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Travel Time Map of Szczecin Main Railway Station

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Abstract. This article presents the research on time accessibility of public transport. The study concerned the territory of Szczecin and travelling from anywhere in the city to the Main Railway Station. A self-gathering measurement data method was used, which was developed by Authors in earlier studies. Szczecin was selected as the test area because of the shape of the city as well as the location and shape of the excluded areas (areas not accessible to pedestrians or cyclists). Two travel maps were created, for daytime and nighttime public transportation.

The study used 162 measurement points arranged in 1x1 km grids. Travel times to the Main Railway Station were calculated with the use of the jakdojade.pl online service. They were calculated for each measurement point and these values were then interpolated with the IDW method.

The travel time maps were evaluated by computing the absolute error on the basis of 10 control points. The absolute error was not greater than 4 minutes, what proves very good accuracy of research.

The results of the analysis were compared with the population distribution in Szczecin. The interdependence of population distribution and accessibility of the Main Railway Station was analysed.

Keywords: self-acting method, travel time mapping, IDW method, Szczecin.

Conference topic: Roads and railways.

Introduction

Travel times presented on maps can play an important role for ordinary users. They can influence people's decisions to use public transportation or no, depending on how long they will travel to the destination point. The role of maps presenting travel times was noticed already very long time ago (Galton 1881; Paulin, Wright 1932). It is of particular importance now, as most big cities are working hard on encouraging residents and visitors to use public transportation and thus reduce the number of cars in the city. Therefore, fast and effective travel time mapping is as important as the spatio-temporal analysis of accessibility (Mesbah *et al.* 2012), which takes on particular importance in the case of time accessibility of health care services (Jamtsho *et al.* 2015; Schuurman *et al.* 2015).

Research on the accessibility time (de Lima *et al.* 2016), its estimation (Soriguera, Robuste 2011), as well as mapping (Cheng, Agrawal 2010) seems to be quite popular even though it presents transit accessibility around a single point or strictly defined locations (e.g. large densely populated districts). In the literature available, there is a lack of studies on fast travel time mapping designed for the general public, taking into account the whole territory of the city and Internet public transport journey planners. Rare studies are based on data collected manually (Tomala *et al.* 2014), which is time-consuming and results in inefficient delivery of frequently changing information based on changes in timetables, bus routes, etc. Therefore, the aim of the study presented is to fill this gap and provide the solution for fast and accurate travel time mapping.

The article presents the study of the development and analysis of the accuracy of travel time maps for different parts of the day (standard and night), calculated with the use of self-acting measurement data collection. This method was developed by the authors and so far, the results obtained with its use were analysed only for Warsaw, which has a well-developed public transportation system and a regular shape of the city. In order to check whether the accuracy obtained as a result of using this method is also sufficient and reproducible for cities with complex shapes, this study was carried out.

Szczecin was selected as a test area because of the city shape as well as the location and shape of the excluded areas. There is a big lake inside the city and a lot of parks and forests, which divide city into two sections. Therefore, to reach the Main Railway Station, people from the half of the city's area have to detour around the lake and forests. This results in an unparalleled area of measurement data interpolation. Research undertaken so far was related to the quite regular interpolation area, meaningthat it can be entered inside a regular square or rectangle. Reliable results of interpolation were obtained, but there has been no study to date for a more irregular interpolation area.

Taking the above into consideration, the study of travel time mapping of the complex city shape was undertaken in the article. Research questions were: does the shape of the city have an impact on the travel time calculation by interpolation? Moreover, is the accuracy of the travel time map for an irregular city shape comparable with the map of

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Warsaw, which has a fairly regular interpolation area? An additional research task was to determine whether the map accuracy for standard and night public transit is comparable. The research presented in the paper is a continuation of the authors' work on the automation of the travel time mapping.

