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Accessibility improvement, territorial cohesion and spillovers: a multidimensional evaluation of two motorway sections in Poland

Keywords: Potential accessibility; Territorial cohesion; Spillovers; Distance decay; Road infrastructure; Poland

Abstract:

The aim of this paper is to contribute to previous methodological studies of the approach to potential accessibility used in the evaluation of development of the road network. This is done by making a three-fold analysis, which combines the overall improvement in the level of accessibility, territorial cohesion, and spatial spillovers. Moreover, we use different spatial dimensions (namely national and international) and different distance decay parameters to estimate both the short trips (e.g. commuting) and the long trips (e.g. business trips or tourism). The results are presented at a very detailed spatial scale (i.e. municipalities – LAU-2 units).

The paper provides empirical evidence of improvement in accessibility, changes in the degree of territorial cohesion, and spatial spillovers resulting from the recent completion of two sections of motorway in Poland. The selected case studies differ according to their location (i.e. national and European, peripheral vs. central location), population density, and the settlement structure around the investment.

The validity of the proposed multidimensional approach to the evaluation of road investments is verified as the combination of different accessibility dimensions and leads to results which differ respecting efficiency, equity and spillover effects. This paper provides arguments to strengthen the need for the tailor-made parameters of potential accessibility indicator and spatial dimension of analysis. They should be adjusted to the main aim of the particular evaluation.

1. Introduction

Accessibility is a key concept in transport analyses for economic, social and planning studies. The improvement of accessibility may lead to several important consequences such as a redistribution of economic activity between regions (Baldwin et al., 2005; Martin, 1998) or in productivity increase (Aschauer, 1989; Bottasso and Conti, 2010; Fernald, 1999). A proper evaluation of the impact of development of the road network has therefore become a crucial tool for strategic planners and territorial policy makers (Sohn, 2006; van Exel et al., 2002; Vickerman, 2000). It may be used to justify support for, or the prolongation or even cancellation of proposed investments, as well as for the prioritization of planned infrastructure projects (Zaucha et al., in press).

Evaluation of improvements in accessibility is essential especially in countries, which are taking a massive leap forward in terms of infrastructure, such as Spain in the 1990s and 2000s (Holl, 2007), or contemporary Poland (Komornicki, 2007; Taylor, 2006). In the case of the latter, it is experiencing an unprecedented development of the high-speed road network, starting from merely a few hundred kilometres at the end of the 20th century, and achieving a network of more than two thousand kilometres today. Since the middle of the first decade of the 2000s, state investments have been supported by European funds giving an additional stimulus to accelerate the development of the transport infrastructure. Thus, the current time is crucial in determining the future shape of the Polish road network. The abovementioned circumstances create perfect conditions for an extensive investigation into changes in accessibility levels.

Furthermore, accessibility is strictly related to space and territory. Therefore, its evaluation should not be limited to the extent to which transport improvements influence the overall accessibility level. The analysis should also be inseparably related to the spatial extent of the impact and the influence the investment has on regional disparities and territorial cohesion. This therefore explains why one can recently observe studies on the territorial impact of transport infrastructure investments (called a spatial spillover effect) at both national (Gutiérrez et al., 2010; Ortega et al., 2012; Yu et al., 2013), as well as international levels (Gutiérrez et al., 2011; López et al., 2009). Most of the studies adopt a common methodology based on a comparison of potential accessibility values in particular scenarios, usually ‘with’ and ‘without’ an investment. Nevertheless, most of the papers neglect dissimilarities in accessibility patterns resulting from both the use of different spatial dimensions (e.g. national vs. international), and the application of different types of decay functions used as impedance forms. Hence, this paper attempts to shed more light on the variations of the extent to which changes of accessibility level can be observed at different spatial dimensions and in relation to different distance decay parameters at a very detailed spatial scale (LAU-2 units).

An approach based on potential accessibility was chosen to analyse the effects of two recently built motorway sections in Poland. The first one is located centrally in a highly populated area, whereas the second is more peripheral, constituting a border section crossing a region with low population density. Therefore, the research work also provides added value through providing empirical evidence of the impact of two different investments on accessibility.

The paper is divided into six parts, including this section. A brief description of recent road developments in Poland is given in section 2, with particular attention focused on the two case studies. Section 3 describes the methodology, including a literature review of techniques for measuring accessibility, measures used, and calculation methods, and the network databases used.

The territorial dimension of the impact of transport investments on changing accessibility is presented in section 4. In section 5, the results of the empirical analyses conducted are presented, with a study of the overall impact at the beginning, followed by the cohesion effect and finishing with an investigation of spillover effects. The final section identifies some conclusions and gives recommendations for further research.

2. Road network development and the role of the evaluated sections of the A2 motorway

The Polish road network is still at an early stage of development (Komornicki, 2007; MRR, 2012; Taylor, 2006). Due to long-lasting negligence in modernising the road network or constructing new roads, by the beginning of the 2000s the motorway network[1] was basically non-existent and consisted of separate, unconnected sections mainly located in the southern and western parts of the country. The total length amounted to 400 km. Due to the unprecedented mobilisation of political and financial resources promoted by the organization of the UEFA Euro Championship in 2012, network development has accelerated since the end of the first decade of the 2000s.

The A2 motorway is an integral part of the TEN-T core network, linking the central Polish cities of Poznań, Łódź and Warsaw with the Polish-German border and Berlin at its western end and, in the future, will extend towards the Polish-Belarusian border, Minsk and Moscow in the east. Together with the north-south A1 and east-west A4, it constitutes the core framework of the motorway system planned for Poland.

The history of the A2 commenced in the 1970s when the political will developed that led to the construction of the first, nearly 50km-long, section in the 1980s. No other sections of the A2 were constructed until 2003. Therefore, for some decades the A2 motorway has neither connected any important settlement areas, nor had a noticeable impact on overall accessibility in Poland. Fortunately, due to the acceleration of works during the years 2003-2012, the missing sections between Warsaw and the Polish-German border have now been finished. The part leading from Warsaw towards the Belarus border is still a project for the future, except for a small section (21 km) close to Warsaw finished in 2012.

