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# ACCESSIBILITY TO VARIOUS DESTINATIONS BY PUBLIC AND PRIVATE TRANSPORT IN SZCZECIN

## *Dostępność do różnych destynacji za pomocą komunikacji miejskiej i prywatnej w Szczecinie*

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**Abstract**: The analysis presented herein is aimed at indicating disparities in accessibility to some selected travel destinations by means of private and public transport in the city of Szczecin. Accessibility is a simple measure of potential interactions between two points in space. For the purpose of the study, an original model of an individual transportation system has been developed using Google Maps API data. In order to do so, some GTFS and pedestrian-related data have been downloaded. To calculate source-destination travel times at certain times of the day for four different parameters of pedestrian motion speed, ArcGIS Network Analyst software has been used. Five research methods have been applied: the proximity measure, the population percentage measure, the cumulative accessibility measure, the potential accessibility index and the potential accessibility quotient. In order to develop an ultimate accessibility rating for housing estates in Szczecin, a synthetic accessibility measure has been developed. The synthetic accessibility measure consists of 9 standardised components/values for both public and private (car) transport. The potential accessibility to the population is part of the synthetic accessibility sub-measure. The isochrones have been drawn in order to analyse the workplaces and secondary schools. Moreover, data concerning accessibility to the nearest kindergarten, primary school, hospital, cinema, shopping centre and indoor swimming pool have also been taken into consideration when calculating the synthetic measure. In the case of potential accessibility measures, it is usually the highest in the city centre. Obviously, the nearer a particular facility, the higher its accessibility measure is. The only disparities between the measures for public and private transport are observed in areas which are not covered by the public transportation network.

**Key words**: GTFS, public transport, private transport, accessibility

## 1. Introduction

Accessibility, as such, is defined as a simple measure of potential interactions between two points in space (Hansen, 1959; Isard, 1954). One of the most frequently used measures is cumulative and temporary accessibility (Niedzielski, Kucharski, 2019; Goliszek et al., 2020; Niedzielski, 2021), which indicates the number of possibilities that may be reached in a given place and within a specific travel time or when using a particular means of transport (Vickerman, 1974; Geurs, van Wee, 2004). The cumulative and temporary accessibility measures are simple not only to calculate but also to analyse. The calculated results do not differentiate travel time unless they are below or above a certain threshold. Also, the way people perceive travel time is not taken into account (Thompson et al., 2019). The second method applied by the authors of this study is the potential accessibility measure based on gravity. On the other hand, this method discounts the attractiveness of destinations by travel costs – the beta parameter which decreases the attractiveness according to travel time (Hansen, 1959; Vickerman, 1974; Geurs, van Wee, 2004). The main disadvantage of the method based on gravity is the fact that the results are more challenging to convey and interpret (Ingram, 1971; Geurs, van Wee, 2004). Notably, the potential and cumulative accessibility measures are strongly correlated. Thus, they may be used interchangeably if needed (El-Geneidy et al., 2016). That is why the main research methods used for the purpose of this study are the temporary and cumulative accessibility measures.

Daily accessibility measures have multiple practical applications, including effective traffic management in urban areas. Data on daily accessibility allows, for instance, to determine times of the day when the accessibility is limited or the period of time during which the most significant differences in accessibility by private and public transport are observed. Having such knowledge, passengers and commuters in urban areas may be able to assess travel times quite precisely and choose the most suitable means of transport. Hence, this study focuses on determining differences in accessibility measures for both public and private (car) transport in the city of Szczecin.

The main objective of this study is to imply different accessibility methods for public and private transport and to present them in the form of a standardised index. Furthermore, the different methods of accessibility by public and private transport in the form of an index have been compared with each other, which at a local level has shown differences in accessibility to different destinations.

The paper uses commonly used methods of transport accessibility, which are presented in the form of standardised results. The contribution of the article to the development of science is not significant. Of great importance is the comparison of public and private transport, which is increasingly common with current computational capabilities and data availability. The contribution of this article is unique in that it takes into account the public transport model made by the author (Goliszek, 2022a).

However, the results of this study can be helpful for planners and decision-makers dealing with the development of public transport in cities. The results presented and, based on them, implementing a new transport policy or modifying an existing one can significantly improve the operation of public transport within a city and benefit both the residents and the operator responsible for transport in the city.

## 2. Scope of the study

The study area does not cover the entire Functional Urban Area (FUA) of Szczecin, as the authors used data on public transport published by the Roads and Transport Management Office (ZDiTM). The Office does not collect data on private and public carriers providing services in the neighbouring municipalities. Narrowing the study area and focusing only on the city within its administrative boundaries resulted in excluding services provided by the inner-city rail (managed by the Przewozy Regionalne company). If the study area covered not only the city itself but also the neighbouring municipalities, where lots of commuters reside, the development of the private transport model would be much more complicated and time-consuming. This is due to the fact that the authors would have to include numerous additional road sections.

The city of Szczecin, characterised by a river-port layout, is a relatively large city that covers an area of 300,55 km$^2$. The city is the capital of the West Pomeranian Voivodeship, and in 2019 (20.06.2019), it had a population of 402,1 thousand people and a density of 1347,1 p/km$^2$. Therefore, Szczecin is the fourth largest and seventh-most populated city in Poland. The city has been divided into 1869 census areas based on data provided by the City Hall. These spatial units were taken into consideration when calculating the accessibility measures, and they have become the so-called transportation spatial units. Such a large number of spatial units allowed the authors to conduct in-depth and precise analyses.

According to the 1990 administrative division of Szczecin (with some slight changes in boundaries of some districts and housing estates that have been introduced since then), the city consists of four districts: Zachód (West), Prawobrzeże (Right Bank), Północ

(North) and Śródmieście (Downtown). The districts are divided into 37 housing estates (Fig. 1).

The Szczecin road network is 804 km long. In order to analyse accessibility by private transport (car), the whole network has been taken into consideration. The data on travel times for selected sections of the road network was downloaded in October and November 2018. In order to construct the individual transportation model, over 60 thousand map loads (travel time data sent) with X and Y coordinates were generated (downloaded) in real-time between 5.00 am and 10.00 pm (Goliszek, 2021).

The city is divided by the Oder river and the port infrastructure, which makes it more difficult for the Prawobrzeże dwellers to commute to the districts located on the left bank (Śródmieście, Północ, Zachód). There are two bridges that allow crossing the river, and they are located on roads DK10 and DK31. In the housing estate called "Międzytorze-Wyspa Pucka" in Śródmieście, the two-lane DK10 bifurcates, and part of it becomes a three-lane regional road No. 115. As for the public transport, until 2015, the only possible way to cross the Oder was by bus. In order to make it more convenient for the passengers, the city authorities decided to expand the already existing tram network and launch a fast tram line crossing the river. The first stage of the project has already been finished, and on 29th September 2015, the first section (4 km long) of the new line was launched. The project was implemented under EU development policies during the programming period 2001-2013. The second and last section of the line is to be launched after 2025.

