Road and railway potential accessibility of Poland in the European dimension

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Abstract

The main goal of the paper is to present the results of the potential accessibility model, which enables simulations of changes of accessibility in Poland to be performed due to the opening of the model to the international dimension. The most important conclusions from the analysis of potential accessibility are as follows. The spatial distribution of potential accessibility depends most upon the value of the beta parameter appearing in the exponential distance decay function and upon the spatial scale (national vs. international variant of the analysis). The opening up of the potential model to the entire European continent significantly changes the image of accessibility in Poland, in particular when long trips are taken into account. For shorter trips the areas located along the German border benefit, mainly owing to the proximity of Berlin, yet the highest accessibility still remains in Warsaw and Upper Silesia (as in the national variant). For longer trips the areas with the best accessibility are Lower Silesia (south-western part of Poland), along with the areas bordering Germany and the Czech Republic. The accessibility level decreases in a north-easterly direction. Railway accessibility changes to a much smaller extent when the model is opened to the European dimension. The results of the study may find application in planning analyses, in strategies, in relation to cohesion, regional and transport policies, and also in the transboundary context.

Keywords: potential accessibility, spatial scale, distance decay, Poland.

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1. Introduction

Accessibility is a widely used term and plays an important role in many scientific fields. It constitutes one of the main research areas within the domain of transport geography. An essential element of the material dealt with here is its practical application, in that analyses of accessibility result not only in diagnostic descriptions of problems relating to the movement of people and goods, but also provide the primary

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prerequisite for the implementation of an appropriate transport policy designed to promote territorial cohesion. The international (European) dimension has an increasing significance in analyses of accessibility. This is clearly visible in everyday contacts relating to the inhabitants of border areas and, when considering long trips, also over the entire area of the country.

Potential accessibility is a widely used method for the measurement of the effects of transport investments. However, only a few studies exploit the potential accessibility concept using high spatial resolution (LAU-2) both at the national and international scale. Therefore, the main goal of the paper is to present the model of potential accessibility of municipalities from the national and international point of view. The methodological objective is the verification of potential accessibility at the national and international level by considering various different parameters of the so-called distance decay function.

The subject under investigation is the surface accessibility of Poland. Surface accessibility is understood in the study as the accessibility "achieved" owing to the modes of "surface" transport, i.e. automobiles (road accessibility) and passenger trains (railway accessibility). Therefore the calculation refers both to the road and railway network. The potential model has been developed in the Institute of Geography and Spatial Organization in Warsaw. The analyses presented in this paper use the potential formula and railway timetable provided in the research project 'Multimodal public transport accessibility of Polish gminas'. The research was funded by the National Science Centre allocated on the basis of the decision no. DEC-2012/05/E/HS4/01798. The travel speed model and the road network layer have been prepared within the research project 'Transport infrastructure development and modal shift in Poland in the years 2000-2010'. The research was funded by the National Science Centre allocated on the basis of the decision no. DEC-2011/01/D/HS4/01862.

2. Methodology

Hansen (1959) suggests that accessibility can be seen as "the potential of opportunities for interaction". According to Bruinsma and Rietveld (1998) accessibility is the "attractiveness of a node in a network taking into account the mass of other nodes and the costs to reach those nodes via the network". Geurs and Ritsema van Eck (2001) suggest that accessibility is determined by several components: the land-use component (the spatial distribution of activities at destinations and the demand for these activities), the transport component (the travel time, cost or effort of travelling between the origin node and destination node), the individual component (the needs, abilities and opportunities of individual travellers) and temporal component (the time restrictions of individual travellers and availability of activities at different times of the day).

There are different approaches to the methodology of measurement of accessibility. On the basis of a literature survey five groups of methods were identified (Geurs and Ritsema van Eck 2001, Spiekermann et al. 2013, Komornicki et al. 2010, Rosik 2012):

– the infrastructure-based accessibility measure – the regional infrastructure equipment is evaluated by its quantity and quality,

– the distance-based accessibility measure (travel-cost accessibility) – distance, time or cost of travel to where the activity is sought (a single destination or a set of destinations),

– the isochronic-based accessibility measure (daily accessibility) – assessment of a set of destinations available within a particular travel distance, time or cost from the origin,

– the potential-based (gravity-based) accessibility measure – accessibility is measured by the number of activities (opportunities) which can be reached in a certain distance, time or effort weighted by the travel distance, time or effort to do so,

– the person-based accessibility measure – analysing accessibility at the individual level; the models take into account the individual behaviour of the transport network user and focus on the person's ability to participate in activities through space and time.