In this paper we concentrate on the impact of two separate sections of the A2 motorway on accessibility. These were located in the central and the western parts of the country (i.e. the sections from Łódź-Warsaw and from the Polish-German border to Nowy Tomyśl, respectively), both completed in 2012. Both sections selected are of a similar length (91 vs 106 km). However, they differ in location from both a national as well as an international point of view. Figure 1 provides a brief description of the case studies selected, supplemented by an overview map of the future Polish high-speed road system.

[1] The Polish Highway Code distinguishes two types of high-speed road: “motorways” (‘A’ category) and “express-roads” (‘E’ category). Bearing in mind their different speed limits (140kmh and 120kmh, respectively), we classify both of these categories as part of the ‘motorway network’ in this paper, as opposed to other ‘dual-carriageways’ which are excluded as the latter are not necessarily equipped with grade-separated junctions.

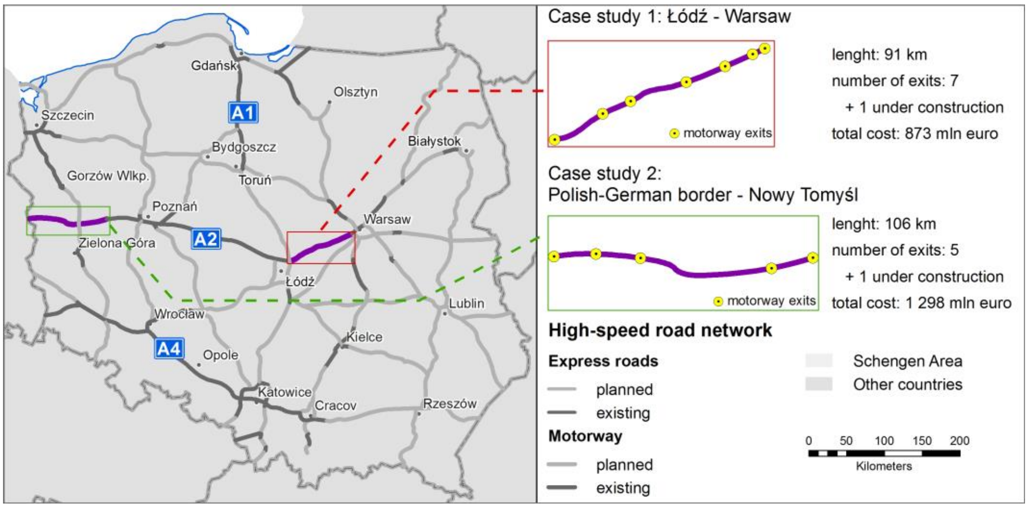

Fig. 1. The Polish high-speed road network and basic characteristics of the case studies selected

2.1. Case Study 1: Łódź-Warsaw

This section is centrally located in the country connecting the capital with the third most populated city in Poland and running through relatively densely-populated areas. It is crucial for both transit as well as local traffic, facilitating commuting within and between the metropolitan areas of both the cities connected together. The motorway improves the accessibility of residents of the south-western part of the Mazovia region to the major Polish job market of the country (Warsaw). Moreover, it connects Warsaw to Poznań and, together with the A1 motorway (partially under construction), it is the fastest route from Warsaw to the northern (Gdańsk) and southern (Upper Silesia and Cracow) parts of the country, facilitating connections between almost all of the most important economic centres in Poland. At the international level, the section constitutes the missing link in the main transport corridor in the Warsaw metropolitan area. Therefore, the case study analysed does have an international significance in spite of its location in the centre of the country.

2.2. Case Study 2: Polish-German border-Nowy Tomyśl

The location of the second case study, by contrast, is peripheral from a national perspective, although it is closely connected to the European core, constituting the shortest route from Poznań and central Poland to Berlin. The section crosses the Lubuskie region, which is characterised by low population density, with no regional cities surrounding the section analysed. Thus its importance for commuting and any other kind of local traffic is rather limited. Nevertheless, the section examined is crucial for Poland's international connections, as it links the central part of the country with Germany and Western Europe.

3. Measuring accessibility

As accessibility is a multidimensional phenomenon there exists a wide range of accessibility measures including infrastructure-based, travel cost, cumulative, potential and person-based (cf. Baradaran and Ramjerdi, 2001; Bruinsma and Rietveld, 1998; Geurs and Ritsema van Eck, 2001; Geurs and van Wee, 2004). We use a Hansen/Harris-type potential accessibility indicator that includes relations between all pairs of origin-destination nodes within the network, taking into account (1) the greater importance of larger centres than smaller ones and (2) the diminishing attractiveness of more distantly located destinations (Hansen, 1959; Harris, 1954). The simplest formula for the indicator is:

$$A_i = \sum_j g(M_j) f(c_{ij}) \text{ [1],}$$

where $g(M_j)$ is the function of destination attractiveness, which can be measured e.g. in terms of population, and $f(c_{ij})$ is a distance decay function. Compared to other methods, e.g. the travel cost or cumulative approaches in particular, potential accessibility provides an opportunity to avoid the shortcomings linked to arbitrary methods of selecting destinations (travel cost approach) or the limited scope of the study (cumulative approach). Moreover, potential accessibility analyses are being used to identify where the territorial effects of the infrastructure investment investigated are located (Gutiérrez et al., 2010; Ortega et al., 2012).

