IOP Conference Series: Materials
Science and Engineering

PAPER • OPEN ACCESS

Mobility in Transportation Surveys

To cite this article: Paulina Olenkowicz-Trempała *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1203** 032007

Mobility in Transportation Surveys

Paulina Olenkowicz-Trempała[1], Aleksander Sobota[2], Jacek Chmielewski[1], Jan Kempa[1], Bertha Santos[3,4], Jorge Gonçalves[3,5]

[1]Faculty of Civil and Environmental Engineering and Architecture, UTP University of Science and Technology in Bydgoszcz, 85-796 Bydgoszcz, Poland
[2]Faculty of Transport and Aviation Engineering Silesian University of Technology, Department of Transport Systems, Traffic Engineering and Logistics, Krasińskiego 8, 40-019 Katowice, Poland
[3]Department of Civil Engineering and Architecture, University of Beira Interior, Calçada Fonte do Lameiro, 6200-358 Covilhã, Portugal
[4]CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal
[5]CITTA, Faculty of Engineering of the University of Porto, Building G 4th floor, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

paulina.olenkowicz@utp.edu.pl

Abstract. An attempt to identify key factors impacting trip generation in different size cities is presented in this paper. Mobility is the fundamental factor in transport demand models, both for the present state and those for forecast scenarios. Moreover, research on inhabitants' mobility plays an important role in the process of urban and rural traffic modelling. It comes from the fact, regular transport surveys make it easier to determine factors impacting the number of trips taken by inhabitants in any selected study area, and to determine trends in these factors. Presentation of example results of mobility rate based on transportation surveys taken in various areas of Poland is the main goal of this paper. Results of analyses of selected macro-economic factors in transportation systems shaping are presented either. The trends in the number of inhabitants and their age composition, and motorization rates are those factors. They impact mobility ratios in the study area. Values of mobility ratio were developed based on the results of surveys which have been done in Poland till now, and on the authors' research. Mathematical regression models in estimating mobility ratio versus the selected independent factors are the results of this research either.

1. Introduction

Improvement of the quality of life in urban areas is one of the biggest challenges for civilization. It can be achieved by new technical solutions, which are adequate to the demands of present society. Transport and its technical solutions play one of the key roles in it. Almost every day people have to do trips to fulfil their obligatory and facultative demands of life. Many transportation analyses have to be done to develop adequate technical solutions, which enable efficient and fluent everyday trips. Checking the impact of the given technical solution on transport systems plays an important role in the planning and design process. Macroscopic transport demand models (TDM) are the most common mathematical tool used by engineers. As the development of such a mathematical macroscopic transport demand model is a very time and money consuming process, this technique is still not a common use practice in Poland.

And that's why new solutions to develop a transport demand model in a faster and simpler way are the subject of new research work, which is referenced in [1, 2].

The determination of a mobility rate is one of the first phases while the macroscopic transport demand model is developed. Especially at the first stage of model development, the correct determined mobility rate gives the possibility to review the correctness of assumptions taken by the engineers. That's why the method of mobility ratio estimation without expensive transportation surveys is the subject of this paper.

An attempt to develop mathematical models describing the correlation of a mobility rate and the selected factors of the study area was made by the authors. What is really important, these selected factors must be included in an open-access up-to-date database, which is permanently updated by new data. GUS (Central Statistical Office of Poland) is such a database in Poland.

2. The role of mobility rate in transport demand models

In this paper, a transport demand model is a mathematical representation of inhabitants behaviour in trips. TDM for the present state is developed at the very beginning. It enables verification of the correctness of all assumptions and factor. Then, based on it, TDMs are built for forecast scenarios (typically for every 5 years). It is a complicated and hard process to develop TDM, where lots of data need to be collected, like demographic data, socio-economic data, land-use data and so on [3, 4]. Complex transportation analyses, which may it be possible to improve transportation systems and make everyday trips easier and safer, require the usage of TDM, and that is why there is a need to develop it. Moreover, there is a need to use TDM to develop transportation plans, which are required by Polish regulations [5]. A transportation plan has to be developed, to define public transit, transportation demand estimation and forecast, forecasted funds, modal split preferences, the rules of public service regulations, required level and standard of service, and how information on public transit service is planned to be shared.

TDM is one of the key tools to support modern transport management, including transport planning and designing, and decision on transport network reconstruction. It enables [6]:

- the full scope of transport system performance,
- analysis and estimation of transport system service, mainly by determination of main its functioning attributes (e.g. passenger flows, traffic volume),
- road network optimization and determination of the most favourable location and technical and operational parameters reconstructed or new investments.
- cost and benefits analyses to determine the effectiveness of transportation investment (what is especially important for cofounded transportation investments by UE);
- determination of changes in traffic conditions as the result of road network changes, like closures of selected road, turn-pipes, side works, new road links constructions etc. (e.g. selection of optimal solution for such activity);
- optimization of traffic management in transport systems (e.g., permanent road signing and marking).