Methods and materials

In the study, the same methodology and data was used to develop the travel time maps of the Main Railway Station in Szczecin for standard and night public transportation. Measurement points were the base of the travel times calculation. The self-acting measurement data gathering method was used to designate the location of measurement points and travel time calculation for them. This method was developed by the authors and adopted in the authors' own software (Moscicka *et al.* 2016). It is based on automatic measurement point distribution in a regular grid and self-acting measurement of travel time for them.

In the case of both maps of Szczecin, the size of the grid is 1 km, which means that distance between any two neighboring measurement points is exactly 1 km. This distance was considered sufficient to obtain a satisfactory accuracy of the travel time maps (Moscicka *et al.* 2016). The measurement points were not placed inside areas which are impassable due to their topographical features, or those which are closed. There is a big lake inside the city, therefore the territory of Szczecin is not regular. The map of the city districts and lake location is presented in Figure 1. Consequently, in the territory of Szczecin, a grid with 162 measurement points was automatically designed. The same measurement points were used in a standard and night case study. The map of measurement point distribution in Szczecin is presented in Figure 2.

For each measurement point, travel time was calculated with the use of the www.jakdojade.pl (jakdojade 2016) Internet service, which allows user to plan travel using public transportation in major Polish cities. With the use of the developed software travel times for each measurement point were automatically calculated. In the measurement, the type of transportation that would enable the fastest journey was defined. The calculations took into account both direct and indirect connections and determined the shortest possible journey time. The time for changes (5 minutes) as well as walking speed to the stop (3–5 km per hour) (Bielecka, Bober 2013) werealso defined. The total length of travel time was calculated as a sum of walking time to the stop, time spent waiting for transport and driving time in all participating vehicles (Schnabel, Lohse 1997). The travel times were calculated twice for each measurement point: at weekday morning (7:00) rush hours and night (2:00). Data was collected throughout March 2016.

Data received for each measurement point was interpolated for the whole territory of Szczecin with the use of the IDW (Inverse Distance Weighted) (Childs 2004) interpolation method. Interpolation was performed separately for standard and night data. The aforementioned excluded areas were excluded from the interpolation areas. The rules for the selection of types and size of excluded areas were developed by the authors (Tomala *et al.* 2016). Such areas include parks, rivers, cemeteries, airports, military areas. In the case of Szczecin, areas larger than 8 ha were excluded. The exceptions are the watercourses, which due to their specific location and structure, were excluded when larger than 4 ha. The excluded areas in Szczecin, created with the use of OpenStreetMap data (OpenStreetMap 2016) are marked on the maps in gray.

To verify the accuracy of the results obtained, the absolute error (AE) of 10 control points, which were not used in the interpolation was calculated. Control points distribution is presented in Figure 2. Absolute error is the difference between the measured value (on the map) and the exact value (from the www.jakdojade.pl service). The modules of absolute errors were calculated, because it does not matter which way the measured value differs from the exact value. The same control points were used to calculate AE for standard and night data.

The results of travel time calculation were compared with the population distribution in Szczecin, as well as distance of measurement points from the target point. The data on the population was obtained from the Polish Main Statistical Office. Their source is the National Census of Population and Housing conducted in 2011. The data was organized in a grid of 1x1 km and contains information on the total population in the area of 1 km^2, and information about the structure of the population (broken down by gender and age group). Data on the entire territory of Poland is distributed in the format of a shapefile and available free of charge. Distances were calculated as straight lines between each measurement and target point. In the study, the number of people from the grid square where this measurement point is located has been assigned, to each measurement point, together with the distance of this point to the Main Railway Station.

