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AN ANALYSIS OF THE INFLUENCE OF TRAVEL TIME ON ACCESS TIME IN PUBLIC TRANSPORT

Summary. Sustainable mobility is a priority for transport systems in urban areas. Contemporary planning of transport systems assumes an increase in the role of public transport in everyday trips. To increase the share of trips using public transport, it is essential to improve the accessibility of public transport stops. The accessibility of such stops depends primarily on the distance between the trip origin and the stop. Many factors influence the distance that passengers are willing to travel. This paper discusses the relationship between the access time to the bus stop and travel time. To study such a relationship, various statistical methods may be applied. This paper presents the results of the analysis performed based on the data on trips made by inhabitants of Bielsko-Biała, gathered during the building of its transport model.

Keywords: public transport, travel time, access time, bus stops

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1. INTRODUCTION

According to the goals of sustainable development and sustainable mobility, public transport should be the priority mode of transport in urban areas [1-7]. Hence, contemporary transport systems should provide the connectivity of such a system, which means the possibility of travel between origin and destination points using means of public transport. There are numerous advantages of public transport over individual transport, for example, enhancement of the environmental features (that is, air quality), reduction of congestion and decrease of noise level [8-10].

The system of public transport consists of many elements, which influence the usability from the perspective of passengers [11, 12]. One of the elements of this system is the infrastructure. The accessibility to public transport infrastructure influences the decision on the transport mode to be chosen by transport users. This paper focuses on the accessibility to bus stops, measured by the access time to them. Literature shows many different approaches to the analysis of the accessibility to the bus stops. In [13], the authors show analysis based on the geo-information systems. Based on the road network data, they developed isochrones of the walking distance to the bus stop. This approach is useful when seeking new locations for bus stops. In the case of the analysis of the whole public transport system and a better understanding of passenger's behaviour, the tools of statistical analysis may be useful [14].

The main goal of this paper was to examine the relationship between two important variables associated with trips made using public transport in urban areas - the access time to bus stops and the travel time. It focuses on examining the impact of travel time on access time.

Several statistical methods were applied to achieve this goal. To study the strength of the relationship between the analysed variables, the analysis of correlation was used. Subsequently, to map the influence of travel time on access time, the analysis of regression was applied. It allowed creating mathematical models by the fitting of several chosen functions that describe the relationship, such as linear, exponential, power and logarithmic. The analysis of the quality of the fitting of the functions was also performed to evaluate them.

The data for the analysis were collected during surveys research in Bielsko-Biała, at the stage of building its transport model [15].

This paper is organised as follows: Section 1 entails the introduction, section 2 provides further information about the research issue, section 3 presents applied statistical methods, section 4 contains the results of the analysis and section 5 of the paper presents conclusions and propositions for future work.

2. REVIEW OF RESEARCH ISSUE

The functioning of a public transport system is influenced by many factors [16], associated with different aspects of the operation of the system, such as the layout of the network, timetable, fares, condition of vehicles and the location of stops. This paper focuses on factors concerning the location of public transport stops, as they play a vital role in the system. From passengers' point of view, one of the most important factors associated with the location of the stop is the distance that they have to travel to reach the stop. Therefore, the distance between the trip origin and the location of the public transport stop has a significant influence on the decision on the mode of transport they choose. This distance may be represented in units of length and may be expressed in units of time too. In the latter approach, the duration of the travel between the trip origin and the stop is usually called access time. An analysis of the distances between trip origin and public transport stop may be useful in studies on the determination of the location of stops (using geo-informational systems data) [13] and to perform a comprehensive assessment of the system of public transport [14].

Many authors have taken up the issue of determining the acceptable distance between the trip origin and the stop. Although the results of each study vary, it is possible to set general ranges both for bus and railway transport. In the case of bus transport, most authors suggest that a bus stop should be located 400 to 600 [m] from the trip origin, whereas in railway transport these distances are longer, even up to 800-1,000 [m] [17-20].