Four-step transport demand models are the most common idea of TDM [7-10] or integrated transport - land use models described by Zipsera [11, 12] and Mazurkiewicz [13]. Land use models are intended to forecast the effect of changes in the transport network and land-use identified by traffic analysis zone (TAZ) as the location of activities. These effects are strictly correlated to the shape of the road network.

Four-step models start with land-use data, where demographic and transportation attractiveness data are correlated with a given type of trip. It consists of four steps [14-16]:

IOP Conf. Series: Materials Science and Engineering 1203 (2021) 032007 doi:10.1088/1757-899X/1203/3/032007

- trip generation - determines the frequency of origins or destinations of trips in each zone (TAZ) by trip purpose,
- trip distribution - matches origins with destinations, often using a gravity model function,
- mode choice or modal split - calculates the proportion of trips between each origin and destination that use a particular transportation mode,
- traffic assignment - allocates trips between an origin and destination by a particular mode to a route, based on its attractiveness.

Trip generation is the first step of this TDM. Inhabitants' mobility ratio (number of trips per one person in a given period of time) is one of the crucial data in this point. And this can be determined based on the analyses of inhabitants' transportation behaviors [17]. And these inhabitants' transportation behaviors depend on so-called transportation homogeneous inhabitant groups. That's why the way inhabitants are divided into these groups has to be defined by the model's authors (e.g. student, employed, unemployed). In addition, representatives of individual groups and their trip motivations should be identified (it is necessary to establish the relative number of trips of each group in each motivation, e.g., to work, shopping, school, etc.). The location of the trip destination is not determined at this step. Only the number of trips is computed for every group of inhabitants. All possible transportation modes are considered, motorized and non-motorized ones, among TAZs as well as and inner trips (inside the selected TAZs). Determination of trips number between TAZ *a* and b for a given period is the result of the trip generation step.

The second step is to compute trip demand matrices, which describe all trips among TAZs. The spatial trips distribution consists in determining a two-dimensional matrix, the elements of which reflect the demand (number of trips) between individual transport zones [18]. The methods of developing trip matrices can be divided into two main groups: factoring and synthetic models. Factoring models use previously known dependencies (e.g. historical matrices) and, based on the determined trends (based on the growth factor), enable computing of these matrices (e.g. using the Fratar method described in [19] or Furness method given in [20]). The second group consists of synthetic methods, in which the gravity function is most often used (equivalent to an entropy maximizing model), assuming that the number of trips between two TAZs is proportional to their attractiveness, considering the impact of the impedance between these TAZs (like distance or time) [19].

Trips generated in the second step are split among all available means of transport in the third step of the four-step TDM. And this step is called "modal-split". This split is depended on the availability of the transportation system, the generalized cost of trips by each of them, and the individual preferences of inhabitants, where vehicle owning plays a key role. The results of surveys with inhabitants of the study area are typically the base for the modal split function formulation and parameterization.

Trips assignment is the last, the fourth step of the four-step TDM. It allocates trips between an origin and destination by a particular mode to a route. Transportation networks are loaded by trips, vehicles, and passengers. Maps of traffic flows for different transportation system can be plotted for the whole study area.

The questionnaire surveys are the base technique for data on the transport behavior of the inhabitants of a given area collection in Poland. Due to the scale of the problem, the research must be conducted on a representative sample of respondents, which must reflect the entire population related to this area. The average number of trips per the selected time period (day, rush hour, etc.) is determined based on the survey data. Then, based on this data, the percentage of people in the sample in relation to the total number of people in the population, the total number of trips in the study area is determined. To verify the number of trips computed by the first step of TDM, its comparison to the number of inhabitants in the population multiplied by the mobility ratio may be done. Therefore, the mobility ratio is a good measure that can be used to calibrate the traffic generation model.

3. Comprehensive transport studies as a source of data for transport demand models

Determination of data on transportation behavior of inhabitants of the study area, traffic, and passenger counts, as well as freight traffic data (vans and trucks) are the main goals of comprehensive transport studies (CTS) [21, 22].

The first Polish CTS were done in Warsaw in 1969, and then in Cracow and Lodz. The methodology developed by the American Bureau of Public Roads in 1944 was used in these studies. Later, this methodology became very popular, and it was used in many countries around the world [23]. In Poland, comprehensive transport studies have been done more often since 2020, and they are mainly used to parametrize TDM for the selected areas of Poland.

The scientific community sought to conduct surveys by state institutions (e.g. GUS) in order to determine the transport behavior of inhabitants in Poland. The first such attempt on the national level was done by GUS in 2015. It was done according to the American methodology but in very limited substantive content. The results were presented in Warsaw in 2015. [24].

The following research can be done as a part of comprehensive transport studies [1]:

- survey households in the study area,
- survey drivers on the cordon of the study area,
- survey of passengers of public transit on the cordon of the study area,
- traffic volume counts and its composition at screen lines (most often created by railway lines, bridges etc.),
- traffic volume counts and its composition at cordon lines,
- traffic volume counts and its composition in the most important junctions of the road network,
- trip production and attraction by selected places (shopping centers, large-area car parks, etc.),
- the number of travelers (demand) in public transit,
- the number of travelers using railway stations, bus stations, etc.,
- freight traffic in the study area,
- the impedance function parameters of the road and street network elements of the study area.