3.1. Distance decay

According to the gravity-based methodology, the importance of a travel destination *j* is positively correlated to the destination's attractiveness (the so-called 'mass') of the unit *j* and negatively correlated with distance (travel length, time or cost) from an area (point) *i* to *j*. Therefore, the results of the analysis are highly influenced by a distance decay function used for equation [1]. Notwithstanding the fact that different types of distance decay function were tested for the accessibility analysis, including the negative power (e.g. Hansen, 1959; Holl, 2007; Kotavaara et al., 2011), logistic (Geurs and Ritsema van Eck, 2001) or negative exponential function (Neutens et al., 2010; Yoshida and Deichmann, 2009), it is not the aim of this paper to review these approaches (for a comparative review consult: Kwan, 1998; Reggiani et al., 2010). Thus, the methodology applied was based on the negative exponential function, one of the most commonly used in relevant studies (e.g. Fotheringham and O'Kelly, 1989; Kwan, 1998; De Vries et al., 2009; Neutens et al., 2010) on accessibility at the national as well as international level (Schürmann and Talaat, 2000; Spiekermann and Schürmann, 2007). Hence, the impedance function adopted in the proposed methodology is as follows:

$$f(c_{ij}) = exp(-\beta c_{ij}) \text{ [2].}$$

We chose time as a distance decay element to be investigated. A particular value of the parameter *β* can be calculated based on the assumption that the half-time value of destination attractiveness (i.e. its 'mass') should be acquired at a median travel time typical for a specific travel purpose (Spiekermann et al., 2013). Therefore, it is possible to estimate the potential accessibility for different types of travel (e.g. short- and long-distance trips) by adopting differing values of parameters *β*. In the analysis we adopt two different *β* parameters: 0.023105 and 0.005775. The first corresponds to a median travel time of 30 minutes and is used to estimate the potential accessibility for short-distance trips, e.g. commuting or shopping based on empirical results derived from the Warsaw Traffic Survey (2005). The latter assumes 120 minutes trips referring to median travel time for business and tourism (KMR, 2008).

3.2. Travel times

Travel times in Poland are based on travel speeds by private car applied to different road categories (motorways, express roads, dual-carriageway roads, main (national), secondary (regional) and tertiary (local) roads), reduced if the road is located within built-up areas. Furthermore, the maximum speeds derived from the Polish Highway Code[2] were adjusted down for driving impediments (topography and population density)[3]. Travel time between municipalities is then obtained based on time-distance between nodes in the road network that represent analysed pair of municipalities. Moreover, the time-penalties for gaining the origin node and ending the trip at the destination unit need to be included in the total travel time between particular spatial units. The total penalty is then obtained by the sum of half of the internal origin and destination travel time values, determined using a formula [3]. For travel times in the European context we use four road categories (motorways, dual carriageways, national roads and local roads) and take into account local maximum speeds lowered on local roads close to Poland. Finally, waiting times are involved on the external border of the Schengen Area, and are based on the average data for the period 2010-2011 provided by the Polish Border Guard.

3.3. Self-potential

When calculating the accessibility level through the use of the distance decay function, the proper incorporation of self-potential became a crucial factor influencing the results (Bröcker, 1989; Bruinsma and Rietveld, 1998). In the analysis presented, self-potential is included, derived from the estimation of the internal travel time of the area *i* (t_{ii}). The formula involved was proposed by Rich (1978; see also: Keeble et al., 1982; Gutiérrez et al., 2011):

$$t_{ii} = \frac{0{,}5 * \sqrt{\frac{area}{\Pi}}}{\overline{v_{ii}}} \quad [3]$$

and the assumed mean travel speed is 20 km/h.

3.4. Accessibility at national level

Taking the abovementioned into consideration, the potential accessibility indicator at national level for all *i* municipalities is calculated according to the formula:

$A_i = M_i \exp(-\beta t_{ii}) + \sum_j M_j \exp(-\beta t_{ij})$ [4],

where M_i and M_j are the populations of municipalities *i* and *j*, respectively, $M_i \exp(-\beta t_{ii})$ is the value of the self-potential of municipality *i*, and $\sum_j M_j \exp(-\beta t_{ij})$ stands for the sum of potentials resulting from all other Polish municipalities *j*.

[2] i.e. 140 km/h for motorways, 120 km/h for express roads, 100 km/h for dual-carriegeway roads and 90 km/h or 50 km/h for other roads outside / within built-up areas, respectively.

[3] The adopted travel speed model is precisely described by Rosik, 2012; summary in English is also available in Więckowski et al., 2012.

3.5. International dimension

Despite some promising attempts (e.g. Spiekermann and Aalbu, 2004; Więckowski et al., 2012), there is a substantial shortage of researches combining a very detailed spatial scale (e.g. LAU-2 units) and the international dimension. Hitherto researches mostly focussed on the impact of transport infrastructure development on accessibility at the national level (e.g. Holl, 2007; Ortega et al., 2012) or they provide very general results at international (e.g. European) level (e.g. Spiekermann and Schürmann, 2007). Hence, the approach adopted in the study presented here combines both elements, i.e. usage of very detailed administrative units (municipalities, LAU-2 according to Eurostat nomenclature) with an international dimension. Therefore, the total value of the indicator applied is calculated for international potential accessibility as follows:

$A_i = M_i \exp(-\beta t_{ii}) + \sum_j M_j \exp(-\beta t_{ij}) + \sum_k M_k \exp(-\beta t_{ik})$ [5],

where $M_i \exp(-\beta t_{ii})$ and $\sum_j M_j \exp(-\beta t_{ij})$ are explained as in [4], and $\sum_k M_k \exp(-\beta t_{ik})$ introduces the external (international) potential (Tóth and Kincses, 2011), calculated on the basis of population distribution across all k units distributed in the whole of continental Europe including five federal districts of Russia, Turkey and Great Britain, where k units in the area in proximity with the Polish border are similar to those for Polish municipalities (units used for calculation within Poland) and those located farther are increasingly larger as their influence on the indicator value diminishes. Therefore, the term ‘international dimension’ in this paper is understood as an accessibility indicator that takes into account both national and international trips, while in ‘national dimension’ the indicator is calculated only on a basis of national trips.

