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How will new orbital motorways reshape accessibility in Bratislava metropolitan area?

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Abstract. Dynamic economic expansion of metropolitan regions in post-communist central Europe induces dynamic traffic growth, which calls for new transport network solutions and improvements to existing transport infrastructure within the regions. This is also the case of Bratislava as the capital city of post-communist Slovakia, which has recently been facing new economic and urban development challenges. A booming labour market, intensive suburbanisation processes, traffic expansion and urban (re-)development bring new conflicts and demand for grand-scale transport projects. An ongoing upgrade of the motorway system in the region of Bratislava will result in the construction of a substantial part of an orbital motorway surrounding the southern and eastern parts of the city. The potential effects of the motorway network-upgrade projects on the city urbanism are probably immense. This paper attempts to evaluate the possible changes in accessibility within the road network after completion of motorway upgrading project D4/R7 in the metropolitan area of Bratislava. The interaction potential of both population and jobs was applied here to assess possible impacts of road network enhancement on accessibility of places of residence and of work.

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1. Introduction

The contemporary period of economic and social development in Europe raises questions about the role of upgrading transport infrastructure in recent and future flexible mobility in the service of sustainable economic development in metropolitan areas. A permeable transport infrastructure is necessary for flexible access to the labour market (e.g., Levinson, 1998; Ong and Blumenberg, 1998; Zhang et al., 1998; Gutiérrez et al., 2010; Grengs, 2010; Cheng and Bertolini, 2013). Apart from access to jobs, the road network supports all economic activities and integrates the global, regional and local economic systems (e.g., Rietveld, 1994; Lakshmanan, 2011; Ivanová and Masárová, 2013). There are numerous studies focusing on metropolitan areas whose transport networks have been facing growing traffic demands and showing how increases in car traffic after the Second World War induced the creation of orbital motorways around expanding cities (e.g. Linneker and Spence, 1996; Gutiérrez et al., 2010; Martín et al., 2010).

Generally, according to numerous studies (e.g., Gutiérrez et al., 2010; Lakshmanan, 2011; Chmelík and Marada, 2014), the main impacts of road infrastructure investments (and construction of orbital motorways in particular) in metropolitan areas are:

- spatial changes in urban environment,
- land-use changes,
- territorial re-organisation of economic activities,
- restructuring the image of the landscape,
- changes in travel behaviour and transport-mode preferences,
- accessibility pattern changes.

The construction of orbital motorways (often termed “beltways”, especially in American literature) is a common road network upgrade strategy in highly urbanised metropolitan areas, and brings many improvements. In addition to the main mission of orbitals in redistributing road traffic and diverting transit traffic (Giuliano, 2004), they also contribute to spatial redistribution of human and economic activities (Linneker and Spence, 1996; Gutiérrez et al., 2010). As Gutiérrez and Gómez (1999: 1) state, “a typical feature of the mature contemporary metropolis is the presence of orbital motorways”.

Outside Western societies, the effects of recent investments in metropolitan road networks have been increasingly reported in other countries where car traffic appears to be a dominant mode of transport that is growing hand in hand with booming national and local economies. Frequent studies focusing on emerging economies show cases of cities in India or China, as described, for example, by Pucher et al. (2007), but similar phenomena are reported from post-communist societies in Europe, where road transportation has quickly become the leading mode of transport (Pucher and Buehler, 2005; Marada, 2006; Horňák and Bačík, 2013; Bul, 2016) and Western lifestyles and thriving economies are increasing congestion risks in large urban agglomerations. Lagging trends in mobility features in post-communist Europe result in solutions also lagging behind, and so many central and eastern European metropolises facing growing road congestion have been planning and completing motorway beltways only recently in their urban development. However, as noted by Pucher and Lefevre (1996) or Marada (2006), compared to Western societies, all transport system transformation processes in the post-communist countries were subject to rapid changes and adaptation to global mobility trends in an extremely short time after the communist regime collapsed.

Post-communist metropolitan areas are witnessing immense changes. Economic and social restructuring and adaptation to both global and local needs bring new challenges and cause huge investments in their infrastructure, including transportation networks (e.g., Marada, 2006; Horňák and Bačík, 2013; Bartosiewicz and Pielesiak, 2014; Taczanowski et al., 2018). We see metropolitan transportation networks adapting flexibly to developing and changing urban structures, and *vice versa*.

In respect of the trends mentioned above, the main aim of the paper is to analyse the possible impact of new orbital motorway sections within the urban and suburban districts of the city of Bratislava (the capital of Slovakia) on interaction potential (accessibility), expressed by volumes of both residents and jobs (i.e. population and employment potentials, respectively).

2. Theoretical background

2.1. Spatial mismatch between places of residence and work, and impacts of new orbital motorways

Spatial interactions between places of residence and job concentrations have obviously been a matter of interest among various experts, including scientists and political representatives. As mentioned in the introduction part of this paper, special attention is paid to these interactions in highly urbanised areas of large economic urban cores where an efficient and flexible transport infrastructure is inevitable for job accessibility. In some developed countries (such as the United States of America or Australia) the spatial mismatch between location of residential districts and job concentrations has been anchored and strengthened by the immense involvement of individual passenger car use (e.g., Levinson, 1998; Kawabata and Shen, 2007; Grengs, 2010; Scheurer et al., 2017). On the other hand, compared to American urban environment, most European metropolitan areas have been focusing on developing public transport systems as part of their long-term policies (for more differences, see Pickup and Giuliano, 2005). Many post-communist countries were still witnessing rather generous subsidies for their public transport systems in the beginning of the 1990s, but in recent years their modal-split structure increasingly resembles that reported in Western Europe (e.g., Pucher and Buehler, 2005; Horňák et al., 2013; Taczanowski, 2015; Król and Taczanowski, 2016; Marada and Květoň, 2016). Thus, the growing dominance of individual transport has led to greater expansion of the motorway network in Central European post-communist societies, including Slovakia with its capital city of Bratislava.

Methodically, Cheng and Bertolini (2013: 101) point to the following three sub-systems of job accessibility: transport, workers (with their places of residence) and jobs (and their locations). These three sub-systems are characterised by various spatial and non-spatial elements that contribute to high variability of job accessibility. However, all three above-listed subsystems are dynamic and tend to transform themselves in time, and they are upgraded by slightly different urban planning approaches depending on the focus applied (land-use planning, transport planning, social policy, environmental management, etc.; for more, see Cheng et al., 2013).

What is the mission of orbital motorways in upgrading job accessibility related to distribution of residents in metropolitan areas? As emphasised by Sutton (1999) or Martín et al. (2010), orbital motorways were originally constructed to divert heavy transit traffic away from city centres in highly urbanised metropolitan areas. With following urban sprawl and intensive suburbanisation processes, the orbitals tend to become an integral part of expanding cities and their booming hinterland belts. The main reason is that they often generate intensive processes of economic decentralisation within the metropolitan area, hence the redistribution of human activities (including economic and residential ones) within the territory (as described by, for example, Linneker and Spence, 1996 or Martín et al., 2010).