Research results are used at various phases of the four-step model construction and operation [2]. Surveys, freight traffic observations, trip production and attraction are used in all steps of TDM construction, and traffic volume and public transit passenger counts are used in model verification and calibration. The tests of the impedance function for road sections are used to formulate an empirical equation of links impedance in the road network.

As it was mentioned, the mobility ratio is determined based on the results of surveys. These surveys are done in the selected sample of households. The everyday trips are identified. Trips frequency (mobility), time of day, intensity, and the way there are done, are the subject of interest. Moreover, the reasons and trip destinations are examined [25]. The survey is non-full sample research, and an important issue is the appropriate selection of the test sample (sample group subject to the study), so that the result can be generalized to the whole population. The random sample method is the most popular one to select a test sample. In the case of TDM, it is important to estimate a test sample for TAZ, to meet the demographic structure of inhabitants and their transportation behaviour. When determining the research sample, attention should be paid to the absolute sample size of the studied population, the smaller it is, the greater the percentage of inhabitants should be tested.

Research is conducted around the world to reduce the costs of data collection by aggregating transport regions [26] or to reduce the research sample size [27, 28] (traditional approach – in household surveys). The use of GPS devices is still an expensive technique and not yet fully proven. Nevertheless, these devices are readily used for mobility research, but their use is limited to data collection and interviews revision [29]. There are also attempts to use the trajectory trace recorded by mobile phones [30], but, at present this is more of a preliminary research attempt than a practical action. Focus research is the other activity [31], in which a small group of respondents is interviewed in detail about their transport behavior. These interviews are conducted by psychologists to assist in the process of identifying and characterizing transport behavior. Also, noteworthy is the technique of expert research, in which the opinions of professionals involved in travel modelling constitute the basis for the creation of procedures and mathematical formulas describing the processes of trips [32].

4. Review of mobility studies in Poland

The largest number of studies that recorded mobility data (taking into account the scope and number of studies performed) was carried out in the last decade. CTSs are rarely performed as they involve high financial costs. On the other hand, if the authorities of the study area even raise funds for the implementation of CTS, other problems are observed. Difficulty in data collection due to the many refusals of respondents is one of the most serious problems. Table 1 presents the values of mobility rates broken down by city size, determined based on selected studies of transport behavior in Poland.

Table 1. Inhabitants' mobility rates by a city size

No.	City size	*City*	Mobility rate	*Survey year*	Date source
1	to 100 000 inhabitants	Piekary Śląskie	1.84	2018	[23]
2		Mysłowice	1.43	2018	[33]
3		Krosno	1.90	2008	[23]
4		Siemianowice Śląskie	1.67	2018	[33]
5		Jaworzno	2.18	2018	[33]
6	from 100 000 to 200 000 inhabitants	Ruda Śląska	1.94	2018	[33]
7		Bytom	1.95	2018	[33]
8		Chorzów	2.31	2018	[33]
9		Gliwice	2.06	2018	[33]
10		Bielsko-Biała	2.20	2015	[34]
11		Rybnik	1.60	2018	[33]
12		Rybnik	1.62	2015	[23]
13		Dąbrowa Górnicza	2.36	2018	[33]
14		Opole	1.28	2016	[35]
15		Kielce	2.12	2015	[23]
16		Olsztyn	2.20	2009	[23]
17		Rzeszów	2.04	2015	[36]
18		Rzeszów	1.80	2011	[36]
19		Rzeszów	1.86	2009	[23]
20	from 200 000 to 500 000 inhabitants	Gdynia	1.65	2015	[23]
21		Gdynia	1.61	2010	[23]
22		Sosnowiec	1.89	2018	[33]
23		Szczecin	1.9	2016	[23]
24		Szczecin	1.25	2010	[23]
25		Toruń	2.23	2016	[37]
26		Bydgoszcz	2.25	2013	[38]
27		Katowice	2.14	2018	[33]
28		Gdańsk	2.1	2016	[23]

29		Gdańsk	1.93	2009	[39]
30	from 500 000 to 1 000 000 inhabitants	Poznań	1.7	2013	[23]
31		Wrocław	1.7	2018	[23]
32		Wrocław	1.87	2010	[23]
33		Łódź	2.40	2013	[40]
34		Kraków	2.02	2013	[23]
35	over 1 000 000 inhabitants	Warszawa	1.99	2015	[23]

Table 1 presents the results of mobility research carried out in the selected large cities above 500,000 inhabitants (five cities), in medium-sized cities from 200,000 up to 500 thousand inhabitants (seven cities) and in small towns below 200 thousand inhabitants (sixteen cities). Based on Table 1, it can be noticed the greatest mobility rate equal to 2.40 is observed in Lodz (studies performed in 2013). On the other hand, the lowest mobility rate was recorded in Szczecin (research carried out in 2010). The average mobility rate for large cities was determined as 1.95 (six mobility results), for medium-sized cities 1.90 (ten mobility results), and for small cities 1.91 (nineteen mobility results).