2.1 Potential accessibility indicator.

Potential accessibility is based on the negative exponential distance-decay function which produces the well-known potential accessibility indicator. The closer the opportunity (mass of each other region), the more it contributes to accessibility. The larger the opportunity, the more it influences the accessibility (Spiekermann et al. 2013).

The travel time between any pair of transport zones was calculated by applying the method of identifying the shortest travel routes according to Dijkstra's algorithm. Eventually the potential accessibility of a municipality *i* (road transport) or subregion *i* (railway transport) was calculated using the following index:

$$A_i = M_i \exp\left(-\beta t_{ii}\right) + \sum_j M_j \exp\left(-\beta t_{ij}\right) + \sum_k M_k \exp\left(-\beta t_{ik}\right)$$

where:
A_i – accessibility of a municipality/subregion *i*,
M_i – own mass (population) of a municipality/subregion *i*,
M_j – mass (population) of a municipality/subregion *j* located in Poland,
M_k – mass (population) of a transport zone *k* located outside of Poland,
t_{ii} – time of an internal trip within a municipality/subregion *i*,
t_{ij} – travel time between the municipality/subregion *i* and *j*.
t_{ik} – travel time between the municipality/subregion *i* and transport zones *k* located outside of Poland.

This accessibility involves three potentials in the form of the so-called own potential, i.e. $M_i \exp\left(-\beta t_{ii}\right)$, internal potential, i.e. $\sum_j M_j \exp\left(-\beta t_{ij}\right)$ and external potential, i.e. $\sum_k M_k \exp\left(-\beta t_{ik}\right)$.

2.2 Distance-decay.

The parameter β determines the slope of the distance decay effect. The potential model is very sensitive to the particular distance decay function that is used (Haynes et al. 2003). There are a number of distance decay functions specified in the literature (for a review see Geurs and van Eck (2001) and Martínez and Viegas (2013)). The exponential function is tightly linked to the travel behaviour theory (Handy and

Niemeier 1997) and is most useful in explaining population distribution (Song 1996). Therefore, we have adopted the most frequently used exponential function which assumes a variation in exponent parameters which depends on the spatial level of analysis. In general, we assume that the more locally we look, the shorter is the trip length and more rapid is the distance decay (higher β values). A short glance at the literature suffices to illustrate the difficulties in assessing the proper value of the exponent at each of the spatial levels analysed (Table 1).

Table 1. Potential accessibility studies with exponential decay at international and national level

Authors	Spatial scale	β parameter	Details
Schürmann and Taalat (2000)	European	0.003	Lorries
Stępniak and Rosik (2013)	European	0.005775	Cars
Schürmann and Taalat (2000)	European	0.007	Cars
Schürmann et al. (1997)	European	0.010	Cars
Reggiani et al. (2010)	National	0.009	Commuters in Germany
Stępniak and Rosik (2013)	National	0.023105	Cars
Stępniak et al. (2013)	National	0.034657	Population
Geurs and Eck (2001)	National	0.039	Dutch National Travel Survey
Spiekermann et al. (2013)	National	0.04621	Medical doctors

Source: own analysis.

In this model, the value 0.0347 was used for the potential accessibility to the population measured for short trips, and the value 0.005 was used for the potential accessibility to the population measured for long trips.

2.3 Spatial scale.

It is a characteristic feature of earlier studies on transport accessibility issues in Poland that the study area was limited to the territory of the country (Musiał-Malagó, 2005; Komornicki et al. 2010). However, in the European literature transport accessibility is analysed not only in the local, regional and national contexts, but also, which is of particular importance for the subject matter of this paper, in the international context, including the European or global one (see, e.g., Spiekermann and Neubauer, 2002, or Spiekermann and Schürmann, 2007). There are also some studies in Poland which take into account the European dimension (Stępniak and Rosik 2013; Więckowski at al. 2014).

