Accessibility to Passenger Rail Transport in the Łódź Province

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This article presents results of research devoted to spatial diversification of accessibility to passenger rail transport in the Łódź province. The analysis was conducted on the basis of a full inventory of railway connections of carriers providing their services within the boundaries of the region. Calculations were made in reference to 158 train stations and train stops as well as the population of 4,965 settlement units. Two variants of reaching a train stop by passenger were distinguished: on foot and using individual car transport. Both solutions include a number of border variants in the form of maximum equidistances of access on foot and isochrones of travel by car. Research proceedings were based on two-step floating catchment area (modified for the purposes of research into effectiveness of public rail transport), which provides for train frequency and travel time to individual stops from the topological perspective.

Keywords: accessibility, public transport, rail transport, the Łódź province.

1. INTRODUCTION

It must be clearly stressed that a prerequisite to ensure transport accessibility of the given town or city consists in providing adequate access not only to elements of infrastructure but also to transport services. These two elements are closely interrelated since using these services is impossible without an adequately easy access to infrastructure (Gadziński 2010). On the other hand, even quite an easy access to this infrastructure does not guarantee transport accessibility on a desired level. The maximum accessibility level of different useful places, persons, goods and services which are often not far from one another, is dependent not only on access to transport itself but also on other elements (e.g. financial means) which contribute to reaching these places, persons or services (Kolarski 1976). Transport only makes it possible to reach the destination but does not focus on the use of the abovementioned goods, services, work places or education available in this destination (Polish Transport Diagnosis 2011).

The point of departure for achieving the aim of the article, which is assessment of accessibility to passenger rail transport in the Łódź province, is the assumption that the research deals with accessibility from the intraregional perspective. This means that this article does not cover the topic of connections resulting from the functioning of public transport in supraregional relations. From the standpoint of everyday journeys, public transport developed adequately to passenger needs plays a key role as it allows to reach work and educational institutions as well as use social infrastructure which is not available in the place of residence of inhabitants of one of 4,965 researched towns and localities of the Łódź province (Bartosiewicz, Marszał 2011).

Assessment of spatial accessibility was conducted in relation to 158 stations and train stops on the basis of connections between all possible pairs of towns of the Łódź province with access to rail transport. The analysis was carried out taking into account such variables as the number of connections (number of train pairs) and travel times from the topological standpoint. The number of connections was calculated through counting connections on a weekday, including both direct and indirect ones. For purposes of this work connection is understood as a single journey by public rail transport between the last stop within administrative boundaries of the journey's starting town and the first stop within the boundaries of the

destination town. In bilateral relations between towns connections were counted once only. Such a choice of variable was motivated by the fact that the number of connections from the given town and the number of connections to the same town are often equal (if there are some differences, they tend to be rather insignificant). Consequently, one connection is understood as a single rail service which caters for the journey between two towns in both directions. Due to the characteristics of the railway network of the Łódź province and a limited offer of carriers, substitutability of connections between individual towns is relatively small, which is why it was possible to scrutinize all the possible connections (Wiśniewski 2015).

In order to establish the number and other details of rail connections the author of this analysis used data published by PKP PLK and TK Telekom in the form of digitalized timetables and information included at http://www.rozklad-pkp.pl/.

Analysis of accessibility of passenger rail transport in the Łódź region was conducted in October 2015.

After a part introducing the topic of the article, the work deals with a characteristics of source materials and the methodology used in it. Subsequently, research results are presented and they are followed by conclusions in the final part.

2. LITERATURE REVIEW

If we want to characterize the most general concept of accessibility, it should be noted that it is the ability to create relationships between more than one element of the set (Komornicki et al. 2009). With the above assumption, it is possible to identify the key characteristics for clarification subject of accessibility. Firstly, it is the occurrence in the socioeconomic at least two elements which are the source and destination of availability that are mutually reachable (unilaterally or bilaterally). The second characteristic refers to the means of communication, acting as a carrier of the link between the aforementioned points, breaking its resistance in the form of socio-economic and politico-administrative or natural. Such perceived accessibility implies the existence of two complementary to each other concepts available - in terms of transport and planning.

