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ŁÓDŹ ACCESSIBILITY BY PUBLIC TRANSPORT

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Abstract. The article presents the results of research devoted to differentiation of spatial accessibility of Łódź with the assumption that travelers from the Łódź province relocate using public transport. The analysis was conducted on the basis of a full inventory of bus, minibus, tram and railway connections reaching Łódź and 410 stops located within one-hour access isochrone to the region's centre. The research accounts also for the distribution and the number of population of 2,419 towns and localities of the Łódź province. The calculations were based on the two-step floating catchment area method modified for the purposes of research into public transport effectiveness.

Key words: public transport, spatial accessibility, Łódź province.

Introduction

Accessibility to public transport conditions adequate comprehensive development on the given area. It enables efficient relocation between the place of residence and workplace or educational institution. Well-organized public transport with suitable frequency and timetable during the day contributes to a decrease in congestion in vehicle traffic and reduces journey time (Wiśniewski 2015).

The assumption that this research refers to accessibility from the interregional perspective became the point of departure for assessment of transport accessibility of Łódź in the light of public transport. This means that this work does not deal with the topic of connections resulting from public transport operations at the supraregional level. From the everyday journeys viewpoint it is of key importance for inhabitants of the Łódź province to have access to public transport which meets their individual needs and allows travelling to the workplace and educational institutions as well as to use social infrastructure not present in the place of their residence but available in the region's centre. (Bartosiewicz & Marszał 2011).

Regional public transport in the Łódź province contributes to development of completely new opportunities of shaping connections in the settlement systems. Units which have so far developed separately may be combined in a single common structure. Consequently, the power of mutual links of the whole settlement system increases and the significance of distance between individual centres shrinks for the benefit of a journey time. A fragmented geometrical shape which does not preserve investment continuity is characteristic for settlement structures based on regional public transport. An effective system of public transport connections contributes to function deconcentration (Pięciński 1977).

Transport organization

Organization of public transport in the Łódź province is typical of the whole country. Passenger rail services are provided by the PKS companies, private minibus carriers, communal transport companies (such as Miejskie Przedsiębiorstwo Komunikacyjne in Łódź), Łódź Agglomeration Railway, Przewozy Regionalne and PKP InterCity. In the light of the conducted research, the most important role in the structure of transport services is played by connections provided by the PKS companies. These operators cater for the highest number of connections, covering the largest area of the province. The highest number of connections is provided between the region's largest towns as well as along the most important transport routes (mainly national roads) (Fig. 1.). The PKS companies are located in thirteen towns of the Łódź province. Most carriers provide local connections, mostly within a single district. Companies provide also (although to a lesser extent) regional connections (predominantly to Łódź). Some vehicle transport companies offer also the national connections mainly aimed at accessing larger towns or tourist destinations.

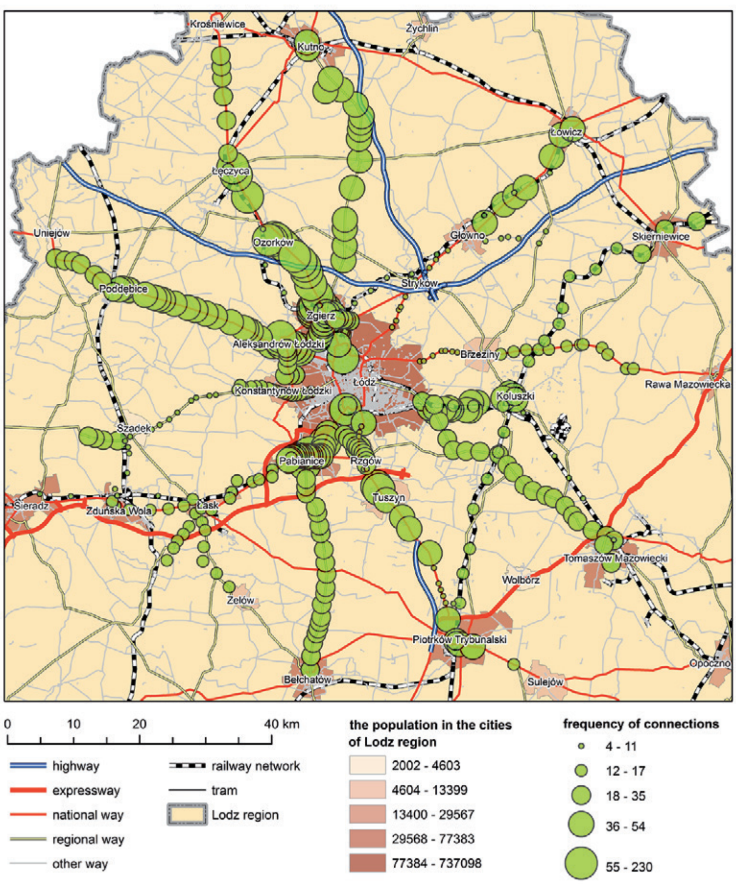

Figure 1. Frequency of connections with Łódź from local transport stops within one-hour isochrone

Bus transport

The widest scope of connections is offered by the PKS companies from Łódź. These companies in Łódź provide connections mostly to the region's capital along the main exit roads in the direction of Głowno, Brzeziny, Ujazd, Tuszyn, Łask, Lutomiersk, Poddębice or Łęczyca. These are predominantly regional scale services . In every case there are at least over a dozen services per 24 hours on weekdays. In turn, the remaining carriers play a vital role in catering for more important transport routes. These include, above all, connections between Łódź and the abovementioned towns. For some directions it is important that they include long-distance routes which are at the same time provided as accelerated or fast connections, which brings about certain consequences as buses stop far less frequently i.e. only on some selected stops. Consequently, they increase transport accessibility of usually larger centres of the province.

The offer of PKS carriers from the Łódź region is supplemented by connections provided by the companies situated in towns of provinces neighbouring with the Łódź province. They tend to cater only for areas adjacent to the Łódź province. In the majority of cases, communal localities located near the province's boundary are the terminus for such connections. Besides, many long-distance bus lines operated by PKS companies from the entire Poland run through Łódź. Their role in organizing the province's public transport may be assessed twofold. It is significant in the case of connections between the towns as buses tend to stop exclusively on their territory.