Inspired basically by Gutiérrez and Gómez (1999), we agree that beltways must be completed to bring substantial effects in the territory, but this is not the case of Bratislava, where plans to complete the full circumferential motorway reach far beyond

2030. The size of a metropolis is also a subject in research matters. Compared to similar studies (e.g., Linneker and Spence, 1996, focusing on London; Gutiérrez and Gómez, 1999, on Madrid), the city of Bratislava with its metropolitan region is home to roughly 600,000 residents. However, the dynamics of development in Bratislava region, as one of the most successful economic areas within post-communist Europe, suggests that some changes might soon be detectable, no matter what size the city is.

2.2. Application of population and employment potential models in research

Redistribution of population or jobs may be examined by various approaches. Inspired by Gutiérrez and Gómez (1999) and some other studies applied in domestic literature (Kusendová, 1993; Marenčáková et al., 2006; Nováková, 2007), our decision to apply population and employment potential models in the researched area is supported by the availability of sources data on job and population spatial distribution.

Processes, flows and interactions among locations are not concentrated in points of space, but "travel" in it (Korec and Rusnák, 2018: 83). The intensity or volume of possible interactions among social or economic groups or other entities located in differing locations can be analysed by using so-called potential models. These have been conceptually, empirically as well as historically associated with the gravity model suggesting that two territorially separated groups of people generate a mutual interaction in proportion to the product of the sizes of the groups, and that this interaction is impeded by the frictional effect of the intervening distance between these two groups (Rich, 1980). In other words, the volume of interaction between two points (locations, cities) is a positive function of their population sizes (mass) and an inverse function of the distance between them. This potential interaction may be of goods, telephone calls, migration volumes, and a whole range of other social and economic contacts, such as journeys to work, shops, school or entertainment (Rich, 1980). Potential models have appeared frequently in the human geography literature (Molodikova and Khanin, 1986; Weber and Hirsch, 1999; Lukermann and Porter, 2005; and others) explained by rates (or indices) of intensity of possible interactions between social or economic groups in different locations. They can also be interpreted through the measure of accessibility of a location by people residing in all parts of the area being examined. In accordance with the type of the mass, the terms "interaction", "economic" or "contact" potentials can be used alternatively (see Clark in Rich, 1980: 12; Westaway in Rich, 1980: 12).

3. Research methodology

3.1. Research area and database preparation

The research area (Fig. 1) is identical to what Bezák (2000, 2014) identified as the nodal region of Bratislava city (also named FUR – the Functional Urban Region of Bratislava). As of the latest population census (in 2011) the region embraced 126 municipalities with 654,914 residents in total, which makes it the largest nodal region of Slovakia in terms of population size. The same data source reports that the number of those commuting daily (by various means of transport) to the city of Bratislava within the research area is over 143,000. The geographical position of the region is extremely eccentric and located at the south-western border of the country. Bratislava nodal region (representing our research area) borders on Hungary to the south (length of shared border is 33 km), Austria to the west (106 km) and the Czech Republic to the north-west (2.6 km). The rest of the region's border faces the territory of Slovakia (202 km). A specific feature of Bratislava's position is the proximity of Vienna (61 km) which makes them a unique twin – two European capital cities located close to each other. These two metropolitan regions together with neighbouring regions of Brno (Czechia) and Győr (Hungary) represent one of the most progressive macroregions of Central Europe called CENTROPE (e.g. Wiesböck and Verwiebe, 2017). The south-eastern part of the research area shows an extreme share of daily car commuters. Based on the 2011 population census, in many municipalities located here, the share of daily commuters using cars is nearly 80% of all daily commuters. The whole south-eastern sector of the metropolitan region suffers with frequent congestion that results from the underdeveloped transport infrastructure, the lack of motorway network in south-eastern outskirts of the city core, and an excessive suburban growth in the respective part of the city's suburban belt (more information in Šveda and Barlík, 2018). According to the analysis of the official motorway authority in the country (NDS, Národná diaľničná spoločnosť, a.s., [National Motorway Company]), the project to upgrade the metropolitan area motorway network should improve the network capacity by building 27 km of D4 motorway and 32 km of the R7 expressway (see Fig. 1). The whole project (also titled D4/R7) includes southern and eastern sections of the so-called Zero-orbital motorway (officially titled the D4 motorway) and an adjacent part of the R7 expressway that should later connect Bratislava with central and eastern Slovakia. The whole D4/R7 project, with a total of 59 km, will be a substantial part of the orbital beltway surrounding the capital city, and the official deadline for the project completion is 2020 (see Bratislava Bypass PPP project: Motorway D4 and Expressway R7, 2019). Moreover, the project also includes an upgrading of the existing D1 motorway that should increase the capacities of the whole motorway network within the area.

To interpret the expected changes of the interaction potential surface within the research area, two different territorial divisions of the research area were applied. The first is purely geometric, as we divided the research area into four concentric rings with different distances from the centre point (up to 5 km, 5 to 10 km, 10 to 25 km and over 25 km) located at the crossroads of Mlynské Nivy and Karadžičova streets in the Old Town of Bratislava. Two inner annuli roughly cover the area of the capital city while the outer belts separated by the 25 km circle include the suburban hinterland of the city (see Fig. 1).

In the second approach, the research area was split into the following four zones: city core, city margin, near hinterland and far hinterland (Fig. 1), as identified by Šveda (2011). This author analysed an intensity of suburbanisation processes within the functional urban region of Bratislava (identified by Bezák, 2000). The aforementioned four zones include individual city boroughs and its hinterland municipalities based on various suburbanisation signs (such as migration, daily work commuting, land-use changes, construction intensity, socio-demographic changes, see Fig. 1).

A comparison of elementary statistics of the aforementioned research area sub-units is shown in Tables 1 and 2.

A specific feature of the northern part of Bratislava region is a military area (Fig. 1), which is extremely sparsely populated due to its specific functions. Although this area is home to only a few residents, it is included in the analysis and in some aspect may deform the final results.

In this paper, we tried to apply the interaction potential to show how much the potential surface of the research area represented by number of potential interactions will change after the construction of new sections of motorways and expressways. Construction of the new road network sections will provide better accessibility to certain elements (points, areas) by shortening the distances and travelling times necessary to reach them. In our model, these accessibility improvements will be represented by higher interaction potential values.

The preparation of the input database included three steps related to the interaction potential calculation algorithm.

In the first step, the input data necessary for examining the interaction potential were collected. These included statistics on number of permanent residents and number of jobs. These were extracted from the official 2011 population census results available for population grid centroids generated within the GEOSTAT project of the Statistical Office of the Slovak Republic (GEOSTAT project, 2014). This population grid contains a network of evenly spaced centroids (1,000×1,000 m). The database on distribution of residents was available basically within the population grid. However, the volumes of jobs representing individual grid units (unobtainable from the official GEOSTAT sources) were calculated from the municipality-level data by mechanical redistribution copying the distribution of residents within the research area. Thus, all centroid points of inhabited cells within the metropolitan region of Bratislava were considered as calculation points (827 grid points in total).

Within the second phase, the target distribution of the interaction potential was set up, represented by 1,733 centroids within the regular grid network (including all inhabited ones) extracted from the GEOSTAT project data source. For our calculations, only the points located up to 1,000 m from the nearest road were considered, while the other centroids were considered points with a zero potential.

