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Relations between theoretical and real-time accessibility for inter-regional, intra-regional and intra-urban car journeys: The example of Poland

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Abstract. The article presents the results of research devoted to comparing accessibility in terms of theoretical and real travel times by car at inter-regional, intra-regional and intra-urban scales. The research strives to achieve three types of aim. The methodological aim is to assess the suitability of the data for research into transport geography, in particular with regard to accessibility. This objective also focuses on developing a method for acquiring and processing source data from suppliers. The cognitive goal is to analyse the spatial differentiation of theoretical and real travel times at different spatial scales. In terms of application, the focus is on the use of real travel time data for transport planning. Data on theoretical travel times includes the author's own calculations based on analyses whose key assumption is that cars move on a road network at the maximum speeds allowed by the law with all other variables being excluded. The other source of data (on real travel times) is the Distance Matrix Response provided by Google Maps APIs. Due to methods such as isochrones and cumulative accessibility it was concluded that data obtained from Google servers is highly useful for research into transport geography, including time accessibility analyses. The patterns presented here however cannot be treated uncritically or used for unrestricted analysis. With regard to the cognitive goal, it should be emphasized that spatial variations in travel differences, resulting from theoretical and real variants for journeys between regional cities in Poland, between settlement units within one region, or within one of its large cities, are heterogeneous depending on the nature and length of the journey. Therefore, depending on the spatial extent of analysis, divergences in travel times should be expected.

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1. Introduction

The reason for research is the wish to analyse, in terms of car transport, differences in accessibility. This results from calculations based on data referring to travel times for a matrix of points (origin and destination) at different spatial levels: national, regional and local. The sources include the author's measurements based on analyses whose key assumption is that cars move on the road network at the maximum speeds allowed by law with the exclusion of all other variables (such as congestion, weather conditions or the driver's personal features) (Bottasso, Conti, 2010; Kotavaara et al., 2011). The method also takes into account local speed conditions, such as restrictions in built-up areas, nevertheless it is largely arbitrary. Another source of data is the Distance Matrix Response provided by Google Maps APIs. This service makes it possible to obtain data on real travel times between any two points on the surface of the planet which can be reached by a given transport mode, i.e. as long as they are connected by an adequate transport network. The algorithm will be explained later in the article (Wiśniewski, 2016, 2017).

The research was conducted at three spatial levels: inter-regional, intra-regional and intra-urban (Fig. 1). This has enabled analyses of journeys of differing durations, accomplished on road networks of differing character (including standard of the roads), and running through areas of diverse development which might affect journeys in a variety of ways and to differing extents (Bruinsma, Rietveld, 1998; Chen, 2004; Cohen, Paul, 2007). The inter-regional analysis included journeys between the 18 province capitals which are seats of government and local authorities at a regional level. With regard to intra-regional scale analysis, journeys between all settlement units (towns and villages) within Łódź province administrative boundaries were considered. Journeys accomplished within a city were analysed using the example of Łódź, a city covering 293.25 km^2 and inhabited by 658 573 people. All the data used in the article was downloaded from the supplier in August 2016.

To compare theoretical and real travel times it was necessary, in the first place, to construct a matrix of journey origins and destinations. They comprised provincial capitals in the case of inter-regional connections (18 x 18 matrix), all settlement units in the Łódź region for intra-regional connections (4 968 x 4 968 matrix), and artificially generated research points for intra-urban connections (21 347 x 21 347 matrix). These points were vertices of a square of sides of 100 m constructing a network inscribed within the administrative boundaries of Łódź (Kwan, 1998). Only those points which could not be accessed due to the lack of a road network (e.g. located on a reservoir) were excluded.

The article has three kinds of aim: methodological, cognitive and applied. The first includes an assessment of the suitability of the data for research in the field of transport geography, with particular emphasis on accessibility. The second focuses the spatial differentiation of travel time differences resulting from theoretical and real variants at particular spatial levels: national, regional and local. In terms of application, its main value is the use of real travel time data for transport planning taking into account deviations from theoretical travel times.

Considerable interest in the topic of accessibility is reflected in numerous publications. It is worth mentioning research by Ingram (1971), Spieker-