The interdependence between population, distance and ease of access of the Main Railway Station was analyzed with the use of statistical and computational intelligence methods. It was calculated for a week day morning rush hour (7 a.m.). We calculated correlations between travel time (t) and distance (d) as well as travel time (t) and population (p). For this purpose, we used the Pearson correlation coefficient (Gibbons, Chakraborti 2003) and the Spearman correlation coefficient (Spearman 1904; Corder, Foreman 2014). We also modeled these relationships with non-linear regression methods (Seber, Wild 1989). To model the relationship between all three variables, a Takagi-Sugeno Fuzzy Inference System (TSFIS) (Jang *et al.* 1997) was built. TSFIS is a non-linear model based on the concept of fuzzy set theory, fuzzy if-then rules and fuzzy reasoning. A typical rule of TSFIS may be expressed as "if x is low and y is high then z = ax + by + c". The scheme of TSFIS is shown in Figure 3. For each rule the activation level is calculated based on the degrees to which the antecedent (if) part of the rule is fulfilled. The output is the aggregation of the rule outputs weighted with the activation level of each function.

To each model room mean square error (RMSE) has been calculated. All the calculations were done in Matlab R2014a, using standard functions of Statistics, Curve Fitting and Fuzzy Logic Toolboxes.

Fig. 1. Districts in Szczecin

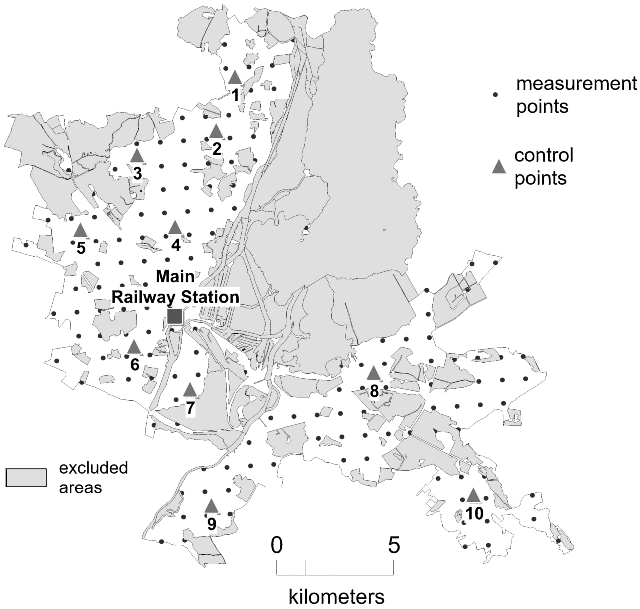

Fig. 2. Measurement and control points distribution in Szczecin

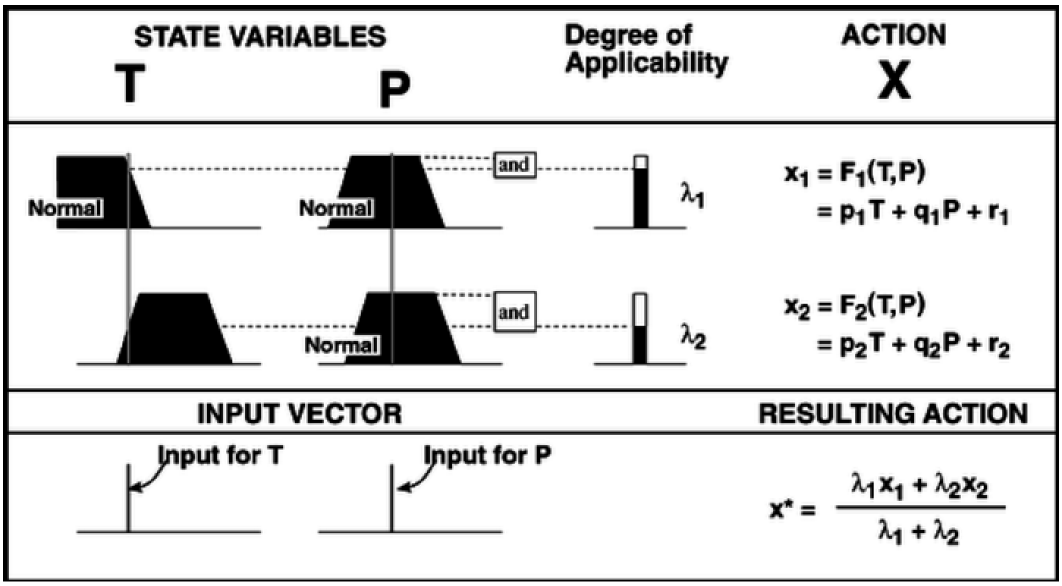

Fig. 3. A two input, two rule Sugeno FIS (p_n, q_n and r_n are user-defined constant)
(Fuzzy inference systems 2016)