In the third step, the rate of impedance was set up. The impedance was calculated as travel time generated by a Network Analyst set of tools (New OD Cost Matrix subtool) in the ArcGIS environment. The travel times were computed among a network of 827 source and 1,733 target points. The time necessary to travel from a source point to any target point using the existing ("before" version) and planned ("after" version) road network, was expressed in minutes. The travel time calculations respected maximum travel speed limits, lowered to average travel speeds detected at morning and afternoon peak times in the middle of the working week (Wednesday) on sections of regular traffic congestion. The road network layer of the research area was gained from the WMS OpenStreetMap (Geofabrik, 2018). Our "before" version worked with the existing road infrastructure, while the "after" version also included a planned motorway network of D4 and R7 and connecting new road infrastructure and an upgraded version of the existing D1 motorway. The data on localisation, speed limits, assumed speeds during peak times, and locations of congestion within both the existing and the planned road network were taken from the web resources of the National Motorway Company, Slovak Road Administration company, WMS Maps Google (source of contemporary congestion) and materials analysing the effectiveness of the D4/R7 project (VÚD, 2016, NDS, 2017, SSC, 2017, Google, 2018).

Figure 1 shows the research area, network of source and target grid points, as well as existing and planned road infrastructure.

3.2. Calculation methods

A mathematical model derived from Newton's gravitation model originally applied in physics (Harris, 1954) was used for the calculation of the interaction potential of both population and jobs. The interaction potential of a point *i* can be explained as a positive result of the mass of all other points within the research area reduced by an impedance rate elicited by the need to overcome the distance between point *i* and all other points in the area. The mathematical equation of the interaction potential model is as follows:

$$IP_i = \sum_{j=1}^{n} \frac{M_j}{d_{ij}}$$

where: IPi represents the interaction potential of point i; Mj is the mass (expressed as a population size or number of jobs) of point j; and dij is the travel time necessary for the journey from i to j (minimum 1 minute).

In the case that $i=j$ (so called self-potential of point i), distance d_{ii} was mechanically set to 1 minute (analogically with Kusendová, 1993; or Paulov, 1993). This step helps to avoid overvaluing the potential of point i, because in the case $d_{ii}=0$ the potential of point i would be infinitely large. Also, this meets the condition that the rate of self-potential of point i must not exceed its own mass size (of residents or jobs).

For the overall evaluation of our results in the urbanisation and concentric zones (see Tables 1 and 2), we use the location quotient (LQ) – a ratio of ratios that is a widely used geographic index. It is used to measure and map relative distributions or relative concentrations of a subarea within the area as a whole (Kempf-Leonard et al., 2005) or to measure the relative distribution of the first variable (expected proportion, in numerator) to relative distribution of the second variable (existing proportion, in denominator). A value of 1.0 indicates that there is the same proportion of the first variable compared to the proportion of the second variable in a given area. A value over 1.0 indicates that the first variable is bigger than the proportion of the second variable, while a value less than 1.0 works conversely.

4. Empirical analysis and findings: reshaping accessibility with new motorways

The following section provides some basic interpretations of the research results. The text comments

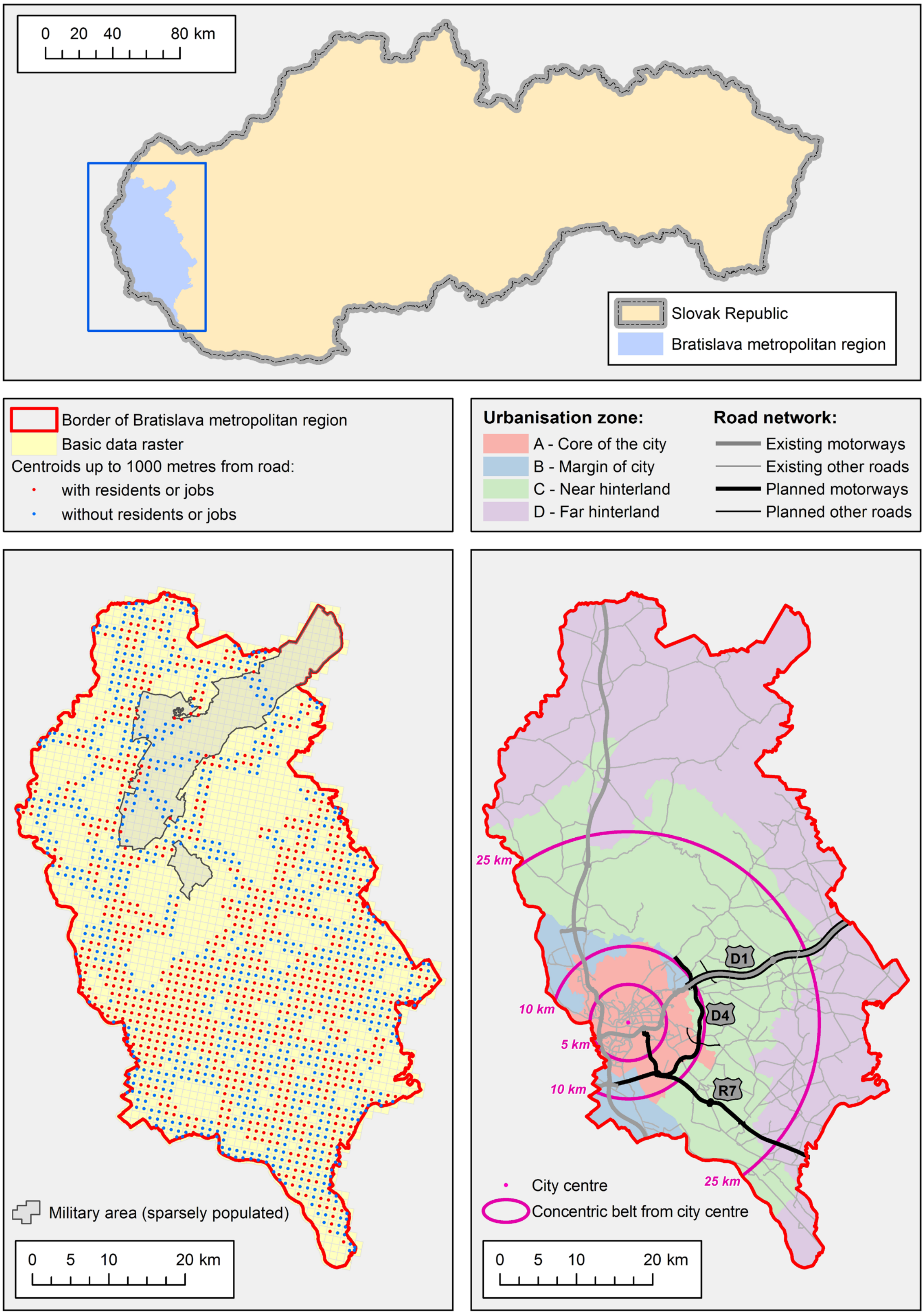


Fig. 1. Research area of Bratislava metropolitan region
Sources: VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018

only on principal results, as the detailed calculation outputs are presented in the figures and tables enclosed. Firstly, we reveal potential changes in accessibility related to distribution of residents and jobs. Later in this chapter, predicted changes in interaction potentials of both residents and jobs will be interpreted.