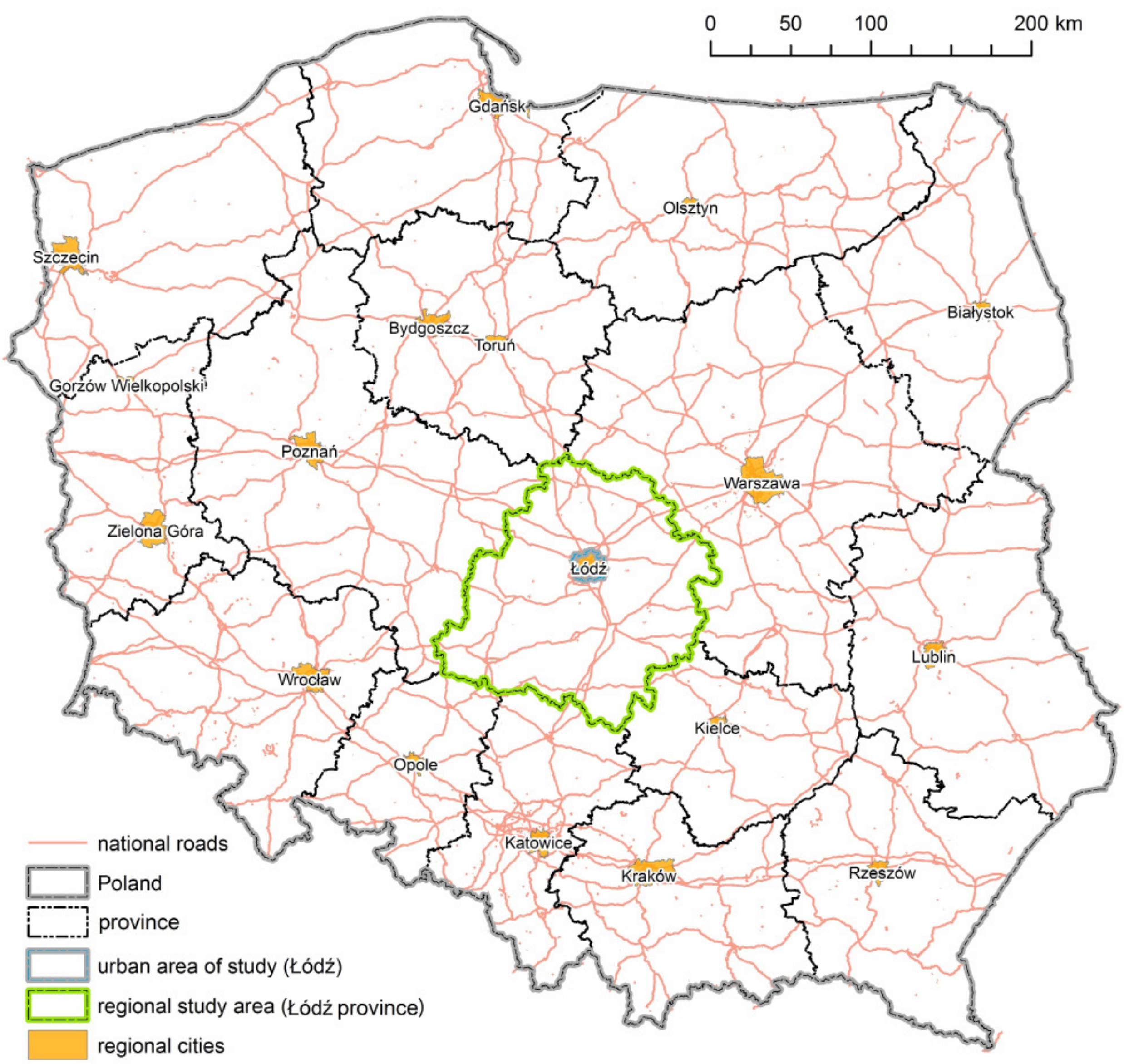

Fig. 1. Research areas: inter-regional, intra-regional and intra-urban levels
Source: Author's own work

mann, Neubauer (2002), Guzik (2003), Komornicki et al. (2010), Rosik (2012), Stępniak, Rosik (2013), Koźlak (2012) and Wiśniewski (2015). Research has also been done with the use of data on traffic transmitted in real time but there are far fewer publications in this field. These include however those by Rose (2007), Bar-Gera (2007), Becker et al. (2011), Calabrese et al. (2010), Gao, Liu (2013), Iqbal et al. (2014), Bartosiewicz, Wiśniewski (2015) and Wiśniewski (2016, 2017).

2. Source materials and research methods

In order to accomplish the research aims it was necessary to collect data on the road network in Poland as well as the distribution of its settlement units and population. Information about routes so as to calculate the maximum speeds on individual segments of the road network was obtained from the resources of the 'General Directorate for National Roads and Motorways' (GDDKiA), provincial road authorities responsible for Poland's 16 provinces, as well as the Polish cartographic database (BDOT) and OpenStreetMap (OSM) so as to calculate theoretical travel times. The research includes data on the distribution of all settlement units in Poland together with their number of inhabitants. A central point was generated for every settlement unit and was given a population in accordance with data from the Ministry of Internal Affairs and Administration, the Main Statistical Office and local government offices.

The following procedure allowed theoretical travel times to be calculated. The first step consisted in the construction of a transport network on the basis of which travel times were subsequently calculated. At this stage every segment of the network was ascribed the maximum speed allowed depending on the type of road. This allowed the segment's travel time to be estimated and finally the quickest routes between journey origins and destinations to be selected in accordance with Dijkstra's algorithm. Obtaining data concerning real travel times requires more discussion. Firstly, the use of the term 'real' needs to be explained. In accordance with the instructions presented by the service provider, travel time between any two points is defined as the 'perennial' average (earliest measurements from 1 January 1970) of vehicles between these points. It is necessary here to show how Google gets information on travel routes. Data is obtained from sensors located on roads, from taxi corporations, government services, private database distributors and on an anonymous basis from users of such software as the mobile version of Google Maps for Android, IOS, Symbian, Windows Phone which give access to their location. The service provider collects data concerning the routes followed by the devices and is able to specify how long a journey between two specific points, normally in real traffic conditions, will be through averaging all the data. This averaging by the service provider requires a brief comment. The maximum period of data collection, of course, depends on location. This is obviously related to the level of economic development and the widespread presence of vehicles registering their geographical position. Under Polish conditions, the data collection period is much shorter and in addition, the service provider does not supply a precise algorithm for averaging the results. It is not possible to determine how the measurements were made by Google or to recognize its weaknesses.

In order to interpret results correctly, it is important to understand how the average speed on each segment of the road network is calculated. The service provider collects average speed information transmitted from individual vehicles (e.g. GPS, mobile phones) and assigns them to the road segment which they are currently located in. Each signal develops the average. The theoretical variant determines a 'net' journey. This is the time needed to complete it without resting or eating, but also without restrictions due to traffic or congestion. The real variant based on data provided by Google assumes 'gross' driving conditions, which defines the time taken to travel from the beginning to the end of a journey, but also without any breaks.

Before downloading data from the service provider it is necessary to accept license requirements and obtain a suitable API key. Application parameters include starting and destination points (it is possible to feed one or more locations in the form of geographical coordinates), 'movement mode' (means of transport), exclusions (of journeys made on roads of certain standards), or traffic models (the 'perennial' average, the longest or the shortest travel times in this period). Construction of matrices and juxtaposition of theoretical and real travel times between all starting and destination points for each research level allowed comparative analyses to be obtained as well as analyses within individual databases. On the basis of the material prepared in this way the author used an isochrone method taking into account information on the distribution of the region's and the city's populations.

3. Inter-regional level

The first stage of the research concerns connections between provincial capitals in Poland; 324 were generated for both the theoretical variant and the 'real' one for the purposes of the research (Fig. 2). The distribution of the largest urban centres relative to one another and their connection by road results in durations from under one hour to as many as eight.