A high mobility rate may result from the high attractiveness of the study area, which may encourage people to do several trips a day. The list shows the mobility rate values below 2, which may indicate, for example, the low attractiveness of transport areas or a large share of the number of people who are past that productive age does not travel, in relation to the number of people in productive age who usually make the largest number of obligatory journeys. The different research methodology in this research, which is not standardized in Poland, has an impact on this value.

5. Mobility models including one independent variable.

The process of developing mathematical models describing the number of residents' trips on an average working day was carried out in accordance with the diagram presented in Figure 1.

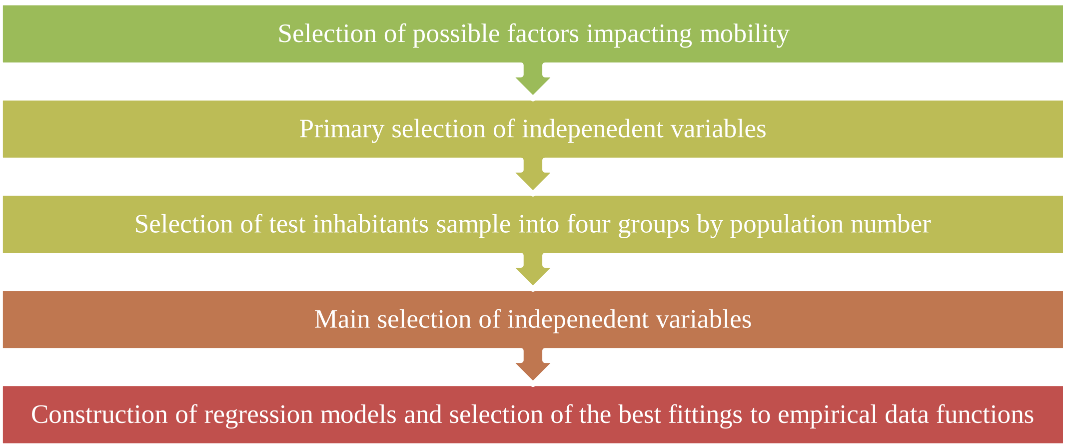


Figure 1. The schema of mathematical mobility models' construction

During the construction of TDM, factors that may affect mobility were identified. It consisted of the analysis of categories, groups, subgroups and characteristics of the data collected in the Central Statistical Office database that could potentially affect the mobility rate. The database of the Central Statistical Office consists of 33 categories, 225 groups, 1,522 subgroups and 100,190 features, as shown schematically in Figure 2.

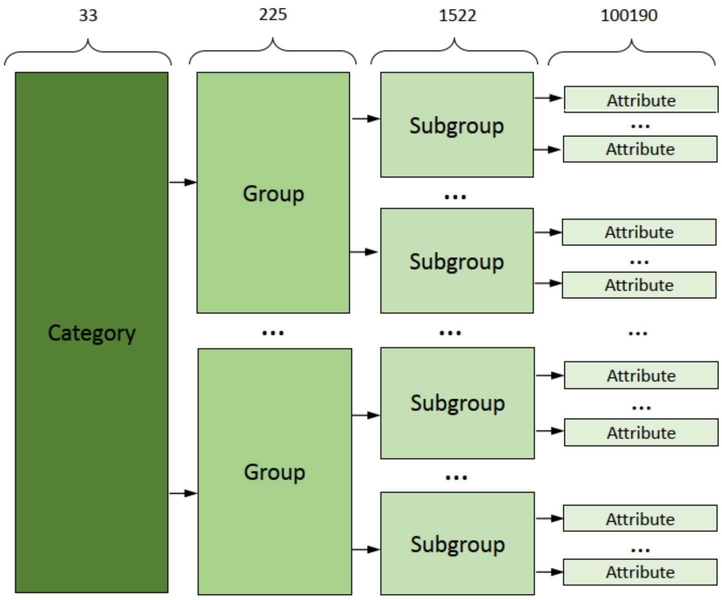


Figure 2. Database structure, which includes the list of analyzed factors, that can impact mobility.

Then, the initial selection of independent variables was made. These variables were selected on the basis of expert knowledge, discussion, and literature review. In further analyses, only the data available for localities with counties rights were used. The variables that were adopted for the analyses include city population [number of inhabitants], number of cars in the city [pcs.], motorization rate [cars / 1000 inhabitants], price of 1 liter of gasoline in Poland [PLN], unemployment rate [%], the number of people of production age in the city [persons], the length of road network [km/10 thousand inhabitants], the average monthly gross salaries in relation to the national average [%], water consumption per capita [m^3], entities of the national economy per 1000 inhabitants [pcs.], entities of the national economy per 1000 inhabitants of working age [pcs.], housing resources - number of apartments [pcs], city budget revenues per capita [PLN], city budget expenditure per capita [PLN], city area [km2], population [person /km^2].