4.1. Travel time

The disproportion between places of residence and concentration of jobs in Bratislava region, as values of location quotient indicate, is evident from Tables 1 and 2. These show that the location quotient comparison supports our elementary expectation about uneven spatial distribution of residents and jobs in the research area. While more than three quarters of all jobs are concentrated in the city of Bratislava, only half of the region's population resides there. This indicates a considerable mismatch between spatial distribution of residents and jobs in the area.

Values of location quotient vary with the proportion of jobs in a subarea to the proportion of residents in the same area. The values of LQ tend to decrease with growing distance from the central point. In the first ring (0–5 km) as well as in the urbanisation zones A and B (core and margin of city) the values over 1.00 suggest a higher proportion of jobs than values expected based on number of residents. In contrast, values below 1.00 (the rest of the concentric zones and urbanisation zones C and D) indicate fewer jobs compared to expectations based on the population size.

This disproportion between places of residence and concentration of jobs generates high volumes of daily journeys to work, bringing about numerous instances of traffic congestion on a daily base.

According to our analyses (see Fig. 2), the improvement in time accessibility of the city centre that upgrading the motorway network will bring will affect about 55% of the region's residents. This means that for over 356,000 inhabitants the time necessary to travel from the place of residence to Bratislava's city centre will be 0.01 to 21 minutes shorter (3.04 minutes shorter on average). The most positive change in accessibility (of 15–21 minutes) will be observable in the south-eastern sector of the area due to construction of the R7 expressway. About 9% of the residents might perceive a change of over 5 minutes (Table 3).

4.2. Interaction potential of residents

The maps in Fig. 3 show the distribution of the interaction potential of residents before and after construction of new motorways, the maps in Fig. 4 demonstrate absolute and relative changes between both versions of the motorway network configuration.

The best accessibility values can be observed in the city centre. As expected, the interaction potential values decrease from the centre towards the hinterland.

New parts of the motorway network will increase the absolute values of interaction potential of residents in all zones, but the rates of increase will vary. The north-western part of the study area will remain nearly without change. On the other hand, the impact of the new motorways is clearly perceptible in the south-eastern part (Fig. 3). The most significant growth in interaction potential value will be visible in the zone 10–25 km from the centre point and in C zone (the near hinterland). Some new enclaves or areas with positive change in the potential compared to the "before" version may appear on the outer edges of both zones A and B (Fig. 4) which means that these will represent areas with relatively high interaction potential after upgrading the motorway network. Generally, the most significant growth in total interaction potential of residents will be observable in concentric zones between 5 and 25 km and C zone, while the central positions (A and B zones, up to 5 km) and outer rings (D zone, over 25 km) will register no change or only a slight change in potential (Fig. 3).

The location quotient (Tables 4 and 5) indicates that, in general, the new motorways will help reduce discrepancies between the distribution of residents' interaction potential and the distribution of residents. Tables 4 and 5 also suggest that the highest disproportion between the population interaction potential and distribution of residents will remain on the outer edge of the research area (in both zone D and the zone over 25 km from the centre point).

Table 1. Distribution of residents and jobs in Bratislava metropolitan region sorted by concentric belts

Concentric belt (km)	Number of residents	Proportion of residents (%)	Number of jobs	Proportion of jobs (%)	LQ[a]
0,00 – 4.99	243,009	37.1	301,194	61.5	1.66
5.00 – 9.99	144,980	22.1	77,386	15.8	0.71
10.00 – 24.99	170,481	26.0	78,207	16.0	0.61
25.00 and more	96,444	14.7	32,649	6.7	0.45
Total	**654,914**	**100.0**	**489,436**	**100.0**	**1.00**

[a] LQ (location quotient) = proportion of jobs / proportion of residents

Sources: GEOSTAT, project 2014, ŠÚ SR, 2018, authors' calculations

Table 2. Distribution of residents and jobs in Bratislava metropolitan region sorted by urbanisation zones identified by Šveda (2011)

Urbanisation zone	Number of residents	Proportion of residents (%)	Number of jobs	Proportion of jobs (%)	LQ[a]
A - Core of city	378,007	57.7	371,008	75.8	1.31
B - Margin of city	31,980	4.9	29,414	6.0	1.23
C - Near hinterland	168,011	25.7	70,230	14.3	0.56
D - Far hinterland	76,916	11.7	18,784	3.8	0.33
total	**654,914**	**100.0**	**489,436**	**100.0**	**1.00**