The remaining question is how the state border discourages and stimulates interaction (Rietveld, 2012), influencing on potential accessibility level. The concept of ‘border effect’ is broadly discussed in literature concerning the gravity model, especially in terms of freight (Nitsch, 2000; Chen, 2004) and car travel (Pieters et al., 2012). There are difficulties with the application of the gravity model approach with respect to the Polish case, due to the lack of data on traffic flows and the geographical specificity of borders (e.g. the mix of Schengen and non-Schengen borders). Therefore, we decide not to include the decrease of intensity of spatial interaction on the Polish borders (cf. Gutiérrez, 2001; Gutiérrez et al., 2010; Spiekermann et al., 2013, among others) and to consider the ‘border effect’ only as a time penalty at the non-Schengen borders.

3.6. Variants of the analyses

Following the abovementioned process it is felt that the evaluation of selected motorway sections should be multiscalar, i.e. it should include different spatial dimensions and apply to different trip lengths by using diverse parameters β. Therefore, we adopt a fourfold, two-dimensional approach that includes distance decay type for short / long trips in national / international dimension.

4. Impact of infrastructure development on accessibility

4.1. Potential accessibility changes

The assessment of improvements to the transport infrastructure should include two principal elements: its efficiency and its impact on territorial cohesion (Bröcker et al., 2010; Martin, 1998; Spiekermann and Wegener, 2008). Efficiency is usually expressed in terms of relative or absolute changes in the value of the overall accessibility indicator (Holl, 2007; Spiekermann and Schürmann, 2007). In order to measure the territorial impact of developments in the road network, the scenarios before and after completion of the investment analysed are compared and the potential accessibility indicator (A_i) is calculated for every single municipality. Furthermore, the evaluation of the impact of the new investments is carried out on accessibility, using the ONAE indicator (Overall National Accessibility Effect), calculated as a population-weighted average change in the accessibility level at national level between analysed (A_S) and baseline (A_B) scenarios:

$$ONAE = \frac{\sum A_{iS} * P_i}{\sum P_i} - \frac{\sum A_{iB} * P_i}{\sum P_i} \quad [6].$$

Potential accessibility calculations were made in the OGAM application (Pomianowski, 2012).

4.2. Impact on territorial cohesion

The impact on territorial cohesion is understood as the spatial distribution of effects that produce diminishing disparities between regional accessibility levels (Gutiérrez et al., 2011; López et al., 2008; Ortega et al., 2012). Transport infrastructure investments are usually assumed to have a positive impact tending to increase territorial cohesion (EC, 1999, 2004; TA2020, 2011; Zaucha et al., in press). However, the direct relationship between the development of transport infrastructure and improvement in cohesion is far from being obvious (López et al., 2008). The territorial dispersion of accessibility values is calculated using the Accessibility Dispersion index, which is based on the coefficient of variation (López et al., 2008; Ortega et al., 2012). The index is calculated using the following formula:

$$AD = \frac{SD_{A_i}}{\frac{\sum A_i * P_i}{\sum P_i}} \quad [7],$$

where A_i is the value of the potential accessibility indicator calculated for unit i, P_i is a population of unit i and SD_{A_i} is the standard deviation of A_i values weighted by population. The higher AD values mean a more polarized distribution of accessibility. Then, the percentage difference between AD values obtained for each of the case studies and the baseline scenario is analysed, with a negative change standing for an increase in cohesion.

4.3. Spillover effects

New motorway sections, or more generally, transport infrastructure improvements, involve an increase in accessibility level in areas near to them, as well as entailing a spread of the positive effects over the furthest located, peripheral areas. In the previous case the corridor effect is considered, while in the latter, the spatial spillover effect is present. The accessibility improvement resulting from infrastructure development in the immediate vicinities of road improvements is quite obvious. A broad range of studies provide empirical proofs for regional benefits in terms of manufacturing firm location (Cheng and Stough, 2006; Cieślik, 2005; Coughlin and Segev, 2000; Guimarães et al., 2000; Holl, 2004), earning level (Chandra and E. Thompson, 2000), property values (Cohen and Paul, 2007), population distribution (Kotavaara et al., 2011) or economic growth in general (Banister and Berechman, 2001), among others. Notwithstanding this, a growing body of literature suggests that the impact of transport infrastructure development extends further than the limits of its neighbouring area (for review see Yu et al., 2013). Nevertheless, the impact of infrastructure development should decrease with increasing distance from the location of the investment (Ozbay et al., 2007). The analysis of spillover effect should provide, then, an answer to the question concerning the real impact resulting from road infrastructure development in one region on its neighbouring regions (Pereira and Roca-Sagalés, 2003).

There is still the question of how to distinguish between areas located in and out of the investment corridor, i.e. those neighbouring an axis of transport infrastructure and those located further away. The distinction may be carried out on the basis of the administrative division of the study area (e.g. Ortega et al., 2012). An alternative method is to use a buffer established on the basis of straight line distance (Holl, 2004). We adopt a mixed approach, taking into consideration municipalities located within a 50 km straight-line distance from the nearest section node, as well as different spillover levels, by analysing areas located within regular 50 km intervals from the transport corridor, including the farthest area exceeding 200 km.

5. Empirical results

5.1. Setting the scene

The starting point for all the analyses carried out is the existing road network at the beginning of 2012. This scenario does not include the two motorway sections selected for further analysis. It is presented to provide essential information on the regional disparities in levels of accessibility for the four variants analysed (Fig. 2). Logically, the diversity of indicator values is greater for a higher β value than for a lower one. The comparison of accessibility patterns between the national and international contexts clearly highlights the influence of densely populated areas located outside the western and southern border, while the connectivity to the east is considerably reduced by time penalties at the external border of the Schengen Area. In consequence, two poles of higher accessibility are highlighted in the case of short distance trips (the central one comprising Warsaw and Łódź metropolitan areas, and the southern one containing the Upper Silesia conurbation plus Cracow), however in the international dimension a third one arises along the Polish-German border. For long distance trips, the impact of international connections is even more dramatic, resulting in the transfer of higher accessibility values from the central to the western and south-western part of the country.