Having data on the number of inhabitants in the study cities, the values of the considered independent variables were allocated to one of the four groups. The criterion for the cities' division into individual groups was conventionally adopted by the authors of the positional measures of the distribution of the number of inhabitants of the analyzed cities, the so-called quantiles. The lower quantile ($k_{25\%}$), the median ($k_{50\%}$) and the upper quantile ($k_{75\%}$) were determined. Therefore, the studied population in terms of the number of inhabitants was assigned to the ranges of the variability of the adopted quantiles, and the results are presented in Table 2.

Table 2. Groups of samples according to inhabitant's number.

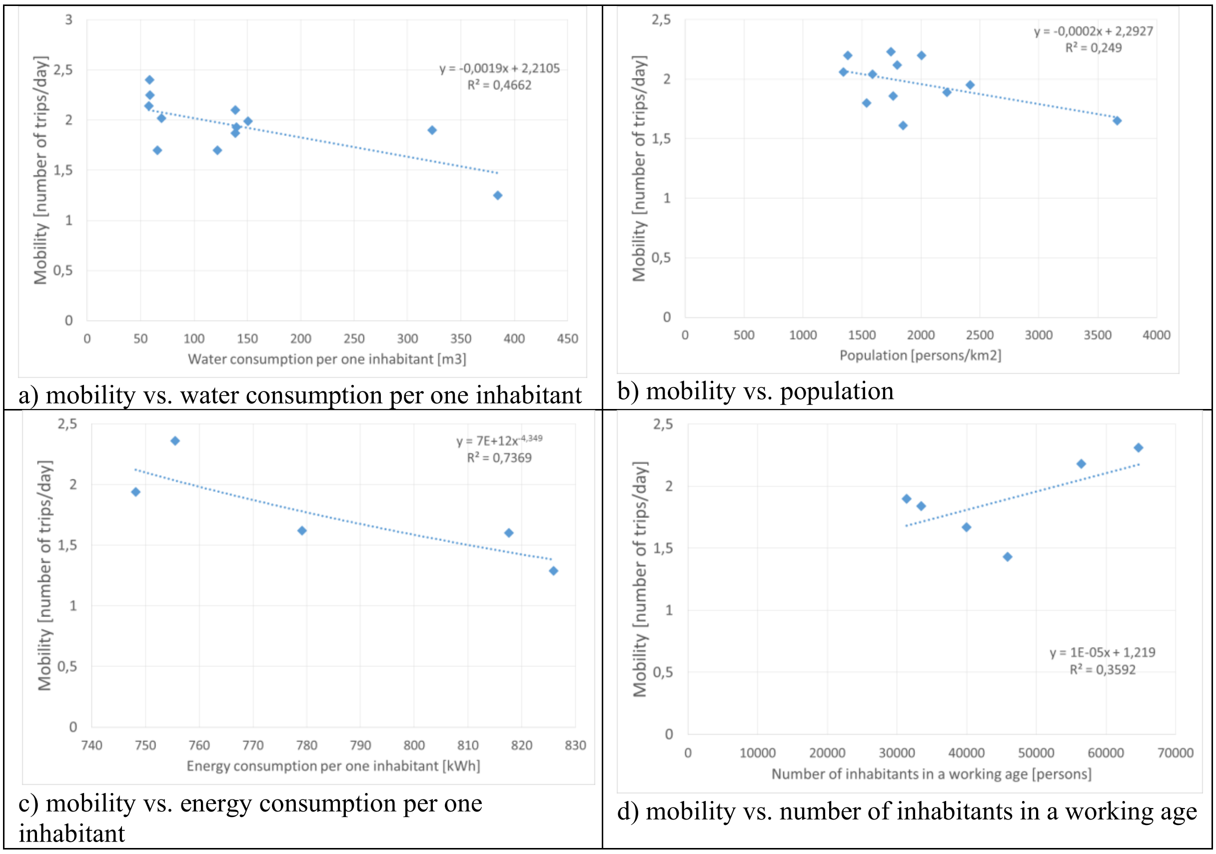
No.	Quantile	*Inhabitants range*	Number of cities in given range	*Sample of the dependent variable*
1	*inhabitants number*> $k_{75\%}$	over 251,297	9	12
2	$k_{50\%}$<*inhabitants number*≤ $k_{75\%}$	from 138,000 to 251,297	9	12
3	$k_{25\%}$<*inhabitants number*≤ $k_{50\%}$	from 107,590 to 138,000	4	5
4	*inhabitants number*≤ $k_{25\%}$	below 107,590	6	6

In the next step of the analysis, the main selection of pre-selected independent variables was made, which consisted in:

- selection of variables according to the variance value (variables showing a very small data scatter were excluded); such variables were considered those for which the coefficient of variation (the ratio of the standard deviation to the mean) $V_i \leq 0{,}2$;
- the exclusion of variables showing strong mutual correlation; the value of the coefficient of correlation R_x between the examined independent variables was determined and those for which $R_x \geq 0{,}7$;
- exclusion of variables showing too weak correlation with the dependent variable, i.e. those for which $R \geq 0{,}2$).