In the case of inter-regional journeys, it is roads of the highest standard (motorways and express-

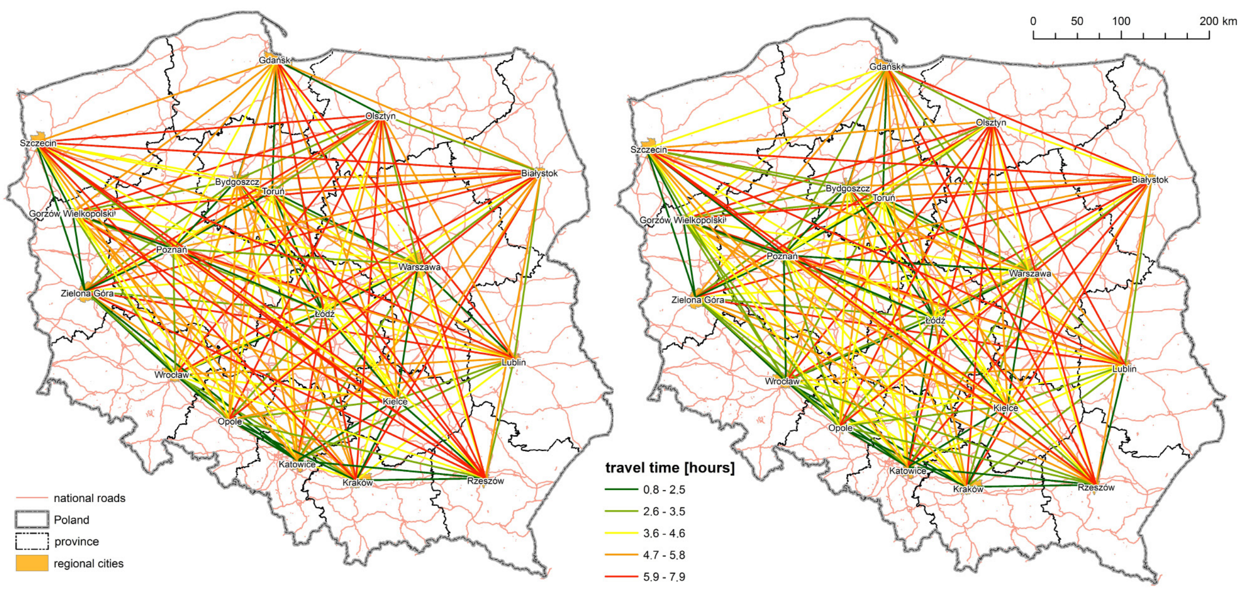

Fig. 2. Spatial differentiation of theoretical (right map) and real (left map) travel times by car between provincial capitals in Poland
Source: Author's own work

ways) that are particularly important. Their routes in Poland are roughly latitudinal or longitudinal but despite investments there are still not enough diagonal network elements (Rosik et al., 2015). This is why, irrespective of the research variant, centres located near roads of the highest standard, such as Szczecin-GorzówWielkopolski-ZielonaGóra-Wrocław-Opole-Katowice-Kraków or Poznań-Łódź-Warszawa or Gdańsk-Toruń-Łódź, have the highest accessibility in relation to one another in terms of travel time. The juxtaposition of theoretical and real results inter-regionally points to discrepancies ranging from gains in relation to theoretical times amounting to almost 80 minutes and losses by as much as nearly 4.5 hours. The most apparent are the time gains in bilateral connections between Olsztyn and Białystok located in the north of Poland. This seems to be particularly positive, taking into account the infrastructural backwardness of eastern Poland and shows that despite deficiencies in the road network (and its low standard), drivers travel markedly faster than is allowed by the regulations. This kind of reasoning should be based, however, on topology and such an analysis only partially confirms this pattern. From this perspective, only Olsztyn has relatively good accessibility. Each of the 18 provincial capitals has topological decelerations in relation to theoretical travel times by car. It is clearly varied and ranges from over 47 to over 90 hours (Fig. 3). It is important to emphasize the role of congestion in shaping the real time of travel. According to an accepted research principle, the points between which the measurements are made are city centroids. Although these are points based solely on the shape of city boundaries, they lie in those parts of cities that have very heavy traffic. Thus, the time needed to pass through differs significantly from the theoretical.

It is only this approach that reveals the particularly good situation of Gdańsk. Compared to other centres, this is a city from which travel by car to other regional cities has the smallest time losses in relation to the theoretical. The situation of Gorzów Wielkopolski and Bydgoszcz, on the other hand, seems problematic. Looking at theoretical and real travel times by car for individual inter-regional connections (Fig. 4), it can be concluded that the longer the journey, the greater the time loss in relation to theoretical possibilities. At the same time, it is worth stressing the considerable variation here.

4. Intra-regional level

The juxtaposition of theoretical and real travel times between settlement units in Łódź province (topologically - cumulative times between any point and