The study method applied at the national and international level is usually potential accessibility, although important capacities in this respect are also offered by such methodologies as cumulative accessibility or distance-based accessibility. The study here reported used potential accessibility as the basic method of inquiry (Table 2).

In this paper, for road transport the study area encompassed the entire European continent, while for railway transport it was more or less the area of direct passenger railway connections from Poland. Yet, from the methodological standpoint one ought to split the spatial ranges concerning the origins and destinations of travel. The origins are uniquely located on the territory of Poland, while the destinations are located across the continent. For this reason all the maps showing the results of the analysis have been limited to the area of Poland. In the case of road transport, 2 321 transport zones (travel origins) have been distinguished in Poland at the municipal level. In railway transport 60 transport zones have been distinguished (origins of travel) at the subregional level.

Table 2. European and transboundary potential accessibility studies

Authors	Spatial resolution	Origins/Destinations	Spatial scale	Transport modes
Keeble et al. (1982)	NUTS 1; NUTS 2	GDP in NUTS 2 (EWG) and NUTS 0 (other)	EU9; EU12	Heavy load vehicles
Spiekermann and Wegener (1996)	Raster cells	Population	EU27+2	Rail
Copus (1999)	NUTS 2; NUTS 3	Population, GDP	EU15+2+12	Road
Wegener et al. (2001)	NUTS 3	Population, GDP	EU15	Road, rail, air
Schürmann and Talaat (2000)	NUTS 0, NUTS 3	Population, GDP	EU15+12	Road
Spiekermann and Schürmann (2007)	NUTS 3	Population	EU27+2	Road, rail, air multimodal
Spiekermann and Aalbu (2004)	NUTS 3, LAU 2	LAU 2	Scandinavian countries	Road, rail, air multimodal
Stępniak and Rosik (2013)	Poland (LAU-2)	Population	Europe (destinations)	Road
Więckowski et al. (2014)	Polish-Slovak borderland (LAU-1)	Population	Europe (destinations)	Road

Source: own analysis based on Spiekermann et al. (2013).

The number of destination zones is, naturally, much broader than that of the travel origins. The former encompasses not only the subset of the travel destinations in Poland, which is identical to the set of travel origins (each travel origin is at the same time also a travel destination), but also a subset of travel destinations located outside of Poland (for road transport across the territory of the whole European continent). The territory of Europe outside of Poland was divided into 212 transport zones for road transport and into 25 transport zones for railway transport. Furthermore, following Schürmann and Taalat (2000), we assume that the closer (in travel time) to the Polish border the units are, the more they contribute to the accessibility potential of the study area. Therefore, closer to the Polish border the smaller units are chosen, even the LAU-1 units are taken into consideration.

2.4 Travel times and speeds.

Both in road and railway transport, the element of distance decay that has been selected (from among such factors making up the generalised cost as time, cost and convenience of travelling) is time. The travel speeds for private cars were adjusted down for driving impediments. The model includes 14 categories of road in Poland (Rosik 2012). The average speed in Poland was calculated for road sections taking account traffic regulations and some other variables influencing the speed of vehicles such as, for instance, the number of inhabitants in a buffer zone of five kilometres around the section, the existence of a built-up area, and the topographic features of the area. For each road category, and for each variable influencing the travel speed, different parameters were applied producing the appropriate speed-limit-related reductions of travel speed.

In general the travel times for road transport were estimated for more than 12 000 road sections, including local roads. Internal travel times within the transport zones were estimated by equating the area of the district with that of an equivalent circle and assuming that the average distance travelled inside the transport district equals half of the radius. Therefore the self-potential calculation is based on the internal travel time (e.g. Gutiérrez et al., 2011; Rich, 1978) using the formula:

$$t_{ii} = \frac{0,5\sqrt{\frac{S}{\pi}}}{\overline{v_{ii}}} \times 60$$

where t_{ii} stands for the internal travel time, S – for the surface of a unit i and $\overline{v_{ii}}$ – for the average travel speed within a unit i.

Waiting times at the eastern border were estimated using information from the Border Guards Speeds. Travel times on roads outside Poland were estimated on the basis of road category and the highway regulations of the particular European countries. For railway transport the sources of information on travel times were web-based train timetables.