Results and discussion

As the result of the research, two accessibility maps of the Main Railway Station in Szczecin were developed. These maps are:

- Travel time map of the Main Railway Station in Szczecin during the day (Fig. 4).
- Travel time map of the Main Railway Station in Szczecin during the night (Fig. 5).

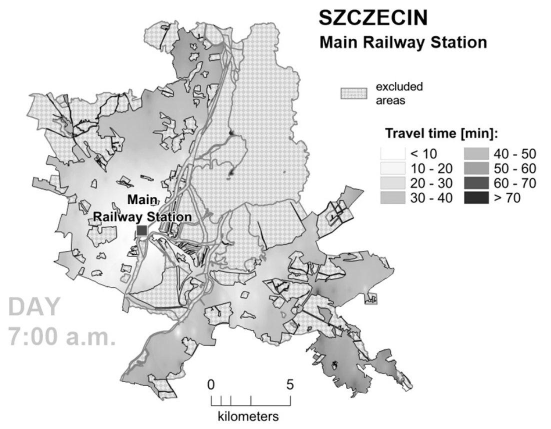

Fig. 4. Travel time map of the Main Railway Station in Szczecin (day)

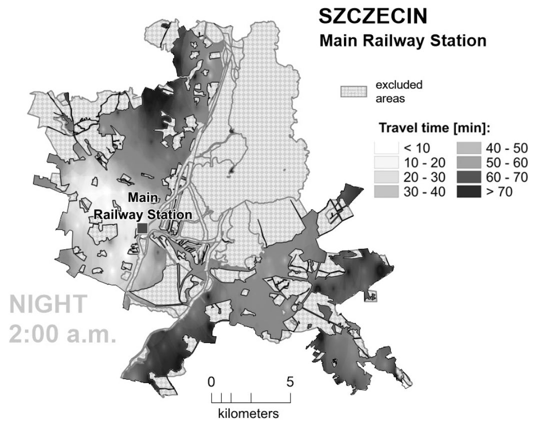

Fig. 5. Travel time map of the Main Railway Station in Szczecin (night)

Both maps present travel times using 10-minutes isochrones; therefore, it is easy to compare accessibility in these two case studies. Analyzing the results of interpolation on both maps, many interesting comments can be formulated.

As a result of the interpolation, travel times to the Main Railway Station in Szczecin from anywhere in the city during the day vary from 6 to 98 minutes. During the day, 30% of the area of Szczecin can reach the main station in less than 30 minutes, whereas 13% of the city has to travel to the station longer than 1 hour.

Looking at the map, it is clear that the western part of the city has better accessibility to the railway station than the eastern part. The shortest travel times – about 10–20 minutes – are in the city centre, which is self-explanatory given the location of the railway station. The time increases to 60 minutes in the northern part of the left-bank Szczecin (Skolwin district).

It is worth to note that the southern part of Dąbie Lake and the Odra River are a kind of border of the short travel times. On the eastern part of the watercourses (called Prawobrzeże), even though the distance to the station is not so long, travel times increase significantly. Only the central part of Prawobrzeże (Słoneczne and Zdroje district) has travel times of about 30–40 minutes. The remaining part of this area needs about 60 minutes to reach the main station during the day, while Płonia district, located on the south-eastern end of the city, requires an even longer time.

The accessibility map of the Szczecin Main Railway Station during the night is really surprising. Travel times to the station vary from 9 to 91 minutes. This means that we can reach the main station from some parts of the city faster at night than during the day. People from almost 23% of the city can reach the main station in fewer than 30 minutes and more than 25% of the city needs more than 60 minutes. In comparison to traveling during the day, these results are very attractive.