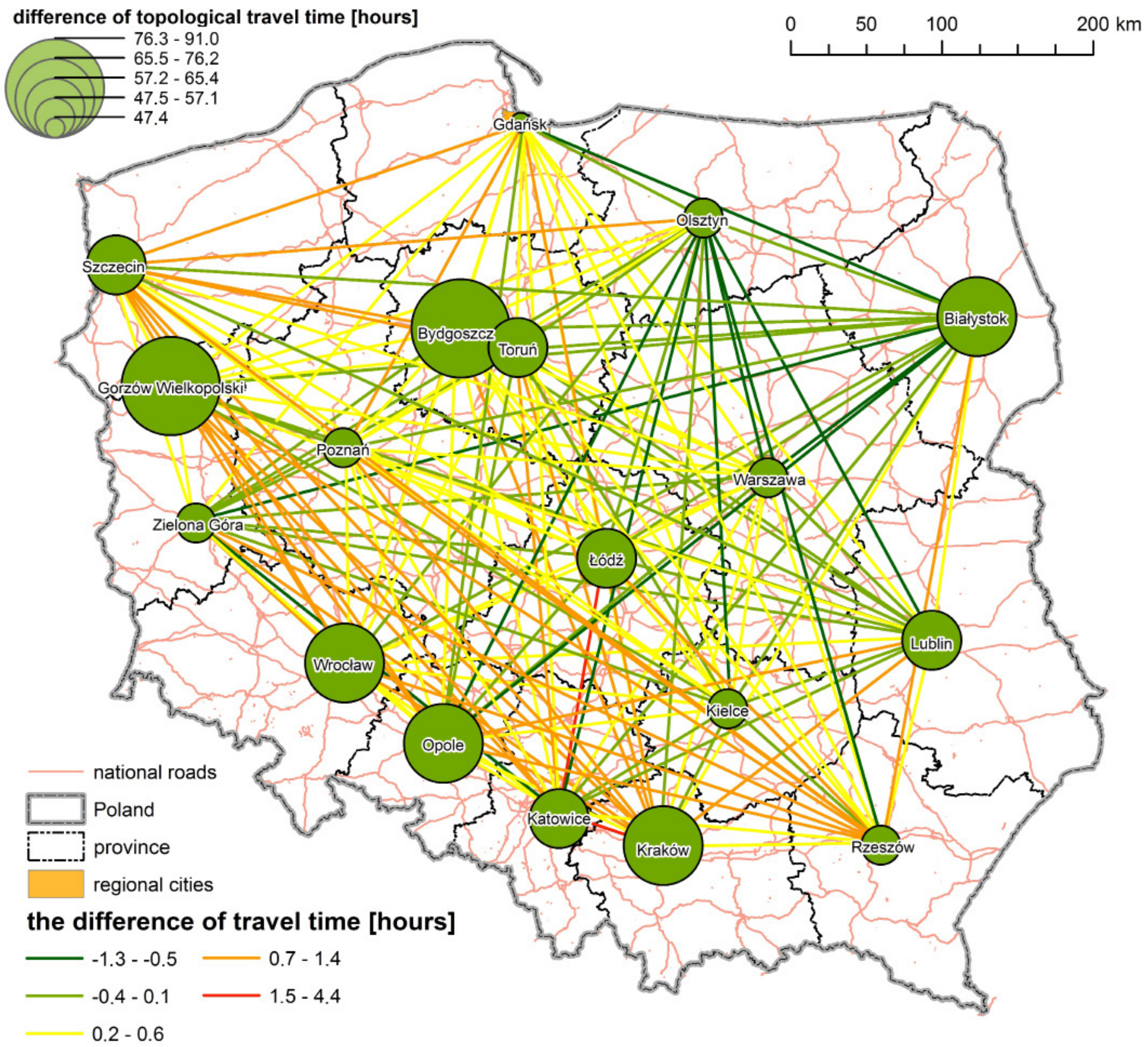

Fig. 3. Spatial differentiation of the differences in real and theoretical travel times by car for provincial capitals in Poland (presented bilaterally and topologically)
Source: Author's own work

all other points in the analysis) gives rise to the generalisation that driving around the region on average takes longer than if driving at the maximum speeds allowed by the law (Fig. 5). A different conclusion seems impossible if it is assumed that drivers observe the law. Single journeys show, however, that drivers are capable of covering a given route in a much shorter time than permitted by law (Wiśniewski, 2017).

An increase in topological travel time (either theoretical or real) when travelling away from the region's geometric centre naturally results as accessibility was analysed solely within the province; its administrative border being a barrier for journeys. If research into the accessibility of settlement units were subject to wider research, the introduction of this kind of barrier would have to be considered a mistake. It is of key importance in this research, however, for differences in travel times and their pattern within province boundaries. Analysis of spatial differentiation of theoretical travel times by car reveals the important role of the region's motorways and expressways for the accessibility of the province's settlements. Isochrones clearly 'follow' the

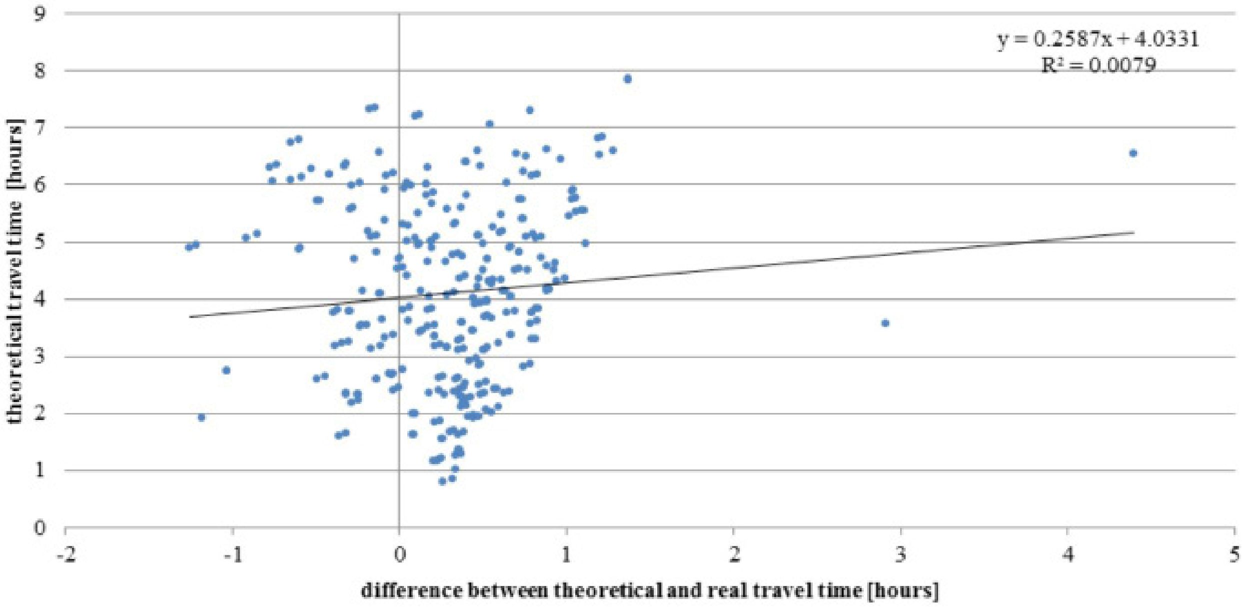

Fig. 4. Correlations between theoretical travel times by car relative to real times for provincial capitals in Poland
Source: Author's own work

course of the A1 and A2 motorways and the S8 expressway, extending the area of greatest accessibility both latitudinally and longitudinally. The isochrones for identical travel times based on real data evens out this positive aspect, it is still visible but less explicit.