Nevertheless, many studies have shown that these values may be influenced by numerous factors associated with the features of the trip, passengers or the surrounding of the stop [21]. In [22], the authors state that the period of the day or the motivation of the trip may have an impact on the distance that passengers accept. Authors of the paper [23], point out that the age of passengers determines the maximal distance they are willing to travel between the trip origin and the bus stop. Other studies [18, 24, 25] have shown that the characteristics of the street network (that is, its connectivity or amenities for pedestrians) as well as the built environment may also have a significant influence on the distance that passengers accept to reach the public transport stop.

In this paper, the authors focused on the impact of travel time as a chosen characteristic of the trip. Total travel time (TTT) in public transport, as presented in Figure 1, usually consists of several components related to the travel stages and change of mode of transport, that is, access time (AT), waiting time at the stop (WT), in-vehicle time (IVT), transfer time (TT), covering both walk time and transfer wait time and egress time (ET). Because the total travel time includes access time, these variables cannot be treated as independent ones. Thus, access time has been excluded from the total travel time and as the main research issue, the relationship between the access time to the bus stop and the travel time without the access time (TTWAT) has been adopted, as shown in Figure 1. Travel time without the access time is understood as a sum of times of subsequent stages of the trip: waiting time, in-vehicle time, transfer time and egress time with the exclusion of the access time. For this study, access time is treated separately, although in most cases, it is the component of the sum that constitutes the total travel time.

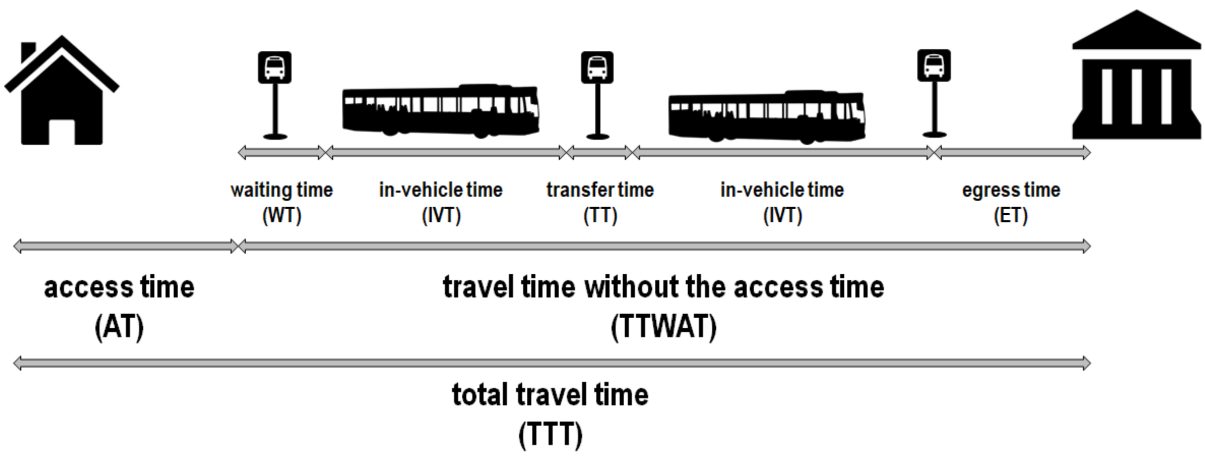

Fig. 1. Components of total travel time

The goal of this paper is to determine if TTWAT affects AT in the case of bus transport. It is associated with the research question whether passengers that plan longer trips by public transport bus accept longer access time to the bus stop. Should the dependency be proven, it will allow proposing guidelines for the location of bus stops.

3. STATISTICAL ANALYSIS

To examine the influence of TTWAT on AT, a statistical analysis, which included several statistical methods, was performed. The general scheme of the statistical analysis is presented in Figure 2. Among the statistical methods exploited are:

- methods of conducting empirical research, which allowed gathering empirical data on components of total travel time,
- methods of grouping data, which allowed preparing classes of data, for further analysis,
- methods of estimation of central tendency measures, which allowed determining average values of each variable, and choosing them as representative values for each class,
- methods of correlation analysis, which allowed estimating the strength of the relationship between variables,
- methods of building regression models including the choice of the various functional forms of model and goodness-of-fit measures, which allowed preparing equations of regression between analysed variables and evaluate the mapping.