Minibus transport

The second group of carriers comprises private companies offering minibus services (in some cases some routes are operated also by buses). These are companies which have their offices in the Łódź region and provide their services on one or two routes at the most, having not more than about a dozen of vehicles or so at their disposal. Regular passenger services tend to be the core activity in the case of these companies. Some of them extend their offer to include irregular services (e.g. tourist ones). Within the Łódź province there are about 80 carriers of this type. They cater for the main routes on which the demand for transport services is the greatest and their spatial range is considerably limited. Services provided by private minibus carriers are the most common in the broadly understood Łódź agglomeration. Entrepreneurs offer connections on the routes between Łódź and localities in the neighbouring districts along more important transport routes. In many cases the routes are serviced by a number of carriers and not infrequently bus connections represent the dominant form of public transport.

Urban transport companies

Urban (communal) transport companies play a far less significant role in transport organization (which corresponds to the policy of local government units responsible for the arrangement of connections). They tend to be responsible only for the local connections (within the given communal unit). From among 17 such carriers just a few offer connections on the routes going beyond the area of the given commune (excluding suburban connections which cover the area of the rural commune under the same name as the town, e.g.: bus connections on the routes between the town of Zduńska Wola and the rural commune of Zduńska Wola, or the town of Kutno and the rural commune of Kutno) (Kowalski & Wiśniewski 2013).

Tram transport

The tram network in Łódź is one of the fourteen tram networks in Poland with track width of 1,000 mm. Nowadays, there are 17 tram lines operating within the boundaries of Łódź and 5 tram lines which connect Łódź with the neighbouring towns (communes). The tram network comprises of 23 tram termini, 5 of which is located outside the urban area of Łódź.

Development of this branch of transport in Łódź in recent years has been closely connected with accomplishment of the Łódź Regional Tram project (Łódzki Tramwaj Regionalny) (Feltynowski 2009). The aim of launching the Łódź Regional Tram was to improve transport connections between the core of the Łódź Metropolitan Area and Pabianice and Zgierz on the section of 28 km in total. In the initial phase of the project, there were also plans to incorporate the line to Ozorków into the system. Nevertheless, the project in this shape was abandoned. Consequently, until now only the state of technical infrastructure on the area of Łódź was considerably improved and modern tram rolling stock was purchased as part of accomplishing the regional tram project. Subsequent activities were to focus on unification of tariffs and implementation of the electronic city card together with the information system for the passenger on the whole public transport system (Pielesiak 2012).

Eighteen bus lines go beyond the administrative boundary of the city of Łódź and in addition reach Zgierz, Skotniki, Imielnik, Dobra, Stryków, Kalonka, Skoszewy, Natolin, Brzeziny, Andrespol, Stróża, Ludwików, Rzgów, Gadka Stara, Niesięcin and Aleksandrów Łódzki. Apart from this, a single line is managed by a carrier from Zgierz and has its destination stop next to the Łódź Kaliska station.

Train transport

The public transport system in the Łódź region is complemented by railway services. It must be remembered, however, that their role and spatial range are explicitly conditioned by the trajectory of railway lines. Passenger rail services, important from the point of view of regional public transport, are provided on the following routes: Łódź – Sieradz, Łódź – Kutno and Łódź – Koluszki (Piotrków Trybunalski – Radomsko) – Skierniewice. They are operated by the Przewozy Regionalne company (commissioned by the Marshal's office in Łódź in the form of regional and InterRegio trains), which is responsible above all for regional passenger connections on the abovementioned routes. Trains of this carrier stop at all the stations on the given route, which is of key importance for accessibility from the local perspective. Train connections are also provided by the PKP IC company, which is responsible for supraregional accelerated connections.

The significance of rail transport in the Łódź province seems to be distinctively lower in comparison with its role in the other regions of the country. Railway lines run through merely a small part of the province's communes and, moreover, in some cases their routing does not correspond to the contemporary layout of the settlement. In many cases the stations and stops are situated at a large distance from the centres of localities, therefore hindering free use of railway transport. In addition, it is already the abovementioned railway network layout in Łódź itself that poses a problem. Construction of a cross-town railway line is a solution which would enable effective operation of two stations which are equally important for dealing with station railway traffic but which are not directly connected. The infrastructure investments combined with a redesigned system of regional connection network management preparing it to be included in the high-speed rail (Massel 2008) may result in creation of a railway node catering for transit traffic (Pielesiak 2012).

A change in the unfavourable situation is also caused by the launch of the Łódź Agglomeration Railway. Infrastructure modernization accompanying it and the increased number of places where trains stop offer an opportunity of making the Łódź Agglomeration Railway an important element of the region's transportation system. It may also bring about transformations in the structure of railway services in the broadly understood area of Łódź agglomeration. Railway services are provided between the Łódź Kaliska station and Pabianice, Łask, Zduńska Wola and Sieradz along the line no. 14. The agglomeration railway runs between Łódź Kaliska, Zgierz, Głowno and Łowicz along the line no. 15. The third direction includes Łódź Widzew, Zgierz and Kutno (line no. 16). The agglomeration railway connects also the Łódź Fabryczna station with Koluszki (line no. 17). This connection will not go beyond the boundaries of Łódź, as it will join the Łódź Kaliska station with Chojny and Widzew stations (line no. 25/540). In the longer term, rail is also supposed to reach towns beyond the boundaries of the Łódź province (Paczkowski & Budler 2012).

Research assumptions

The aim of this research is to determine accessibility of Łódź with the assumption that the province's population relocates using public transport. Individual planes of the research (in relation to distance, time and cost) refer to bus, minibus and train transport. Measurements were taken between Łódź and every stop operated by any carrier and situated within one-hour isochrone of access by means of transport to the first stop within the city's boundaries. After the introductory part, the article focuses on characteristics of source materials of the research and the employed research approach. Its subsequent part presents the results of the analysis which was carried out as well as their commentary in the conclusion part.

Materials and research methods

Accessibility assessment of Łódź was conducted on the basis of connections between all stops accessible by the given means of transport within the 60-minute isochrones of access of these transport means according to the timetable. The performed analysis took four basic variables into account: number of connections, their length, journey cost and time. Each and every one of them brings important information on how the local transport system functions. In turn, combination of all of them gives a full picture of their impact on transport accessibility of the metropolitan centre. In the circumstances, when carriers compete on the market rather than for the market of transport services, the number of connections (frequency of services) provides measurable information about the attractiveness of individual connections. Carriers keep launching the new connections until the demand for services is met, having the profitability of services in mind. On this basis, the decision-makers responsible for the transport policy may decide on the form of service organization on the given area.