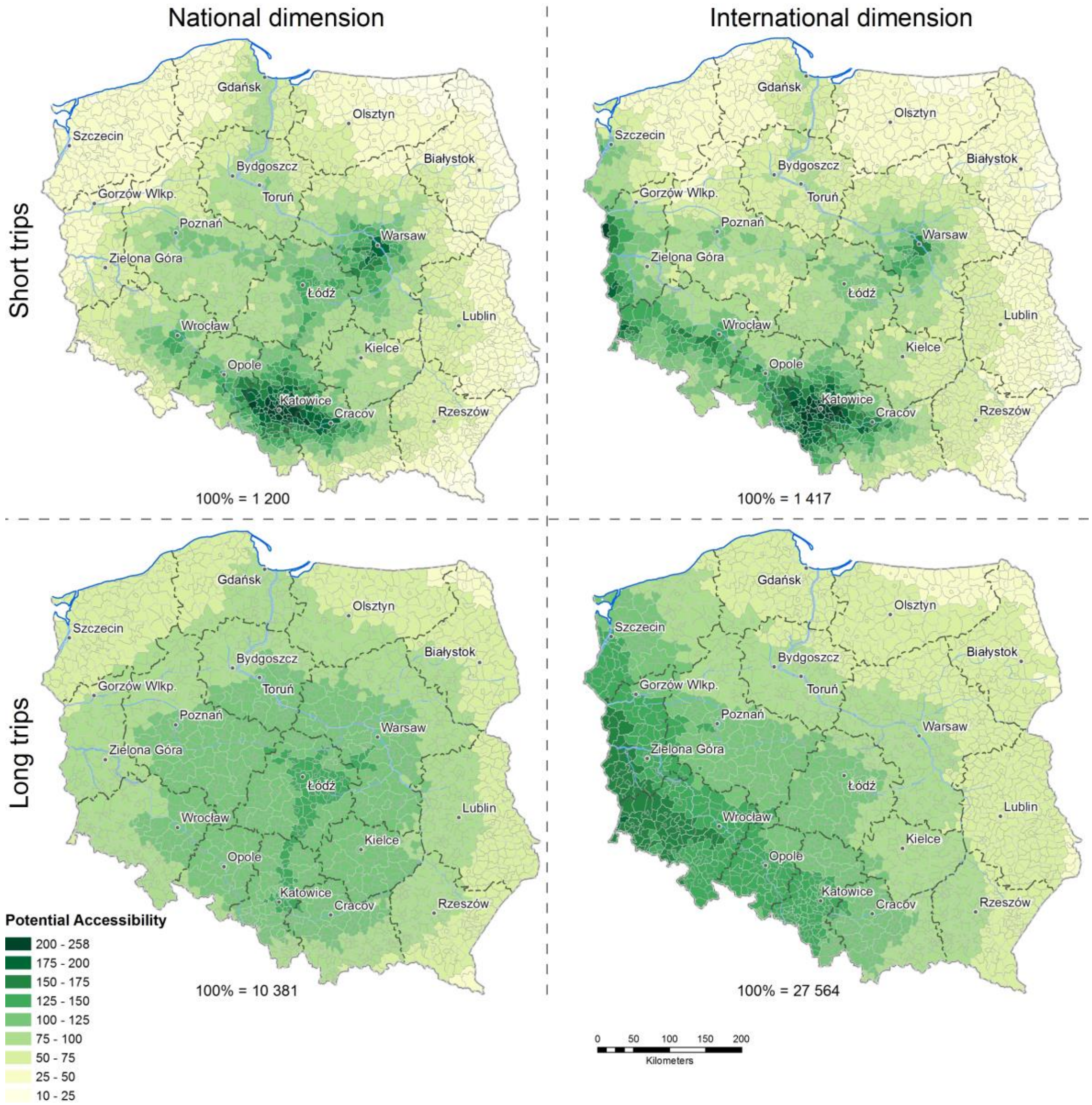

Fig. 2. Potential accessibility: baseline scenario

5.2. Overall changes

Table 1 presents relative accessibility changes resulting from completion of the investment. The completion of a new section of the motorway has a greater overall impact on accessibility in Case Study 1 as it connects two highly populated metropolitan areas enabling commuting between the capital and its western suburbs, and it facilitates travel between the eastern and western parts of the country. The central location of the section results in it being awarded a higher importance for short trips than for long ones. Nevertheless, the accessibility improvements are similar, regardless of the accessibility dimension.

The accessibility change resulting from the completion of Case Study 2 demonstrates a completely different pattern. The peripheral location of the investment causes marginal accessibility improvement in a national context, regardless of trip length. By contrast, international accessibility changes are higher, especially when we adopt a distance decay for long trips.

Table 1. Improvement in potential accessibility

	baseline scenario	Case Study 1 Łódź – Warsaw			Case Study 2 Polish-German border – Nowy Tomyśl		
	value	value	ONAE[a]	Relative change	value	ONAE[a]	Relative change
National short trips	1 200	1 218	18	1.49%	1 201	1	0.06%
National long trips	10 381	10 504	123	1.19%	10 386	5	0.05%
International short trips	1 417	1 436	19	1.28%	1 430	13	0.88%
International long trips	27 564	27 869	305	1.11%	28 227	663	2.40%

[a] ONAE – Overall National Accessibility Effect

5.3. Towards territorial cohesion or polarisation?

Table 2 sheds some light on the direction of change in terms of disparities in regional accessibility. It is clearly visible that central location in the densely populated area (Case Study 1) induces an increase in polarisation, especially on the national dimension. The exception concerns accessibility in international dimension analysed with the use of distance decay for long trips. In this case the key question is that the new central section will improve accessibility of the poorly accessible north-eastern regions of the country, by facilitating their connection to Germany and western Europe. By contrast, the relatively low baseline accessibility level in the areas surrounding Case Study 2 (Fig. 2) lies behind the improvement in territorial cohesion. Reducing travel times from peripheral, poor accessible municipalities, to highly populated areas on the other side of western border of the country is translated into the concept that disparities between poorly accessible regions and the central part of the country markedly decrease.