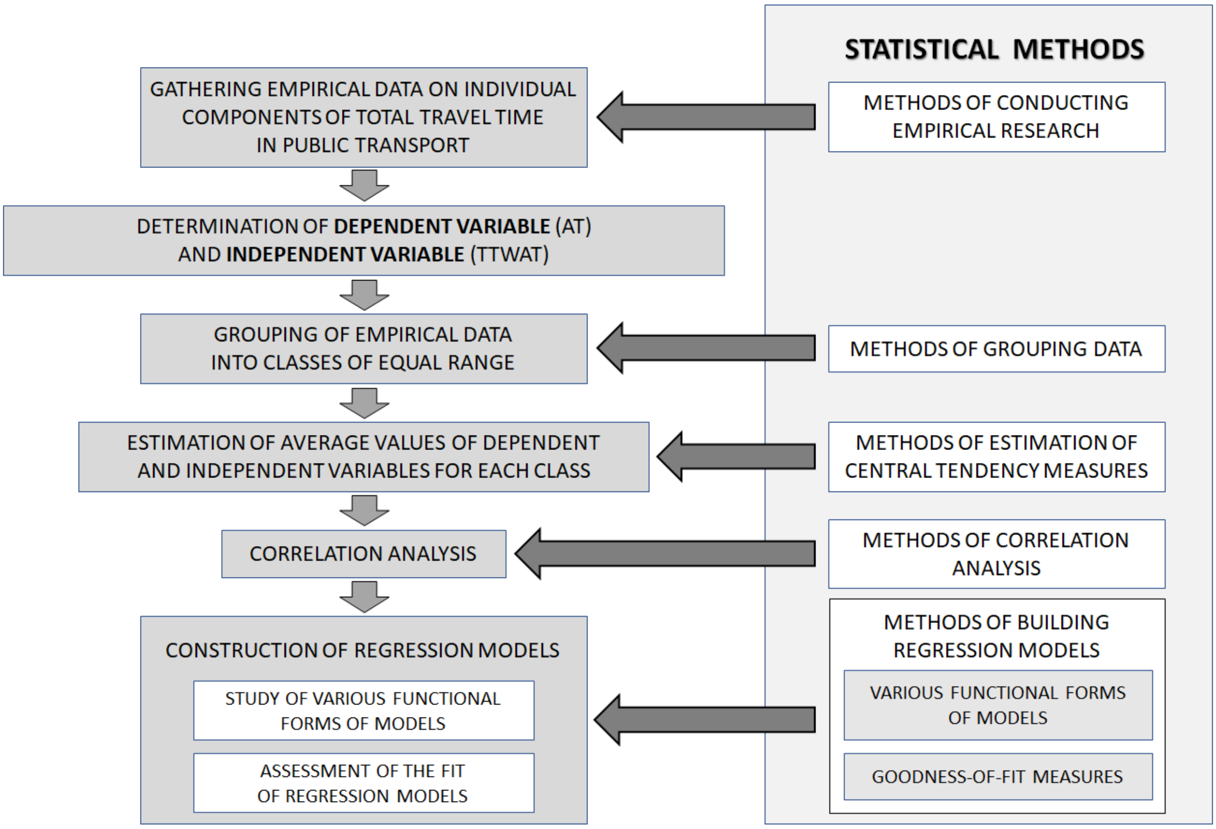

Fig. 2. General scheme of the statistical analysis

Analysis of correlation and regression assumes the occurrence of the dependent variable and a set of independent variables, which have a lasting influence on the dependent variable. The goal of the following analysis was to examine the influence of the travel time without the access time on the access time to the stop, therefore, the travel time without the access time was chosen as the independent variable and access time to the stop as the dependent variable.

The analysis requires the collection of data about trips made by public transport users. It was necessary to gather data about the access time to the bus stop and TTWAT in the case of each trip. Data was collected from a household survey, that is, to build the transport model. More so, it is important to ensure the appropriate size of the sample, so it can be treated as representative.

In the case of large sets of data, it is convenient to group units into classes of equal ranges [26]. Classes pertain to the independent variable, which is TTWAT.

