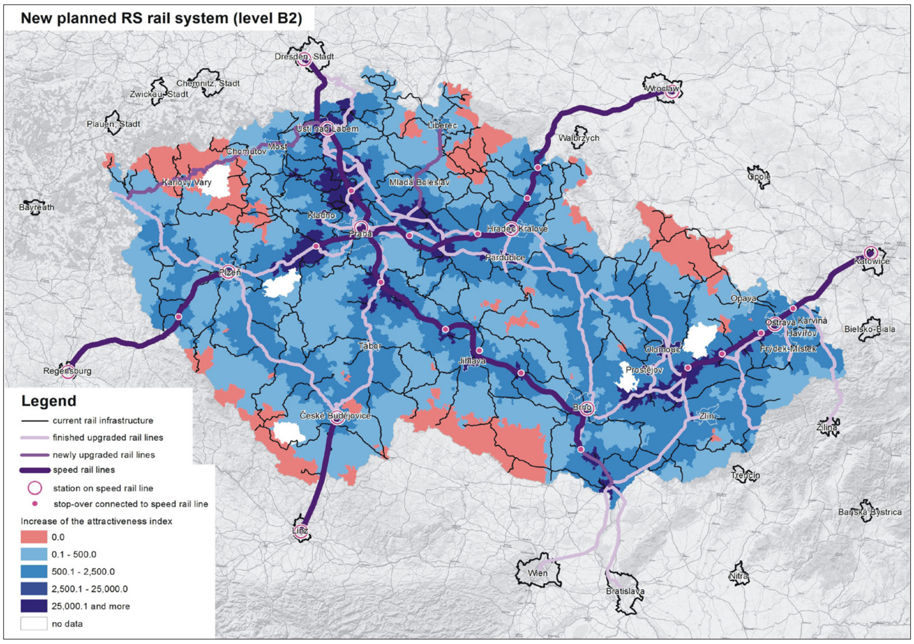

Fig. 8: Territorial benefit from the new planned rail infrastructure, option B2
Sources: data by SŽDC, 2012; SŽDC, 2014; Šlegr, 2012; authors' calculations

5.3 Benefits from and efficiency of the alternative options

A comparison of the alternative options in terms of their benefits and infrastructure investments and related investment costs is shown in Figure 10.

The comparison shows that the benefits from the model assessments prefer the rail investment to additional construction of motorways. The completion of the upgrading of standard rail lines is less costly and more beneficial for commuting than continuing motorway construction.

Comparisons from the point of view of increased unitary benefits induced by the various options and the marginal increase in efficiency from additional investments are depicted in Figure 11.

Apparently, the highest efficiency, i.e. largest increase of benefit units related to investment volumes, can be accomplished by the completion of upgrading the existing railways (level A). The marginal efficiency that describes the further increase of benefit units per unitary investment at level B varies significantly among the variant options but it is generally higher at level C.

5.4 Spatial equity of the benefit distribution

These options were tested for the spatial equity of benefits resulting from infrastructure improvement. Figure 12 shows the Lorenz curves for the planned motorway projects and for the A, B, C levels of rail development, with options B1, B2 and C2. The spatial distribution of benefit from new road infrastructure is