Furthermore, the longer are the trips, the more even is the distribution of improvement of accessibility, thus the impact on territorial cohesion still more visible; paradoxically indifferently as to whether it is positive or negative. The choice of distance decay parameters may significantly influence the results of the investment evaluation, irrespective of the location of the investment.

Table 2. Impact on territorial cohesion of road infrastructure improvements

	baseline scenario	Case Study 1 Łódź - Warsaw		Case Study 2 Polish-German border – Nowy Tomyśl	
	AD	AD	Relative Change (%)	AD	Relative Change (%)
national short trips	0.554	0.558	0.70%	0.553	-0.13%
national long trips	0.212	0.214	0.97%	0.211	-0.14%
international short trips	0.531	0.530	0.00%	0.527	-0.74%
international long trips	0.294	0.288	-2.08%	0.285	-2.86%

5.4. Spatial distribution of the impact on accessibility improvement

Supplementing previous analyses, Table 3 provides information which focuses on the spatial distribution of the improvements by presenting the changes in accessibility observed in the successive 50-kilometre-buffers mapped separately along both motorway sections examined. Figures 3 and 4 visualise the spatial distribution of relative change in potential accessibility within particular municipalities, giving additional evidence concerning its directions and the extent to which improvement fans spread out from the ends of the sections. The fans obviously reach further when long trips distance decay is taken into consideration.

At the regional scale the accessibility improvement registered covers both corridor (up to 50 km) and successive spillover levels, however in most variants they mainly concentrate within the direct vicinity of the investment. An exception is only made when considering Case Study 2 in its international context, due to its location in the vicinity of the national border.

The spatial distribution of the impact on accessibility across the subsequent buffers strips obtained for short national trips suggests that there is hardly any difference between both case studies (Table 3), regardless of their peripheral/central location, or the population density in the area around the investments. However, the positive relative changes are more widely spread out from the Łódź-Warsaw section than takes place in the second case study (cf. fig. 3 and 4).

The central location of the previous section results in it being true that in all variants analysed the distribution of accessibility changes is quite similar. However, in the case of long international trips, spillovers reach out farther in a north-easterly direction, leading to a positive impact on cohesion (Table 1). In other variants, the relatively high baseline accessibility level in the vicinity of the investment produces increasing polarisation.

The improvement in accessibility produced by the construction of a peripheral section of motorway (Case Study 2) is strongly limited (fig 4). The exception is provided by long trips type of distance decay, especially in the international dimension, where the effect is extremely wide-ranging, reaching municipalities located even at the eastern border of the country. As a result, the cohesion impact in this variant of the analysis is significantly higher.

Table 3. Spillover effect of road infrastructure improvement

			Case Study 1 Łódź – Warsaw					Case Study 2 Polish-German border – Nowy Tomyśl				
			up to 50 km	50-100 km	100-150 km	150-200 km	more than 200 km	up to 50 km	50-100 km	100-150 km	150-200 km	more than 200 km
number of municipalities			169	266	382	460	1 044	78	143	174	252	1 674
population (thousands)			4 823.9	2 939.3	4 572.7	9 547.1	16 186.1	1 117.7	2 357.0	2 778.3	4 164.5	27 651.5
national dimension	short trips	average pop weighted base accessibility level	1 796.9	1 110.8	1 044.8	1 433.7	944.3	785.4	975.5	846.8	1 035.6	1 296.2
		average pop weighted relative change	6.0%	1.9%	1.1%	0.5%	0.2%	2.7%	0.3%	0.1%	0.0%	0.0%
		average pop weighted absolute change	104.4	21.0	11.1	4.9	1.2	13.9	3.1	0.6	0.3	0.1
		aggregated pop weighted absolute change (% of ONAE[a])	73.2%	14.7%	7.8%	3.4%	0.8%	77.7%	17.2%	3.3%	1.4%	0.3%
	long trips	average pop weighted base accessibility level	12 671.7	11 600.2	11 033.8	10 885.3	8 995.3	9 550.3	10 193.3	9 416.4	10 281.7	10 542.6
		average pop weighted relative change	3.1%	1.4%	1.2%	0.9%	0.7%	1.0%	0.1%	0.0%	0.0%	0.0%
		average pop weighted absolute change	392.7	157.4	123.5	90.6	55.6	83.0	12.3	3.5	2.8	2.1
		aggregated pop weighted absolute change (% of ONAE[a])	47.9%	19.2%	15.1%	11.1%	6.8%	80.0%	11.9%	3.4%	2.7%	2.0%
international dimension	short trips	average pop weighted base accessibility level	1 813.9	1 133.9	1 098.1	1 640.5	1 309.5	1 388.6	1 293.4	1 359.3	1 314.5	1 450.6
		average pop weighted relative change	6.0%	1.8%	1.0%	0.4%	0.1%	9.2%	6.5%	1.5%	0.7%	0.1%
		average pop weighted absolute change	106.3	21.2	11.2	4.9	1.2	123.6	88.6	17.3	7.4	1.8
		aggregated pop weighted absolute change (% of ONAE[a])	73.4%	14.7%	7.7%	3.4%	0.8%	51.8%	37.1%	7.2%	3.1%	0.7%
	long trips	average pop weighted base accessibility level	25 504.8	24 309.6	25 139.2	29 118.2	28 538.1	36 643.2	33 301.4	33 986.7	31 506.6	25 469.5
		average pop weighted relative change	4.9%	2.0%	1.3%	0.9%	0.4%	5.0%	6.5%	2.9%	3.0%	2.2%
		average pop weighted absolute change	1 212.5	433.0	277.8	186.5	88.3	1 733.2	2 036.5	802.6	723.8	479.2
		aggregated pop weighted absolute change (% of ONAE[a])	55.2%	19.7%	12.6%	8.5%	4.0%	30.0%	35.3%	13.9%	12.5%	8.3%