For the purposes of this article, the authors have created an original model of private transport operation in Szczecin using Google Maps API data, which had been downloaded with the help of a dedicated application written in Python 2.7. A primary grid of roads and footpaths has been created on the basis of the Database of Topographic Objects (BDOT10k) . The created road network depicts travel times between particular road sections (sections between the junctions) in 15 min intervals. Data on the travel times apply to selected weekdays–from Tuesday to Thursday and certain times of the day–from 5.00 am to 10.00 pm. Limiting the study to the period between Tuesday and Thursday allows to exclude increased pre-and post-weekend traffic from the analysis. The application written in Python allows to generate map loads and download data on travel times between selected X and Y destinations. Google Maps API data has been


Fig. 1. Division of Szczecin into districts and housing estates based on data from Szczecin City Hall.

Source: own elaboration of the authors

assigned to particular sections of the urban road network (Goliszek, 2021). The only restriction limiting the free-or-charge use of the portal is that it is possible to generate no more than 2500 map loads per day per API (Mercurio 2008; Schwartz 2010; Wang, Xu 2011).

Travel times for the means of public transport were calculated in several steps. First, a network database was created on the basis of the General Transit Feed Specification (GTFS) data with the use of the "Add GTFS to network dataset" tool (Fig. 2). GTFS is a universal data format used worldwide to download data concerning timetables and the location of stops. It allows for to calculate of accessibility measures for public transportation systems for a selected time period during the day. The GTFS provide information on timetables and other geographic data, e.g. stops coordinates or bus/tram routes in the text. format (Goliszek, Połom, 2016; Karner, 2018; Goch et al., 2018; Stępniak et al., 2019). Szczecin was the first city in Poland for which the GTFS data has been made available online (Rosik et al., 2021b; Rosik et al., 2020). The set of data used for the purpose of this study includes text files uploaded by ZDiTM in October 2018, and the above-mentioned tool creates a network database (stops and public transport lines).

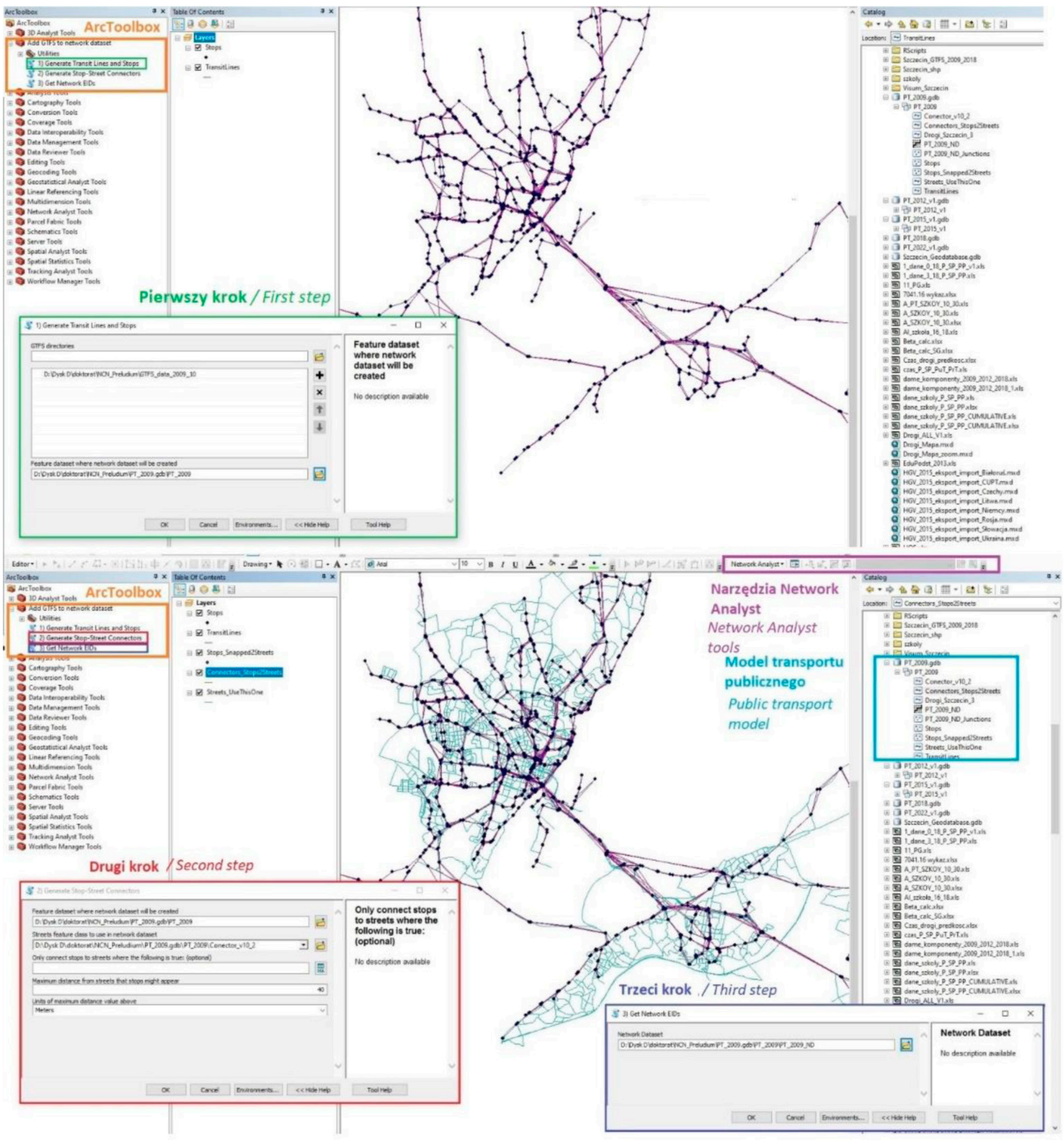


Fig. 2. Creating public transport models in ArcGIS.

Source: View from ArcGIS 10.2

Next, the network database was supplemented by a set of the OSM data on pedestrian traffic with walking speeds assigned. The pedestrian paths are connected in order to create a unified model of public transport. The network database includes all elements of the "door-to-door" journey, which are: reaching a tram/bus stop, waiting for a tram/bus, changing (if necessary) and journey duration (Salonen, Toivonen, 2013). The door-to-door approach assumes that there are several time-consuming travel components that shall be taken under consideration when calculating total travel times. They are as follows: reaching a tram/bus stop, waiting for a tram/bus, changing (if necessary) and walking back according to the times used in the pedestrian model. As for the private transport model, there are also four components–reaching a car, driving time (calculated using Google Maps® API data), parking and walking to the final destination. The values that are added as the parking time equal the walking time between the centre of a particular census area and the nearest road/street. In fact, it is virtually impossible to measure parking time due to its variability in different cities in Poland. Actually, it may be random values. The only places where the parking time may be assessed are some newly built buildings with monitored parking areas (Goliszek, 2021).

In the next step, ArcGIS Network Analyst was used to calculate travel times for a selected hour of the day, taking four different parameters of pedestrian speed into account. The final source-destination matrix includes data on pedestrian travel times if they are faster than the transit. The source-destination matrix was calculated between centres of 1869 census areas, which results in 3 493 161 source-destination relations with travel times (by public transport) assigned (ZDiTM Szczecin).