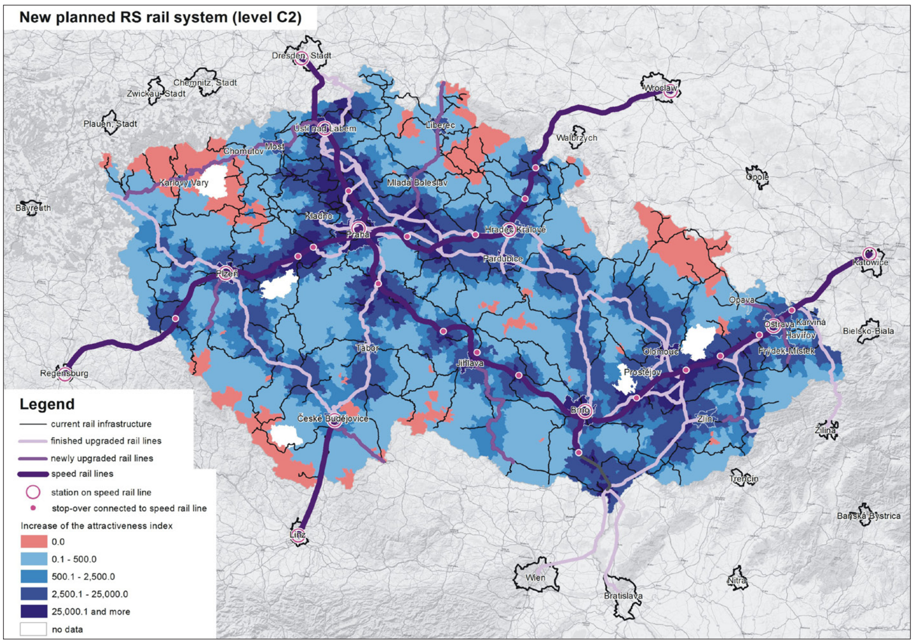

Fig. 9: Territorial benefit from the new planned rail infrastructure, option C2
Sources: data by SŽDC, 2012; SŽDC, 2014; Šlegr, 2012; authors' calculations

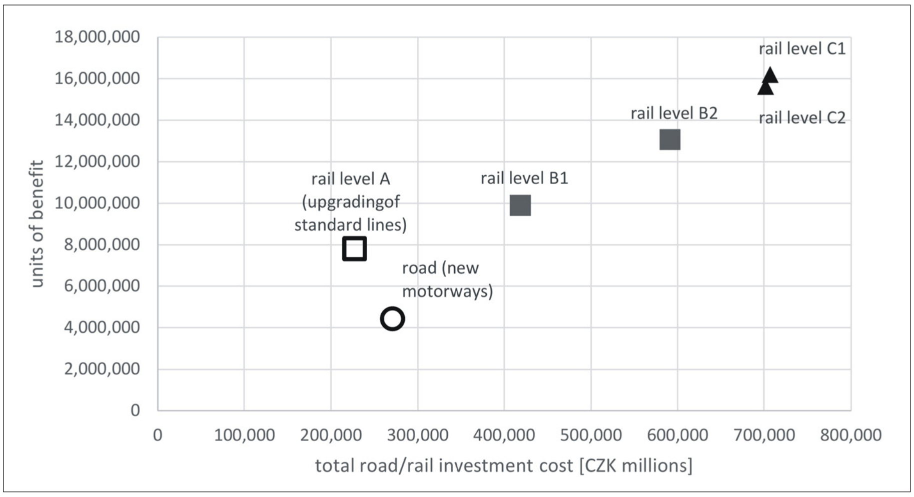

Fig. 10: Total benefits from the options of infrastructure investments related to their investment costs
Source: authors' calculations

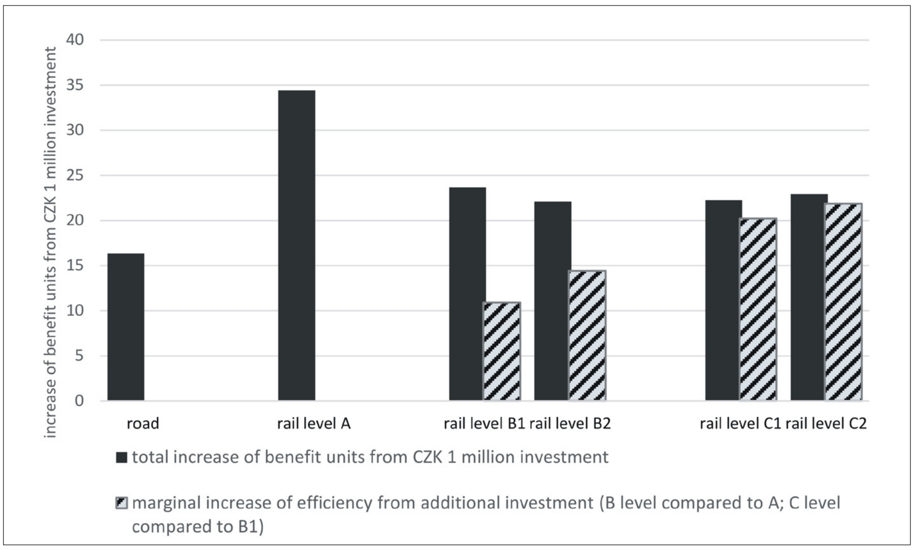

Fig. 11: Increased unitary benefit and marginal increase of efficiency induced by investment in transport infrastructure. Source: authors' calculations

less unequal than in the case of rail investments. The successive levels of development of speed connection railways tend to increase this spatial inequality.