2.5 Temporal scope.

The temporal scope of the study includes the years 2010-2011 for the network data, and the year 2008 for the population data. The state of the road network was brought up to the situation as of the end of 2011. Railway connections have been considered according to the railway timetables in operation in June 2010. In 2011 an analysis was also carried out of the waiting times for passenger cars at the border crossing points at the Polish borders.

3. Results at the national level

The assessment of potential accessibility for each of the modes analysed (road and railway) is presented on four maps. The maps reflect both the differentiation according to spatial scale (intranational and international variants) and the variation of the distance decay parameters (short vs long trips).

In the "national" variant for short trips, the most accessible areas in the context of the entire country are the Metropolitan Area of Warsaw and the Upper Silesia region, the areas along the latitudinal motorway routes A2 (to Poznań) and A4 (to Wrocław), and, though to a lesser extent, the areas of the remaining large cities with high population densities. In general two big poles of better accessibility are observed. One central pole created by the Warsaw metropolitan area and Łódź (the third biggest city in Poland) in the centre of Poland and the second big pole in southern Poland consists of the Upper Silesia conurbation and Cracow (the second biggest city in Poland). The worst situation in terms of road accessibility is visible in the border regions, in particular in north-western and north-eastern Poland (Fig. 1).

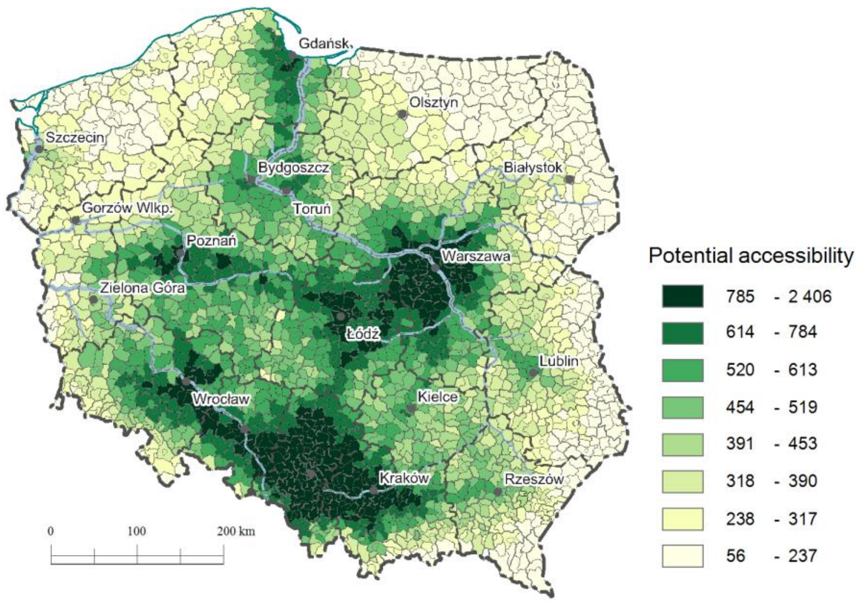

Figure 1: National variant. Road accessibility. Short trips
Source: own analysis.

Let us assume an increase in distance travelled (long trips) and consequently a smoother exponential distance decay function. In this case the accessibility pattern is a little bit different. The area of higher accessibility concentrates within the triangle between Konin, Warsaw and Katowice. The accessibility diminishes in the direction of all the borders and the more accessible motorway corridors are less visible than in the case of short trips. However, north-eastern Poland is still one of the least accessible parts of the country (Fig. 2).