Within the meaning of Karlqvist (1975), accessibility is a reference to the basic features of the behavior of people who seek to maximize contacts, showing therefore possible low activity, defined as the effort required to sustain them. Limiting the effort in the form of cost of movement it is identified with the accessibility also in the economic literature (Vickerman 1974). Hansen (1959) defines accessibility as the potential occurrence of interaction, which should be understood in social and economic terms (Handy, Niemeier 1997). Further analysis of the literature allows us to understand the concept of accessibility as the ease of occurrence of these interactions in space. Due to the subject of the article seems particularly relevant definition Bruinsma and Rietveld (1998) endearing accessibility, as the attractiveness of a particular node on the network, taking into account the weight of the remaining nodes located in it and the costs of relocating them using this network. The same point of view of accessibility presents Ingram (1971), by presenting it as an inherent feature of places associated with the method of overcoming the resistance of space in the form of distance or time. Other authors (Dalvi, Martin 1976) consider accessibility as the ease of access to any activity, from anywhere, using a specific transport system. It was also indicated that the accessibility of location is characterized by relating it to opportunities, activities and resources achievable in other locations. In this perspective, the location may be recognized as spot (city), linear/band (transport corridor) and surface (region). Warakomska (1992) 'divided' accessibility in terms of the object of analysis of the accessibility of the area, the accessibility of the transport network and the transport network topological accessibility. The first of them sets forth, among others, the density of the transport network in the region, the other - the distance to the network element, and the accessibility of topological be characterized by the methods of the graph. Accessibility is a commonly used expression, but is not associated with including its respective definition much less determine the tools to measure it (Gould 1969). In this research the basic variable determining transport accessibility levels of the given stop is understood as the accumulated journey time between this stop and all the remaining 158 stops in the Łódź province. This feature has a decisive meaning in this research as it determined the choice of a concrete connection analyzed in different aspects. It was assumed that while choosing a connection the traveller is guided mainly the criterion of time. The following key was used while choosing a connection to be analyzed: in the first place the connection which

enables to move the fastest from one town to another was selected where journey time was more important than the necessity to change. Connections which did not involve the necessity to change were chosen if there were connections of identical journey time. If these two features did not differentiate the connections in any way, the criterion of journey cost was taken into consideration and a lower price constituted a deciding element. The last differentiating variable was the distance to be covered using the chosen connection. Nevertheless, it has only theoretical character since in this research there was no need to compare connections in this respect.

It was assumed that potential passengers reach the train station on foot or by private car. Six maximum equidistances were adopted: 250, 500, 750, 1,000, 1,500 and 2,000 m for pedestrians. The Manhattan distance metric was adopted to establish distances between the central point of town/locality and the stop (Olszewski and others 2013).

In Poland it customarily assumed that the affected area of public transportation covers an area with a radius of 500 m to 1 km. This means that residents can reach the stop, walking anywhere from 6 to 12 minutes on the assumption that the average speed of their movement is 5 km/h (Majewski, Beim 2008). Of course, this model does not reflect the ability to generate the stop demand for public transport services, even if it would be carried out in all directions and at maximum frequency. This is due to the fact that each resident may have a different distance limit, with which resigns the use of the stop. In addition, for a hypothetical public transport user count next to a distance as possible conveniences to help reach the stop or barriers to its achievement. The impact of these factors is different for each resident, and is strongly determined by individual characteristics of each user, such as their age, health, sex, place of residence, etc. (Gadziński 2010). Generally in the literature can be found methodological problems associated with the distance limit for different types of transportation. In Britain the maximum distance to come to the bus stop in the city adopts a contour line of 640 meters, while the regional rail or subway 960 meters (Majewski, Beim 2008). German planners in turn consider the maximum way to come to the bus stop distance of 300 meters, tram 400 meters, while the regional rail 500 meters (Loose 2001). Differences in determining the distance limits with respect to the means of transport due to a number of issues of principle. Greater distance from the tram stop in relation to the bus stop cause a reduction in capital expenditure incurred on the construction of new tram lines, while the assumption that residents are able to continue to walk to the bus stop, where they can more quickly and more comfortably reach destination.

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 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 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 costs connected with changing the means of transport, both multimodal and within one 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.