The Gini index (Tab. 1) confirms the findings of the Lorenz curve. The spatial exclusivity of the benefits from increased accessibility by speed connection railways results in decreasing spatial equity with each additional speed connection line.

6. Discussion

The application of the gravity model in Huff´s interpretation, combined with the assessment of attractiveness by the "centre comprehensive size" (KV) and distance decay functions, proved to be useful in determining territorial benefits from changes induced by transportation investments.

This model was used for the assessment of territorial impact from the point of view of users such as daily commuters but it can be applied for any other users, e.g. non-daily commuters, day business trippers, distributors of perishable goods, etc., with adequately-defined distance decay curves. Hence, the focus of this application of the model on daily commuters considers only one segment of the benefits from new and/or improved transportation infrastructures; nevertheless, this segment is considered the most important, owing to the large and ever increasing numbers of commuters as witnessed by censuses (cf. Hudeček, 2010; Maier and Franke, 2015). Also, the size of the country and the fine grain of spread of its regional centres emphasise the importance of commuters among potential users.

The benefits calculated by the model consist of the commuters' time savings in the existing commuting catchment areas of the centres, plus the widened choice of centres to commute to within an acceptable time distance by increased speed on improved infrastructure. The calculation of benefits summarises the time savings for present commuters as well as the "new" accessibility of more distant centres, which widens the choice of centres accessible for commuting. This widened choice is increasingly important with prospects of volatile and even precarious job markets in the future (Korunka and Kubicek, 2017; Scherschel et al., 2012). The higher the increase in travel speed, the larger the time savings of present commuters and the wider the choice of additional centres. Thus, the increased benefits are commensurable with the population affected by the new or improved infrastructure and to the increase in travel speed/decrease in time spent travelling, resulting from it.