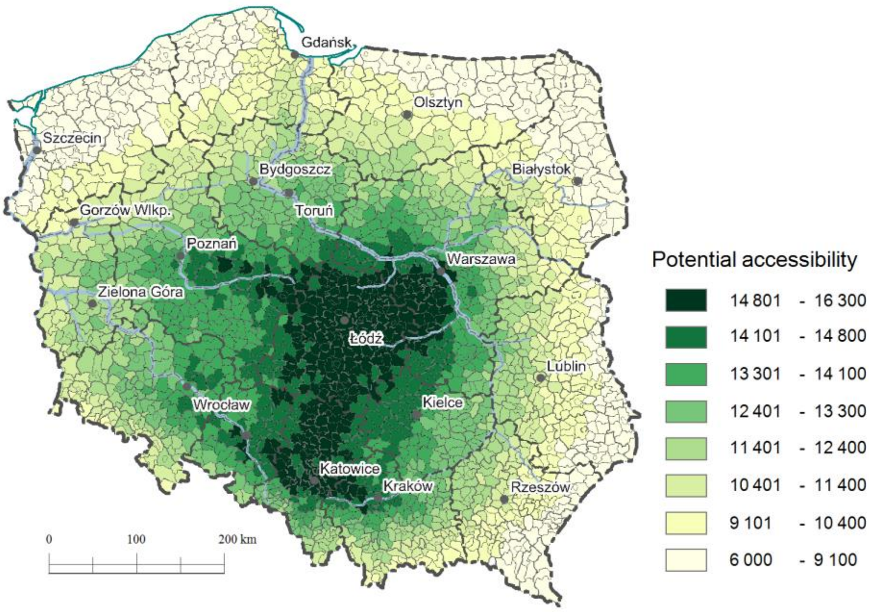

Figure 2: National variant. Road accessibility. Long trips
Source: own analysis.

In the area of railway transport bigger regional differences in accessibility are observed resulting from a combination of uneven access to the railway network of various density. One can identify areas in central Poland that are relatively worse off in terms of accessibility (e.g. the north-western part of the Mazovia region) than some areas of peripheral location, this being connected with the very poor quality of the railway network over some lines in central Poland. On the other hand, Szczecin in north-western Poland is relatively well-accessed by train due to the good quality of the railway line linking Szczecin with central Poland. The accessibility of north-eastern Poland is still very poor which indicates a need for the acceleration of work on Rail Baltica (Fig. 3).

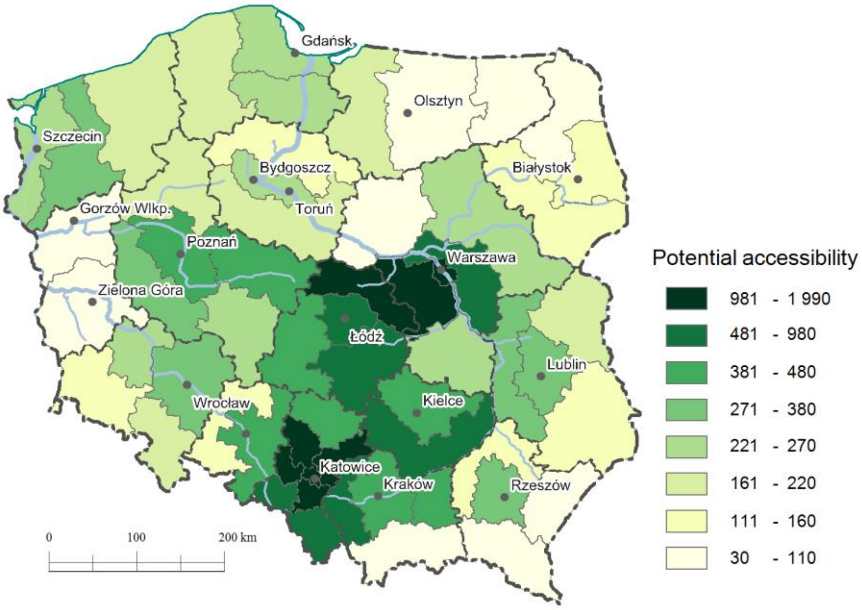

Figure 3: National variant. Railway accessibility. Short trips
Source: own analysis.

The accessibility pattern for long trips in the case of railway transport is very close to the accessibility pattern for short trips. A slightly higher concentration of better accessibility areas in the central regions is visible. However, there are still the well-accessed cities of Gdansk (in the north) or even Białystok, Lublin and Rzeszów (in eastern Poland) surrounded by areas with the poorest railway accessibility. This is due to the fact that direct interagglomeration trains operate to Warsaw and Cracow, the two largest cities in Poland, and there is no possibility for travellers to transfer to one of the sub-regional centres in Eastern Poland during the trip (Fig. 4).