[a] LQ (location quotient) = proportion of jobs / proportion of residents

Sources: Šveda, 2011, GEOSTAT project, 2014, ŠÚ SR, 2018, authors' calculations

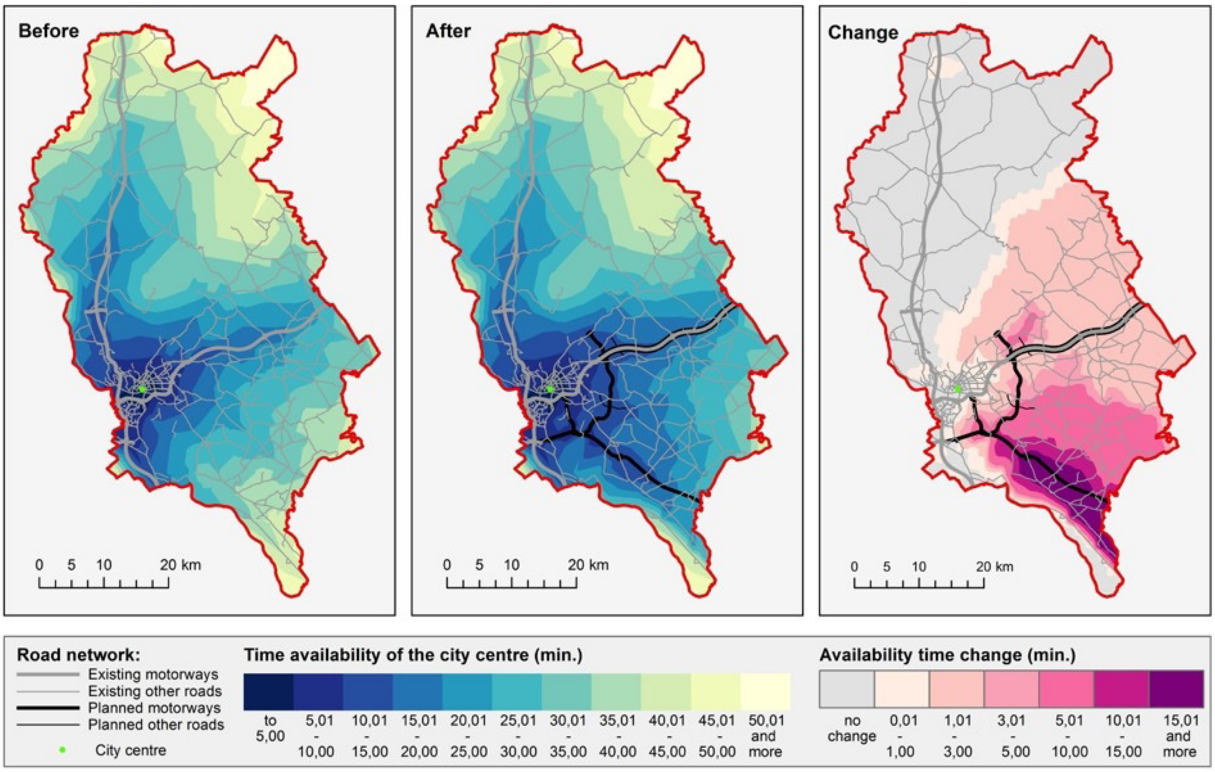
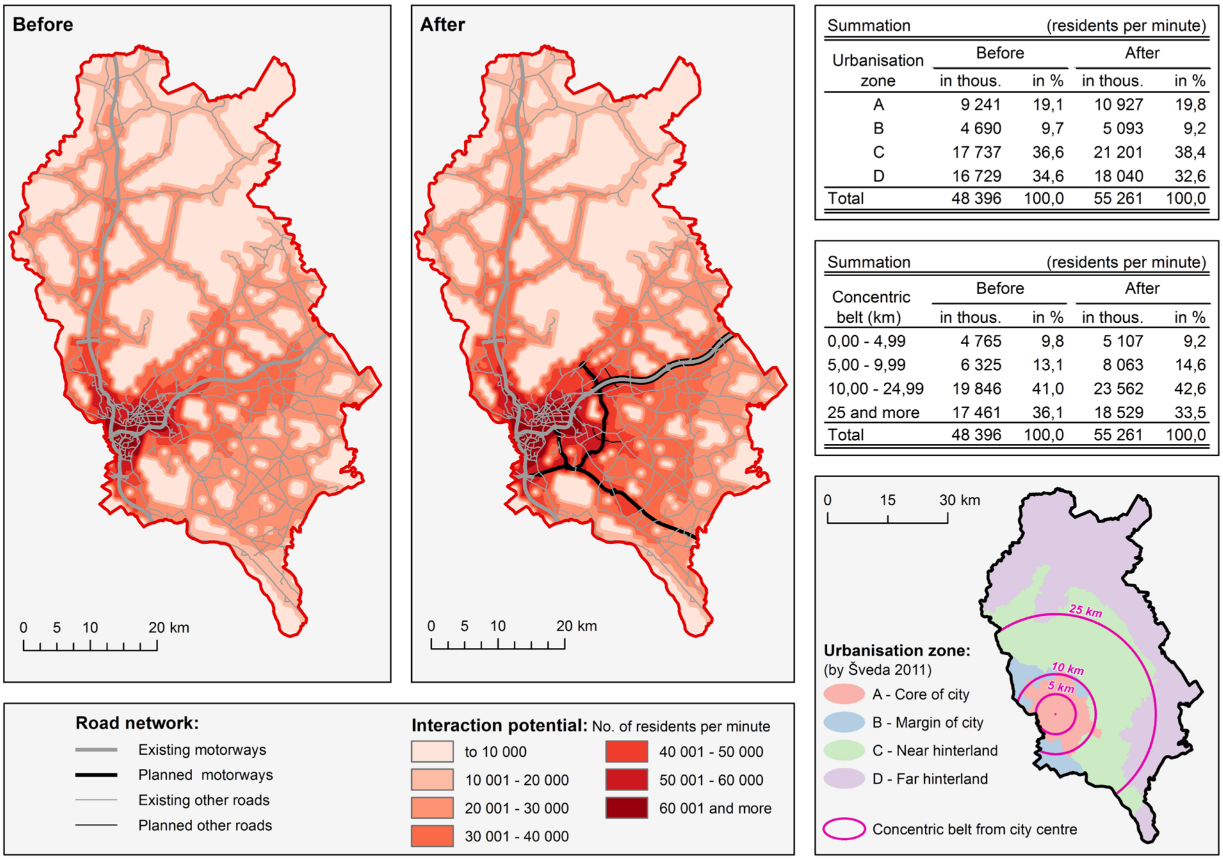


Fig. 2. Time accessibility to Bratislava centre before and after construction of new motorways
Sources: VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018, authors' calculations

Table 3. Summarisation of change in time accessibility to Bratislava centre

Time travel change (in minutes)	Residents	Proportion (%)	Cumulative proportion (%)
no change	298,852	45.63	45.63
0.01 – 1.00	122,708	18.74	64.37
1.01 – 3.00	158,189	24.15	88.52
3.01 – 5.00	20,201	3.08	91.61
5.01 – 10.00	27,837	4.25	95.86
10.01 – 15.00	12,982	1.98	97.84
15.01 – 21.00	14,145	2.16	100.00
Total	**654,914**	**100.00**	-

Sources: VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018, authors' calculations



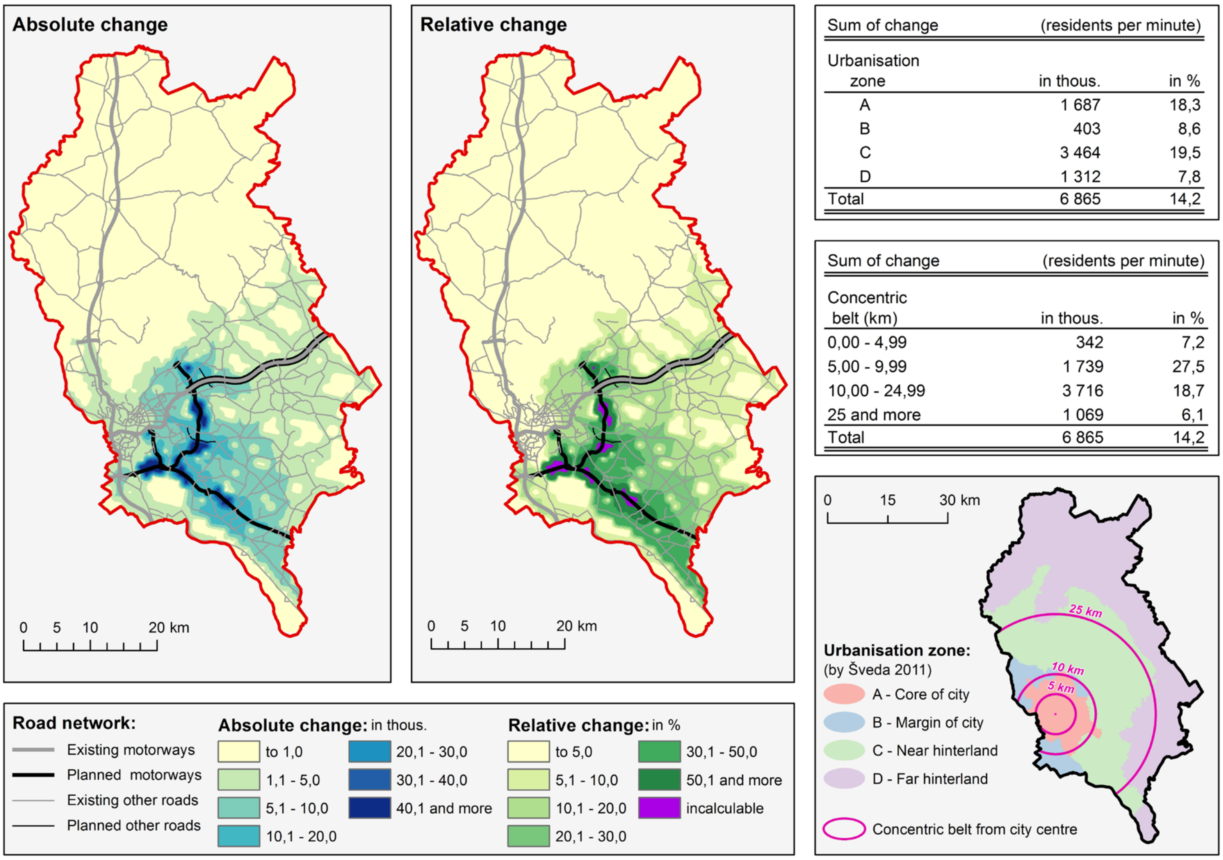
Summation (residents per minute)