In the variant of reaching the train stop by car, units of car journey time define the distance between each of the analyzed stops and individual towns/localities where potential passengers live. It was assumed that changes of journey speed are affected only by traffic regulations related to the maximum permissible speed. In this way all other factors, such as congestion or weather conditions, were excluded from the research. The passenger going to the train stop moves along the shortest route between two points which each time is delineated in accordance with the Emapa Transport+ Europa application. Two maximum isochrones of 15 and 30 minutes were adopted.

3. RESEARCH METHOD

Research based on spatial closeness tends to assume that the user is rational in his or her choices and uses the closest facility to get access to the given service. The two-step floating catchment area method (2SFCA) was used for every of the above-mentioned variants of access to the train stop (Yang and others, 2006; Luo and Qi, 2009;

McGrail and Humphreys, 2009; Hawthorne and Kwan, 2012, Stępniak 2013) in a version modified in such a way as to reflect the gist of the research in the best possible manner. A dynamic development of a whole family of floating catchment area methods (such as 2SFCA, E2SFCA, O2SFCA, 3SFCA, extended kernal density 2SFCA) (Radke, Mu 2000, Lou and Qi 2009, Ngui and Apparicio 2011, Wan and others 2012, Polzin and others 2014) was possible due to intensive development of GIS programming, particularly the functions concerning transport analysis.

In the first part of the two-step floating catchment area method the impact area of every stop is established, assuming the border value of access distance on foot (250, 500, 750, 1000, 1,500 and 2,000 m) or by car (15 and 30 minutes). Subsequently, an individual indicator R_j is calculated for every point where the train stops. This indicator is a product of the quotient of weight of individual stops and the number of people living in towns/localities marked by the given equidistance or isochrone of access on foot or by car and the reversal of time of access to the given stop in the topological perspective. It was assumed that the weight of stops would be the number of trains reaching it in twenty four hours (frequency).

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

where:

S_j – weight (number of connections in the topological perspective) of stop j,

Cj – accumulated train journey time from stop j to the remaining stops in the Łódź province,

P_i – number of inhabitants of town/locality i,

d_{ji} – distance/time of access on foot/by car between stop j and town/locality i,

d_{max} – equidistance/isochrone delineating the maximum distance/time of passenger's access on foot/by car to the train stop for individual variants of the research.

In this way the theoretical load of individual stops and train stations was calculated. It should be assumed that choosing the given stop as the initial one for the train journey potential passengers limit their availability for other users yet at the same time they do not limit it for other places where the train stops. In the second part of the employed method of analysis the attention shifts to towns and localities where potential passengers live. An area is designated for every centroid representing each of 4,965 towns or localities i, as in the first stage of the analysis, using the adopted border value of the distance of access on foot or by car to the stop. Subsequently the accessibility indicator A_i is calculated for every town/locality i included in the research and it represents a sum of values R_j for all stops located within the individual area of town or locality i:

$$A_i = \sum_{j\epsilon\{d_{ij} \leq d_{max}\}} R_j$$

The main advantage of the method is undoubtedly the opportunity to study both the accessibility (proximity), and availability, and also look at the accessibility of space at the same time on the side of supply and demand. Moreover, testing using the proposed method, due to the possibility of resorting to GIS software, it is fairly simple. The advantages should also include high legibility and easy interpretation of results, as well as comparability of the results obtained in different sections of time and space. The proposed method offers great application potential, and the results of analyzes carried out from its use can produce more accurate results than other commonly used methods, such as analysis of the value of the number of inhabitants per one stop. The analysis results are also more reliable than in the case of testing using another method, often used in recent years, a kernel density function (Yang et al, 2006). Innovativeness of the proposed test method applies to its completeness. Commonly used in literature, methodological approaches recognize only individual variables characterizing the functioning of public transport. For example Sobczyk (1985) in the rate of communication gravity, recognizes only the frequency of connections and does not include the supply of transport. Benenson et al (2011) in his research, devoted to the availability of space in Tel Aviv, capture all the stages of passenger transport, but does not mention the specific characteristics of the transport relations. Rietveld (2000) examining the accessibility in terms of cycling to railway stations, recognized multimodality issues, however, does not consider the characteristics of railway links. The presented method of research is an attempt to approach the widest range of demand and supply factors affecting the level of availability. Simultaneously avoiding devoid of spatial elements and, artificial in this kind of research, the border effect. The test

procedure is part of the same trend research as carried out by Gutierrez et al (1998), Choi and Jang (2000), Jovicic and Hansen (2003), Oh and Choi (2004), Jin and Wang (2004), Giannopoulos and Boulougaris (2007), Sung and Oh (2011), Xu et al (2007), Chen et al (2015), Cheng et al (2015) and Vale et al (2016).