## 3. Methods

The study is based on data for the source and destination journeys using transport models, including journey times. In order to analyse transport accessibility, five research methods have been used:
(1) the proximity measure,
(2) the population percentage measure
(3) the cumulative accessibility measure
(4) the potential accessibility index
(5) the potential accessibility quotient.

At the final stage of analysis, when creating the accessibility rank of housing estates, all the measures were standardised, and a synthetic measure was created.

The first method applied was the proximity measure showing the shortest distance to selected destinations. The analysis covered 15-minute intervals at different times of the day: between 7.00 and 9.00 am for hospitals, 5.00-7.00 pm for shopping centres, 6.00-8.00 pm for cinemas and indoor swimming pools. The disparities revealed provided information concerning the longest and shortest travel times by public and private means of transport at different times of the day (Goliszek, 2017b; Goliszek, 2019).

The population percentage measure was the second method used in the context of reaching the nearest available services. For each isochrone of accessibility, a percentage of the population having accessibility to a selected service was calculated. The analysis covered different age groups: hospitals – all citizens of Szczecin, indoor swimming pools – citizens aged between 7 and 65, shopping centres – citizens aged 15 years and more, cinemas – citizens aged between 15 and 65. The accessibility maps created as part of the analysis described herein present the phenomena in 5-minute intervals and a maximum 60-minute journey time. The last accessibility interval consists of areas located more than 30 minutes away from a selected service.

The third method applied is the cumulative opportunities measure calculated for specific transport areas in a particular period of time or within a given travel distance. It is calculated as follows:

$$A_i = \sum_{j=1}^{j} B_j O_j \tag{1}$$

Where: $A_i$ is accessibility to services in transport area *j* calculated for census area *i*, $O_j$, with possible interaction with *j*. $B_j$ takes the binary value 1 if transport area *j* falls within a certain access threshold to area *i*. If the time threshold is too high, $B_j = 0$.

The cumulative accessibility measure is often used as a simple and direct way of determining spatial inequalities in accessibility to e.g. public amenities (Talen, Anselin, 1998; Gutierrez, 2001; Talen, 1996). It is also a simple indicator showing if a given object is accessible within a given isochrone (Miller, 1991; Goliszek et al., 2020).

In this study, the cumulative measure has been used to determine accessibility to kindergartens, primary schools, high schools and workplaces by means of public and private transport (Goliszek, 2017a). The map shows the percentage of all destinations (educational facilities and workplaces) accessible within specific periods of time (Rosik et al., 2021a). As for the kindergartens, primary schools and high schools, the benchmark was the total number of educational facilities in the city. The cumulative accessibility to workplaces is a percent of all workplaces in Szczecin which can be reached from a given transport area within a specific time period. Both analyses were done for 8.00 am on weekdays.

The fourth accessibility method used for the purpose of the study presented herein was the potential accessibility index. Potential accessibility is measured using the potential–gravity method. In this study, travel times between two census areas in Szczecin ($i$ and $j$) is expressed by $t_{ij}$. Selection of the means of transport (public or private) determines the travel time between $i$ and $j$. This parameter was reduced by the spatial resistance function value $f(t_{ij})$. The attractiveness of a given destination is expressed by the population $POP_j$. The formula for the potential accessibility is as follows:

$$A(POP)_i = \sum_j POP_j f(t_{ij}) \quad (2)$$

In the case of urban areas, the results are significantly affected by the function of spatial resistance applied. In Szczecin, which is a medium-sized city, the spatial resistance function includes shorter time distances. The most often used type of the spatial resistance function in potential accessibility studies is the exponential function (Beria et al., 2017; Stępniak, Goliszek, 2017; Thompson et al., 2019; Merlin, 2020), i.e.: $f(t_{ij}) = exp(\beta t_{ij})$, where β differentiates the level of destination attractiveness reduction. In order to determine time for the spatial resistance function, data published in the study entitled „Comprehensive Traffic Research in Szczecin 2016" (CTR) was applied. In this study, the average travel time for means of public transport in Szczecin was approximately 30 min. The adopted value of the spatial resistance function parameter for the period of 30 min is −0.023105 (Goliszek, 2021; Goliszek, 2022b; Rosik et al., 2020).

For the purpose of this study, the authors calculated potential accessibility indexes for public and private transport in 2018 and for public transport only in 2009, 2012 and 2015. In order to take account of daily changes in accessibility (time component), potential accessibility has been calculated for a specific period of time, namely from 5.00 am to 10.00 pm in 15-minute intervals.

Different people (citizens) may have different accessibility levels assigned when certain demand-supply limitations are applied. It may consider, e.g. workplaces requiring highly-qualified employees. Such workplaces can usually be found in highly accessible inner-city locations. However, well-educated managers often live in single-family house estates in the suburbs. For them, the city centre is less accessible. The uneven distribution of demand and supply in cities is something normal, and that is why the so-called competition effect should be taken into account (Geurs, Ritsema Van Eck, 2003; Geurs et al., 2009; Shen, 1998).

The fifth research method applied, i.e. the potential accessibility quotient, takes account of the competition effect. The following quotients have been selected by the authors:

1) potential of kindergarten places to potential of population aged between 3 and 6 years old,
2) potential of primary school places to potential of population aged between 7 and 15 years old,
3) potential of high school places to potential of population aged between 16 and 18 years old,
4) potential of workplaces to potential of the working-age population (18-60/65 years old).

Similarly, demand depicts the potential of citizens representing different age groups, i.e. $POP_{3\text{-}6/7\text{-}15/16\text{-}18/18\text{-}65}$ and P – the number of children in kindergartens, SP – in primary schools, PP – in high schools and MP – the number of workplaces. The formula is as follows:

$$A_i(\mathrm{POP}_{3\text{-}6/7\text{-}15/16\text{-}18/18\text{-}65})_i = \sum_j \mathrm{POP}_{3\text{-}6/7\text{-}15/16\text{-}18/18\text{-}65\ j} f(t_{ij}) \quad (3)$$

Supply depicts a comparison of the potential accessibility and the number of places in kindergartens – P, the number of places in primary schools – SP, in high schools – PP and the number of workplaces – MP (the numerator):

$$A_i(\mathrm{P/SP/PP/MP})_i = \sum_j \mathrm{P/SP/PP/MP}\ _j f(t_{ij}) \quad (4)$$

There are numerous studies on children commuting to schools, especially those living in peripheral areas (Catling, 2005; Parnell, Patsarika, 2011; de Kadt et al., 2014; Lin et al., 2014; Zelinsky, Kubak, 2014; Kučero et al., 2015; Loo, Lam, 2015; MacKenzieet et al., 2017; Stephens wt et al., 2017; Gilliam, Gulløv, 2019). However, the most frequently studied issue is potential accessibility to workplaces. The term „potential of workplaces" was used by M. E. O'Kelly and W. Lee (2005), M. E. O'Kelly and M. A. Niedzielski (2009) and M. A. Niedzielski and E. E. Boschmann (2014) and others. The ratio between the potential of workplaces, places in the educational facilities and the citizens of different age groups in the census areas has been presented as the potential quotient ($Qi$). It is calculated as follows:

$$Q_i = \frac{A(P/SP/PP/MP)_i}{A(POP_{3-6/7-15/16-18/18-60/65})_i} \quad (5)$$

All the research methods selected and presented are frequently used in transport research. Using these methods and standardising the results has made it possible to determine the level of accessibility by public and private transport and to compare the two modes of transport in terms of accessibility to selected travel destinations. The research methods used can have a sizeable practical dimension for planners and those involved in implementing public transport within a city or region.