Urbanisation zone	Before		After	
	in thous.	in %	in thous.	in %
A	9 241	19,1	10 927	19,8
B	4 690	9,7	5 093	9,2
C	17 737	36,6	21 201	38,4
D	16 729	34,6	18 040	32,6
Total	48 396	100,0	55 261	100,0

Summation (residents per minute)

Concentric belt (km)	Before		After	
	in thous.	in %	in thous.	in %
0,00 - 4,99	4 765	9,8	5 107	9,2
5,00 - 9,99	6 325	13,1	8 063	14,6
10,00 - 24,99	19 846	41,0	23 562	42,6
25 and more	17 461	36,1	18 529	33,5
Total	48 396	100,0	55 261	100,0

Fig. 3. Interaction potential of residents before and after construction of new motorways.
Sources: VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018, GEOSTAT project, 2014, authors' calculations



Sum of change	(residents per minute)	
Urbanisation zone	in thous.	in %
A	1 687	18,3
B	403	8,6
C	3 464	19,5
D	1 312	7,8
Total	6 865	14,2

Sum of change	(residents per minute)	
Concentric belt (km)	in thous.	in %
0,00 - 4,99	342	7,2
5,00 - 9,99	1 739	27,5
10,00 - 24,99	3 716	18,7
25 and more	1 069	6,1
Total	6 865	14,2

Fig. 4. Value changes of interaction potential of residents
Sources: VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018, GEOSTAT project, 2014, authors' calculations

Table 4. Distribution of interaction potential of residents in Bratislava metropolitan region – concentric belts (in comparison with distribution of residents)

Concentric belt (km)	Interaction potential of residents				Residents		LQ[a]	
	Before		After					
	Residents per minute	Proportion (%)	Residents per minute	Proportion (%)	Number	Proportion (%)	Before	After
0,00 – 4.99	4,765	9.85	5,107	9.24	243,009	37.1	0.27	0.25
5.00 – 9.99	6,325	13.07	8,063	14.59	144,980	22.1	0.59	0.66
10.00 – 24.99	19,846	41.01	23,562	42.64	170,481	26.0	1.58	1.64
25.00 and more	17,461	36.08	18,529	33.53	96,444	14.7	2.45	2.28
Total	**48,396**	**100.00**	**55,261**	**100.00**	**654,914**	**100.0**	**1.00**	**1.00**

[a] LQ (location quotient) = proportion of interaction potential of residents / proportion of residents
Sources: VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018, GEOSTAT project, 2014, authors' calculations

Table 5. Distribution of interaction potential of residents in Bratislava metropolitan region – urbanisation zones by Šveda (2011) (in comparison with distribution of residents)

Urbanisation zone	Interaction potential of residents				Residents		LQ[a]	
	Before		After					
	Residents per minute	Proportion (%)	Residents per minute	Proportion (%)	Number	Proportion (%)	Before	After
A - Core of city	9 241	19.09	10 927	19.77	378007	57.7	0.33	0.34
B - Margin of city	4 690	9.69	5 093	9.22	31980	4.9	1.98	1.89
C – Near hinterland	17 737	36.65	21 201	38.36	168011	25.7	1.43	1.50
D – Far hinterland	16 729	34.57	18 040	32.65	76916	11.7	2.94	2.78
Total	**48 396**	**100.00**	**55 261**	**100.00**	**654914**	**100.0**	**1.00**	**1.00**

[a] LQ (location quotient) = proportion of interaction potential of residents / proportion of residents

Sources: Šveda, 2011, VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018, GEOSTAT project, 2014, authors' calculations

4.3. Interaction potential of jobs

The maps in Fig. 5 and Fig. 6 (distribution of interaction potential of jobs before and after construction of new motorways and absolute and relative changes between both versions) show very similar patterns to what is seen in Fig. 3 and Fig. 4 (interaction potential of residents). In both scenarios, the highest accessibility of jobs is observed in the city centre. However, the new sections of the R7 expressway and D4 motorway will raise values of interaction potential of jobs particularly in the south-eastern part of Bratislava region (Fig. 5).

Considering the individual zones within the research area (see Tables 6 and 7), the highest growth in interaction potential values will be detected in the belt between 10 and 25 km from the centre point and in zone C (the near hinterland).