[a] ONAE – Overall National Accessibility Effect

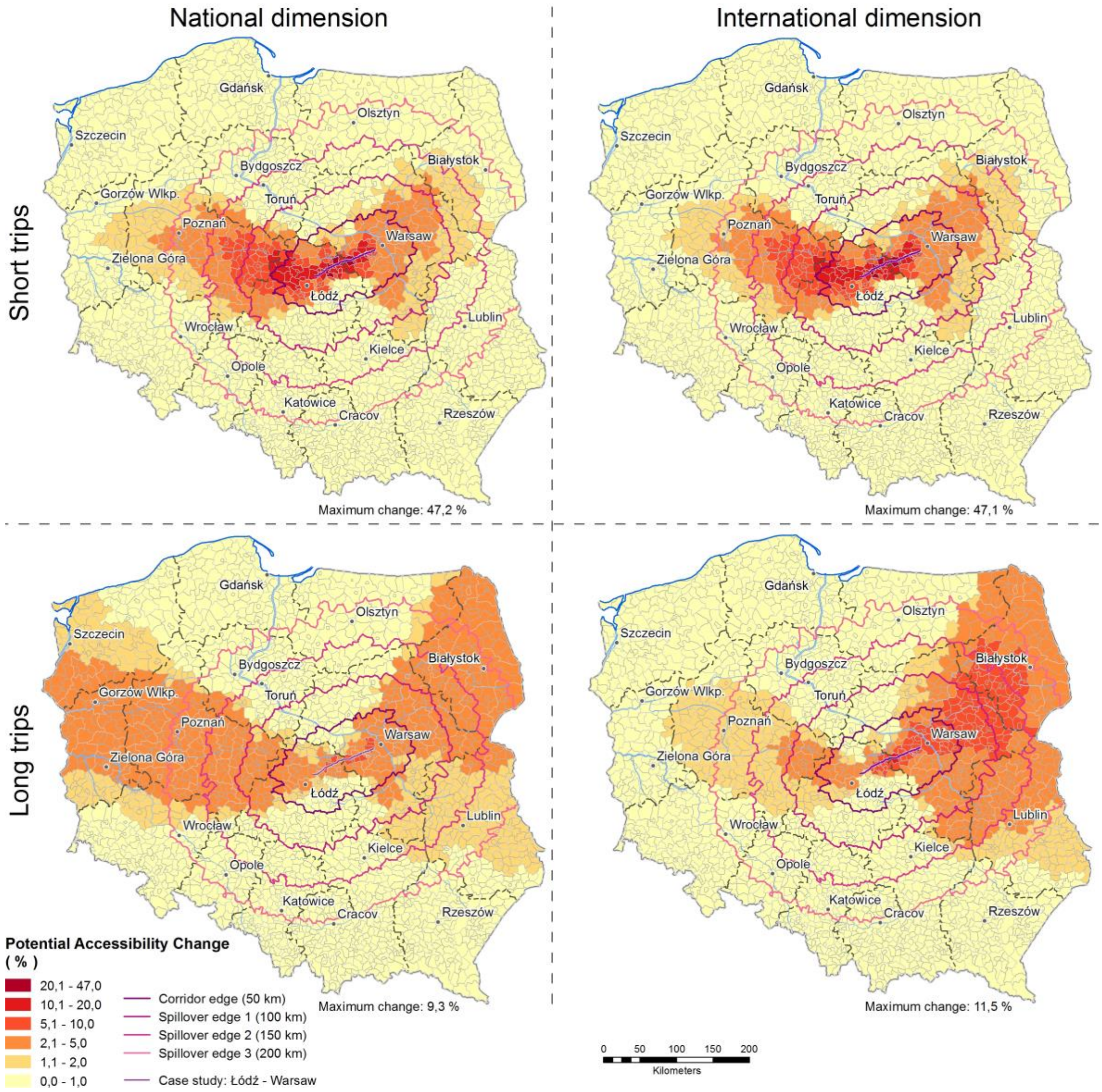

Fig. 3. Relative **c**hanges in potential accessibility: Case Study 1 (Łódź – Warsaw) vs baseline scenario