The length and time of services, and in particular combination of them, allows for drawing conclusions on the effectiveness of local connections (development of public transport lines – the ratio of the actual physical distance between the initial and final stop to the distance between them in a straight line) or time of servicing the stop and at the same time indirectly on how the whole transport system of the area works, including congestion levels or low and density of traffic. The cost, on the other hand, refers to accessibility as even if there is a connection on the given route, its price may exclude some potential passengers from using public transport. This research uses the abovementioned variables in order to specify how they affect spatial accessibility of Łódź as far as local passenger transport services are concerned.

Materials

The first research variable, i.e. the number of connections, was established by calculating journeys by the given means of transport on weekdays with the exclusion of accelerated and fast connections. The connection is understood as an individual journey by any means of public transport between the last stop within the administrative boundaries of Łódź and the selected stop which can accessed within 60 minutes. Using one-hour research boundary resulted from the practice of applying this value in research devoted to the metropolitan areas in Poland. The time of reaching the central city which does not exceed one hour (postulated, among others, by Dümmler, Thierstein 2002) was used, for instance, in the process of delineation of the metropolitan area of Poznań (Delimitacja POM, WBPP, 2006) or Lublin (Studium Urbanizacji Lubelskiego Obszaru Metropolitalnego 2009). Connections were calculated once only in the case of bilateral connections between stops. Such a choice of the variable was motivated by the fact that the number of connections from and to Łódź is the same (if differences occur, they are of no importance). In this way one connection is understood as a single service providing a journey between stops in both directions.

Both direct and indirect connections were analyzed in the case of train and tram connections. Due to the characteristics of the rail and tram networks of the Łódź province and limited offer by carriers, substitutability of connections between individual towns is relatively low, which is why it was possible to include every possible connections in the analysis. In the case of bus connections, the analysis comprises only direct connections. In their case, very high substitutability levels result from wide offer of carriers and almost a complete lack of determination of journey route by a far better developed road network.

An attempt to specify the total number of connections (irrespective of their directness) may be encumbered with a serious error due to, for instance, purely theoretical interchange places (established arbitrarily by the author) which offer more opportunities to change than it is possible in the case of train or tram connections. In order to establish the number and other details of train connections the author used data made available by Polskie Koleje Państwowe S.A. in the form of digitalized timetables and information included at http://www.rozklad-pkp.pl/. In the case of tram connections the source of data was information included in the Internet service of the Miejskie Przedsiębiorstwo Komunikacyjne company in Łódź (http://www.mpk.lodz.pl/). The widest scope of data sources was used to establish characteristics of bus and minibus services, using data published by the Road Transport Department of the Marshal's Office in Łódź. Data obtained in this way was supplemented by information from Internet websites of individual carriers as well as the Internet service of the Polish Chamber of Road Transport and Freight (http://autobusowyrozkladjazdy.pl/). If there was no information available in the above sources, field research was conducted in order to obtain timetables directly from carriers, information boards on stops or town halls and facilities (most frequently shops) situated near stops. Such a wide selection of data sources on public transport services allowed, on the one hand, collecting quite a comprehensive set of necessary information and, on the other, made it possible to verify it to the extent where it overlapped.

Another analyzed variable was the actual physical distance between the individual stops where moving by public transport was assumed. Distances were measured once the journey route was charted on the map. The results were used both for the purposes of the research into the spatial scope of public transport impact but also as a space resistance indicator for accessibility levels calculated in the subsequent part of the article.

Journey time is the third variable describing transport accessibility levels of Łódź considering public transport. It was assumed that passengers were guided mostly by the criterion of time while choosing a connection. On the whole, the total journey cost comprises of three elements: time, cost expressed in money and effort (Hoogendoorn-Lanser 2005; Horowitz, Thompson 1994; Van Hagen 2011). It is worth, however, making a reference to the other elements influencing the mobility chain (Schakenbos et al. 2016). Its functioning is becoming an increasingly important element both in considerations of public transport designers and decision-makers in charge of local authorities.

Travelling by public transport usually involves one or more shifts from one form of transport to another which require some substantial effort on the part of passengers. This is why the costs connected with changing the means of transport, both multimodal and within a single form of transport, should be commonly included in analyses of demand for public transport. Transfer costs, beside the cost in units of time or money should also find their place in models used to select public transport journey routes in the form of generalized cost functions (Belcombe et al. 2004).

The following key was used to select connections for the analysis. In the first place, the connections which enabled the quickest relocation from one stop to another were chosen (in the case of journey by train and tram time proved more important than the necessity to change). If there were connections with similar access time, those that did not force passengers to change were selected. If these two features did not differentiate the connections, the criterion of cost was employed and the lower price constituted the deciding element. The last variable was distance to be covered while choosing the given connection. This variable, however, is purely theoretical as there was no necessity to compare connections in this respect in the course of this research.

Another variable which characterizes connections between towns is journey cost. The research assumes purchasing the cheapest possible full-fare one-way ticket which enables to reach the first stop within the administrative boundaries of Łódź. In the case of train connections this assumption refers to the purchase of a second-class train ticket.

In order to make research results more realistic, apart from including the characteristics of individual means of passenger public transport, the research was supplemented by the distribution and the number of potential passengers. The analysis comprises the number of population of all towns and localities which were included within the adopted equidistance of passenger access to the stop (Olszewski et al. 2013). In order to avoid a situation when buffers around stops overlap the research shifts from analysis on the level of stops to that on the level of nodes. The procedure of generating nodes will be presented later in the article. Every town/locality is represented by a central point (centroid) with the assigned number of the population of the given unit. Geolocalization of central points and the number of population were taken from the database of the Central Statistical Office and the PESEL system of the Ministry of Internal Affairs.