Finally, the process of standardisation was applied to create a synthetic measure of accessibility to the educational facilities and workplaces by means of public and private transport. The standardisation procedure involved an essential measure which is the ratio of the difference between a not-standardised variable and population average and the population standard deviation accordingly to the following formula:

$$z = \frac{x - \mu}{\sigma} \tag{6}$$

where:
x – not-standardised variable,
μ – population average,
σ – population standard deviation.

The synthetic measure falls between 1 and 10, and it has been calculated with the following formula:

$$Ms = w \cdot 10 \tag{7}$$

$$w = \frac{k}{\#Z} \tag{8}$$

where:
K – standardised variables *z* in descending order,
k – position of the element being part of set Z is set K,
#Z – the size of set Z,
w – auxiliary variable rounded off to the first decimal place.

The standardised values were grouped into deciles, and as such, they were depicted on the maps. Only the measures (variables) which characterised accessibility to different destinations in the city have been taken into account: 9 for public and 9 for private transport (18 in total) (Berežný, Konečný, 2019).

## 4. Results

Potential accessibility to the population by both private and public transport is part of the partial synthetic measure. The isochrone-based method has been used in the cases of workplaces and high schools (the number of workplaces and places in high school available in isochrone is up to 30 minutes). Additionally, the proximity measure has also been applied to the nearest kindergarten, primary school, hospital, shopping centre and indoor swimming pool for a specific period of time. The proximity measure was used for the kindergartens and primary schools as those services are directly linked to the number of citizens.

The analysis of single accessibility measures, which have been standardised, revealed that for both public and private transport, there are places of better and worse accessibility. In the case of the potential accessibility index, the highest accessibility is usually in the city centre, as most of the highly demand services are located there (Fig. 3). However, when analysing the proximity measure, it has become clear that the accessibility is usually better in the area surrounding a place where a given service is provided. The map is slightly more differentiated, and there are some isolated places, e.g. in Prawobrzeże, where the accessibility is very high (Fig. 3 and 4).

The differences between single accessibility measures for means of public and private transport are visible on the maps only in places which are not covered by the public transportation system. Obviously, in such places, the accessibility by private transport is much higher. In most cases, the standardisation procedure revealed similar pictures. However, the overall accessibility is higher for private transport (cars). Smaller disparities for private transport shown on the maps result from the fact that minimum and maximum average travel times for cars are lower (Fig. 3 and 4).

The synthetic accessibility measure determining areas in Szczecin having the highest accessibility consists of 9 standardised measures for both public and private transport (Tab. 1 and 2). The measure falls between 1 and 10, where 1 means the highest accessibility and 10 – the lowest. According to this measure, some housing estates in Śródmieście – Centrum, Stare Miasto and Śródmieście Zachód – have the highest accessibility. Such a result for this part of the district has been affected by the selected destination and measures of accessibility applied to this study (potential and cumulative measures). As for the other housing estates which surround the city centre, the average accessibility is also high. Międzytorze – Wyspa Pucka is the only exception. However, it is an area having a low population density with numerous allotments and industrial objects located there. There are not many services provided in this part of the district and, subsequently, the transport network is underdeveloped.

In the case of Północ district, the average value of the synthetic accessibility measure is 6,6 for private transport and 6,8 for the public network. In the southern part of the district, the accessibility measure takes high values, e.g. in Niebuszewo, Żelechowa and Warszewo. However, the further north, the lower level of accessibility with its lowest point in Skolwin housing estate. The analysis of accessibility in Północ district has shown that its housing estates are internally differentiated. Warszewo housing estate is an excellent example as it has the average level of accessibility in the south and low, or even very low, in the north. It is directly affected by location of selected destinations