By denoting the number of class as, it is possible to determine the set of all classess as:

$$\boldsymbol{K} = \{1, \dots, k, \dots, \overline{K}\} \tag{1}$$

where $\overline{K}$ is interpreted as the number of classes that have been created in the case of a given data set.

For each k-th class, the middle of the range denoted as $t_{\mathrm{t}}(k)$ and empirical value $t_{\mathrm{w}}(k)$ have been determined. The value $t_{\mathrm{w}}(k)$ has the interpretation of average access time corresponding to the range of TTWAT from the k-th class. Vectors containing values of independent and dependent variables, for each class have been determined as:

$$\mathbf{T_t} = [t_{\mathrm{t}}(k): \quad k \in \boldsymbol{K}] \tag{2}$$

$$\mathbf{T_w} = [t_{\mathrm{w}}(k): \quad k \in \boldsymbol{K}] \tag{3}$$

The basis for building the regression models is the analysis of correlation between the variables. Correlation is a statistical relationship between variables. It allows determining to what degree variables remain in a linear relation. One of the useful tools in correlation analysis is the scatter plot, which allows to tentatively assess the strength and direction of the dependency between variables. In the case of linear relation between two variables, it is possible to use the Pearson correlation coefficient. Its estimator for a set of empirical data may be presented as:

$$r(\mathbf{T_t}, \mathbf{T_w}) = \frac{cov(\mathbf{T_t}, \mathbf{T_w})}{S(\mathbf{T_t}) \cdot S(\mathbf{T_w})} \tag{4}$$

where:
$cov(\mathbf{T_t}, \mathbf{T_w})$ – covariation between variables $t_{\mathrm{t}}(k) \in \mathbf{T_t}$ and corresponding $t_{\mathrm{w}}(k) \in \mathbf{T_w}$.
$S(\mathbf{T_t})$ – standard deviation of variables $t_{\mathrm{t}}(k) \in \mathbf{T_t}$,
$S(\mathbf{T_w})$ – standard deviation of variables $t_{\mathrm{w}}(k) \in \mathbf{T_w}$.

Often, apart from the value of Pearson coefficient of correlation $(\mathbf{T_t}, \mathbf{T_w})$, the value of coefficient of determination $r^2(\mathbf{T_t}, \mathbf{T_w})$ is calculated. It describes the proportion of the variance of the dependent variable that is explained by the variance of the independent variable (or variables).

The relationship between dependent and independent variables can be expressed in form of a mathematical equation. Regression models are built as functions of various mathematical forms. For variables $t_{\mathrm{t}}(k) \in \mathbf{T_t}$ oraz $t_{\mathrm{w}}(k) \in \mathbf{T_w}$, the best mapping has been obtained for functions presented in Table 1.

Tab. 1

Mathematical forms of regression models for the relations between AT and TTWAT in public transport

Regression model	Mathematical form
linear model	$\widehat{t_{\mathrm{w}}}(k) = \beta_0 + \beta_1 t_{\mathrm{t}}(k), \quad k \in \boldsymbol{K}$
exponential model	$\widehat{t_{\mathrm{w}}}(k) = \beta_0 e^{\beta_1 t_{\mathrm{t}}(k)}, \qquad k \in \boldsymbol{K}$
power model	$\widehat{t_{\mathrm{w}}}(k) = \beta_0 t_{\mathrm{t}}(k)^{\beta_1}, \qquad k \in \boldsymbol{K}$
logarithmic model	$\widehat{t_{\mathrm{w}}}(k) = \beta_0 + \beta_1 \ln(t_{\mathrm{t}}(k)), \qquad k \in \boldsymbol{K}$

Source: authors' research

where:
$\widehat{t_{\mathrm{w}}}(k)$ – theoretical value of dependent variable (access time to the bus stop) corresponding to TTWAT from k-th class.

To assess the quality of the fitting of the function of regression, different measures can be used. Among most common, one can enumerate the residual variation ${S_{\mathrm{r}}}^2$, which can be calculated as:

$$ {S_{\mathrm{r}}}^2 = \frac{1}{(\overline{K} - n)} \sum_{k=1}^{\overline{K}} (t_{\mathrm{w}}(k) - \widehat{t_{\mathrm{w}}}(k))^2 \tag{5} $$

where:
n – number of parameters of regression.