After the essential selection of independent variables, the determination of regression models was started. The following functions were analyzed: linear, power, logarithmic, exponential, and polynomial.

The results of the selected four models are presented in Figure 3.



a) mobility vs. water consumption per one inhabitant

b) mobility vs. population

c) mobility vs. energy consumption per one inhabitant

d) mobility vs. number of inhabitants in a working age

Figure 3. Dependency models – mobility versus selected independent variables: a) cities over 251,297 inhabitants, b) cities between 138,000 and 251,297 inhabitants, c) cities between 107,590 and 138,000 inhabitants d) cities below 107,590 inhabitants - [own study]

As it can be observed, the results of the modelling process do not indicate a strong correlation between the dependent and independent variables in all cases. The highest value of the coefficient of determination is characteristic for the relationship between the mobility rate and energy consumption from supplier per capita [kWh] determined for cities with the number of inhabitants from 107,590 to 138,000 and is $R^2 = 0.737$. On the other hand, the model developed for cities with 138,000 to 251,297 inhabitants has the lowest value of this coefficient. In this case, the dependence of mobility on electricity consumption per 1 city resident is characterized by a determination coefficient of $R^2 = 0.249$. According to the authors, the low values of this coefficient are related to the fact that only models with one independent variable were developed. Future attempts to build models with many independent variables may translate into higher values of the coefficient of determination.

6. Conclusions

Attempts to develop a model of the dependence between the mobility rate and the other factors describing: the demographic, social and economic determinants of traffic formation are presented in this paper. Identification of independent variables reflecting the discussed conditions was made. An important criterion for the selection of these variables was their availability. Therefore, it was decided to analyse the widely available and annually updated database of the Central Statistical Office (GUS). Out of 100,190 traits, 19 were selected by eliminating the following variables:

- the inhabitants number,
- the number of vehicles in the study area,
- the motorization rate [veh./1000 inhabitant],
- the gasoline price per one liter [PLN],
- the unemployment rate [%],
- the number of inhabitants in production age,
- the length of road network [km/10 thousand inhabitants],
- the average monthly income in relation to the national average salary [%],
- the total water consumption [m^3],
- entities of the national economy per 1000 inhabitants,
- entities of the national economy per 1000 inhabitants in production age,
- the housing stock – number of apartments,
- the city budget per 1 inhabitant [PLN],
- the city expanses per 1 inhabitant [PLN],
- the water consumption per 1 inhabitant [m^3],
- the electricity consumption per 1 inhabitant [kWh],
- the gas consumption per 1 inhabitant [m^3],
- the number of road accidents,
- the area [km^2], population density [persons/km^2].

The synthetic character of these variables (i.e. generally reflecting other factors determining the formation of traffic) was another important criterion for this selection.

The mobility rate was adopted as a dependent variable in this study, which was identified on the basis of a literature review of 35 Comprehensive Traffic Studies prepared in Poland over 10 years (between 2008 and 2018). CTSs were conducted in cities of all sizes. Therefore, it was decided to group data in terms of the number of inhabitants. The decision was also justified by the observations presented in the literature. It was noticed that the inhabitants' transportation behavior differs depending on the city size.

The mathematical models describing the relationship between the mobility rate and the previously mentioned independent variables are the result of this research. The intention of the authors was to build a model that can be easily used by engineers and not involve a large amount of work to collect necessary data (therefore the Central Statistical Office database was used). However, due to the extensive subject scope of the issue, only models with one independent variable were built. Therefore, the values of the determination coefficients for these models are at a low or medium level. The highest values of the coefficient of determination were determined for cities for the 50% quantile - dependence of the mobility rate and electricity consumption per one inhabitant, and the smallest for the quantile group 75% - dependence of the mobility rate and population.

Acknowledgment(s)
This article has been supported by the Polish National Agency for Academic Exchange under Grant No. PPI/APM/2019/1/00003.