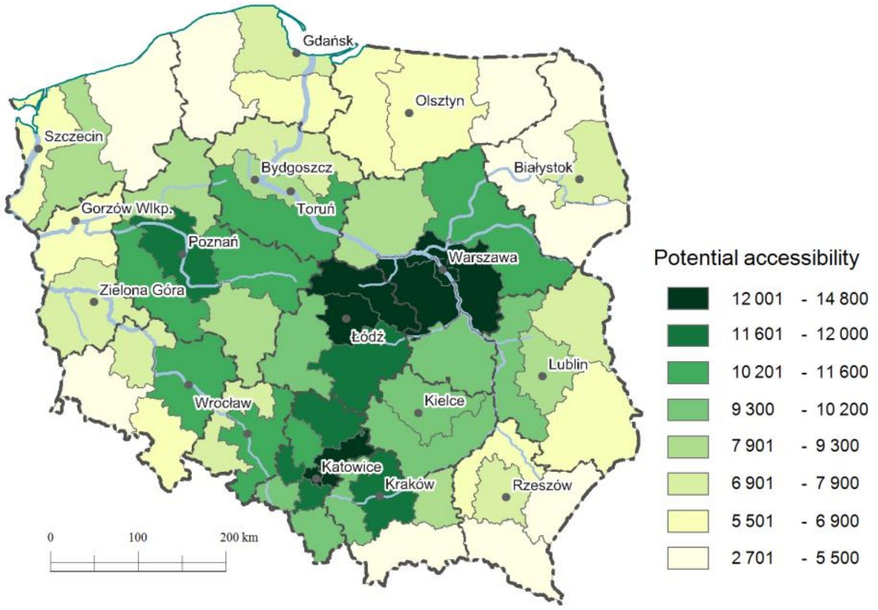

Figure 4: National variant. Railway accessibility. Long trips
Source: own analysis.

4. Results at the international level

The opening up of the potential model to the entire European continent ("European variant") changes significantly the accessibility pattern within Poland. Although the highest accessibility remains in Warsaw and Upper Silesia, the areas situated along the German border gain for shorter trips, mainly owing to the proximity of Berlin. Therefore, we can suggest a third 'pole' of better accessibility along the Polish-German border. The southern 'pole' of Upper Silesia and Cracow also gains due to the proximity of Ostrava and the densely populated north-eastern part of the Czech Republic. The area of poor accessibility lies along the Baltic coast between Szczecin and Gdańsk (Middle Pomerania region) and in Eastern Poland (north-eastern in particular) (Fig. 5).

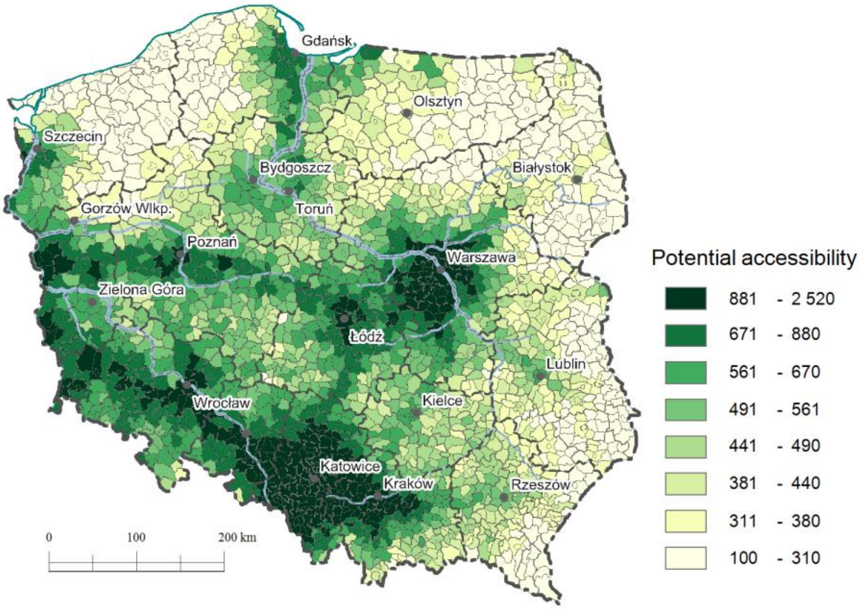

Figure 5: European variant. Road accessibility. Short trips
Source: own analysis.

At international level, when long trips are taken into account, the accessibility pattern is completely different to the one obtained at national level. For long trips the best accessibility is found in Lower Silesia along with the areas bordering Germany and the Czech Republic, while accessibility decreases in a north-easterly direction (Fig. 6). The accessibility pattern in Poland is very similar to the one obtained by Spiekermann and Schürmann (2007). This is not surprising due to the very similar methodological assumptions concerning the potential model in general and its details.