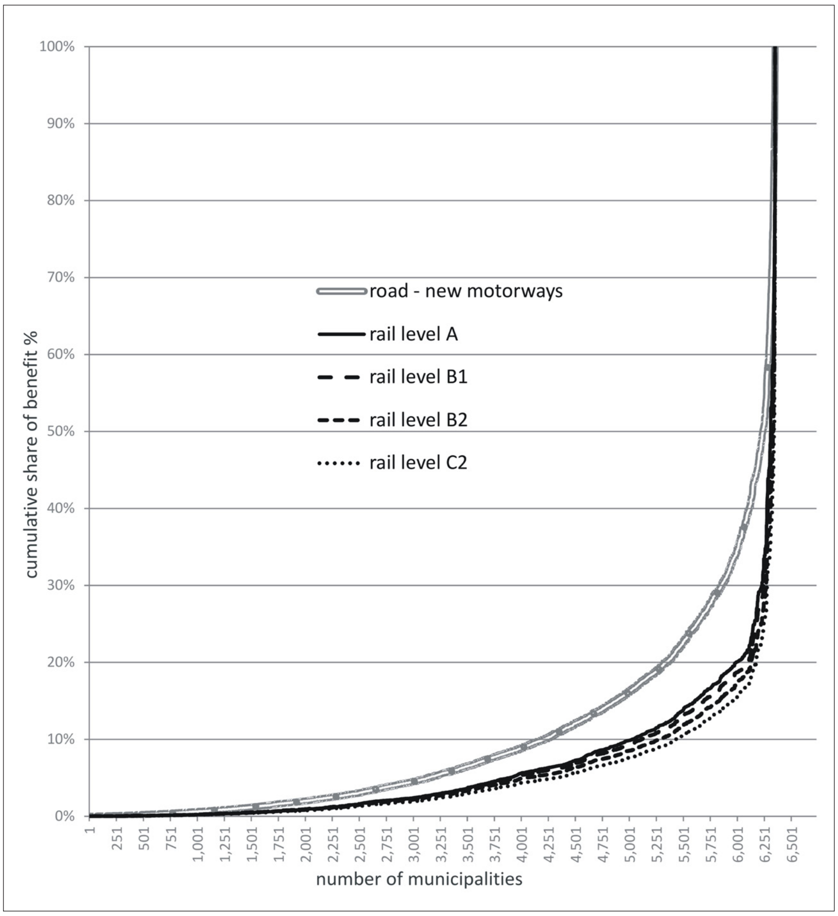

Fig. 12: Comparison of Lorenz curves for the benefits of motorway projects and rail options A, B1, B2 and C2
Source: authors' calculations

Level/option	Road – new motorways	Rail level A	Rail level B1	Rail level B2	Rail level C2
Value of Gini Index	0.5982	0.7571	0.7701	0.7901	0.8121

Tab. 1: Gini indexes for the benefits of motorway projects and rail options A, B1, B2 and C2
Source: authors' calculations

Following this line or argument, an effective optimisation of the benefitted population and the speed increase, both against the costs, will bring the highest benefit. This means that similar routes of the previously upgraded railways and the proposed speed connection lines may question the effectiveness of the speed connection system. Both infrastructures would serve the same pool of commuters and their benefits from time savings on the improved or new rail line for short travel distances may not be worth the costs, unless the increase in travel speed on the new infrastructure is significant. If the travel speed is less than 250 km.h^{-1}, the effect of speed connection lines would rather consist in creating new capacity for trains (Šlegr, 2012, p. 115). Besides, a low population density would also reduce the territorial benefit owing to fewer users. This may damage the benefit from increased travel speed in less populated regions. While the increased speed favours areas presently poorly served, the effect of multiple use privileges the densely populated areas, particularly large cities and towns.

The model used for the assessment has certain limitations. Firstly, it is rather static, as it does not consider the long-term effects of changed transportation accessibility on populations (in the "source" places) and jobs (in the job and service centres). As such, it also presupposes that the capacity of centres will be able to adjust to the served population. Obviously, the increased accessibility of job centres will contribute not only to the residential attractiveness of the affected places but, secondarily, it will account for agglomeration benefits in terms of the location of firms in the centres. This may influence the general pattern of job allocation within the country, with impacts on the amount, choice and overall accessibility of jobs outside the corridors of speeded infrastructure lines. In terms of the objectives of this article, which focus on alternatives to the rough comparisons of costs of alternative speed transportation infrastructures, this would enhance the differences among the options, and as such, it deserves another study.

Secondly, the GIS-based calculations of the model simplify the actual spatial conditions by concentrating the source places from which commuters start their journeys, as well as the destination centres, to single reference geographical points. Note, however, that the national scale of the assessment considers only benefit distribution at the regional scale, and this process will obviously not be affected by this simplification.

Thirdly, the model ignores possible congestion effects as it presumes that the new transportation lines will be dimensioned appropriately to the expected traffic loads. On the other hand, the experiences from already-completed transportation improvements by new motorways and city by-passes have shown that the increased capacity of the network would improve the congested segments of the pre-existing roads only temporarily. Additional demand results from the increased offer of transportation capacity after some time (e.g. Braess, 1968; Beck and Bliemer, 2015).

The use of the model based on a single / general distance decay curve and ignoring the time-distance relations within urban areas, is limited to the large scale of a whole country. On the other hand, the national borders cannot be considered as definite limits to the model, which would otherwise distort the outcomes of the model. Therefore, neighbouring centres in other countries were also accounted for, even if some factors relevant to cross-border commuting were not considered, e.g. legal and language barriers.

For more precise assessment of the benefits resulting from the construction of the speed connection rail lines, their potential competitiveness against air transport should also be considered. This would, however, require an analysis on a wider scale and with modified parameters, adequate to account for different uses by different users compared to job locations and everyday commuters.