The standard residual deviation S_{r}, was calculated according to the following formula:

$$ S_{\mathrm{r}} = \sqrt{\frac{1}{(\overline{K} - n)} \sum_{k=1}^{\overline{K}} (t_{\mathrm{w}}(k) - \widehat{t_{\mathrm{w}}}(k))^2} \tag{6} $$

The differences between the empirical and theoretical values of the dependent variable should be low. Hence, the lower the value of standard residual deviation, the better fitted the model

Another measure that has been used to assess the fitting of the function of regression was the coefficient of residual variation V_{r}, that is associated with standard residual deviation and has been calculated as:

$$ V_{\mathrm{r}} = \frac{S_{\mathrm{r}}}{\overline{t_{\mathrm{w}}}} \tag{7} $$

where $\overline{t_w}$ is the average value of the access time to the bus stop estimating as:

$$\overline{t_w} = \frac{1}{\overline{K}} \sum_{k=1}^{\overline{K}} t_w(k) \tag{8}$$

Coefficient of residual variation V_r shows what portion of the mean value of the dependent variable constitutes the standard residual deviation, so in the case of well-fitted models, it takes values smaller than 0.3.

The last measure for assessing the quality of the fitting was the coefficient of convergence φ^2, calculated based on the following formula:

$$\varphi^2 = \frac{\sum_{k=1}^{\overline{K}} (t_w(k) - \widehat{t_w}(k))^2}{\sum_{k=1}^{\overline{K}} (t_w(k) - \overline{t_w})} \tag{9}$$

It takes values between 0 and 1, and the closer to 0 it equals, the better fitted the model.

4. RESULTS

The surveys research, necessary for the analysis was performed in Bielsko-Biała. It is a city in the southern part of the Silesian Voivodeship, located near the Polish borders with Czechia and Slovakia. It is the largest city in the region, having a population of c.a. 170,000 inhabitants [27]. The area of the city is 124.5 km^2. The location of Bielsko-Biała on the background of Silesian Voivodeship is presented in Figure 3.

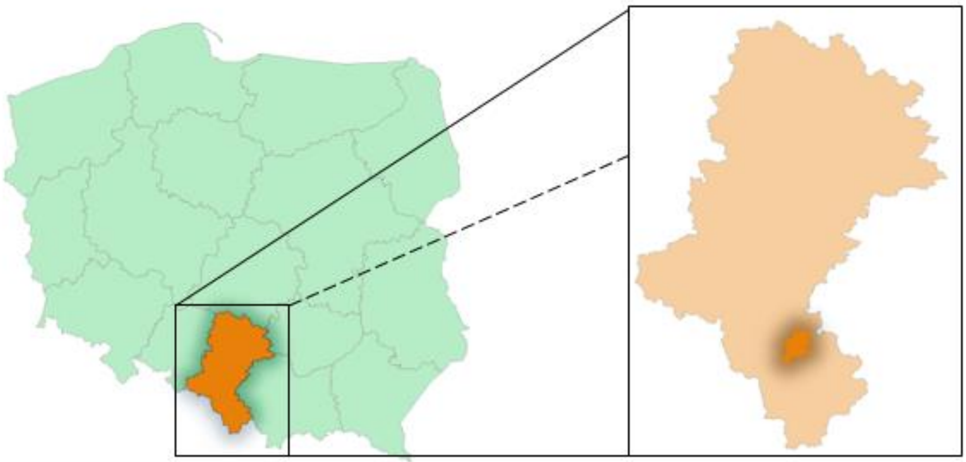

Fig. 3. Location of Bielsko-Biała on the background of the Silesian Voivodeship

The data for the analysis was obtained from household surveys, for the building of the transport model for the city. Inhabitants were asked about their trips made by buses and they declared the duration of the individual components of the total travel time for each trip they made.

According to the data collected during the survey, TTWAT was widely differentiated and varied from low values (ca. 2-3 minutes) to even up to 90 minutes. To perform the statistical analysis, TTWAT has been aggregated into groups of 5 minutes, as presented in Table 2. Only groups with at least 30 observations were considered, and for these groups, the analyses of correlation and regression were performed. These groups have been bolded. For each group, the middle of the range and value of average access time has been determined.