Looking at the map of travel times at night, we can also notice that during the day, the eastern part of the city (Prawobrzeże) has more dark blue spots than the western part. This means that there are longer travel times, reaching upward of 70 minutes. However, there are areas with 30 minutes' travel time regardless of the relatively long distance to the railway station. Such an area is located in the eastern part of the south-eastern outskirts (Jezierzyce district) of Szczecin.

Comparing the two maps, it can be seen that in the city centre there is a larger region with the shortest travel time in the night than during the day. The north-western part of the centre (Pogodno district) has an accessibility time of fewer than 20 minutes, while during the day, it requires about 30 minutes to reach the station. A similar situation occurs on the left bank of Dąbie Lake (Golęcino and Stołczyn districts). Along the bank, there is a brighter area with travel time of even fewer than 30 minutes in the night. The same region is accessible in 40–50 minutes during the day.

The accuracy of the maps has been checked by calculation of absolute errors (AE) for 10 control points – the same for standard and night data. These points were not included in the interpolation. Travel times from control points to the railway station during the day and night were measured on the map. They were compared with the exact values from the www.jakdojade.pl Internet service. On the basis of these measurements the modules of absolute error were calculated. They are presented in Tables 1 and 2.

The differences between exact and interpolated travel times (absolute errors) presented in Tables 1 and 2 are not greater than 4 minutes. They are the same for both maps, which confirms that the results achieved are credible. An additional column in Table 2 presents differences between travel times for day and night. They show that the most significant difference is 21 minutes, whicle most of them are less than 10 minutes. This means that night transportation in Szczecin is almost as good as standard transportation.

The obtained values of absolute errors are similar to those obtained for Warsaw travel time maps (Moscicka *et al.* 2016), where the absolute error was less than 3 minutes. This means that the results achieved after using the self-acting method of measurement point distribution and travel time calculation are repeatable. This confirms that this method can be used for automatic travel time mapping. Moreover, they are independent of the shape of the interpolation area.

Table 1. Absolute error (AE) for standard (day) data

Control point ID	DAY Jakdojade.pl	DAY map	DAY AE
1	52	55	3
2	48	46	2
3	48	44	4
4	28	30	2
5	37	35	2
6	23	20	3
7	27	28	1
8	31	34	3
9	55	51	4
10	54	58	4

Table 2. Absolute error (AE) for night data

Control point ID	NIGHT Jakdojade.pl	NIGHT map	**NIGHT AE**	Difference DAY-NIGHT on the map
1	65	61	**4**	–6
2	70	67	**3**	–21
3	53	51	**2**	–7
4	44	45	**1**	–15
5	26	29	**3**	6
6	30	26	**4**	–6
7	33	35	**2**	–7
8	43	40	**3**	–6
9	69	67	**2**	–16
10	56	54	**2**	4

Analysis of the dependence shows that there is a positive correlation between travel time and distance. The Pearson correlation coefficient is 0.693 and the Spearman correlation coefficient is 0.73. If we would like to fit a line through the points, the power model presented in Figure 6 can be a good fit. It is represented by the function: t = 15.82*d^0.48 and R-square (a measure of model fit) in this model is 0.5. RMSE (room mean square error) is 11.82 minutes, which is not an acceptable value.

The second analysis of the dependence shows that the correlation between time and population is weaker. In this case, Pearson correlation coefficient is –0.445 and Spearman correlation coefficient is –0.6075, this means there is a negative correlation. The relation can be represented by rational model (Fig. 7), which is worse that the first one, because RMSE is 14.18 minutes and R-square is 0.307.