Future research should focus on the study of the potential long-term impacts of the improved accessibility to large centres on their smaller competitors, namely on the possible deterioration of local services and facilities in the affected small centres, whose central functions will not be viable given the level of competition by major centres.

For further development of the assessment model, other segments of users should be incorporated into the assessment of benefits. Possibly their significance could be validated by triangulating the model with data on property price differentials among various places – before and after already executed motorway construction and upgrading rail projects.

7. Conclusions

The planned networks of transport infrastructure will improve the accessibility of jobs and services and, consequently, the attractiveness for living in most places in the Czech Republic. The benefits from improved accessibility, however, will not be evenly spread and there will remain areas that will not benefit at all. Thus, the increased attractiveness of the centres occasioned by their improved accessibility will reinforce the existing polarisation and divergent trends (cf. Maier and Franke, 2015), with consequent increases in inter-regional as well as intra-regional disparities.

Significant improvements will occur in the corridors of new motorways, as these projects serve the hitherto poorly accessible parts of the country, and they will improve accessibility in these parts. Since the total benefit derives from the population density and the centre comprehensive size of accessible centres, total benefit related to the investment costs will be smaller in the case of new motorways than the comparable benefits from the planned rail upgrades and new rail construction, which will serve more populated parts of the country and connect them with major centres.

Given these results, the upgrading of existing railway lines under current planning (level A) represents some start for making railways competitive with road transport. The next levels (B and C) of rail investments consist in constructing new speed connection rail lines. The speed connection routes that do not follow the corridors of upgraded rail lines would bring the greatest effects on accessibility and attractiveness for commuting. The improvement, however, will affect only that part of the country's population connected to the serviced centres. Intermediate stop overs servicing smaller centres along the speed connection lines and, concurrently improved parameters of the existing railways that follow-up on the lines, will intensify benefits from development of the speed connection lines.

The benefits from the new speed connection network that makes their construction costs feasible from the point of view of territorial benefits, indicate that the target speed on them should reach around 250 to 300 km.h^{-1}.

All the investigated alternative plans result in the concentration of the highest increase of attractiveness in two larger territories. The ultimate "winners" would be: first, the wider metropolitan region of Prague, owing to the high value of Prague's "centre comprehensive size" (KV); and secondly, the 'core area' of Moravia, encompassing the city network of Brno, Olomouc, Ostrava and Zlín, by improved interaction between these regional centres, as well as multiple choices of accessing these centres from places between them.

Thus, this will further emphasise the distinction between the monocentric pattern of Bohemia, where the regional centres play the role of higher-rank satellites to Prague, and the polycentric pattern of the Moravia-Czech Silesia region, which lacks the equivalent of a single strong metropolis in its territory. The improved access to Prague from Moravian centres may even strengthen the dependency of the Moravian polycentric system on metropolitan Prague.

Knowledge of the regional and even the sub-regional importance of the speed transportation infrastructure in small countries like the Czech Republic can be useful to other countries of similar size that consider establishing and developing their national speed rail network. For larger countries like France, Spain and Poland, speed rail is or could be an alternative to air transportation. As well as small countries with high population densities and a high number of cross-border and international travels like Belgium and the Netherlands. Countries of the size of the Czech Republic, with mostly a national scale of passenger frequency, cannot rely on the efficiency of fast rail lines that would serve only two or three national centres. Therefore, small countries with mostly internal commuting mobility and relatively lower population density, should consider a combination of classical high-speed railways with branches serving smaller centres alongside the high-speed track.

Acknowledgement

This research work was partly supported by a grant from the Technological Agency of the Czech Republic: TAČR Beta TB0500MD007 "Optimalizace dopravních vazeb na nadmístní úrovni [Optimization of transportation linkages on supra-local level]", provided to the Czech University of Life Sciences in Prague.

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Please cite this article as:

MAIER, K., FRANKE, D. (2019): Assessment of territorial benefits and efficiency from the construction of motorway and speed train networks: The Czech case. Moravian Geographical Reports, 27(3): 140–154. Doi: 10.2478/mgr-2019-0011.