This clear difference can be interpreted in two ways. First, it can be concluded that there are factors which interrupt travel on roads of the highest standards. Examples include congestion at toll booths or motorway slip roads, or weather conditions which do not allow driving at speeds permitted by law (Cohen, Paul, 2007; Bröcker et al., 2010). The second explanation is connected with data on travel time itself. The service provider presents averaged 'perennial' results, and a large part of the

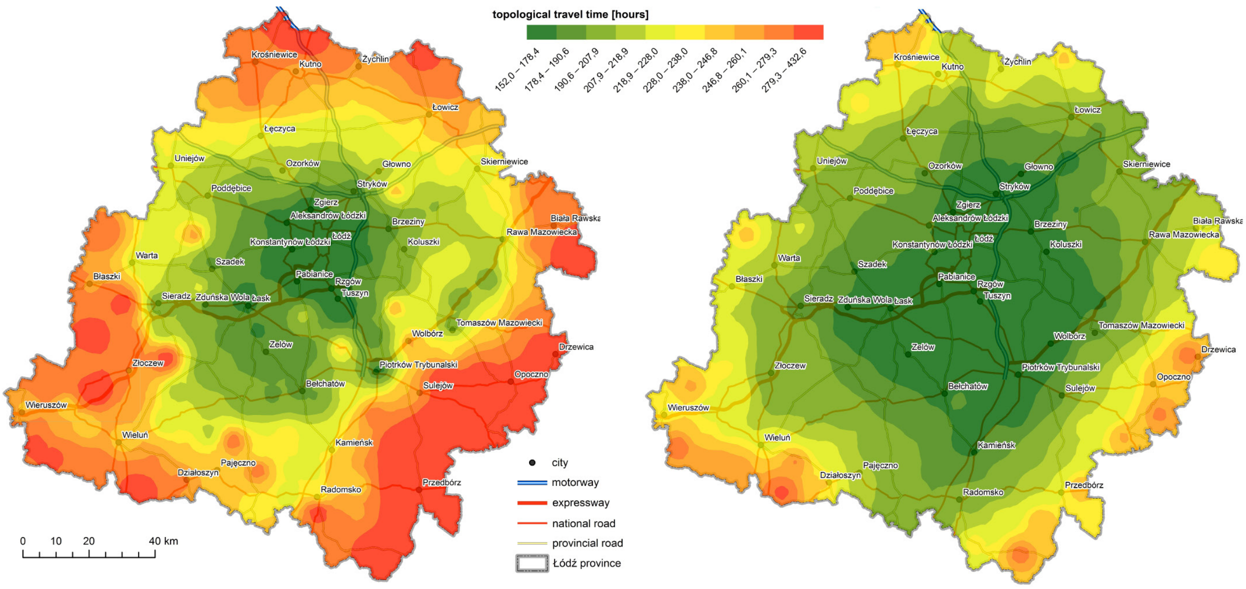

Fig. 5. Interpolated spatial differentiation of theoretical (right map) and real (left map) travel times by car for settlement units in Łódź province (presented topologically)
Source: Wiśniewski, 2017

road network with limited accessibility (motorways, expressways) has only been constructed in Łódź province in recent years. Real shorter travel times resulting from their implementation still represents such an insignificant percentage of all journeys that their impact on the averaged result is limited. Consequently, it is interesting to observe the spatial differentiation in topological theoretical and real travel times (Fig. 6). It is possible to see time losses for journeys from settlement units located along the strip connecting Wieruszów - Wieluń - Bełchatów - Łask - Aleksandrów Łódzki and Uniejów. With respect to the number of journeys (over 12 million) these losses seem insignificant, even though their differentiation is considerable.

Superimposing isochrones on the settlement network and distribution of the province's population specifies which parts of the region have accelerations or decelerations with regard to theoretical travel times by car (Table 1).

Looking at theoretical and real travel times by car for individual journeys (Fig. 7), it can be generalized that the longer the journey, the greater the time loss in relation to theoretical possibilities. At the same time, it is worth stressing the considerable variability since the linear function characterized by the highest determination ratio accounts for it in merely about 30%. In the case of inter-regional connections there are theoretical time journeys varying by up to 3.5 hours and the discrepancies which accompany them range in relation to real time from acceleration slightly exceeding half an hour to a clear deceleration amounting to almost two hours.