4. SYSTEM CHARACTERISTICS

Accessibility to public transport conditions adequate comprehensive development on a given area. It makes it possible for the inhabitants to move freely between the place of residence and the workplace or educational institution. Well-organized public transport with appropriate frequency and timetables during the day contributes to a reduction in congestion in road traffic and it reduces travel time. Before analyzing bilateral connections between towns of the Łódź province, it is necessary to characterize the public transport connection network from the topological perspective.

In the case of rail connections between all stations and stops in the Łódź region the research also comprises an analysis of connections between the province's 24 towns which are connected by railway lines. Regular passenger connections are provided only to these towns. Considering the prerequisite of the research related to the incorporation of both direct and indirect connections into analysis, each town may be accessed from 23 other centres in the Łódź province.

Łódź is characterized by the greatest number of direct connections (18). To reach it from Wieluń, Opoczno, Wieruszów, Żychlin[1] and Kamieńsko it is necessary to change at least once. There are more than 10 direct connections also only to Zgierz (13). Wieluń, Opoczno oraz Wieruszów have the lowest accessibility levels in this respect, which may be attributed mainly to the location of these centres in the province's railway network. Wieluń and Wieruszów are directly accessible only to one another. Opoczno in turn has a direct connection only with Tomaszów Mazowiecki. Specifying the course of connections including changes it was possible to point to those towns in which users were forced to change the train. A timetable analysis points to Łódź as a place with the biggest number of changes. Out of all 276 connection combinations Łódź appears as an interchange station as many as 105 times. In 59 cases the place of changing the train was Koluszki. Timetables point to 24 changes in Tomaszów Mazowiecki, 16 in Skierniewice, 15 in Łowicz, 9 in Kutno, 8 in Piotrków Trybunalski and Zgierz each, 3 in Łęczyca and 1 in Radomsko and Sieradz each. The provision of possibly the fastest train connections between towns of the Łódź province entails a need to change also in towns outside its boundaries. Travelling to Wieluń and Wieruszów, passengers are forced to change in Ostrów Wielkopolski (in the case of 20 connections), Częstochowa (9 connections) but also in Poznań (7 connections), Lubliniec (5 connections), Kępno, Kalety and Krzepice (3 connections each) or Miechów, Katowicach, Sochaczew and Jarocin (1 connection each) (Wiśniewski 2015).

The train lines leading to Koluszki cater for the biggest number of connections within the Łódź province during 24 hours in the topological perspective (351). Only three connections less link the other towns of the province with Skierniewice. Over 300 connections per 24 hours (direct and indirect with a change) also reach only Łódź (334), Kutno (325) and Sieradz (314).

The least accessible train stops, considering the frequency of rail connections, are those situated on the lines leading to Drzewica, which is reached by only 88 passenger trains per 24 hours (including, of course, connections with changes in the topological perspective). Only those stops on the line in the direction of Wieruszów also have under one hundred connections (93). Focusing on bilateral connections, it must be pointed out that the stops with the highest rail connection frequency are located on the line between Łódź and Koluszki reached by 35 pairs of trains daily. A similarly high number of connections can be found between Koluszki and Kutno (34). Passengers beginning their train journey on stops between Koluszki and Skierniewice may use over 30 connections per 24 hours (32). Only one connection, in turn, is available between Opoczno and Drzewica. An analysis of rail connection frequency points to a general tendency showing that it is clearly higher in the case of direct connections.

Train stops in Łódź belong to the most accessible ones in the Łódź province considering the length of train connections in the topological perspective. Also the places where trains stop in Zgierz and Pabianice display high transport

[1] Żychlin does not have a direct rail connection. The Żychlin station is located in Pniewo whereas the town may be accessed by urban buses.

accessibility levels. Under 2 thousand kilometres is the distance which divides the stations in Łask, Koluszki and Stryków from the region's remaining stops.