Stop accessibility

In Poland it is customarily assumed that the zone of impact of public transport stops occupies an area of a radius ranging from 500 m to 1 km. This means that inhabitants may access the stop on foot from 6 to 12 min with the assumption that their average speed is 5 km/h (Majewski & Beim 2008). Of course, this model does not reflect the possibility of generating the demand for public transport services by the stop even if they were provided in all possible directions and with maximum frequency. This results from the fact that every inhabitant may have a distinct border distance which marks the point of resigning from using the stop. In addition, apart from the distance, also the other factors may be important for the hypothetical public transport user, like possible facilities making it easier to access the stop or barriers which hinder such access. The impact of these factors is different for every inhabitant and strongly determined by individual features of every user, such as age, state of health, sex, place of residence, etc. (Gadziński 2010).

Generally, the available literature describes methodological problems connected with the border distance for different means of transport. In Great Britain, the equidistance of 640 metres is considered the maximum distance of access to the bus stop in town whereas in the case of regional rail or underground it accounts for 960 metres (Majewski & Beim 2008). German urbanists, in turn, assume that the maximum way of accessing the bus stop is 300 metres, the tram stop – 400 metres and the regional rail – 500 metres (Loose 2001). Differences in determining the border distances in relation to means of transport result from a number of key issues. Greater distances from the tram stop as compared to the bus stop are decreased by capital expenditure incurred on the construction of new tram lines with the simultaneous assumption that inhabitants are capable of going farther to the stop if they can reach their destination quicker and in more comfortable conditions.

Consequently, this research adopted a few variants of border distance which the potential passenger must cover on foot to get to the stop: 250, 500, 1,000, 1,500, 2,000 and 5,000 m. The Manhattan distance metric was employed while determining the distance between the central point of town/locality and the stop. If the correctness of using the distances of 250 – 1000 m in the research is justified in the literature of the subject, introduction of larger distances (particularly 5 km) may seem contentious. Naturally, it was not assumed that the potential passengers would decide to travel 5 km on foot to get on a bus, tram or train to Łódź. Such a large distance was introduced, nevertheless, in connection with two phenomena. Firstly, the Łódź agglomeration witnesses a spontaneous rise of places in which the assumptions of the *park and ride* idea are put into practice. Cyclists and drivers leave their means of transport on large-format store car parks located in the possibly closest vicinity to the public transport stop from which they may subsequently reach the centre of Łódź. One of the clearest examples of this type of phenomenon is the car park at Port Łódź, a shopping centre where drivers of vehicles parked there continue their journey e.g. by tram from the nearby Chocianowice depot. Surely, they do not gain any discount in the ticket price but, without having to pay for the car park, they may avoid being stuck in traffic jams, using the increasingly efficient public transport. Secondly, such a wide scope of distances of access on foot/by car to the stop reveals areas of particular deficit of accessibility to Łódź as far as public transport is concerned.

The research included inhabitants of 2,419 towns and localities within the boundaries of the Łódź province so as to determine accessibility to Łódź of the region's inhabitants using public transport. The adopted precision of the analysis, with the assumption of a regional scale of the research, allows specifying the extent to which the distribution of 410 stops within the 60-minute isochrone of access by car to Łódź matches the distribution of the region's population.

The 2SFCA method in public transport

Research based on spatial closeness tends to assume that the user is rational in his or her choices and uses the closest facility to obtain access to the given service. This assumption is employed in different methodological approaches in spatial accessibility analyses. Luo (2004) uses simple circles of different diameters whose centre is the analyzed object or centroid representing the given area. The floating catchment area (FCA) method understood in this way contains the assumptions concerning accessibility of services within a circular area. Consequently, services are equally accessible to all inhabitants irrespective of the actual distance from the object.

Luo and Wang (2003) extended that initial approach relying on earlier works by Radke and Mu (2000). Generally, the evolution which they proposed represents a special case of the gravity model reflecting better interactions between the potential users and places where they may use these services. The first step of this method consists in drawing the impact areas of analyzed objects (e.g. stops) which are given some distinguishing attributes (deciding about their accessibility to users). In the second phase, the impact areas are drafted around points representing the sources of potential demand for the analyzed service. Spatial accessibility levels are described by the sum of all points which meet the demand on areas delineated by the given isolines.

New versions of the 2SFCA method appeared as a result of certain limitations of its initial form. Luo and Qi (2009) noticed two main limitations: firstly, the assumption of equal accessibility within the impact area and, secondly, complete exclusion of accessibility of locations which are beyond the boundary of the given impact area. In the updated solutions (e.g. E2SFCA or 3SFCA) (McGrail, Humphreys 2009) parametres of space resistance were used in a model which marks the geographical catchment area. Hence the need for empirical data concerning the use of the given service type to justify and employ such parametres. As obtaining this type of data is extremely difficult, it is a common practice to use characteristic values only locally in upgrades of the method. Notwithstanding some simplifying assumptions, the FCA methods are commonly used in medical geography (Guagliardo et al. 2004; Cervigni et al. 2008; Dai 2010; Wan et al. 2011) or in other research fields such as measurement of accessibility to places of employment (Wang 2000), green areas (Dai 2011) and other urban services (Langford et al. 2008). There was little research, however, into the use of FCA methods in research into transport. One exception may be research conducted by Langford et al. (2012) which describes modifications of the E2SFCA methods for the purposes of transport analyses.

In the case of public transport the time of reaching the given destination is one of the main variables defining local public transport effectiveness. Still in the light of the above reflections in order to illustrate the transport services reaching Łódź in a comprehensive manner, analyses should also include elements of both supply of services (i.e. number of connections, their time, length and cost) and demand for them, i.e. number of inhabitants who may potentially use the services of individual carriers. It is therefore necessary to transfer the basic indicator of the number of inhabitants for one public transport stop/node in such a way so as to consider also the spatial aspect. Making the floating catchment areas more flexible matches the reality to a larger extent, which is of considerable importance for appropriate interpretation of analysis results. This is possible due to the use of the 2SFCA or two-step floating catchment area method, which allows for combining the two aspects of spatial accessibility, namely that of supply and demand, in one research.