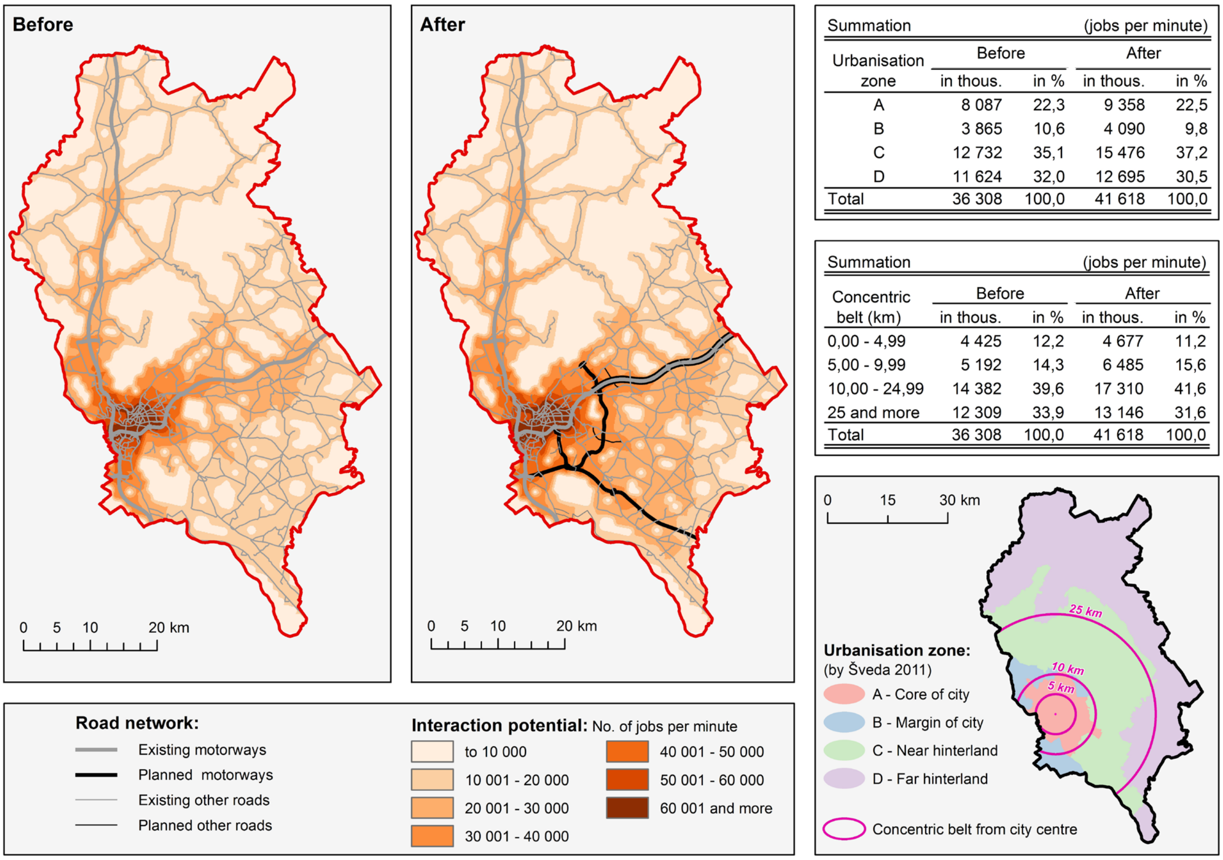
Some new areas of high values of interaction potential of jobs may arise on the outer edges of both A and B zones (Fig. 6), as in the "after" version of the interaction potential of residents (commented above in 4.2). Again, the essential positive changes in interaction potential will be visible in the city's near hinterland (zone C and the belt-zone between 5 and 25 km from the centre point), while the very central parts (up to 5 km) or the edge of the whole area (the belt zone over 25 km from the centre and zone D) will witness no significant changes in interaction potential of jobs, and their share in the total interaction potential of jobs within the research area will decrease (Fig. 5).

The location quotient analysis in Tables 6 and 7 shows that although new motorways will reduce the discrepancy between distribution of interaction potential of jobs compared to job distribution among zones, the imbalance will remain relatively high, especially in zone D (the far hinterland) and in the belt area 25 or more km from the centre.

5. Conclusions

In this paper, we studied possible accessibility changes generated by the construction of new motorway sections in Bratislava metropolitan region using a gravity-based accessibility measure model. Presumed changes in the accessibility to population (the interaction potential of residents) finally turned out to be larger than those related to accessibility to jobs (interaction potential of jobs), though the difference between them is relatively small.

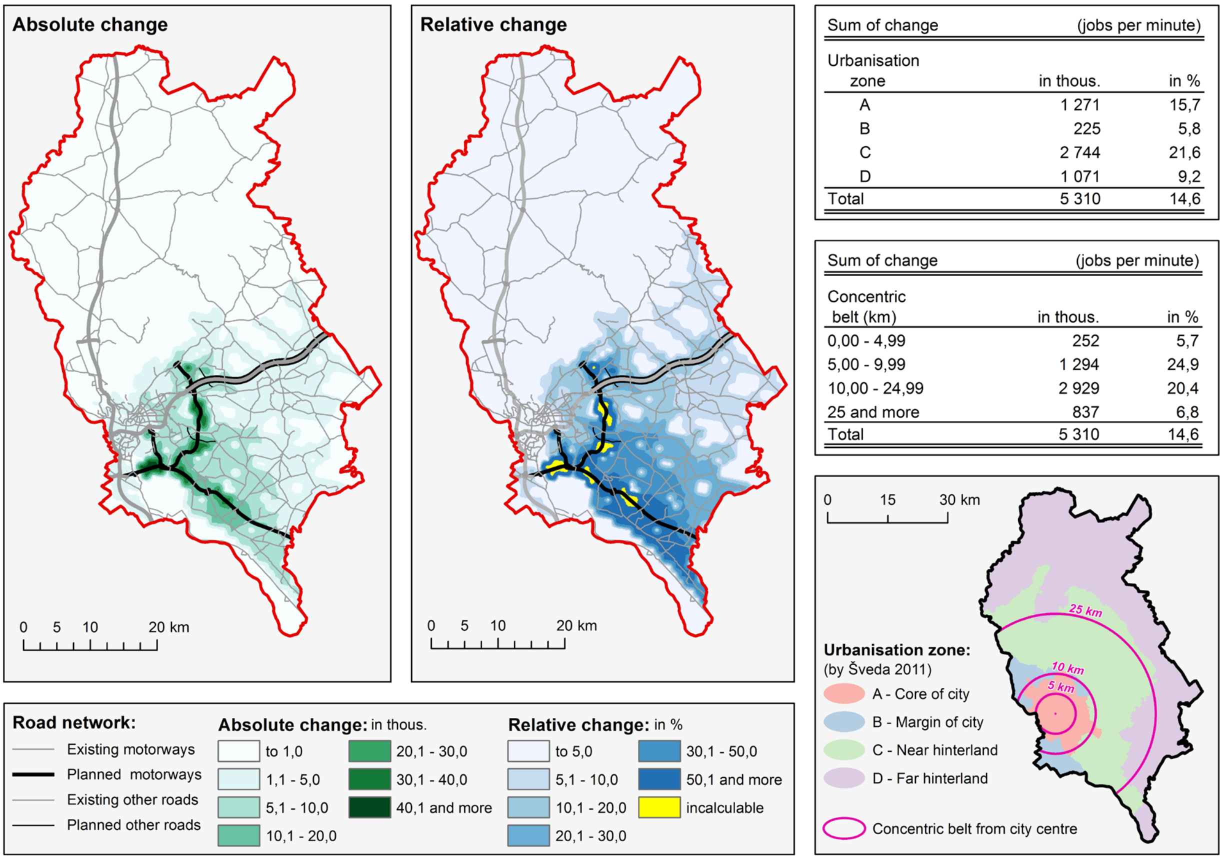
The impact of new motorways does not extend to the whole area of the metropolitan region. According to our expectations, the location of new motorways within Bratislava metropolitan region should



Summation				(jobs per minute)
Urbanisation zone	Before		After	
	in thous.	in %	in thous.	in %
A	8 087	22,3	9 358	22,5
B	3 865	10,6	4 090	9,8
C	12 732	35,1	15 476	37,2
D	11 624	32,0	12 695	30,5
Total	36 308	100,0	41 618	100,0

Summation				(jobs per minute)
Concentric belt (km)	Before		After	
	in thous.	in %	in thous.	in %
0,00 - 4,99	4 425	12,2	4 677	11,2
5,00 - 9,99	5 192	14,3	6 485	15,6
10,00 - 24,99	14 382	39,6	17 310	41,6
25 and more	12 309	33,9	13 146	31,6
Total	36 308	100,0	41 618	100,0