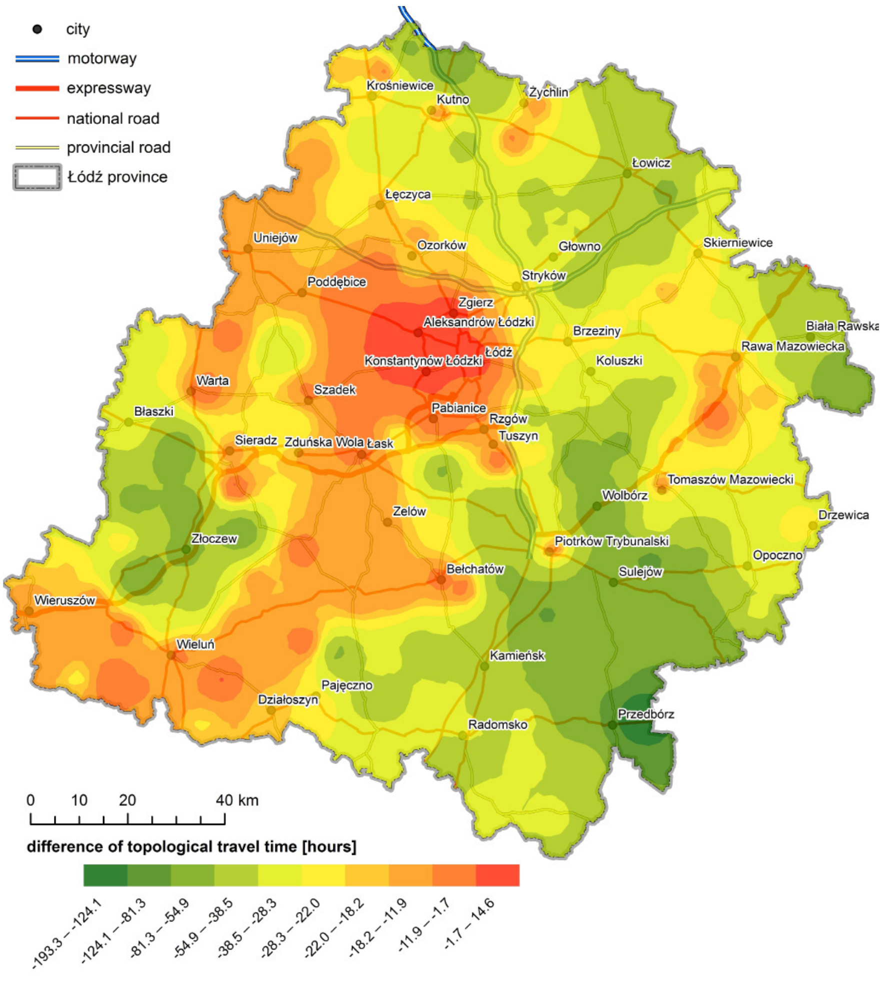

Fig. 6. Interpolated spatial differentiations in real and theoretical travel times by car for settlement units in the Łódź province (presented topologically)
Source: Wiśniewski, 2017

Table 1. Area, settlement units and population of Łódź province relative to isochrones for topological travel time by car

Difference in topological time of journey [hours]	Share of surface area [%]	Share of settlement units [%]	Share of population [%]
-193.3 – -124.1	0.4	0.3	0.1
-124.1 – -81.3	1.0	0.7	0.4
-81.3 – -54.9	10.9	10.8	4.6
-54.9 – -38.5	20.9	21.0	9.3
-38.5 – -28.3	**22.6**	**21.7**	12.2
-28.3 – -22.0	12.7	13.2	8.4
-22.0 – -18.2	8.1	8.8	12.2
-18.2 – -11.9	15.2	15.7	12.4
-11.9 – -1.7	6.2	6.7	8.7
-1.7 – +14.6	2.1	1.1	**31.8**
Sum	**100**	**100**	**100**

Source: Wiśniewski, 2017

Having the above in mind, it may be concluded that travel by passenger car between localities in Łódź province on a regional scale which should last one hour (within the law) will last almost 90 minutes in reality.

5. Intra-urban level

Juxtaposition of theoretical and real travel times by car (topologically) between test points in Łódź allows the generalisation to be made that travelling around the city on average takes longer than if driving at the maximum speeds allowed by the law (Fig. 8).

Analysis of the spatial differentiation of theoretical topological travel times allows the important role of the city's internal ring road, in terms of accessibility, to be seen. Areas of clearly increased topological travel time manifest themselves outside the course of the ring railway line as well (Wiśniewski, 2016). All journeys between the city's central part and areas outside the railway must take place via a limited number of crossings. Although distances between them are not very large in urban space, in the majority of cases they force a driver to make a considerable detour rather than follow a more di-

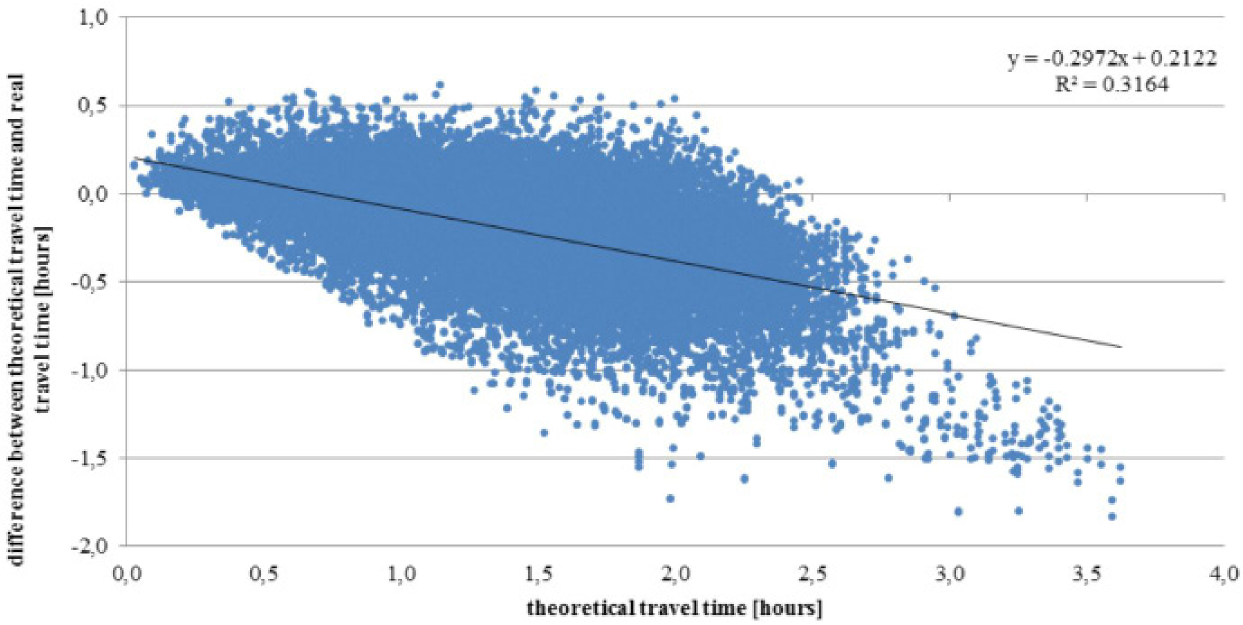

Fig. 7. Correlations between theoretical travel times by car relative to real times for Łódź province settlement units
Source: Wiśniewski, 2017