Similarly, the stops characterized by the highest accessibility levels concerning journey time overlap with those determined by distances. When analysis comprises the time necessary to travel between the stops of the Łódź province, it becomes possible to specify speeds of individual connections. Trains travel at the highest speeds between Łowicz and Kutno with the average speed of 108 km/h. Also trains between Skierniewice and Koluszki go at a speed of over 100 km/h. The lowest average speed (below 20 km/h) is reached on the connection between Opoczno and Drzewica. Also trains going between Ozorków and Stryków do not exceed the average speed of 30 km/h. Such small average speeds result, to a large extent, from the necessity to change.

The last variable which characterizes rail connections is their price. As it is calculated together with the increase in distance, it directly refers to the matrix of distance.

Due to the fact that only connections between train stops were included in the analysis, changes in the proportion of price to distance may result from the choice of PKP InterCity (especially Express InterCity), whose prices are higher than those established by, for example, Przewozy Regionalne (REGIO or interRegio) or Łódzka Kolej Aglomeracyjna. Nevertheless, due to the priority of journey time they were often taken into account in this analysis. The most expensive connection with respect to 1 km is between Łódź and Zgierz as well as Sieradz and Zduńska Wola (nearly 0.8 PLN/km). This results from the fixed minimum fare which does not differentiate connections up to a certain length and clearly lower prices for travelling more kilometres (e.g. train journey of 6 km on the section from Łódź Żabieniec station to Zgierz station costs 4.4 PLN, whereas the train journey on the Łódź Kaliska – Pabianice section, which is 8 kilometres longer, costs only 5.3 PLN).

The cheapest connections (with respect to 1 km) join train stops of the Łódź province which are at the greatest distance from one another. Train journeys between Wieluń and Łowicz comprise the most cost-effective connection. The price for one kilometre on this route does not exceed 15 groszy. Almost an identical fare (15.3 groszy) must be paid for the connection between Drzewica and Błaszki.

5. RESULTS

These regularities related to accumulated frequencies of train connections between individual stops and the time of reaching them from the remaining 157 stopping places were taken into consideration in the spatial analysis, which allowed to determine accessibility of the region's inhabitants to public rail transport in as synthetic way as possible. Firstly, the author adopted a variant in which passengers reach the stop on foot from localities situated at a distance not exceeding 250 and 500 m (fig. 1.), 750 and 1,000 m (fig. 2.) as well as 1,500 and 2,000 m (fig. 3.).