Tab. 2

Classes of TTWAT and average access time to bus stop

Number of the class of TTWAT k	Range of the class of TTWAT $\langle t_{t0}(k) - t_{t1}(k)\rangle$ [min]	Number of observations	Middle of the range of TTWAT $t_t(k)$ [min]	Average access time to bus stop $t_w(k)$ [min]
1	0 – 5	21	2.5	6.38
2	5 – 10	98	7.5	5.28
3	10 – 15	276	12.5	5.64
4	15 – 20	464	17.5	6.48
5	20 – 25	512	22.5	5.86
6	25 – 30	409	27.5	6.20
7	30 – 35	282	32.5	7.02
8	35 – 40	175	37.5	7.49
9	40 – 45	132	42.5	6.86
10	45 – 50	82	47.5	6.32
11	50 – 55	58	52.5	6.86
12	55 – 60	42	57.5	7.12
13	60 – 65	22	62.5	6.68
14	65 – 70	13	67.5	8.38
15	70 – 75	7	72.5	6.43
16	75 – 80	8	77.5	11.88
17	80 – 85	6	82.5	10.83
18	85 – 90	1	87.5	5.00

Source: authors' research

The analysis of correlation was the first part of the analysis. The value of the Pearson coefficient of correlation $r(\mathbf{T_t}, \mathbf{T_w}) = 0.75$ $[-]$, suggests that the relationship between TTWAT and average access time to the bus stop is fairly strong. Positive value of the coefficient also means that the higher the value of TTWAT, the higher the value of the average access time to the bus stop.

To map the relationship between analysed variables, four regression models presented in Table 3, were developed. Parameters of regression for each model were calculated and equation of regression was obtained on this basis.

Tab. 3

The regression models mapping the analysed relationship

Regression model	Equation of regression	Coefficient of determination R^2 [-]
linear model	$\widehat{t_w}(k) = 5.47 + 0.03t_t(k)$	0.56
exponential model	$\widehat{t_w}(k) = 5.48e^{0.0049t_t(k)}$	0.57
power model	$\widehat{t_w}(k) = 4.06t_t(k)^{0.1385}$	0.68
logarithmic model	$\widehat{t_w}(k) = 0.86 + 3.61\ln(t_t(k))$	0.66

Source: authors' research

According to Table 3, the highest value of the coefficient of determination was obtained in the case of the power model. This value is very close to 0.70, which suggests moderate quality – about 68% of the variance of the access time to the bus stop is explained by the variance of TTWAT. Assuming that the minimum value of the coefficient of determination to determine the fitting of the model as acceptable is 0.60, then the logarithmic model offers satisfactory results whereas the linear model and exponential model do not map the relationship between the access time to the bus stop and TTWAT sufficiently.

For each model, a scatter plot containing observations and curves of regression was prepared. They are presented in Figure 4.