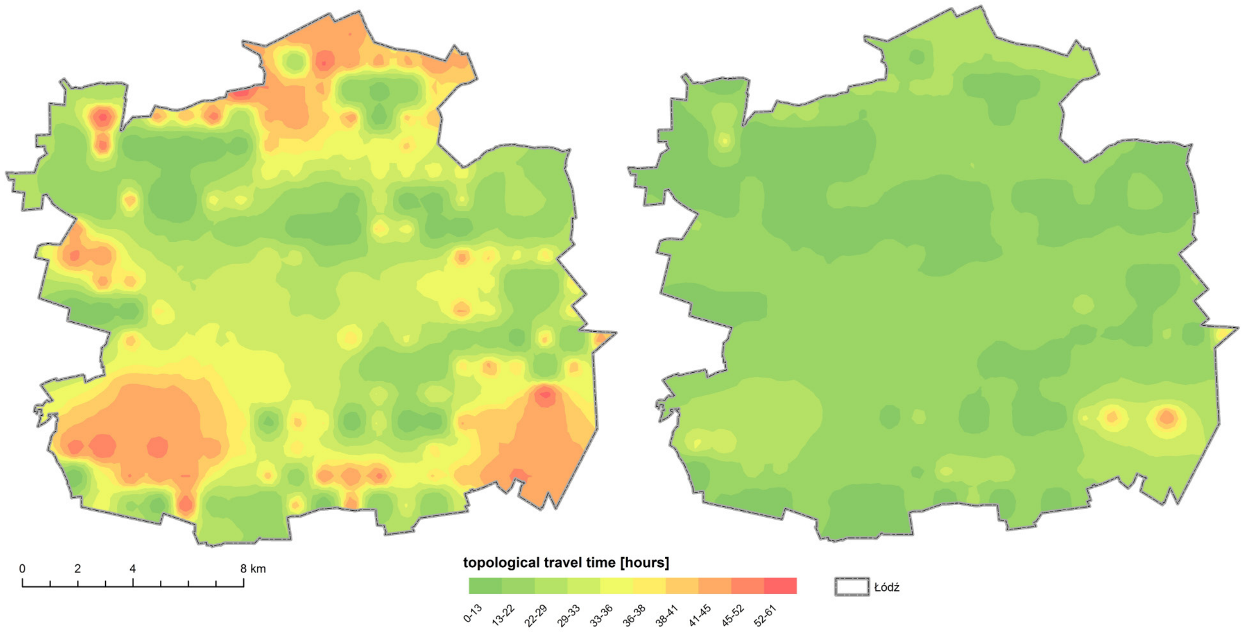

Fig. 8. Interpolated spatial differentiation of theoretical (right map) and real (left map) travel times by car for measurement points in the city of Łódź (presented topologically)
Source: Wiśniewski, 2016

rect route (Neutens et al. 2010, Ortega et al. 2012). These patterns are highlighted by identical travel time isochrones based on real journeys.

This clear difference may be explained by factors which disturb driving on the urban road network. One example is congestion (Pieters et al. 2012), for example waiting time at traffic lights or stoppages related to parking a car or going into or out of premises (Holl, 2007; De Vries et al. 2009). Another explanation is connected with the data on travel time itself. The service provider presents averaged 'perennial' results, and a large part of the road network of limited accessibility (e.g. east-west route, motorways, expressways) has been constructed in Łódź province in recent years. Real shorter travel times still represent such an insignificant percentage of all journeys that their impact on the averaged result is limited.

Consequently, it is interesting to observe the spatial differentiation in theoretical and real travel times by car (Fig. 9). It is possible to see time losses for journeys from the area running from SW to the NE of the city.

Superimposing isochrones on the population of Łódź specifies which parts have accelerations or decelerations with regard to theoretical travel times by car (Table 2).

Table 2. The population of Łódź relative to isochrones for topological travel time by car

Difference in topological travel time [hours]	Share of population [%]
-1.2-6.0	3.81
6.0-10.3	15.67
10.3-12.9	**19.04**
12.9-14.4	17.32
14.4-15.3	13.50
15.3-16.2	12.12
16.2-17.7	14.08
17.7-20.3	3.63
20.3-24.6	0.82
24.6-31.8	0.01
Sum	100

Source: Wiśniewski, 2016

The above breakdown shows that merely 2% of the city's population (and Fig. 9 shows that such cases are highly dispersed) reach their destination slightly quicker than if driving at the maximum speeds allowed by the law on the city's road network. The remaining inhabitants make journeys

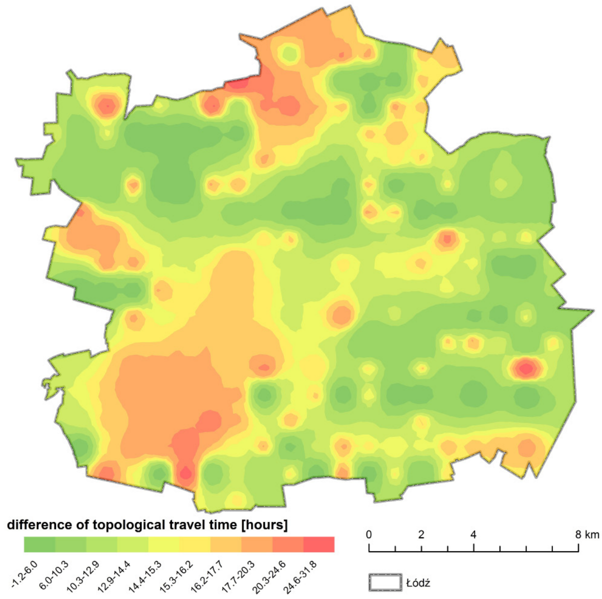

Fig. 9. Interpolated spatial differentiations in real and theoretical travel times by car between measurement points in Łódź (presented topologically)
Source: Wiśniewski, 2016

taking longer. Looking at theoretical and real travel times in the case of individual journeys (Fig. 10.), it can concluded in general that the longer the journey, the greater the time loss in relation to theoretical possibilities. At the same time, it is worth stressing the considerable variability since the linear function characterized by the highest determination ratio accounts for it in merely about 60%. Analyzed journeys within the city do not exceed one hour. Discrepancies in relation to real travel time on intra-urban journeys range from time gains of about 20 minutes to losses of over half an hour.