References

[1] A. Sobota, R. Janecki, G. Karoń., R. Żochowska i in., „Zintegrowany System Zarządzania Transportem na obszarze miasta Bielska-Białej, etap I - wykonanie Modelu Ruchu”, *Praca NB 148/RT-5/13/14. Politechnika Śląska*, Katowice - Bielsko-Biała, 2015 (in Polish).
[2] E. Macioszek, R. Żochowska, G. Karoń: „Problemy gromadzenia danych dla potrzeb modelowania podróży i prognozowania ruchu”, *Ogólnopolska Konferencja Naukowo-Techniczna „Modelowanie podróży i prognozowanie ruchu”, Kraków 18-19 listopada 2010. Zeszyty naukowo-techniczne SITK RP o/Kraków. Seria: Materiały Konferencyjne Nr 94 Zeszyt 153*, Kraków, 2010 (in Polish).
[3] D.A., Badoe, Ch. Chen: “Unit of analysis in conventional trip generation modelling: an investigation*”, Can. J. Civ. Eng. 31*: 272–280, 2004.
[4] E. Cascetta: “Transportation Systems Analysis. Models and Applications”, *2nd Edition. Springer Optimization and Its Application, Vol.29*. New York, 2009.
[5] Ustawa z dnia 16 grudnia 2010 r. o publicznym transporcie zbiorowym (Dz. U. z 2011 r. Nr 5, poz. 13) oraz Rozporządzenie Ministra Infrastruktury z dnia 25 maja 2011 r. w sprawie szczegółowego zakresu planu zrównoważonego rozwoju publicznego transportu zbiorowego (Dz. U. z 2011 r. Nr 117, poz. 684). Ustawa i rozporządzenie wykonawcze wydane z jej upoważnienia określają zakres analiz, założeń oraz ustaleń Planu, 2011 (in Polish).
[6] Transport.um, Badanie ruchu [Online] 2015. Available at: http://transport.um.warszawa.pl/warszawskie-badanie-ruchu-2015/pytania-i-odpowiedzi (in Polish).
[7] R. Żochowsk, G. Karoń, „Model kształtowania mobilności miejskiej w ujęciu systemowo-funkcjonalnym”, *Prace Naukowe Politechniki Warszawskiej, seria Transport. z. 120,* s. 471-480, 2018 (in Polish).
[8] R. Żochowska, „Wielokryterialne wspomaganie podejmowania decyzji w zastosowaniu do planowania tymczasowej organizacji ruchu w sieci miejskiej”, *Adres wydawniczy: Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej*, 2015 (in Polish).
[9] M. Jacyna, M. Kłodawski, M. Wasiak, J. Żak, “Planning the development of sustainable transport system with simulation tools”, *Oficyna Wydawnicza Politechniki Warszawskiej*, 2019 (in Polish).
[10] M. Wasiak, M. Jacyna, K. Lewczuk [i in.], “The method for evaluation of efficiency of the concept of centrally managed distribution in cities”, *w: Transport, vol. 32, nr 4,* s. 348-357, 2017.
[11] C. Glogowski, T. Zipser, „Formy i charakterystyki parametrów splotowego modelu pośrednich możliwości dla ruchu do pracy w dużych aglomeracjach”, *Zeszyty Naukowe Stowarzyszenia Inżynierów I Techników Komunikacji Rzeczpospolitej Polskiej Oddział w Krakowie nr 1(97)/2012*, s. 77-99, 2012 (in Polish).
[12] T. Zipser, J. Sławski, „Modele procesów urbanizacji. Teoria i jej wykorzystanie w praktyce projektowania”, *Tom 1 z 2, studia KPZK PAN, t. XCVIII, Polska Akademia Nauk*, Warszawa 1988 (in Polish).
[13] L. Mazurkiewicz, „Teoretyczne podstawy modeli przestrzennego oddziaływania”, *Wydawnictwo Polskiej Akademii Nauk Instytut Geografii i Przestrzennego Zagospodarowania*, Wrocław 1986 (in Polish).
[14] G. Karoń, „Kształtowanie ruchu w miejskich sieciach transportowych w wykorzystaniem inżynierii systemów”, *Gliwice: Wydaw. Politechniki Śląskiej*, 2019 (in Polish).