For the public transport analysis with the 2SFCA method it is necessary to have data concerning location of public transport point elements, their characteristics, distribution of population and road network or any other transport network. Beside the possibility of including both the side of supply and demand in one research, the method ensures clarity of results presented in an identical way as the indicator of the number of inhabitants attributable to the given stop/node. One certain risk connected with erroneous interpretation of analysis results is a dichotomic division of analyzed stops/nodes. This means that all the objects which are outside the scope of the adopted time of reaching them on foot are considered to be completely inaccessible (Stępniak 2013 after Luo and Wang 2003). This creates a risk of very large differentiation of the indicator values between neighbouring localities divided by the boundary of the adopted distance of reaching the stop on foot. In order to avoid this kind of situation analysis was conducted using very high spatial definition data (all settlement units in the province).

In order to avoid a situation in which there are two consecutive stops of the same public transport line in one buffer it was necessary to transform the system of stops into a system of nodes. The transformation took place according to the following proceeding algorithm: in the first step, the stops in Łódź were grouped and it was spatial vicinity that decided about forming a group. As a result these groups are formed, for instance, by stops on the opposite sides of the street from which the passengers may commence their journey in both directions or stops located within one junction from which it is possible to travel in more than one direction. In the case when the given stop is not located in close vicinity it forms a single-element group. The second step consisted in assigning each stop an identification number of the given group. Subsequently, points of coordinates being their arithmetic mean were generated on the basis of geographical coordinates of stops belonging to the given group. The generated points were assigned both a group identification number and ID for every stop in the group. The outcome was a system of points – nodes representing the actual picture of point elements of the transport network at the same time simplifying its picture and adjusting it to further analyses. The two-step floating catchment area method (2SFCA) (Albert & Butar 2005; Langford & Higgs 2006; Cervigni et al. 2008) was used, yet in a slightly modified version. Spatial accessibility established by means of this method refers both to the factor of supply (in this research it is indicated by the frequency of connections from the given stop) and demand (the number of inhabitants of the given town/locality).

Due to considerable differentiation of individual connections between the given stop and Łódź in terms of frequency, time, cost and length of journey, it was necessary to take these variables into account in the form of the new two-step floating catchment area method. In the first part of the two-step floating catchment area method, the "impact area" of every stop is determined, assuming the border value of the potential passenger's distance of access on foot. Next, the author calculates the individual indicator R_j for every stop being the product of the quotient of weight (frequency of connections) of individual stops to the number of people living in towns and localities on the area delineated by the given equidistance of access on foot by the passenger from the given town/locality and the reverse of time, cost or length of the trip from the given stop:

$$R_j = \frac{S_j}{\sum_{i \in \{d_{ji} \le d_{max}\}} P_i} \cdot \frac{1}{C_j}$$

where:
S_j – weight (frequency of connections to Łódź) of stop j,
Cj – journey time, cost or distance of means of public transport from stop j to Łódź,
P_i – number of inhabitants of locality i,
d_{ji} – distance on foot between stop j and locality i
d_{max} – equidistance delineating the maximum distance of passenger's access on foot to the stop for individual variants of the research.

In this way the theoretical load of individual stops was calculated. It is a particularly important stage of the research as it should be assumed that passengers embarking on their journey from the given stop do not "load" other stops any more.

In the second part of the two-step floating catchment area method the attention is shifted to towns and localities populated by people who are potential passengers travelling to Łódź. For every centroid of town/locality i an area is delineated, as in the first part of the analysis, with the use of the adopted border value of distance of access by foot to the stop. Subsequently, for every town/locality *i* included in the research the author calculates the indicator of accessibility A_i, which is a sum of values R_j obtained for all stops distributed on the area of individual town/locality *i*:

$$A_i = \sum_{j \in \{d_{ji} \leq d_{max}\}} R_j$$

The results of accessibility levels in the numerical form were transformed into five-grade descriptive scale (very low, low, average, high and very high accessibility) to facilitate reception and interpretation of results. For individual variants of the research (walking distance to the step/node) the average value of accessibility was established and the standard deviation of this variable. Boundaries of class intervals represent, therefore, the multiple of the standard deviation added to or subtracted from (depending on whether accessibility is above or below the average) from the average (e.g. very low accessibility is the accessibility level not higher than the average less triple of standard deviation).

Results

The analysis embarks on the network of bus and minibus connections. Considering the frequency of connections, Łódź has the strongest links with the remaining towns of the metropolitan area. It is connected by means of over 100 bilateral connections per 24 hours with Pabianice, Zgierz, Aleksandrów Łódzki, Ozorków, Konstantynów Łódzki, Tuszyn and Rzgów. Coming to analysis of train connections, it must be pointed out that topologically Łódź is reached by 334 connections daily (direct and with a necessity to change). As for bilateral connections it must be noted that the route between Łódź and Koluszki is characterized by the highest frequency of rail connections, with 35 trains daily. The functioning system of connections makes the centre more available than it could be pointed out by, for instance, graph analysis (Wiśniewski 2015).

Tram transport is the last means of public transport which was researched in terms of its effectiveness. Łódź is definitely the most accessible centre considering frequency of tram connections. It is connected with the four remaining centres by means of over 240 direct connections per 24 hours.

A comparative analysis of means of transport began with the factor of frequency of connections. Every service which links Łódź directly is provided with the highest frequency by bus and minibus carriers. The largest disparity in relation to rail services can be found in the connections between Łódź and Pabianice, and the advantage of motor transport frequency exceeds 180 connections in 24 hours. Generally, situation of connections of towns within Łódź Metropolitan Area: Łódź – Aleksandrów Łódzki, Łódź – Tuszyn and Rzgów – Tuszyn, where monopoly of motor transport prevails, is worth emphasizing. The frequency of tram connections clearly exceeds the number of rail services: in the case of the connection between Łódź and Zgierz, the difference in frequency amounts to 90 connections in 24 hours. In the case of the connection between Łódź and Pabianice the disparity does not exceed 29 connections. Such a state of affairs results from a different character of currently functioning rail services and tram transport. Nevertheless, the tram connections do not represent a competitive offer when compared to bus and minibus connections. The need to ensure frequency of transport services as a factor of adjustment of transport services to passenger needs is not always adequately appreciated and put into practice, which is often a result of technical deficiencies (mainly in the rolling stock) as well as inappropriate organization of services.