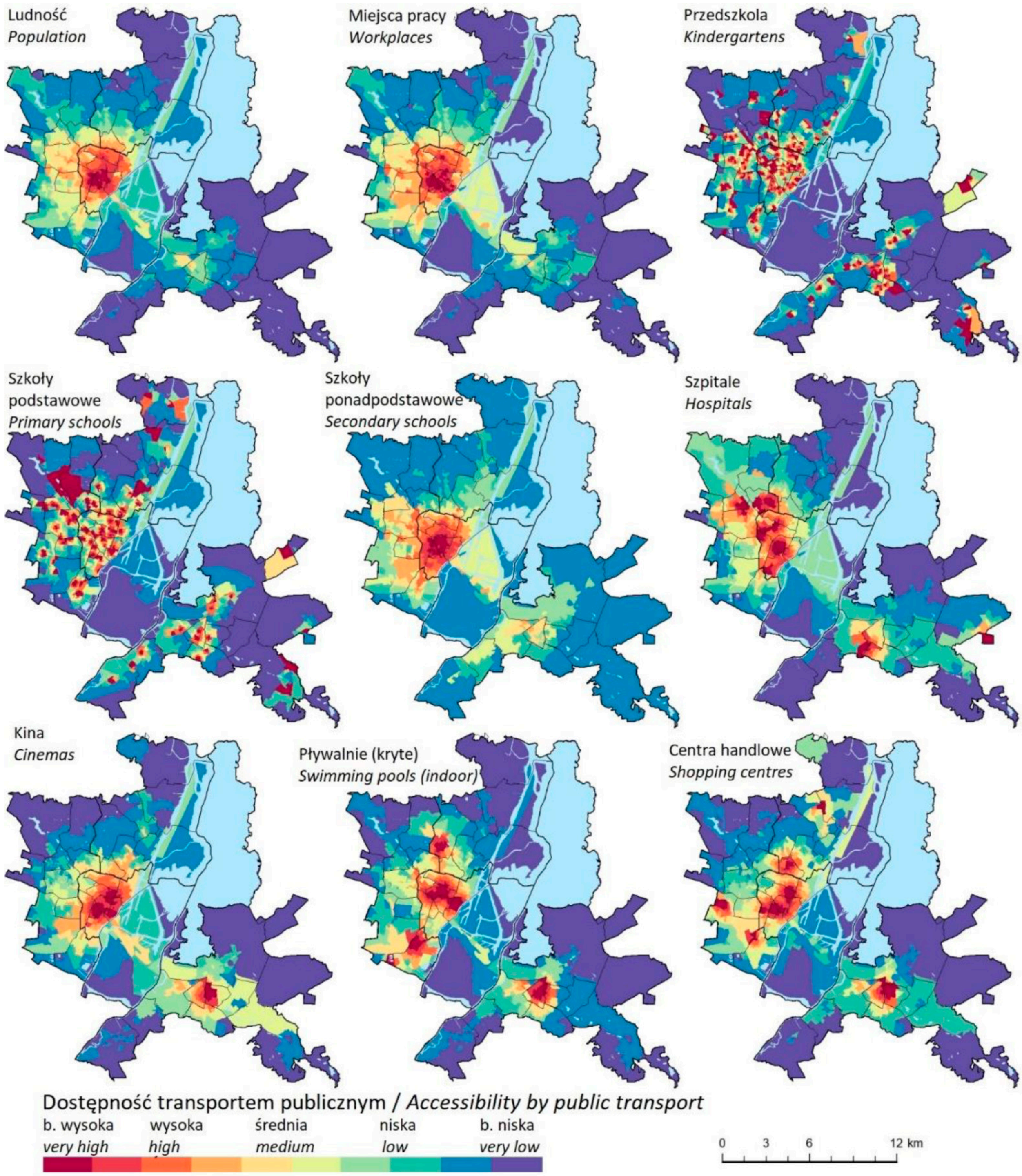


Fig. 3. Results of standardisation of indicators (synthetic measure) of accessibility by public transport in Szczecin based on GTFS data

Source: own elaboration of the authors

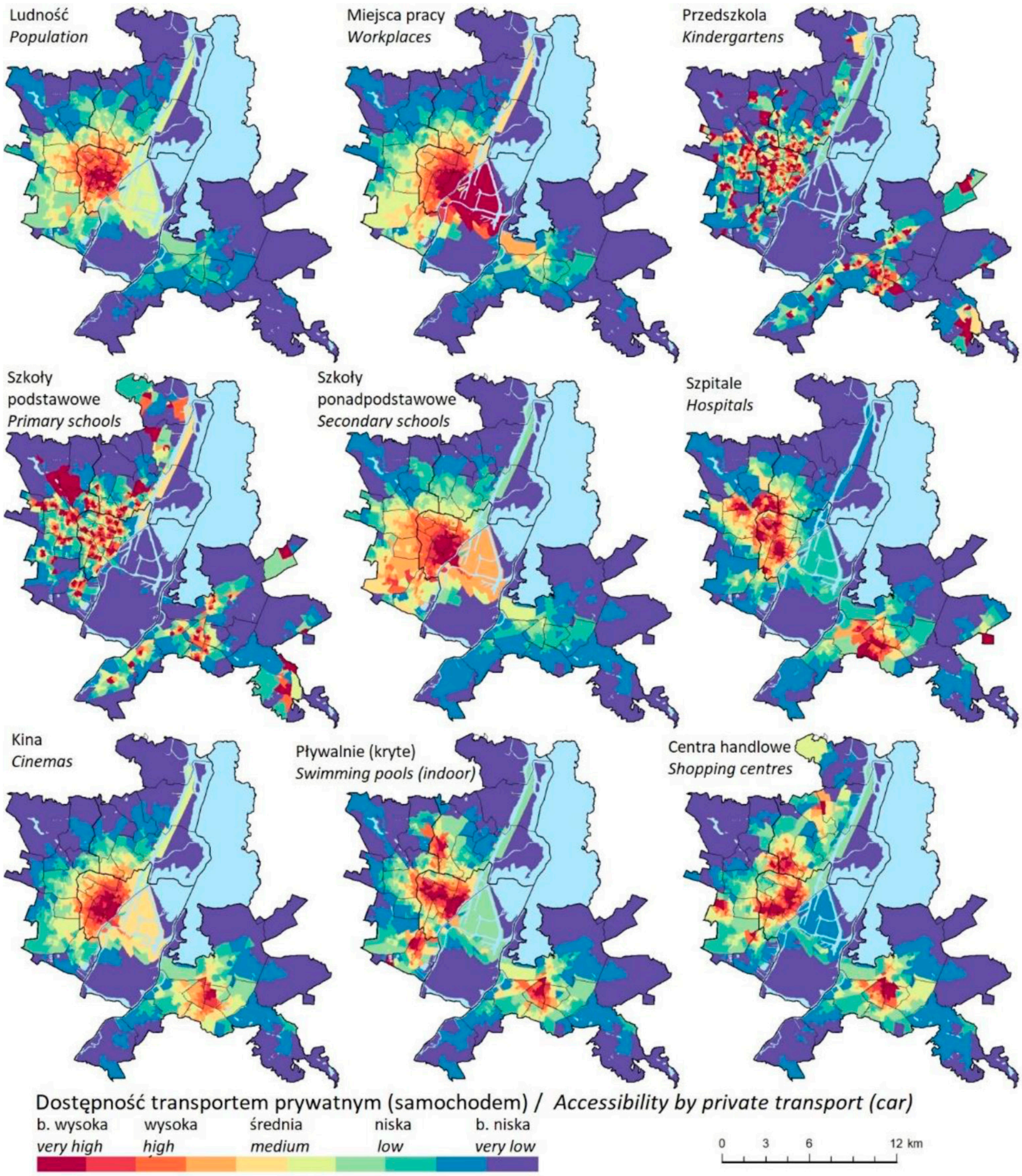


Fig. 4. Results of standardisation of indicators (synthetic measure) of accessibility by private transport in Szczecin based on data and Google Maps API.

Source: own elaboration of the authors

and a centric layout of the streets and public transport system in the city. The southern part of the district has an excellent accessibility to the city centre. Citizens of the north-western part of Skolwin housing estate can easily reach destinations located in the centre of Śródmieście district or in Północ district. That is why the level of accessibility in this part of the housing estate is higher than in other parts of this area located north to Północ district.

The calculated accessibility measure for Zachód district is 6,2 by private transport and 6,0 by public means of transport. Housing estates that neighbour Śródmieście district have usually an average or even high accessibility. These are as follows: Świerczewo, Pogodno and Arkońskie-Niemierzyn. As for the remaining housing estates in Zachód district, the accessibility is relatively low. What is worth mentioning, Gumieńce housing estate is internally diversified in terms of accessibility. The north-western part of the district has relatively low level of accessibility. The district itself is also internally diversified as a result of the particular spatial distribution of selected destinations which are mainly located in Śródmieście (the city centre). Some of them are also directly linked by the public transport routes.

In Prawobrzeże district the average accessibility by car equals 6,9 while by means of public transport is 6,7. Zdroje, Słoneczne and Majowe are the housing estates with the highest accessibility. These estates are located in the district centre where the majority of services are located. Those housing estates are also well-communicated with the city centre by fast tram. Dąbie housing estate is the one with the highest internal diversity. The southern parts of the district have an average level of accessibility while the northern ones – low. In the south-western housing estates of Prawobrzeże district, the accessibility is low or even very low. A similar situation is observed in housing estates located in the south-eastern part of Szczecin. Złom-Kasztanowe housing estate has the lowest accessibility level in Prawobrzeże. It is located in the north-eastern part of the city. Such a high internal diversity of peripheral areas of Prawobrzeże district is caused by a lack of services and underdevelopment of the public transport network. The citizens living there are forced to use their private cars (Fig. 5).