[15] J. Chmielewski, T. Szczuraszek, „Dylematy przy budowie prognostycznych modeli transportowych", *Wydawnictwo Uczelniane Uniwersytetu Technologiczno-Przyrodniczego w Bydgoszczy*, 2019 (in Polish).
[16] J. Chmielewski, T. Szczuraszek, Bydgoszcz, „Wybrane problem modelowania podróży w sieciach transportowych", *Wydawnictwo Uczelniane Uniwersytetu Technologiczno-Przyrodniczego w Bydgoszczy*, 2019 (in Polish).
[17] E. Macioszek, R. Żochowska., G. Karoń: „Problemy gromadzenia danych dla potrzeb modelowania podróży i prognozowania ruchu", *Ogólnopolska Konferencja Naukowo-Techniczna „Modelowanie podróży i prognozowanie ruchu", Kraków 18-19 listopada 2010. Zeszyty naukowo-techniczne SITK RP o/Kraków. Seria: Materiały Konferencyjne Nr 94 Zeszyt 153*, Kraków, 2010 (in Polish).
[18] R. Żochowska, G. Karoń, E. Macioszek, „Wyznaczenie macierzy podróży w sieciach miejskich – klasyfikacja i przegląd metod", *Konferencja Naukowa-Techniczna „Modelowanie podróży i prognozowanie ruchu", Zeszyty Naukowo Techniczne Stowarzyszenia Inżynierów i Techników Komunikacji Rzeczpospolitej Polskiej Oddział w Krakowie, seria: Materiały konferencyjne, nr 94 (Zeszyt 153)*, Kraków 2010 (in Polish).
[19] N. Gaber, "Traffic and Highway Engineering", *Third Edition, University of Virginia, Thomson Learning, Pacific Groove*, 2002.
[20] M. Bell, "The estimation of junction turning volumes from traffic counts: The role of prior information", *Traffic Engineering Control, 25(5*), s. 279-283, 1984.
[21] R. Żochowska, G. Karoń, R. Janecki, A. Sobota, Selected aspects of the methodology of traffic flows surveys and measurements on an urban agglomeration scale with regard to its projects. *Recent advances in traffic engineering for transport networks and systems. 14th Scientific and Technical Conference "Transport Systems. Theory and Practice 2017". Selected papers. Eds*. Elżbieta Macioszek, Grzegorz Sierpiński: Cham: Springer, s. 37-49, 2018.
[22] J. Ortuzar, L. G. Willumsen: "Modelling transport", *3rd Edition. Wiley*, New York, 2009.
[23] J. Gadziński, E. Goras, „Jak zmieniała się codzienna ruchliwość mieszkańców polskich miast? 50 lat badań zachowań transportowych ludności w Polsce", *Prace Komisji Geografii Komunikacji PTG22(4),* s. 8-24, 2019 (in Polish).
[24] A. Rudnicki: „Dylematy metodyczne kompleksowych badań ruchu", *Zeszyty Naukowo-Techniczne Stowarzyszenia Inżynierów i Techników Komunikacji, Oddział w Krakowie, Seria: Materiały Konferencyjne, nr 93, z. 152*, 2010 (in Polish).
[25] A. Ciestoń-Ciulkin, S. Puławska, „Badania zachowań transportowych w miastach z wykorzystaniem Internetu", str. 2751, *Logistyka 6/2014*, 2014 (in Polish).
[26] P.H.L Bovy, G.R.M. Jansen, "Network Aggregation Effects upon Equilibrium Assignment Outcomes: An Empirical Investigation". *Transportation Science, Vol. 17, No. 3*, 1983.
[27] M.E. Smith, "Design of small-sample home-interview travel surveys", *Transportation Research Record Issue Number: 701, Publisher: Transportation Research Board*.
[28] P. Stopher, K. Kockelman, S. Greaves, E. Clifford, "Reducing Burden and Sample Size in Multi-day Household travel survey"*, Transportation Research Board Annual Meeting 2008*, *Washington DC*, 2008.
[29] G. Giaimo, R. Anderson, L. Wargelin, P. Stopher, "Will it work? Pilot Results from the First Large Scale GPS based Household Survey in the US", *Transportation Research Board Annual Meeting 2010, Washington DC*, 2010.
[30] M. Friedrich, K. Immisch, P. Jehlicka, T. Otterstatter, J. Schlaich, "Generating OD matrices from Mobile Phone Trajectories", *Transportation Research Board Annual Meeting 2010, Washington DC*, 2010.
[31] T. Dziedzic, A. Szarata, „Wybrane wyniki kompleksowych badań ruchu w województwie małopolskim"*, IX Poznańska Międzynarodowa Konferencja Naukowo-Techniczna z cyklu Problemy Komunikacyjne Miast w Warunkach Zatłoczenia Motoryzacyjnego*, Poznań – Rosnówko, 19–21 czerwca 2013 (in Polish).

[32] J. Chmielewski, P. Olenkowicz-Trempała, “Analysis of Selected Types of Transport Behaviour of Urban and Rural Population in the Light of Surveys”, *Recent Advances in Traffic Engineering for Transport Networks and Systems: 14th Scientific and Technical Conference "Transport Systems. Theory & Practice 2017" Selected Papers, Springer International Publishing*, 2018.
[33] „Studium transportowe subregionu centralnego województwa śląskiego”, Warszawa, 2018 (in Polish).
[34] „Zintegrowany system zarządzania transportem na obszarze miasta Bielska-Białej”, Bielsko-Biała, 2015 (in Polish).
[35] „Rozszerzenie i aktualizacja do postaci multimodalnej modelu ruchu dla miasta Opola”, Katowice, 2016 (in Polish).
[36] A. Szarata i zespół, „Strategia rozwoju Rzeszowa na lat 2015-2020, Uwarunkowania i kierunki związane z systemem transportowym”, Warszawa, 2015 (in Polish).
[37] „Studium zrównoważonego rozwoju systemów transportowych powiatów bydgoskiego i toruńskiego ze szczególnym uwzględnieniem miast Bydgoszczy i Torunia”, Bydgoszcz 2016 (in Polish).
[38] „Plan zrównoważonego rozwoju publicznego transportu zbiorowego dla województwa kujawsko – pomorskiego”, Bydgoszcz, 2014 (in Polish).
[39] „Kompleksowe badania ruchu na terenie miasta Gdańska 2009”, Sopot-Warszawa, 2009 (in Polish).
[40] „Aktualizacja studium systemu transportowego dla miasta Łodzi”, Warszawa. 2013 (in Polish).