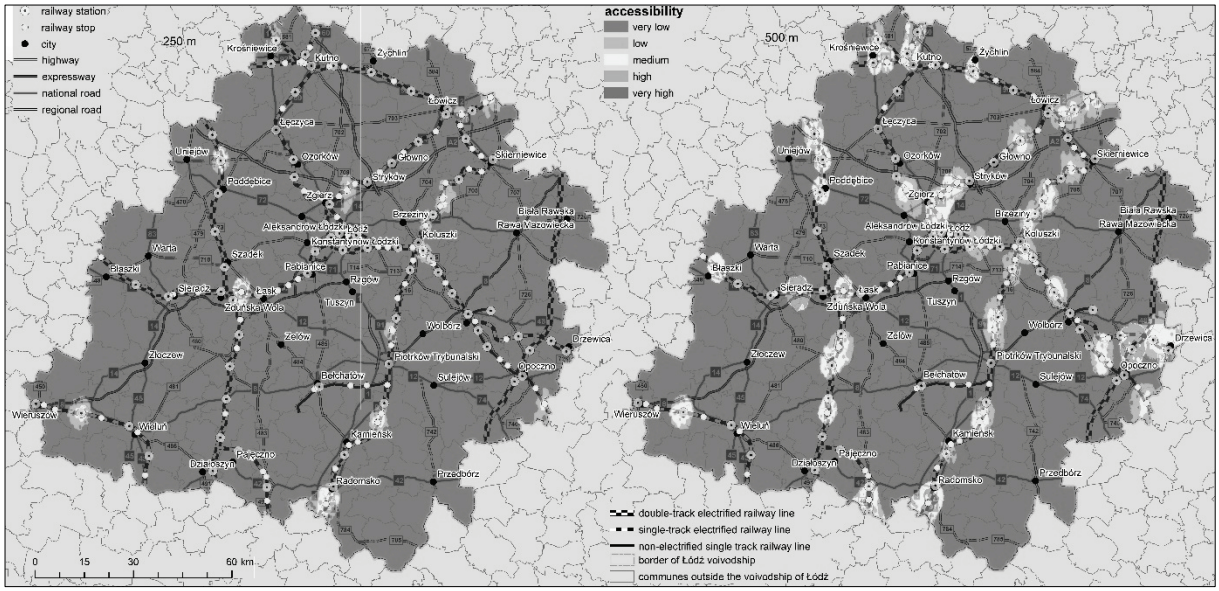

Fig. 1. Spatial differentiation of accessibility to public rail transport in the Łódź province considering accumulated frequency and train journey time as well as the assumption of 250 and 500 m access on foot to the train stop. Source: own work.

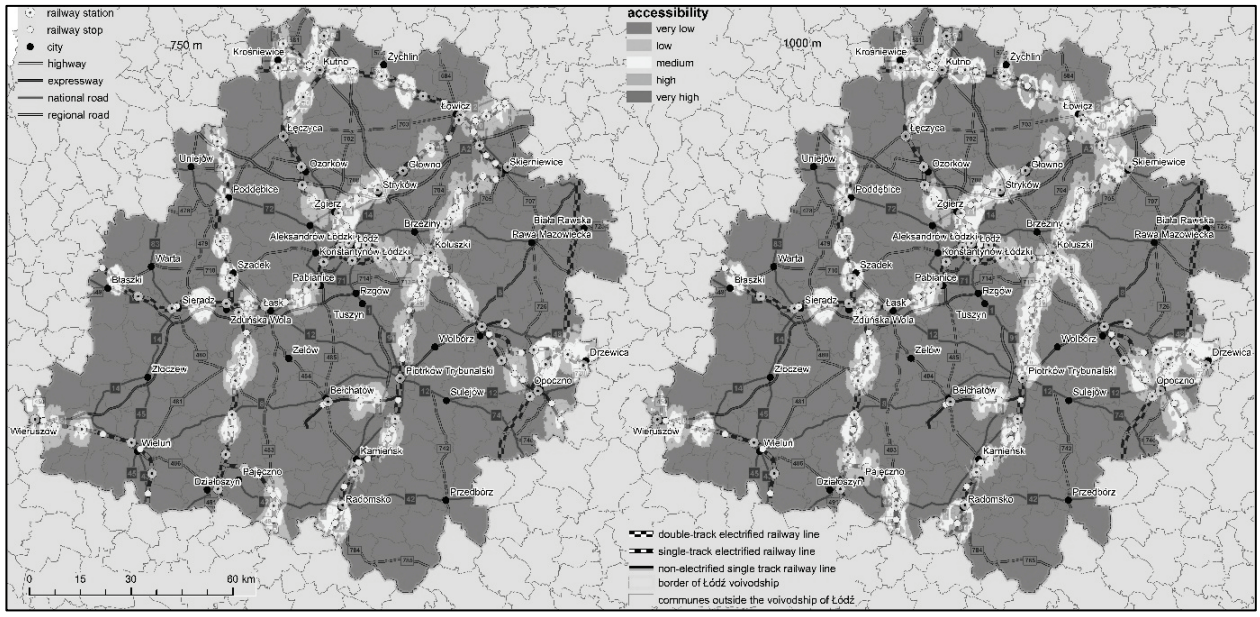

Fig. 2. Spatial differentiation of accessibility to public rail transport in the Łódź province considering accumulated frequency and train journey time as well as the assumption of 750 and 1,000 m access on foot to the train stop. Source: own work.