Łódź is the city with the greatest number of stops in the province, which enable to access it within one hour. There are 410 of them in total, out of which the biggest part is formed by stops operated by the PKS companies (56%). Local public transport and minibus carriers operate almost the same number of stops (about 140). The least numerous group (53) is formed by train stops. Nevertheless, rail allows accessing Łódź from the most remote stop, Skierniewice Rawka, which is located at a distance of 71 km according to data provided by the carrier. In the case of bus connections the farthest stop is Kutno – Troczewskiego, at a distance of only 54 km, though.

The routes along which public transport to Łódź is provided diverge radially in all directions. Łódź, as the region's central city, the largest labour market, seat of administrative institutions and many facilities of considerable regional range (education, healthcare, commerce, culture and entertainment), requires a suitably developed system of public transport enabling access from the whole territory of the province. The number of connections may be diversified as the importance of Łódź may vary (it is far more important for areas immediately neighbouring with the provincial town than for areas located at a greater distance). The frequency of connections ranges from a few per 24 hours as in the case of Szadek to over 200 for Ozorków. Irrespective of this, accessibility of connections should be ensured at least at the minimal level for all inhabitants of the region. Access time to the city also gradually shortens together with decreasing distance. Only in the case of the tram connection between Łódź and Ozorków and train stops ahead of Koluszki, access times are appreciably higher.

The situation accompanying changes in accessibility between Łódź and Poddębice requires to be explained separately in relation to spatial fluctuations in differentiation of accessibility between the research variant assuming 250 and 500 metres of reaching the stop on foot. In the case of a few stops on this route there is a situation in which an increase in the value of border equidistance of reaching the stop decreases accessibility. This is naturally only a relative drop resulting from the used method of classification to individual class intervals of accessibility. For most stops on this route, but also for other connections with Łódź, a surge in accessibility accompanying an enlarged scope of reaching the stop on foot was considerable and markedly increased the average level. In the case of the connection with Poddębice accessibility with the minimum equidistance of reaching the stop on foot was so high that shifting the border distance of reaching the stop on foot obscured the increase which, nevertheless, was relatively insignificant in relation to the other areas.

The use of the two-step floating catchment area method modified for the purposes of research into public transport effectiveness allowed determining the accessibility of Łódź considering time (Fig. 2), length (Fig. 3) and cost (Fig. 4) of access by public transport. A radiant layout of areas with increased accessibility levels is revealed regardless of the adopted research plane or range of distance of access to the stop on foot. It comprises of ten "arms" diverging evenly in all directions. This situation should be regarded as markedly beneficial as it eliminates the areas of particular deficit in accessibility. Introduction of a new factor to the classic two-step floating catchment area method seems to be justified by differences in distribution of the individual zone levels depending on the adopted feature (time, distance, cost), which can be found on maps of spatial differentiation of accessibility. This allows observing how the local transport policy is translated into ongoing changes in accessibility of the regional centre.

An increase in the number and frequency of connections of the Łódź Agglomeration Railway combined with introducing it to the New Łódź Centre to the Fabryczna station will allow inhabitants of units located even at a considerable distance from Łódź for getting to its very centre without time waste connected with, for instance, congestion.

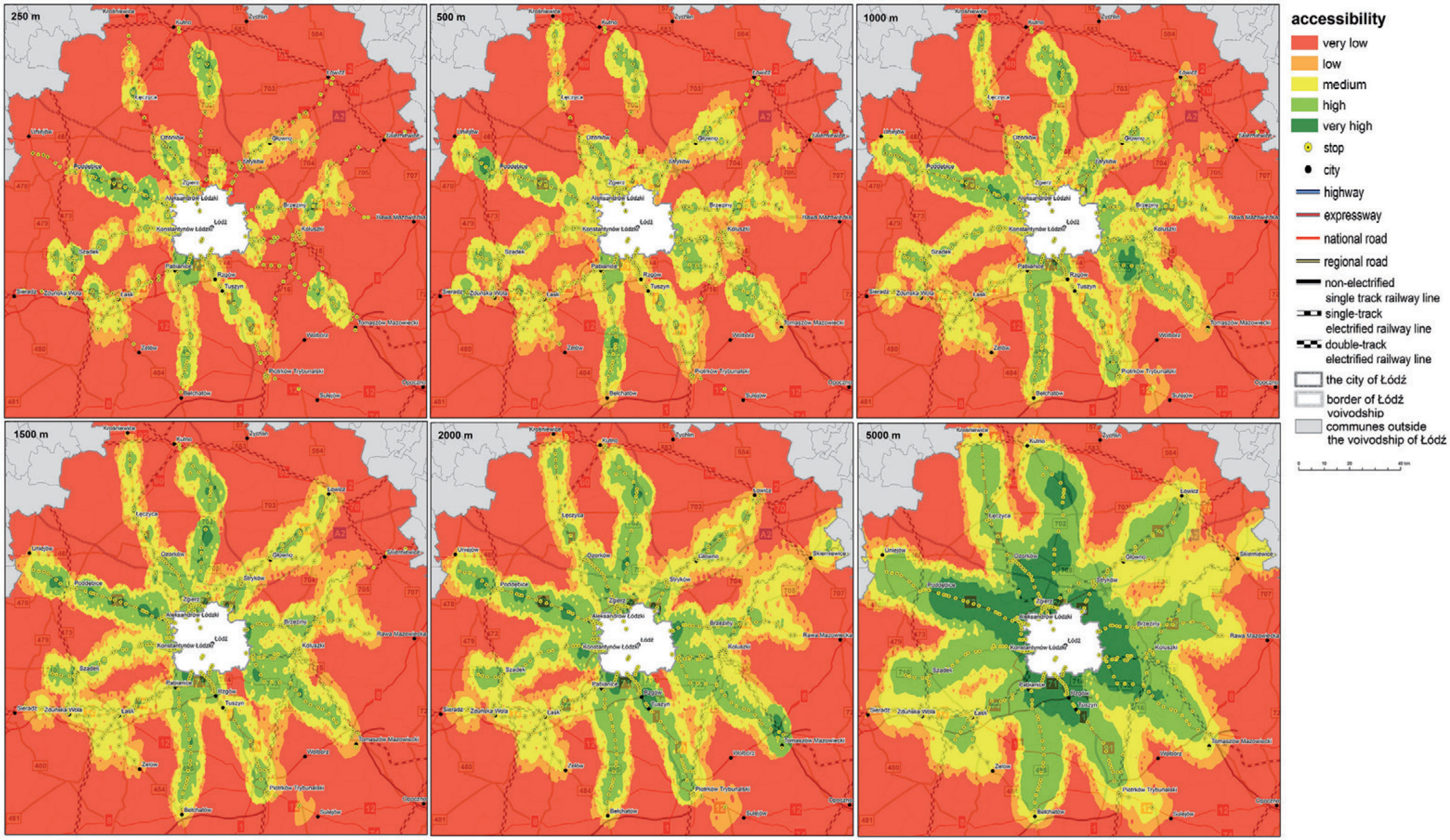

Figure 2. Spatial differentiation of accessibility to Łódź by means of public transport considering access time