Tab. 1. Standardised public transport accessibility indicators at settlement level based on GTFS, Google API and City Hall of Szczecin

| housing estate | Symbol | District | Potential accessibility | Working places | Kindergarten | Primary school | Secondary school | Hospotal | Cinema | Swimming pool | Shopping centre | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Centrum | SC | Śródmieście | 1,4 | 1,2 | 2,7 | 1,2 | 2,6 | 1,6 | 1,2 | 4,2 | 1,3 | 1,9 |
| Śródmieście-Zachód | SZ | Śródmieście | 1,2 | 1,4 | 5,2 | 1,1 | 4,0 | 1,7 | 1,5 | 2,4 | 1,9 | 2,3 |
| Śródmieście-Północ | SP | Śródmieście | 2,1 | 2,2 | 3,6 | 2,1 | 3,0 | 3,3 | 2,2 | 1,3 | 2,5 | 2,5 |
| Turzyn | ST | Śródmieście | 2,3 | 2,2 | 3,5 | 2,1 | 3,6 | 2,9 | 1,4 | 2,6 | 2,2 | 2,5 |
| Stare Miasto | SS | Śródmieście | 2,1 | 1,9 | 5,2 | 2,0 | 4,8 | 2,9 | 3,1 | 3,3 | 3,0 | 3,2 |
| Niebuszewo-Bolinko | SB | Śródmieście | 2,8 | 3,0 | 4,1 | 3,5 | 4,2 | 3,7 | 3,4 | 3,2 | 4,4 | 3,6 |
| Drzetowo-Grabowo | SD | Śródmieście | 3,9 | 3,5 | 5,0 | 2,6 | 4,2 | 2,1 | 3,3 | 5,9 | 4,5 | 3,9 |
| Łękno | SŁ | Śródmieście | 3,1 | 3,7 | 4,4 | 3,5 | 4,9 | 6,1 | 2,7 | 3,5 | 3,8 | 4,0 |
| Nowe Miasto | SN | Śródmieście | 3,9 | 3,4 | 4,0 | 3,6 | 4,8 | 2,6 | 5,9 | 3,4 | 7,6 | 4,4 |
| Świerczewo | ZS | Zachód | 6,7 | 7,3 | 3,3 | 5,6 | 4,2 | 5,1 | 3,1 | 1,7 | 3,1 | 4,5 |
| Niebuszewo | PN | Północ | 4,2 | 4,7 | 4,6 | 5,6 | 4,8 | 6,1 | 4,6 | 5,7 | 2,7 | 4,8 |
| Pogodno | ZP | Zachód | 7,8 | 8,0 | 4,2 | 6,8 | 4,6 | 6,9 | 1,5 | 2,9 | 1,7 | 4,9 |
| Arkońskie-Niemierzyn | ZA | Zachód | 4,5 | 3,8 | 5,1 | 4,3 | 4,7 | 5,9 | 5,5 | 7,4 | 5,9 | 5,2 |
| Pomorzany | ZN | Zachód | 5,6 | 5,7 | 6,0 | 7,6 | 5,4 | 1,9 | 6,3 | 5,1 | 5,6 | 5,5 |
| Zawadzkiego-Klonowica | ZK | Zachód | 6,4 | 5,7 | 5,0 | 5,4 | 5,1 | 6,8 | 6,7 | 2,8 | 5,2 | 5,5 |
| Zdroje | DZ | Prawobrzeże | 4,8 | 4,8 | 4,8 | 4,8 | 5,2 | 4,7 | 6,8 | 6,4 | 7,5 | 5,5 |
| Słoneczne | DS | Prawobrzeże | 6,7 | 7,0 | 5,4 | 5,4 | 5,1 | 5,2 | 5,2 | 5,1 | 5,6 | 5,6 |
| Żelechowa | PZ | Północ | 6,1 | 6,3 | 4,1 | 5,0 | 3,8 | 3,1 | 8,4 | 8,2 | 8,8 | 6,0 |
| Gumieńce | ZG | Zachód | 8,4 | 8,5 | 5,0 | 8,1 | 5,9 | 4,6 | 5,6 | 6,0 | 6,5 | 6,5 |
| Międzyodrze-Wyspa Pucka | MM | Śródmieście | 6,4 | 6,9 | 6,3 | 7,1 | 5,8 | 7,9 | 5,8 | 7,3 | 5,8 | 6,6 |
| Krzekowo-Bezrzecze | ZB | Zachód | 7,2 | 6,7 | 6,8 | 6,6 | 7,7 | 7,9 | 7,8 | 6,7 | 5,5 | 7,0 |
| Majowe | DM | Prawobrzeże | 7,9 | 7,7 | 7,2 | 8,6 | 8,1 | 7,1 | 8,6 | 3,9 | 7,6 | 7,4 |
| Warszewo | PW | Północ | 8,5 | 8,3 | 7,3 | 7,4 | 6,8 | 8,8 | 7,7 | 8,1 | 8,1 | 7,9 |
| Dąbie | DD | Prawobrzeże | 8,0 | 7,5 | 6,6 | 7,3 | 8,5 | 6,8 | 8,9 | 8,9 | 8,9 | 7,9 |
| Bukowe-Klęskowo | DB | Prawobrzeże | 9,2 | 9,3 | 5,7 | 6,8 | 5,7 | 9,9 | 8,1 | 8,7 | 8,8 | 8,0 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Golęcino-Gocław | PG | Północ | 8,6 | 8,4 | 5,4 | 7,4 | 7,0 | 9,4 | 8,9 | 9,1 | 8,6 | 8,1 |
| Bukowo | PB | Północ | 8,1 | 8,1 | 9,9 | 8,1 | 9,8 | 8,5 | 7,5 | 8,8 | 8,6 | 8,6 |
| Głębokie-Pilchowo | ZL | Zachód | 9,1 | 8,4 | 9,8 | 9,0 | 9,9 | 8,1 | 6,4 | 9,0 | 8,1 | 8,6 |
| Kijewo | DO | Prawobrzeże | 8,8 | 8,8 | 6,6 | 8,8 | 9,8 | 7,9 | 9,9 | 7,9 | 9,6 | 8,7 |
| Stołczyn | PT | Północ | 8,7 | 8,6 | 8,6 | 8,7 | 8,4 | 7,2 | 9,8 | 9,4 | 9,7 | 8,8 |
| Osów | ZO | Zachód | 9,0 | 9,1 | 9,8 | 8,6 | 9,6 | 9,6 | 8,6 | 9,6 | 6,1 | 8,9 |
| Podjuchy | DP | Prawobrzeże | 10,0 | 9,9 | 7,1 | 9,0 | 8,1 | 9,0 | 8,7 | 9,4 | 9,3 | 8,9 |
| Żydowce-Klucz | DK | Prawobrzeże | 9,7 | 9,5 | 8,5 | 8,8 | 7,5 | 9,9 | 9,3 | 9,8 | 7,7 | 9,0 |
| Płonia-Śmierdnica-Jezierzyce | DJ | Prawobrzeże | 10,0 | 10,0 | 4,9 | 9,0 | 7,7 | 10,0 | 10,0 | 10,0 | 10,0 | 9,1 |
| Skolwin | PS | Północ | 9,9 | 9,9 | 8,9 | 8,5 | 8,4 | 10,0 | 9,7 | 9,5 | 9,9 | 9,4 |
| Załom-Kasztanowe | DA | Prawobrzeże | 10,0 | 10,0 | 8,8 | 9,0 | 7,4 | 10,0 | 10,0 | 10,0 | 9,9 | 9,4 |
| Wielgowo-Sławociesze-Zdunowo | DW | Prawobrzeże | 10,0 | 10,0 | 9,5 | 9,0 | 9,3 | 7,4 | 10,0 | 10,0 | 10,0 | 9,5 |