Fig. 5. Interaction potential of jobs before and after construction of orbital motorways
Sources: VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018, GEOSTAT project, 2014, authors' calculations



Sum of change		(jobs per minute)
Urbanisation zone	in thous.	in %
A	1 271	15,7
B	225	5,8
C	2 744	21,6
D	1 071	9,2
Total	5 310	14,6

Sum of change		(jobs per minute)
Concentric belt (km)	in thous.	in %
0,00 - 4,99	252	5,7
5,00 - 9,99	1 294	24,9
10,00 - 24,99	2 929	20,4
25 and more	837	6,8
Total	5 310	14,6

Fig. 6. Change in interaction potential of jobs
Sources: VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018, GEOSTAT project, 2014, authors' calculations

Table 6. Distribution of interaction potential of jobs in Bratislava metropolitan region – concentric belts (in comparison with distribution of jobs)

Concentric belt (km)	Interaction potential of jobs				Jobs		LQ[a]	
	Before		After					
	Jobs per minute	Proportion (%)	Jobs per minute	Proportion (%)	Number	Proportion (%)	Before	After
0,00 – 4.99	4,425	12.19	4,677	11.24	301,194	61.5	0.20	0.18
5.00 – 9.99	5,192	14.30	6,485	15.58	77,386	15.8	0.90	0.99
10.00 – 24.99	14,382	39.61	17,310	41.59	78,207	16.0	2.48	2.60
25.00 and more	12,309	33.90	13,146	31.59	32,649	6.7	5.08	4.74
Total	**48,396**	**100.00**	**55,261**	**100.00**	**654,914**	**100.0**	**1.00**	**1.00**

[a] LQ (location quotient) = proportion of interaction potential of jobs / proportion of jobs

Sources: VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018, GEOSTAT project, 2014, authors' calculations

Table 7. Distribution of interaction potential of jobs in Bratislava metropolitan region – urbanisation zones by Šveda (2011) (in comparison with distribution of jobs)

Urbanisation zone	Interaction potential of jobs				Jobs		LQ[a]	
	Before		After					
	Jobs per minute	Proportion (%)	Jobs per minute	Proportion (%)	Number	Proportion (%)	Before	After
A – Core of city	8,087	22.27	9,358	22.48	371,008	75.8	0.29	0.30
B – Margin of city	3,865	10.65	4,090	9.83	29,414	6.0	1.77	1.64
C – Near hinterland	12,732	35.07	15,476	37.19	70,230	14.3	2.44	2.59
D – Far hinterland	11,624	32.02	12,695	30.50	18,784	3.8	8.34	7.95
Total	**36,308**	**100.00**	**41,619**	**100.00**	**489,436**	**100.0**	**1.00**	**1.00**

[a] LQ (location quotient) = proportion of interaction potential of jobs / proportion of jobs

Sources: Šveda, 2011, VÚD, 2016, NDS, 2017, SSC, 2017, Geofabrik, 2018, Google, 2018, GEOSTAT project, 2014, authors' calculations

generate accessibility changes in the south-eastern part of the research area in particular. The situation could change in the future, when the Zero-orbital motorway (D4 motorway) is completed to its full extent.

Equality of spatial distribution was measured by a location quotient. The interaction population of jobs displays larger inequality than that of residents in both versions. After construction of the new motorway sections, inequalities among zones will probably tend to be lower, although the effects on spatial disproportions might be weaker than expected.

According to our calculations, in comparison with the existing network, the essential changes after completion of the upgrading of the planned motorway system will be the following:

- More than 50% of the region's present population will probably witness a positive change in city-centre accessibility (over 350,000 residents).

- The most significant improvements in accessibility (interaction potential) hypothetically generated by the new motorway sections can be seen in areas surrounding the south-eastern part of the D4 motorway and in the south-eastern part of the research area.
- Considering the specifics of individual zones surrounding the urbanisation core of the metropolitan area, the positive effects and improved accessibility will be observable in the second and third concentric zones (and zone C – the near hinterland), while the effect of motorway network upgrading would be smaller in the rest of the zones. This supports our expectations that the new orbital motorway will not directly affect the city itself but will contribute to improving accessibility to the city from its hinterland.
- Similarly, the changes in interaction potentials of both residents and jobs will be visible mainly in the near hinterland of the city (zone C and the belt zone between 5 and 25 km from the centre point).

The new road infrastructure elements could indirectly bring about new housing and office developments in areas where the density of urbanisation is recently relatively low (hinterland of Bratislava). The construction of this type of infrastructure (especially when orbital motorways are considered) could lead to production and business activities relocating from central city districts to well-connected areas close to the new motorway sections (a similar effect was reported by, for example, Linneker and Spence, 1996; or Gutiérrez et al., 2010). In the near future, the development of a Park and Ride infrastructure network on the outer fringe of the city (in the second concentric zone) could redistribute existing transport flows and push part of the passenger car stock out from the city core, which will help further reshape traffic, environmental, general economic and social conditions in the metropolitan area of Bratislava.

We should also emphasise that our results might be distorted by several simplifications and methodical limitations. The most important ones are as follows:

- the use of Census data from 2011 means that recent mobility trends are not included,
- the 1,000×1,000-m grid of points might not be sufficiently representative in terms of real distribution of both residents and jobs,
- the maximum distance limit (1 km) from the nearest road set for the points included in our calculations might also generate some distortions,
- the self-potential derived from accessibility set down to 1 minute can also be a limitation; a different value might bring substantially different results,
- the data on traffic loads and possible congestions do not cover any extreme values, since our traffic model worked only with the average intensity values based on morning and afternoon peak traffic hours (on Wednesday),
- the concentric belts and urbanisation zones applied in the interpretation of the results might affect the general picture, which is why two various delimitations were used,
- distant-future plans for the completion of the D4 motorway (including its north-western section) were not included, due to expectations that this would probably quite heavily affect the accessibility in the whole area,
- our calculations of the potential do not cover adjacent trans-border areas in neighbouring Hungary, Austria and Czechia.

With further improvements to the motorway network in the whole trans-border region (including Hungarian and mainly Austrian parts of the infrastructure) in the distant future, we can expect essential changes in accessibility. However, these are much dependent also on future redistribution of residents and jobs in the region. These redistributions will not be purely a result of upgrading of the motorway system but also of the policies of local authorities in the city's hinterland (in Slovakia as well as in Hungarian and Austrian territories) leading to higher or lower attractiveness for new residents and commercial activities, and such changes are not predictable at this moment. The paper may serve as an example of a planning approach based on a limited database on traffic infrastructure quality. This paper also attempts to use available data on traffic dynamics to model spatial interactions, which is a rather innovative approach that has not so far been applied frequently in planning practice in Slovakia. More reliable results bringing better application opportunities could be achieved with more accurate input data.

The paper ranks among the scientific studies focused on impacts of transport infrastructure investments and shows that these impacts reach far beyond geography. Results of similar studies are applicable in urban planning, traffic predictions, population redistribution predictions, environmental impact assessment procedures, land-use change research and for commercial purposes.

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