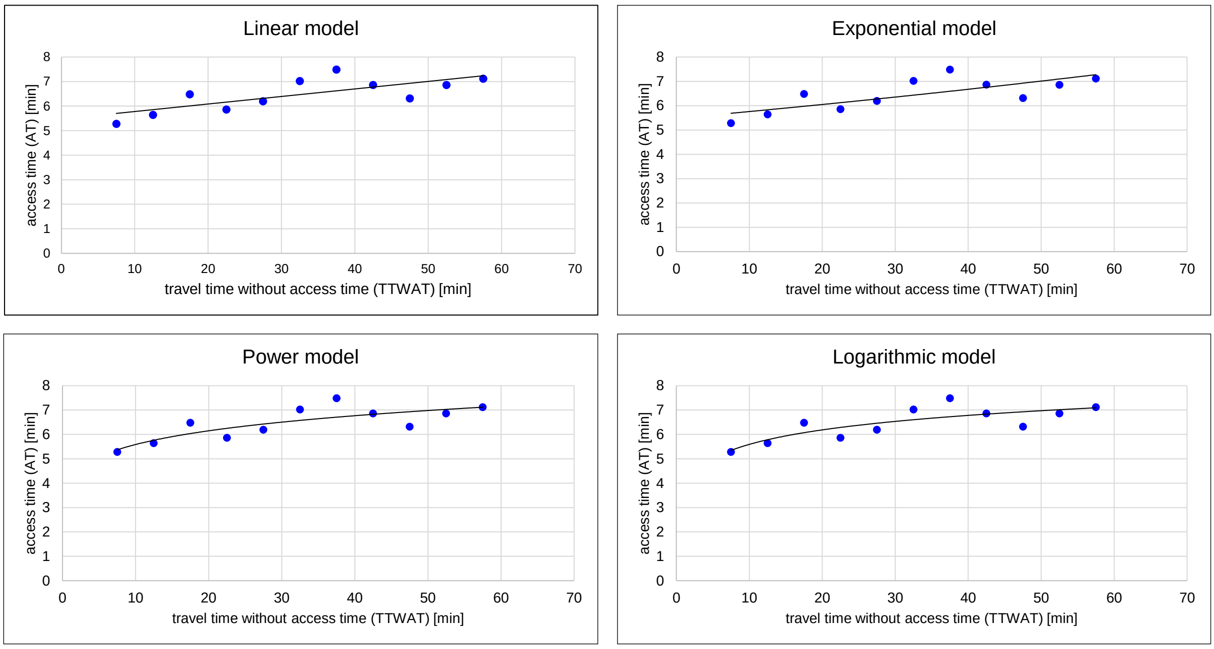

Fig. 4. Scatter plots and curves of regression for each analysed model of regression

In the case of each model, the quality of the fitting was assessed. It allowed determining which model represents the relationship between the access time to the bus stop and TTWAT in the best possible way. Several measures were exploited assessing the quality of the fitting:

- standard residual deviation S_r,
- coefficient of residual variation V_r,
- coefficient of convergence φ^2.

The results of the evaluation are presented in Table 4. Bolded indicates the best value of each measure.

Tab. 4

Goodness-of-fit measures for each analysed model

Model	standard residual deviation S_r [min]	coefficient of residual variation V_r [%]	coefficient of convergence φ^2 [-]
linear model	0.48	7.38	0.44
exponential model	0.49	7.54	0.46
power model	0.43	6.59	0.35
logarithmic model	0.42	6.51	0.34

Source: authors' research

The best value of the coefficient of convergence was calculated for the logarithmic model. In the case of standard residual deviation and coefficient of residual variation, the best values were obtained for such a model. However, it is important to point out that the values of these two measures were fairly similar among all models. The difference between the maximum and minimum values of the measures for the tested models does not exceed 0.1. The logarithmic model also has a satisfactory value of the coefficient of determination (above 0.6). Therefore, it seems that the logarithmic model may be the most useful to map the relationship between the access time to the bus stop and travel time without the access time in bus transport.

5. CONCLUSION

Access time to bus stops has a great impact on decisions transport users make on the choice of the mode of transport. Numerous studies have been focused on determining the factors that influence the value of access time that passengers accept when walking to the bus stop. The goal of this paper was to study the relationship between the access time (as the dependent variable) and one of the characteristics of the travel – the travel time without the access time (as the independent variable).

Statistical analysis was exploited to learn if there is a relationship between these two variables. Based on the results of the analysis of correlation, it was shown that there is a fairly strong dependency between the access time to the bus stop and travel time without the access time. Such a result justifies the construction of regression models to map the relationship.

Four regression models (linear, exponential, power and logarithmic) were chosen for further analysis. The quality of fitting was assessed in the case of each model, using the following measures: coefficient of determination, standard residual deviation, coefficient of residual variation and coefficient of convergence. Results of the analysis of regression and the assessment of fitting of each model show that the logarithmic model may be the best choice to map the relationship between access time and travel time.

Results of the conducted analysis show that passengers of bus transport are willing to walk longer to the bus stop if they are planning a longer trip. It may be a guideline for the determination of locations of bus stops. Future research should be focused on the analyses of the relationship between access time and travel time considering different transport modes (that is, tram transport, railway transport) and different characteristics of travel, to provide a comprehensive view.

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