Tab. 2. Synthetic indicators of accessibility by private transport at settlement level based on GTFS, Google API and City Hall of Szczecin

| Housing estate | Symbol | District | Potential accessibility | Working places | Kindergarten | Primar school | Secondary school | Hospital | Cinema | Swimming pool | Shopping centre | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Centrum | SC | Śródmieście | 1,9 | 1,0 | 3,5 | 1,1 | 3,5 | 3,5 | 1,1 | 1,3 | 2,6 | 2,2 |
| Śródmieście-Zachód | SZ | Śródmieście | 1,3 | 1,3 | 5,1 | 1,1 | 3,8 | 2,2 | 1,4 | 2,1 | 2,3 | 2,3 |
| Stare Miasto | SS | Śródmieście | 1,7 | 2,2 | 2,8 | 1,7 | 2,8 | 2,4 | 1,5 | 4,6 | 1,3 | 2,3 |
| Śródmieście-Północ | SP | Śródmieście | 2,1 | 2,2 | 3,6 | 2,0 | 3,2 | 3,7 | 2,2 | 1,6 | 3,1 | 2,6 |
| Turzyn | ST | Śródmieście | 2,2 | 3,3 | 5,2 | 2,7 | 4,8 | 3,4 | 3,2 | 3,6 | 3,1 | 3,5 |
| Drzetowo-Grabowo | SD | Śródmieście | 2,9 | 1,7 | 4,6 | 3,0 | 5,2 | 7,4 | 2,6 | 2,0 | 3,0 | 3,6 |
| Nowe Miasto | SN | Śródmieście | 3,6 | 2,3 | 5,3 | 2,0 | 5,1 | 3,0 | 2,4 | 5,1 | 5,2 | 3,8 |
| Łękno | SŁ | Śródmieście | 3,0 | 3,1 | 4,1 | 4,0 | 4,2 | 4,1 | 3,7 | 4,3 | 4,2 | 3,8 |
| Niebuszewo-Bolinko | SB | Śródmieście | 3,5 | 4,8 | 3,6 | 3,4 | 4,8 | 3,1 | 5,4 | 2,5 | 7,3 | 4,3 |
| Świerczewo | ZS | Zachód | 7,9 | 6,6 | 3,3 | 7,5 | 3,8 | 3,0 | 3,4 | 2,0 | 3,2 | 4,5 |
| Niebuszewo | PN | Północ | 4,3 | 4,2 | 5,0 | 6,0 | 5,0 | 5,3 | 4,8 | 5,5 | 2,6 | 4,7 |
| Pogodno | ZP | Zachód | 8,1 | 7,1 | 4,5 | 7,8 | 4,4 | 4,6 | 2,0 | 3,2 | 1,8 | 4,8 |
| Międzyodrze-Wyspa Pucka | MM | Śródmieście | 5,3 | 6,0 | 5,5 | 6,3 | 4,9 | 1,8 | 6,9 | 5,6 | 4,1 | 5,2 |
| Arkońskie-Niemierzyn | ZA | Zachód | 4,7 | 5,6 | 5,5 | 4,0 | 5,1 | 6,3 | 5,7 | 7,6 | 5,8 | 5,6 |
| Żelechowa | PZ | Północ | 7,7 | 6,7 | 5,1 | 7,7 | 5,3 | 3,1 | 5,7 | 5,0 | 5,7 | 5,8 |
| Pomorzany | ZN | Zachód | 4,8 | 6,6 | 4,9 | 4,6 | 5,1 | 4,9 | 7,1 | 6,5 | 7,7 | 5,8 |
| Zawadzkiego-Klonowica | ZK | Zachód | 6,5 | 4,9 | 5,4 | 4,8 | 5,9 | 7,5 | 6,9 | 3,2 | 7,2 | 5,8 |
| Gumieńce | ZG | Zachód | 5,7 | 5,2 | 6,3 | 6,8 | 5,8 | 7,6 | 5,6 | 6,7 | 5,5 | 6,1 |
| Warszewo | PW | Północ | 8,9 | 8,7 | 4,7 | 8,9 | 5,0 | 2,6 | 4,5 | 5,9 | 6,5 | 6,2 |
| Zdroje | DZ | Prawobrzeże | 6,3 | 7,9 | 3,9 | 6,7 | 3,8 | 3,5 | 8,7 | 7,9 | 9,4 | 6,5 |
| Słoneczne | DS | Prawobrzeże | 7,1 | 7,9 | 7,0 | 8,0 | 8,0 | 6,9 | 8,3 | 4,1 | 5,7 | 7,0 |
| Krzekowo-Bezrzecze | ZB | Zachód | 6,7 | 6,5 | 7,0 | 5,0 | 7,9 | 8,7 | 7,8 | 8,2 | 5,9 | 7,1 |
| Majowe | DM | Prawobrzeże | 8,6 | 8,2 | 8,8 | 8,4 | 9,1 | 6,2 | 5,1 | 6,8 | 5,9 | 7,5 |
| Golęcino-Gocław | PG | Północ | 8,9 | 8,5 | 7,1 | 8,6 | 6,9 | 8,2 | 6,9 | 7,2 | 6,7 | 7,7 |
| Kijewo | DO | Prawobrzeże | 8,7 | 8,5 | 5,5 | 8,7 | 5,1 | 7,4 | 8,6 | 8,5 | 8,8 | 7,8 |
| Osów | ZO | Zachód | 7,7 | 4,8 | 9,9 | 6,2 | 9,8 | 8,7 | 7,0 | 8,3 | 8,9 | 7,9 |
| Bukowe-Klęskowo | DB | Prawobrzeże | 8,1 | 8,6 | 5,7 | 8,6 | 7,1 | 9,6 | 8,2 | 8,9 | 7,9 | 8,1 |
| Podjuchy | DP | Prawobrzeże | 7,5 | 8,5 | 6,7 | 7,5 | 8,2 | 7,8 | 9,3 | 9,2 | 9,4 | 8,2 |
| Dąbie | DD | Prawobrzeże | 8,1 | 9,0 | 6,4 | 8,5 | 9,6 | 7,1 | 9,4 | 7,6 | 8,4 | 8,2 |
| Bukowo | PB | Północ | 9,9 | 9,7 | 7,0 | 9,5 | 6,9 | 9,4 | 9,4 | 9,4 | 9,2 | 8,9 |
| Stołczyn | PT | Północ | 9,4 | 9,7 | 8,0 | 9,9 | 7,0 | 10,0 | 9,5 | 10,0 | 7,3 | 9,0 |
| Płonia-Śmierdnica-Jezierzyce | DJ | Prawobrzeże | 9,0 | 9,3 | 9,8 | 9,4 | 9,6 | 9,9 | 9,2 | 9,4 | 5,4 | 9,0 |
| Żydowce-Klucz | DK | Prawobrzeże | 9,8 | 9,7 | 8,4 | 9,3 | 7,8 | 9,3 | 9,7 | 9,5 | 9,9 | 9,3 |
| Głębokie-Pilchowo | ZL | Zachód | 10,0 | 10,0 | 5,8 | 10,0 | 7,8 | 10,0 | 10,0 | 10,0 | 10,0 | 9,3 |
| Skolwin | PS | Północ | 9,1 | 9,7 | 8,9 | 9,6 | 8,8 | 9,4 | 9,9 | 9,7 | 10,0 | 9,4 |
| Załom-Kasztanowe | DA | Prawobrzeże | 10,0 | 10,0 | 9,1 | 10,0 | 7,5 | 10,0 | 10,0 | 10,0 | 9,3 | 9,6 |
| Wielgowo-Sławociesze-Zdunowo | DW | Prawobrzeże | 10,0 | 10,0 | 9,4 | 10,0 | 9,1 | 8,2 | 10,0 | 10,0 | 10,0 | 9,6 |