Having the above in mind, it may be concluded that a journey by car on the road network of Łódź which if driving at the maximum speeds allowed by the law could take half an hour will in reality take almost 45 minutes.

6. Conclusions

As for the methodological goal, it should be recognized that the data obtained from Google servers was very useful for carrying out transport geography research, including accessibility analysis, regardless of spatial scale. This data allows variations in accessibility from local through to inter-regional levels to be identified. However, the data cannot be used without taking into account its weaknesses. Only some analysis of accessibility can be based on data from Google sources. One invaluable feature is that the results are averaged, but, at the same

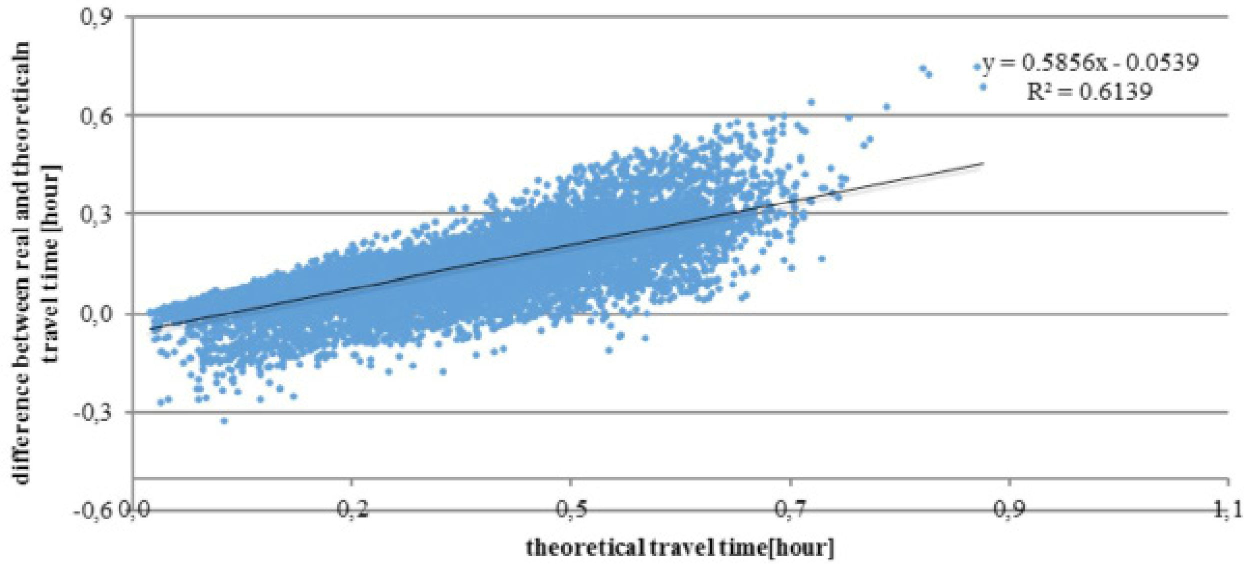

Fig. 10. Correlations between theoretical travel times by car relative to real times for measurement points in the city of Łódź
Source: Wiśniewski, 2016

time, it is a major drawback. Data on average travel times between any two points on the planet collected over many years is undoubtedly an abundant research material that has no distortion of results associated with unusual road events (Wiśniewski, 2017). This data is ideal for investigating transport behaviour aimed at detecting general travel characteristics irrespective of scale or road network density. They cannot be applied successfully where there has been rapid change. At national or regional level, they do not reflect, for example, changes in travel times resulting from new motorway or expressway segments. On a local scale they will not be able to capture a street closure for repair. Additionally, it is worth mentioning licensing restrictions on the number of journeys examined. The volume of data available is unlimited if a fee is paid. Obviously, the data needed can be obtained over a long period (because every 24 hours the free download limit is renewed) however, in 24 hours the servers have collected a large quantity of new data which affects the final average travel time for a given segment. The cognitive result shows that there are considerable differences between theoretical and real-time accessibility at various spatial scales as well as within a single area. The purpose was to adopt a universal approach, so it was decided that research should be at a variety of scales. Of course, it seems reasonable that similar surveys should be carried out for other areas with differing of settlement unit or road network characteristics. Nevertheless, the research shows a combination of travel times in areas with very diverse levels of development and through the road networks of a country, region and city themselves of very diverse standards. Therefore, it can be assumed that the results will not be fully representative but instead will show patterns which might be encountered in other areas. The results at the three spatial levels have yielded very different results in terms of theoretical and real accessibility. The spatial scales differ in both the degree of discrepancy between theoretical and real times and changes to them. Inter-regional as well as local journeys display a similar relation between theoretical and real times. They differ, however, in the number of discrepancies. Regional disparities are characterized by distinctively different, or even opposing, theoretical and real times.

The results have numerous applications. Above all, the analysis indicates that when carrying out transport accessibility studies, one should assume different values of deviations from theoretical travel times by car. Moreover, the results show that transport policy in Poland, both in legal and infrastructural terms, has different spatial effects. This confirms the very large deviations in reality from assumed theoretical travel speeds, both positively and negatively. The research presented may thus serve as a diagnostic tool for analyzing locations for speed control, such as average speed cameras.

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