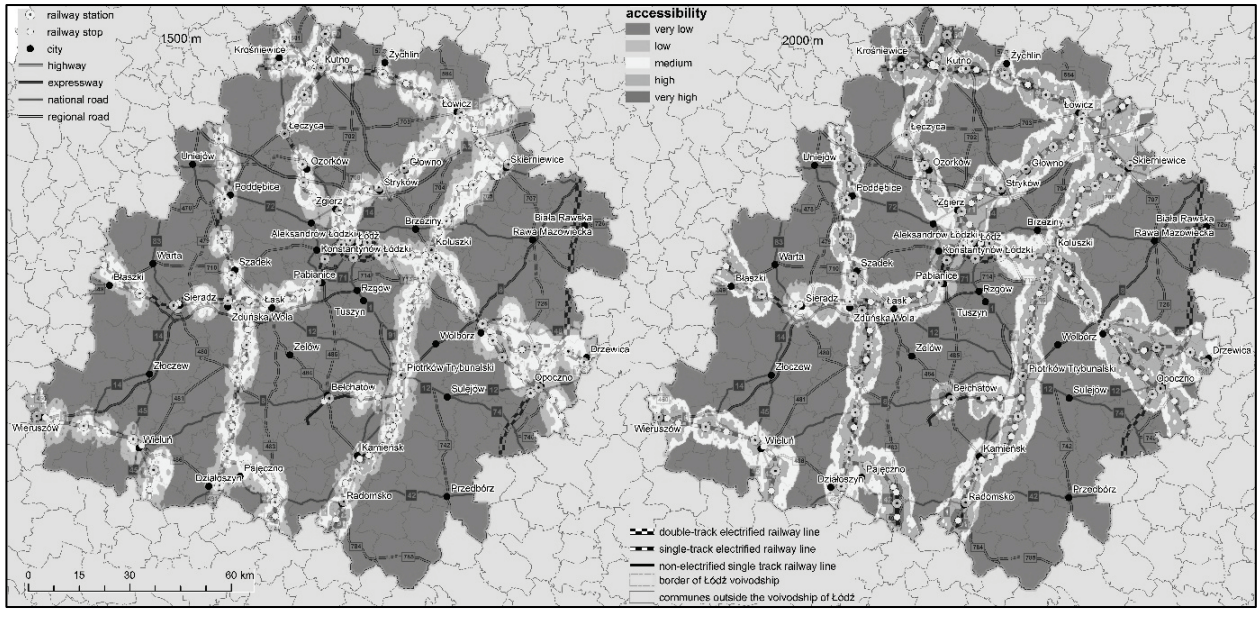

Fig. 3. Spatial differentiation of accessibility to public rail transport in the Łódź province considering accumulated frequency and train journey time as well as the assumption of 1,500 and 2,000 m access on foot to the train stop. Source: own work.

The second variant of the research which assumes that passengers reach the station in their own individual car transport gives a distinctly different picture of spatial differentiation of accessibility to the region's train network (fig. 4.). Considerably better accessibility with the use of car transport entails a clearly bigger potential load of individual train stops. The picture of accessibility levels no longer alludes directly to the course of train lines and location of train stops. It is "distorted" by overlapping of the conditions of accessibility resulting from the course and quality of road infrastructure leading to train stops.