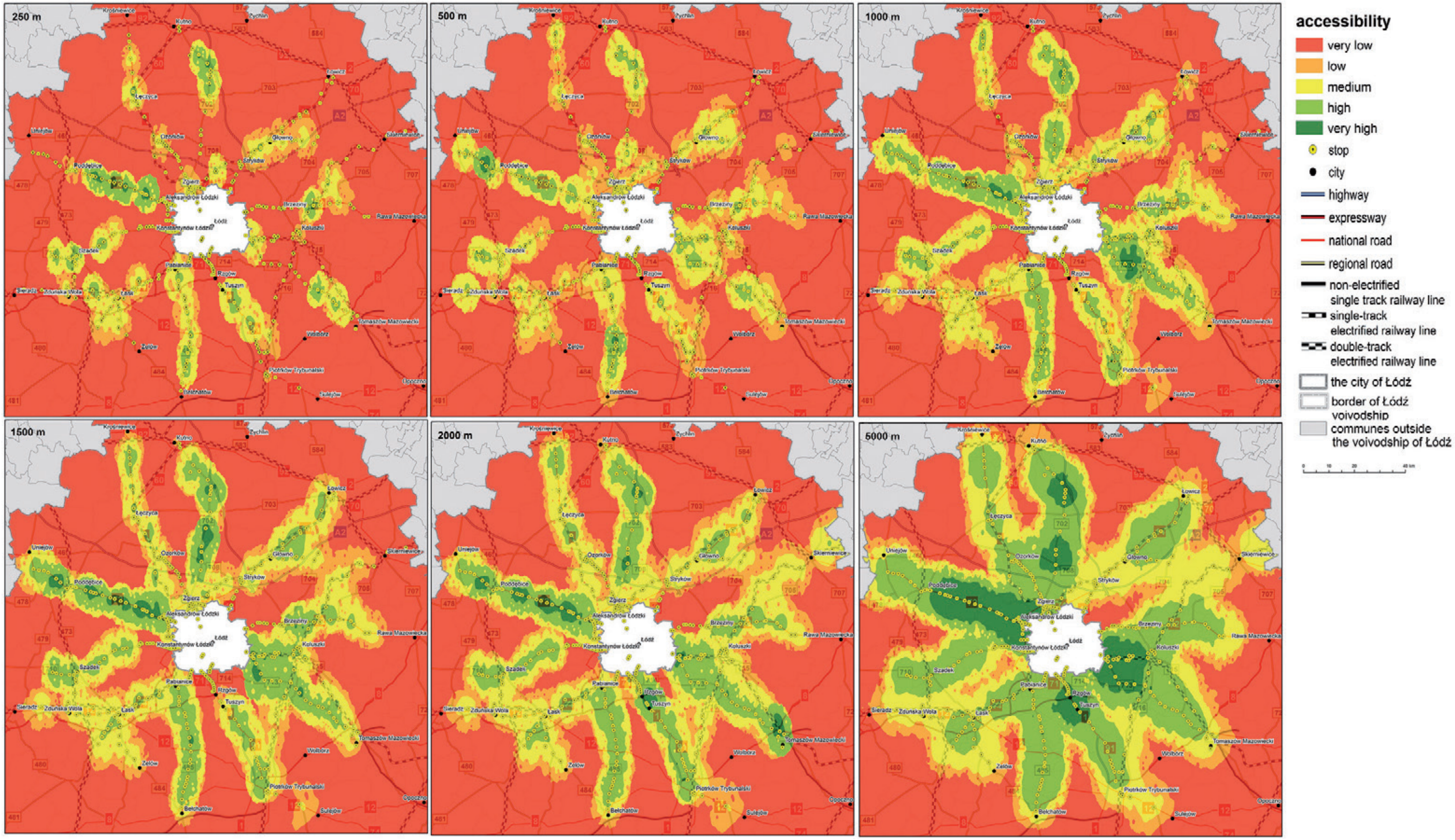

Figure 3. Spatial differentiation of accessibility to Łódź by means of public transport considering access distance