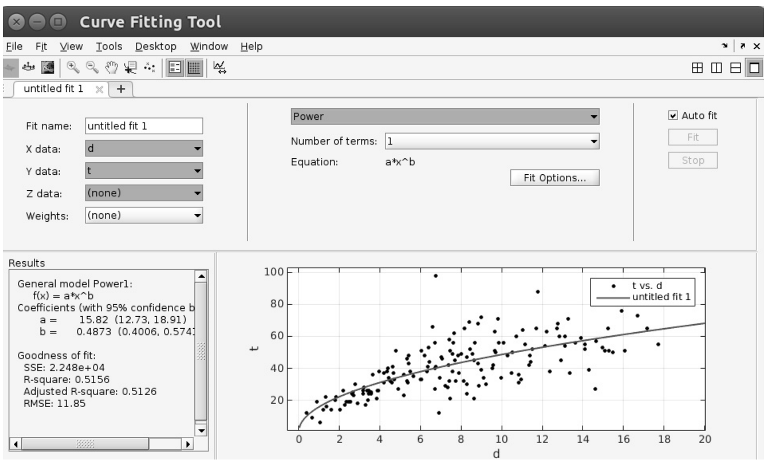

Fig. 6. Power model: dependence between travel time and distance

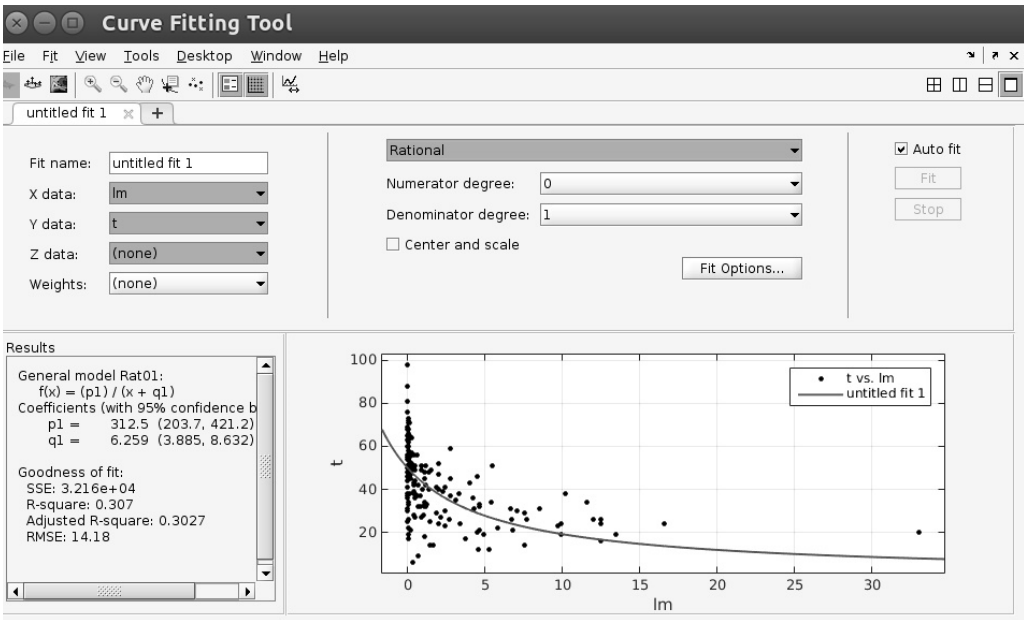

Fig. 7. Rational model: dependence between travel time and population

Results of both models were not satisfactory; therefore, we decided to create a model where the time is expressed as a function of distance and population. Since the relations between those variables are non-linear we decided to use a non-linear model. We used a Takagi-Sugeno Fuzzy Inference System (TKFIS). We obtained a TSFIS with 2 rules and RMSE of 7.24, and mean absolute error of 6.07 minutes. The membership functions of the FIS for both variables are shown in Figures 8 and 9, respectivelly. The rules of the FIS are:

1. If (population is medium) and (distance is short) then t = –0.0498*lm + 3.4528*d + 12.5240
2. If (population is very low) and (distance is long) then t = –10.9779*lm + 0.3897*d + 54.0386

Figure 10 shows a scatter plot of the true values of travel time to the Main Railway Station vs the estimated ones. The observations of training and testing sets are marked with different colors. The points in both cases lie on the diagonal line, meaning that the model is free from a systematic error and can be considered as a good one.