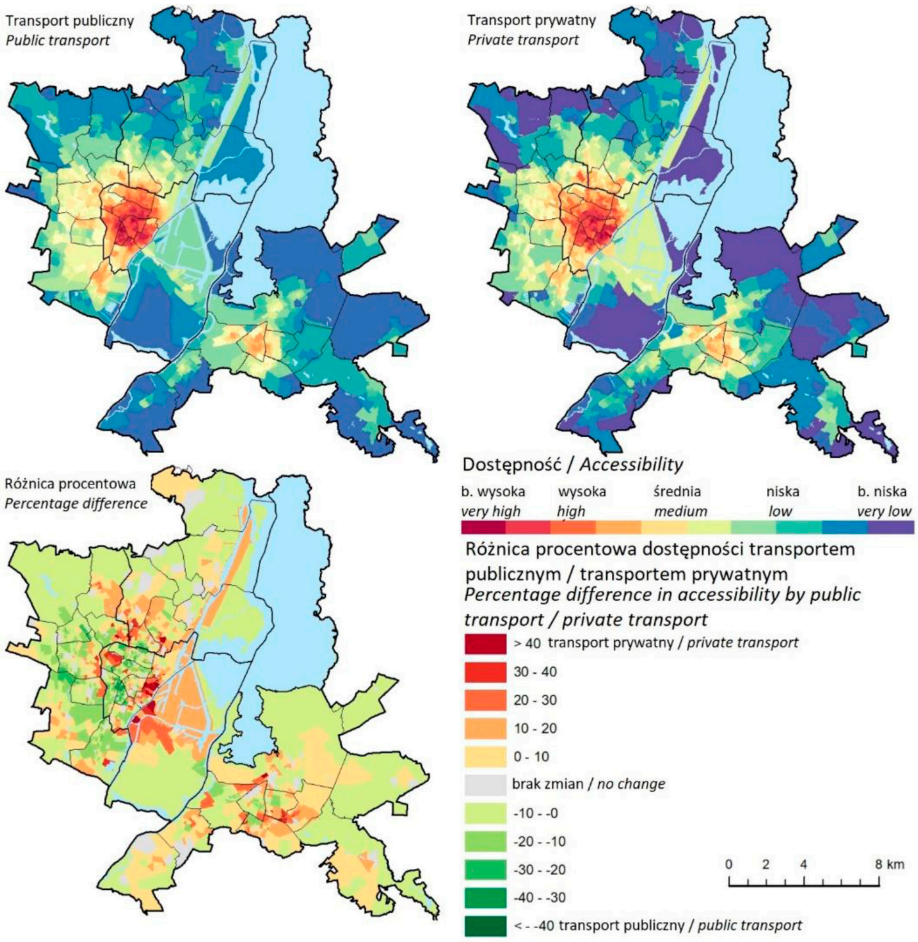


Fig. 5. Synthetic measure of accessibility by public and private transport and the percentage difference between them in Szczecin based on GTFS and Google API data

Source: Own elaboration

## 5. Conclusions

Several different conclusions may be drawn from the study presented herein. Implementing numerous research methods of static and dynamic nature has made the results more reliable. The statistical analysis has been carried out for specific hours and minutes of the day. This type of analysis allows conclusions about the situation (accessibility) at a particular time. The description of this method is an interpretation of a particular slice of time and space. The statistic approach is less complicated in terms of collecting data, and it is beneficial when determining and comparing places of better and worse accessibility. The statistical approach included the following measures: proximity, population percentage, cumulative accessibility, potential accessibility and potential accessibility quotient. Additionally, the standardisation procedure was applied during the final stage of analysis (while calculating the synthetic measure). They were using the cumulative measure allowed to determine the range of accessibility depending on travel times.

The dynamic approach included the proximity, population percentage and potential accessibility measures as well as potential accessibility quotient. Finally, all methods are presented in a static form by means of a method for standardising the results. Here, the ranking method has also been applied (the synthetic measure – standardisation procedure). They are using all the above-mentioned methods allowed to determine disparities in travel times by different means of transport.

The analysis of daily accessibility allowed the authors to indicate times of the day at which the selected destinations can be reached within the same period of time, no matter the means of transport. On the other hand, it is also possible to determine when the disparities in travel times are the greatest. Having such detailed knowledge of travel times (time component), passengers/commuters (individual component) will be able to plan their journey and choose the most convenient means of transport (transport component). Accessibility measures may also be subject to long-term analyses, e.g. several-year periods. For such analyses it is significant to collect data on changes in transportation networks. They may be helpful in assessing how specific infrastructural projects affect accessibility to different areas or services in the city. Unfortunately, in the case of public transport systems, the effects are usually time-delayed and can be observed after adjusting timetables and routes (Goliszek, 2018).

Analysing accessibility measures in Szczecin is particularly interesting as it has a specific urban layout – it is divided by the river and port infrastructure. Additionally, the frequency of ferry services is limited. Not surprisingly, all housing estates located in the city centre, on the left bank of the Oder, have the highest level of accessibility to workplaces and critical facilities (educational, cultural, health care and others). However, in the case of proximity measures, there are several different areas in the city, even in the Prawobrzeże district, having a very high level of accessibility.

Generally, no significant disparities between the means of public transport and private cars have been observed. The only areas having better accessibility by private care are the ones which are not covered by the public transportation network. The standardised results are similar for all districts. Nonetheless, the overall level of accessibility by the means of private transport is higher. Smaller disparities between the standardised transport components for private cars are a result of lower average minimum and maximum travel times.

It is also important to mention some limitations of the analysis for public transport and of the model itself, which only considers the bus and tramway network. Also, the selected destinations could have been supplemented with other destinations, which would have had a positive impact on the results and interpretations of this manuscript.

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