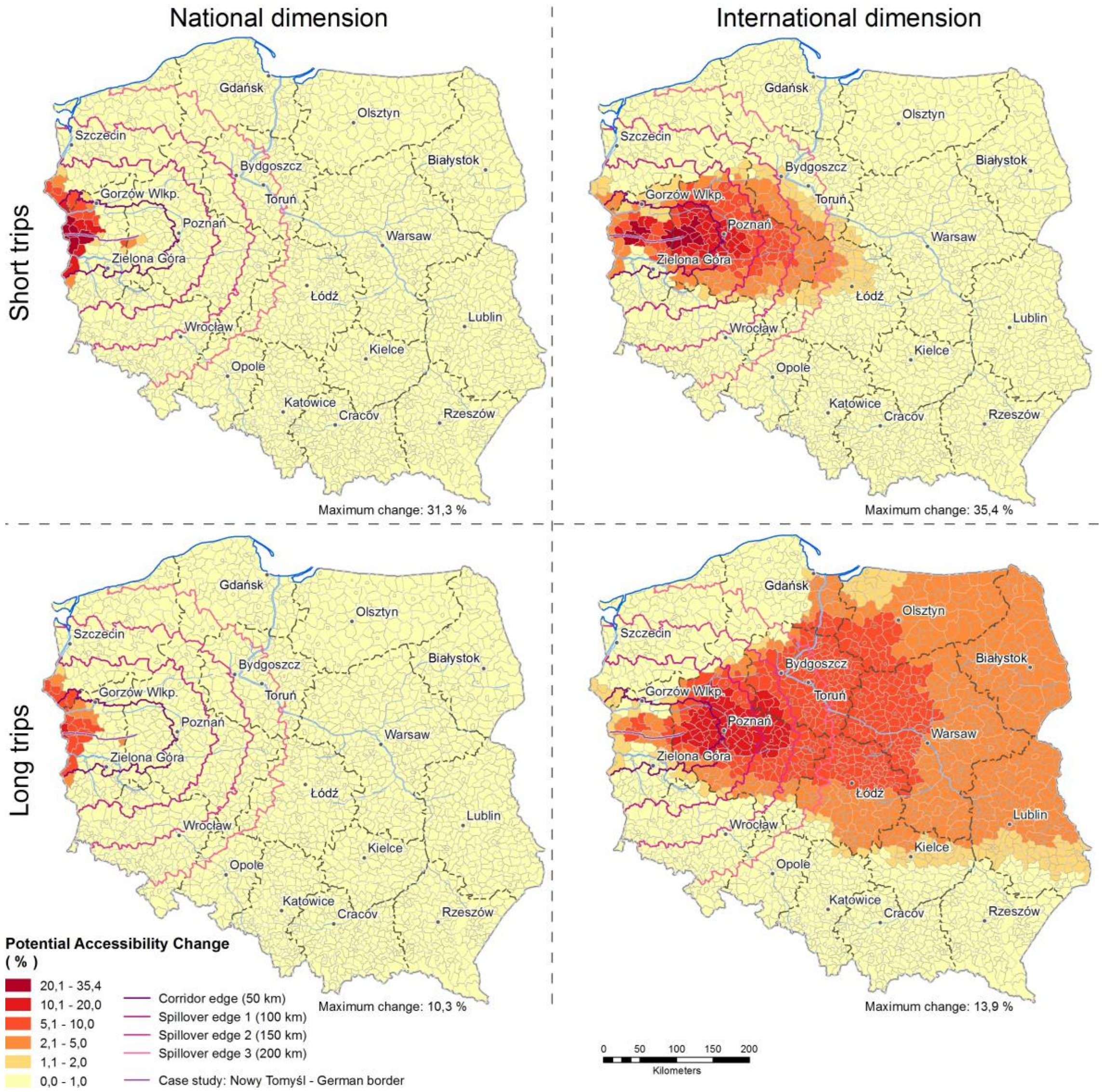

Fig. 4. Relative changes in potential accessibility: Case Study 2 (Polish-German border – Nowy Tomyśl) vs baseline scenario

The contrasting results of the analysis presented confirm the usefulness of the approach presented and provide a strong argument for the need for a multidimensional evaluation of road investments. Logically, adjusting the lower values of parameter *β* reflecting longer trips indicates a more dispersed and a wider spread of the improvement in accessibility. Nevertheless, even adoption of the same distance decay parameters may lead to contradictory conclusions, depending on the inclusion of an international context, or the limitation of the scope to the national perspective. It is clearly visible, in particular when comparing results for distance decay typical for long trips for Case Study 2, which is both peripheral from the national point of view, and central from the international one.

6. Conclusions

The paper describes further investigations into the possible application of potential accessibility analyses in evaluating road network development by taking a three-fold approach, which combines an overall improvement in accessibility level, territorial cohesion and spatial spillovers of the investment. To the best of our knowledge, this is the first study that integrates all abovementioned aspects into one, comprehensive analysis, that additionally uses two different spatial dimensions (i.e.

international and national) and adopts two different types of distance decay (for long and short trips) at a very detailed scale (LAU-2 units). The proposed methodology is tested on two separate sections of motorway, which are similar in length, but differ in location both in terms of population density and settlement structure around the investment, as well as in relation to the centre of the country and European core. We argue that the location of the investment and the incorporation of the international dimension (or not) mostly affect the overall changes in accessibility level. The distance decay function influences the overall scale of changes, but not its pattern. These general conclusions should be further verified based on investigation of other case studies. The adaptability of presented methodology is relatively high, limited only in some exceptional cases, e.g. remote island countries, where comparison between national and international road accessibility is rather fruitless. On the contrary, countries of high level of international connections seems to be particularly predisposed to the analysis, e.g. European states which constitute the Schengen area.

Furthermore, we show that, at the very local scale (LAU2) there is no direct relationship between the accessibility improvement and the reduction in territorial polarisation. The comparison of the results received (Tables 2 and 3) suggests that the impact on territorial cohesion depends on the combination of two issues: the baseline accessibility level in the vicinity of the investment and the spillover pattern. The selected variant of analysis used determines which of them dominate.

As a result, we argue that the combination of different dimensions of accessibility leads to results, which differ with respect to efficiency, equity and spillover effects. On this basis, we try to underline the importance of the multidimensional approach for analyses of potential accessibility, which use the divergent distance decay function into both international as well as national analyses. We do not aspire to provide an ‘absolute truth’, but rather we intend to spread uncertainty concerning the results of potential accessibility analyses based on only one combination of dimensions. There is no single answer on which dimensions are most important and which combination of dimensions fits the best. The answer is beyond the scope of this analysis. However, we can predict that the spatial dimension (national vs. international) is much more important for small centrally located countries than for big, peripheral ones. We also suggest employing an international dimension when investigating the development of the road network financed (or co-financed) from European funds (cf. Gutiérrez et al., 2011; Spiekermann et al., 2013), however in this case the effect of the new sections in neighbouring countries should be included into analysis. By contrast, the national dimension and distance decay for short trips should be taken into consideration, when an investment is to be supported by local authorities.

The analysis provides a set of instruments for the investigation of selected accessibility dimensions (i.e. impedance and spatial scale), however, other dimensions remain untouched (cf. “masses” of origins and destinations, types of transport etc.; Spiekermann et al., 2013). Thus, further research should be directed at delivering a methodology, which allows one to include the remaining dimensions of accessibility. Treating our trial as a general outline, we argue that by using tailor-made parameters of potential accessibility indicator supplemented by well-chosen case studies it is possible to propose a simple, universal methodological framework for comprehensive multidimensional evaluation of transport network investments.

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