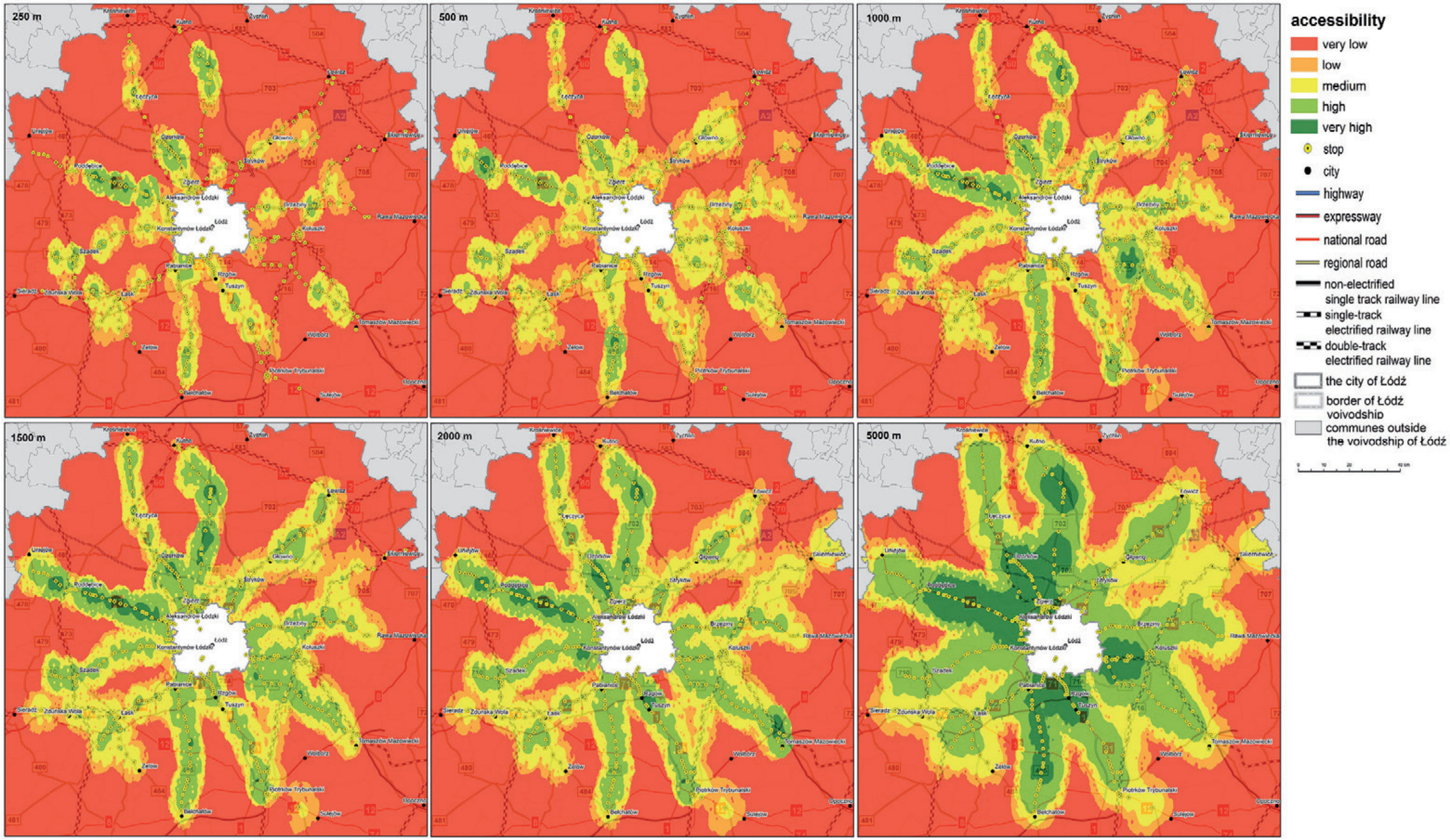

Figure 4. Spatial differentiation of accessibility to Łódź by means of public transport considering access cost

Discussion

Research of this kind represents rich diagnostic material for possible correction of the existing system (*ex post*) or planning its further development (*ex ante*). The areas with the highest levels of accessibility to stops should be considered the potential places of introduction of the system solutions aimed at making public transport connections more efficient through implementation of multimodal solutions. The main advantage of the presented method is the possibility of researching both public transport accessibility and its availability represented by such a variable as, for example, ticket price. Moreover, conducting research with the use of the 2SFCA method is relatively simple due to the possibility of GIS software support. The other benefits of the presented approach include the aforementioned readability and ease of interpretation of results. The 2SFCA method offers wide application possibilities and analysis results carried out with its use enable obtaining more precise outcomes than in the case of commonly used methods based on traditional phenomenon density. An important problem which must be dealt with in the future is the choice of a border value of the scope of the floating catchment area, or in the case of public transport, the maximum walking distance of a potential passenger to the stop. While carrying out research in many distance variants, it would be recommendable to introduce, for instance, the pace resistance function so as to differentiate accessibility within the boundaries of individual equidistances. This would allow including increasingly large areas into the research having at the same time rationality of the passenger whose willingness to use public transport decreases together with a rise in effort which must be made to reach it in mind.

Further work aimed at implementing the FCA method in public transport research should also account for a situation when the time of reaching the stop on foot by the potential passenger is equal or longer than the time of reaching the destination by public transport. In this situation the results obtained may prove that accessibility considered from the point of view of travel by public transport is high although it does not offer the potential passenger any time alternative.

Another issue to be solved in future research is the need to differentiate the scope of the impact area in both steps of the 2SFCA analysis as it should consider different tolerance of the potential passengers in reference to distance to be covered to reach the stop. Apart from the fact that it is conditioned by age or health condition, inhabitants of rural, suburban and urban areas are likely to have different tolerance. This implies a necessity to apply dynamic shaping of the scope of the floating catchment area (McGrail & Humphreys 2009).

Conclusions

The conducted research proceedings allow for concluding that Łódź has convenient bus connections both on the intra-regional, national and international level. Regular rail connections within the province have a clearly smaller territorial scope than bus passenger transport. The city has urban public transport of satisfactory level considering both the number of passengers and the length of lines. Urban centres need to be better connected with Łódź within the Łódź Agglomeration, which should be accompanied by an improvement in the condition of infrastructure and the rolling stock (Łódź Region Development Strategy 2020).

Transport accessibility of Łódź resulting from functioning of public motor, rail and tram transport is clearly conditioned by the number of its potential users. Its location in the settlement network and in the region of towns and localities, from which potential passengers travel to Łódź, is a rather secondary factor. Organization of public transport, although characterized by different efficiency in different parts of the agglomeration, still ensures coherence, if minimal, of all its towns.

The public transport functioning between Łódź and towns or localities within 1-hour isochrone of access does not correspond to the opportunities connected with infrastructure connections. Missed opportunities resulting from the condition and layout of infrastructure may result in an increase in the centre's accessibility levels provided that public transport is effectively managed.

Introduction of *park and ride* solutions linking individual car transport and public transport would be an answer for the grass-roots phenomena described above. A modal shift from individual transport and continuing the journey by public transport seems to be particularly justified in the face of the transport policy created in Łódź and its agglomeration (Wiśniewski 2015b).

The conducted analysis also enables to draw conclusions of methodological nature. The use of the modified two-step floating catchment area method allows including all the most important characteristics of public transport in the analysis. Continuation of research in this respect should focus on possible differentiation of the weight of trip frequency, time, distance or cost of access in the final accessibility indicator. The priority of journey time highlighted in the research into transport accessibility may be reflected, for instance, in the form of introduction of the power function with the given index.

The presented methodological approach may also verify the locations of spontaneously appearing multimodal transport solutions as the potential places of implementation of formalized systems or part of location analysis for planned infrastructure of this type.

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