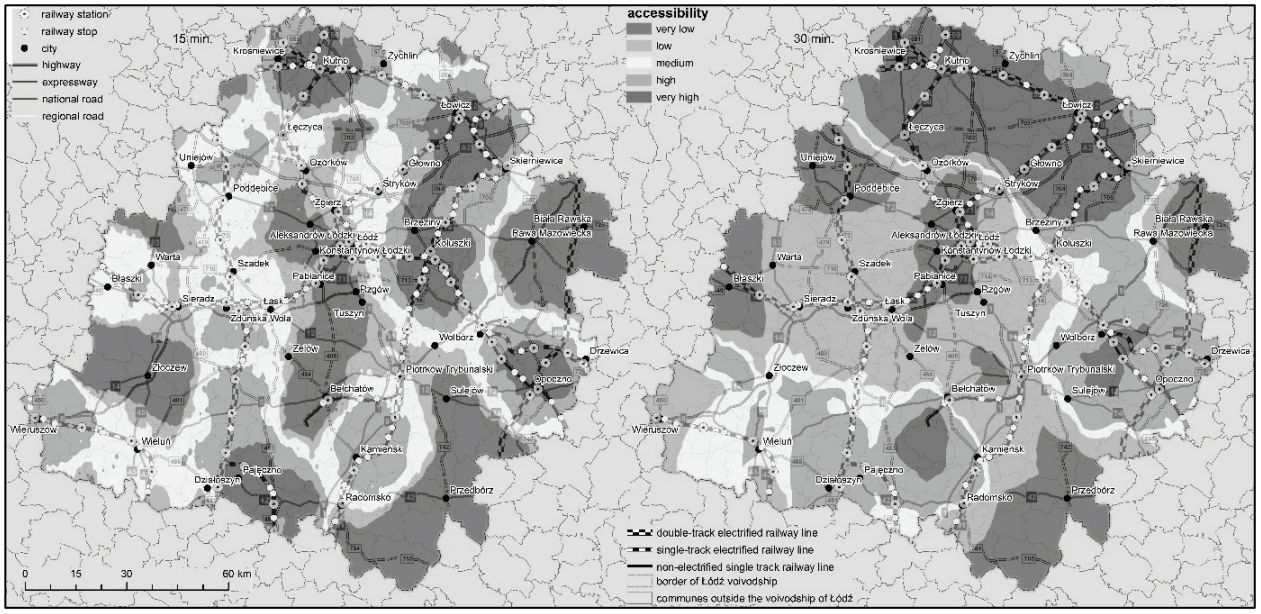

Fig. 4. Spatial differentiation of accessibility to public rail transport in the Łódź province considering accumulated frequency and train journey time as well as the assumption of 15 and 30 min access by car to the train stop.
Source: own work.

The research proceedings also allowed to specify the effectiveness of the regional rail transport network on a relative basis (tab. 1.). frequency of connections which reach larger centres. The distance between towns or localities from the province's centre is rather of minor

Table 1. The number of population and stops available in the adopted border ranges.

	distance of access on foot [m]						**access time by car [min]**		Łódź province
equidistance/ isochrone	**250**	**500**	**750**	**1000**	**1500**	**2000**	**15**	**30**	
population	20315	78496	198289	242266	1318577	1593075	2382869	2498664	**2504136**
share	0.8%	3.1%	7.9%	9.7%	52.7%	63.6%	95.2%	99.8%	**100%**
number of stops	17	47	76	95	133	146	158	158	**158**
share	10.8%	29.7%	48.1%	60.1%	84.2%	92.4%	100.0%	100.0%	**100%**

Source: own work.

6. CONCLUSIONS

Accessibility to passenger rail transport is predominantly determined by the course of railway lines and distribution of stopping places. Their layout is reflected by the fact that it ensures access only to 24 out of 44 all urban centres in the Łódź province. The level of transport connections of the province's settlement network resulting from public rail transport is clearly conditioned by the number of potential users. This is not a correlation as clear as the one in the case of, for instance, car transport. In turn, the location of town or locality in the settlement network and the region is a secondary factor. This is largely due to higher importance in the case rail transport.

In reference to train connections accessibility levels are clearly affected by changes in the volume of population potential of individual towns and localities in relation to distance, time and frequency of connections. Taking into account the distance to the stop in walk length units and access time generally causes clear differentiation of divergence between accessibility levels in relation to the province's individual areas. Implementation of a journey time variable into the analysis brings about, in turn, an evident allusion to spatial layout of transport potential with the assumption of resistance in units of measurement. Łódź, the

regional centre, constitutes a significant barrier for rail connections from the provincial perspective. Disruptions result from the fact that lines are used by both commuter and long-distance trains. Łódź also divides the national rail connection network into two parts which are serviced by two train stations. This makes it more difficult to include rail to the external transport service of the region.

The public transport functioning between rail stops of the Łódź province does not match the opportunities resulting from infrastructure connections. Lost opportunities resulting from infrastructure condition and layout may result in an increase in spatial accessibility levels if the public transport is managed in an effective way. Nevertheless the organization of public rail transport, even though it is characterized by different effectiveness levels in different parts of the Łódź province, does ensure, if minimal, cohesion of all 158 stations and stops as well as accessibility for almost the whole population of the region don the condition that the potential passenger decides on a combined car-train transport.

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 to include larger and larger areas in the research having in mind 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.

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.

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