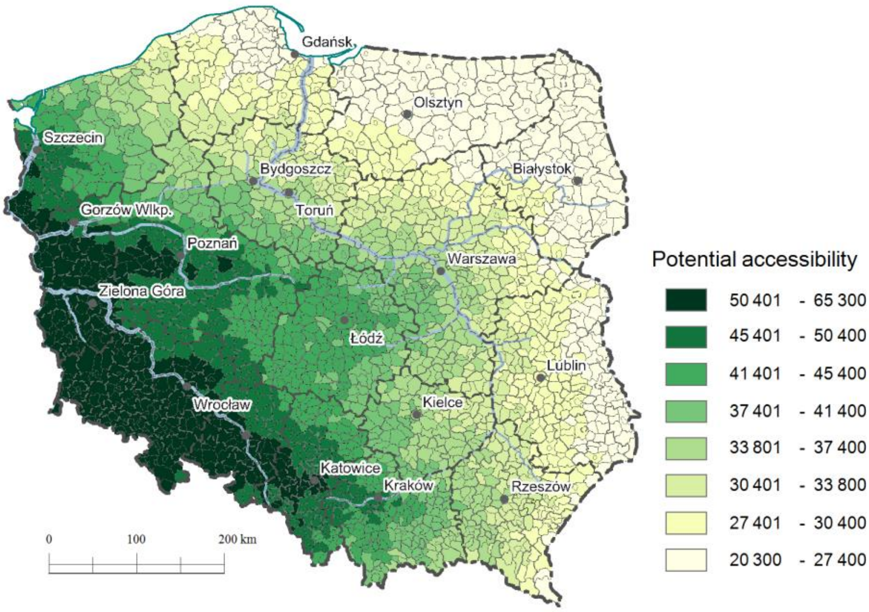

Figure 6: European variant. Road accessibility. Long trips
Source: own analysis.

The opening up of the potential model to the European dimension changes railway accessibility to a much smaller degree than the changes in the pattern of road accessibility. This fact can be explained by the relatively low number of direct international connections, usually operating from the largest agglomerations of Poland (Fig. 7).

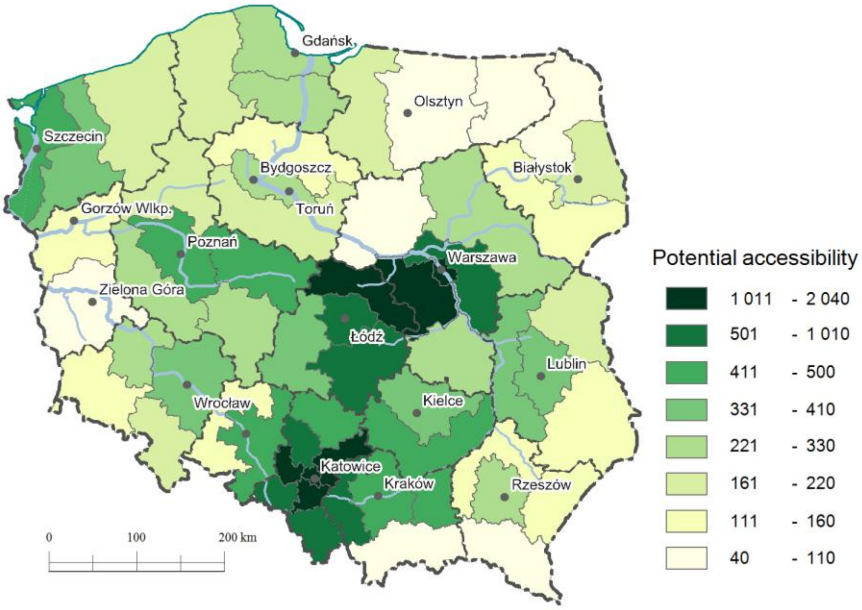

Figure 7: European variant. Railway accessibility. Short trips
Source: own analysis.