Figure 11 shows the surface plot (from 2 different angles) of theTSFIS and the measured data points. Please note that the surface is following the data points well. Note that there are no points for a large population and a long distance, and the resulting surface in that area is effect of extrapolation; therefore, predictions of the time for such points may be wrong. The surface plots and the consequents of the rules (equations) seem to clearly indicate that the shorter the distance, the shorter the time, but also the larger the population, the shorter the time.

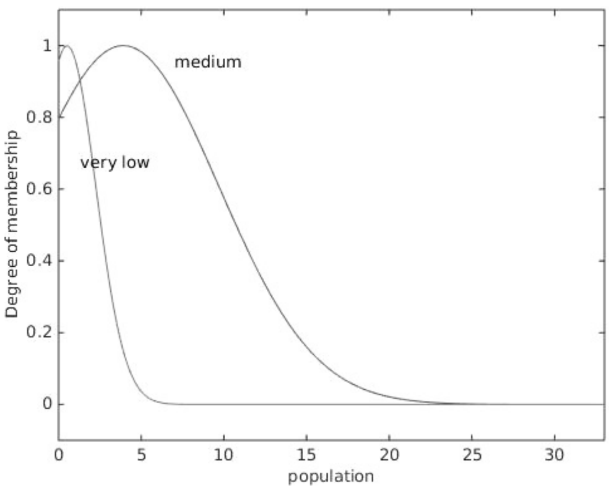

Fig. 8. Membership functions for the population variable for the TKFIS

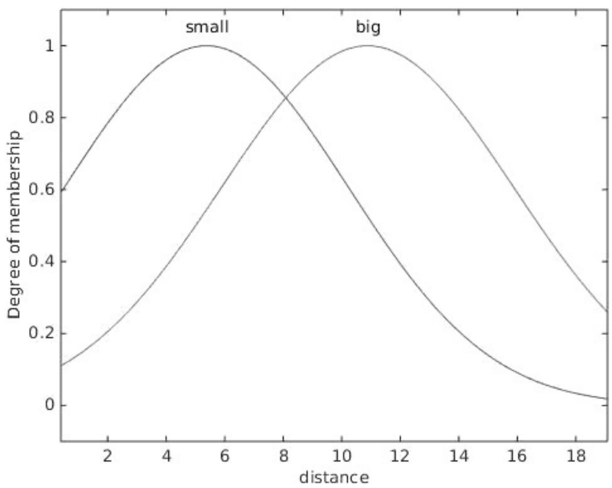

Fig. 9. Membership functions for the distance variable for the TKFIS

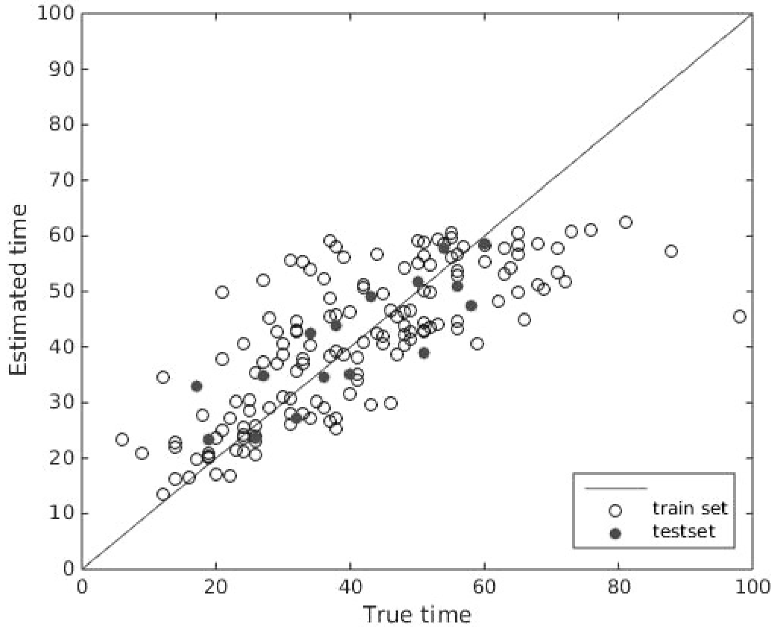

Fig. 10. The true values of travel time to the Main Railway Station vs the estimated time

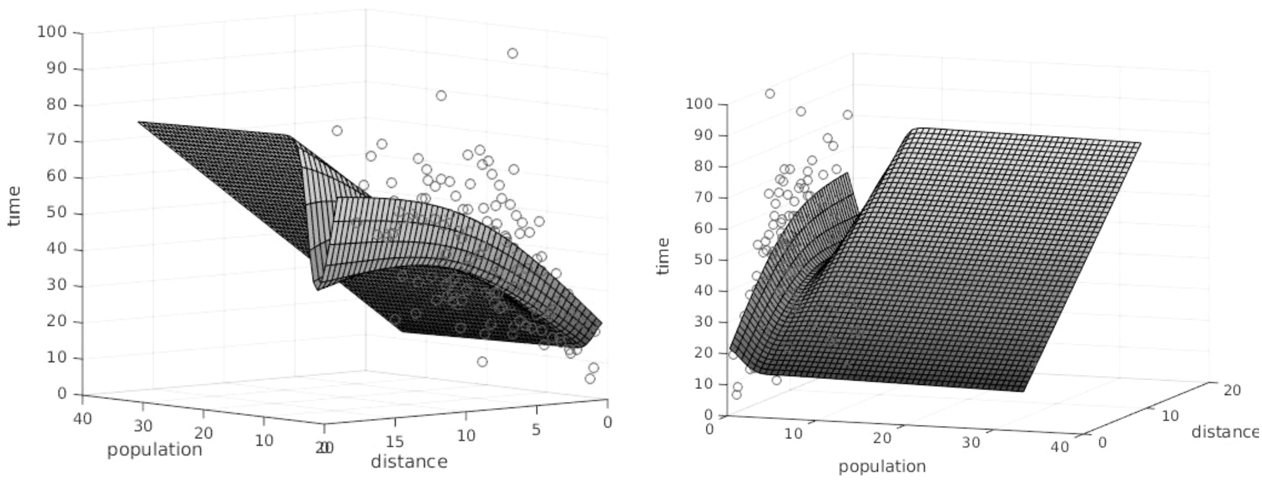

Fig. 11. The surface plot (from 2 different angles) of the TSFIS and the measured data points

Conclusions

The comparative study of the time accessibility of the Main Railway Station in Szczecin during the day and at night provides information on how quickly this destination can be reached from anywhere in the city. Presentating the results on a map and easy visual analysis shows that there are some differences in accessibility, often in favor of night-time transportation. The locations with the worst public transportation are mainly the same for both cases and are situated on the far outskirts of the city. The need of access from these areas may result in the abandoning of public transport and use of private cars or taxis, which greatly accelerates the journey.

The research presented is the first study on travel time mapping in Szczecin, especially in the area of comparison day and night public transportation. It gives the results valuable from the point of view of public transportation policy, because it shows the areas with long travel times in an easy and user-friendly way. It helps the user to decide whether or not they should use public transportation. It also helps policy-makers to change or correct bus routes for better time accessibility, which is often independent on the length of the route.

Self-acting methods of measurement data distribution and travel time calculation provided excellent results in travel time mapping for Szczecin. The method reduces the time of creating maps by 60%, eliminates the impact of manual data collection mistakes, as well as improvea the accuracy of the results achieved. Therefore, it can be said that this method is a step into the fully automatic travel time mapping method.

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