For long trips the cities of Poznań, Wrocław and Szczecin, which are relatively well connected by train with German and Czech towns, gain additional accessibility potential. However, it is still difficult for the inhabitants of capitals of border sub-regions to travel by train to neighbouring countries without changing trains. Therefore the better accessibility refers mainly to the biggest cities. North-eastern Poland and the Polish-Slovak borderland remain the areas with the lowest railway accessibility level at international scale (Fig. 8).

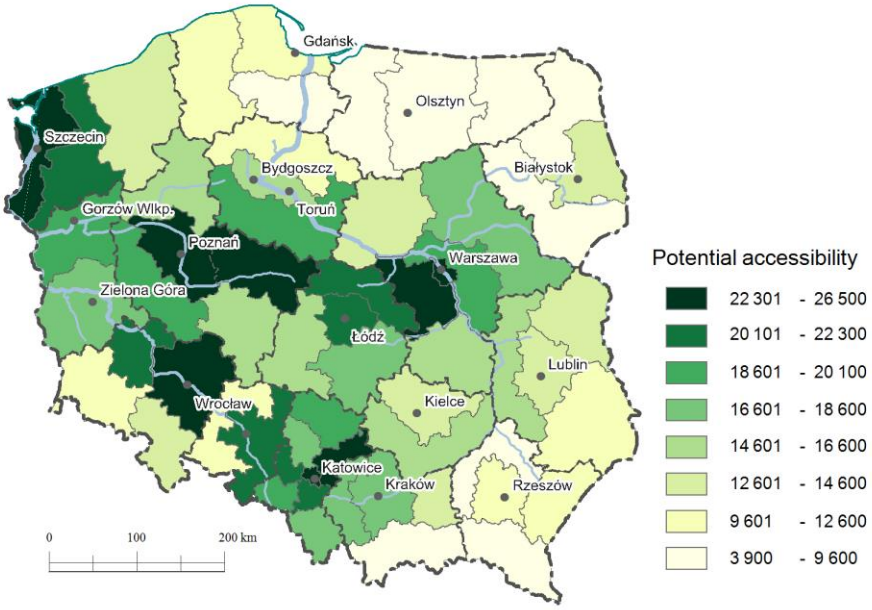

Figure 8: European variant. Railway accessibility. Long trips
Source: own analysis.

5. Conclusions

The most important conclusions from the analysis of potential accessibility are as follows. The most significant influence on the spatial distribution of potential accessibility is the beta parameter appearing in the exponential decay function. Moreover, the opening up of the potential model to the entire European continent significantly changes the image of the accessibility within Poland. For shorter trips the areas situated along the German border gain accessibility potential, mainly owing to the proximity of Berlin, yet the highest accessibility still remains around Warsaw and in Upper Silesia. For longer trips in the international variant, the best accessibility is in Lower Silesia along with the areas bordering Germany and the Czech Republic, and it decreases in a north-easterly direction. Railway accessibility changes to a much lesser extent after the model is opened to the European dimension and the change refers mainly to the biggest cities having direct access by international trains to such centres as Berlin. North-eastern Poland remains the region which is the least accessible in Poland irrespective of the length of trip and spatial scale of the analysis.

The recommendations concerning the priority setting of activities related to the construction or modernisation of particular segments of the transport networks at areas of poor accessibility can be helpful for decision makers and planners at various levels of administration, from local government to central government. The results of the study may find application in planning analyses, in strategies concerning cohesion, regional and transport policies, in particular in the transboundary context. The results obtained ought to be interesting from the point of view of selecting the optimum location of production and service facilities. Entrepreneurs may, based on their knowledge of regional differences in national and international accessibility, take appropriate location decisions and direct their investment efforts to the spatial units that best match their requirements.

The paper presented ought to be perceived as an introduction to the study of transport accessibility in Poland. The respective analyses should be expanded by undertaking further empirical investigations into the proper shape of the distance decay function. These ought to be broadly conceived studies of the influence of distance on the perception of attractiveness of travel destinations, depending not only upon the travel purpose, but also the socio-economic characteristics of the traffic participant (such as income, education, profession and age). It would be interesting to introduce so-called competition effects into the analysis, differentiating demand and supply, depending upon travel purpose and the attractiveness of the travel destination. Development of the analysis in the direction of multimodality and intermodality, with inclusion of the possibility of changing means of transport and modes during travel, constitutes a true methodological challenge, necessarily faced in the case of the extension of the model in the direction of air transport.

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