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Mode choice modelling for urban areas

Modelowanie wyboru środka transportu dla obszarów zurbanizowanych

Abstract

This article addresses the issue of mode choice modelling using a four-stage travel modelling process. The article indicates limitations of the currently used simplified methods of mode choice modelling and proposes the use of a more detailed approach that accounts for additional, statistically significant factors with the use of advanced mathematical tools and discrete choice models. A need has also been identified to include qualitative factors in forecasting the modal split and in the scenario analyses.

Keywords: travel modelling, modal split, mode choice modelling

Streszczenie

W artykule przedstawiono problematykę modelowania wyboru środka transportu w czterostopniowym procesie modelowania podróży. W artykule wskazano ograniczenia obecnie stosowanych uproszczonych metod modelowania wyboru środka transportu oraz przedstawiono możliwości zastosowania bardziej szczegółowego podejścia uwzględniającego dodatkowe, statystycznie istotne czynniki z wykorzystaniem zaawansowanych narzędzie matematycznych, w szczególności modeli wyboru dyskretnego. Wskazano również potrzebę uwzględnienia czynników jakościowych w prognozowaniu podziału zadań przewozowych i analizach scenariuszy.

Słowa kluczowe: modelowanie podróży, wybór środka transportu

1. Introduction

Travel modelling is a mathematical reflection of the behaviour and decisions of transport users and the condition of the transport network. In general, traffic modelling entails identifying and describing the relationship between the volume and structure of traffic, the spatial distribution of traffic, specific explanatory variables and mapping reality or its on the basis of the collected data in order to replace the analysed object in the planned research.

The results obtained from the conducted simulation analyses have a significant impact on decisions regarding transport policy in cities and allow the assessment of the efficiency of the transport system management, including the modal split, which may contribute to a reduction in the total transport costs of up to 30% [13].

The modal split model is one of the most important elements in the development of a transport system model. This kind of model provides a mathematical reflection of the decisions of the transport network users about which modes of transportation they will choose, accounting for the various factors affecting these decisions. The factors include distance, travel time, and also factors that are hard to measure, such as: safety, perceived reliability, punctuality and efficiency, comfort, aesthetics, or a sense of freedom during the journey. The values assigned to each of the factors depend not only on the actual statistics, but also on the mentality and individual attitude of users to modes of transportation, especially collective transport services.

The results of the research presented in this article constitute a synthesis of selected issues contained in the author's doctoral thesis on the issue of travel mode choice modelling in urban areas.

2. The present situation

The current approach to modal split modelling is, in the clear majority of cases, limited to considering the changes of behaviour in relation to the attractiveness of individual forms of transport (individual and collective) expressed by the ratio of the average travel time on said modes of transport. The share of a given mode is greater, when travel time compared to the alternative modes of transport is shorter. However, although previous research [6, 13] shows that time is an important factor influencing the choice of the particular travel mode, there are other factors that influence the decision [2, 5, 9, 12]. One such basic factor may be car ownership. The current general approach does not enable accurate mapping of the transport behaviour of residents, and does not factor in their mobility, preferences and other external factors.

The problem of an approach to mode choice modelling that is too general is particularly noticeable when conducting analyses on the development of the transport system for forecasting purposes when the journey time value for travellers and the level of propensity to choose a given mode of transport in relation to travel time are unknown.

When forecasting transport behaviour this way, the factors that change habits and mentality, as a result of, for example, education or changes in economic status are omitted. Because of such an approach, traffic forecasts are not sufficiently precise, and at the same time, there is a limited possibility to analyse scenarios that account for the impact of other factors on the share of individual modes of transport (e.g. transport policy).

Meanwhile, forecasting the travel mode choice is the basic stage required to conduct a cost-benefit analysis for planned investment projects in the transport sector in Poland for which beneficiaries apply for financial assistance from European Union funds. Therefore, it is particularly important that the traffic forecasts (including modal split) are as precise as possible, since their results, among other things, determine whether a given project would be considered sound for implementation.

In recent years, a lot of studies have been conducted on factors that influence the choice of travel mode, in particular, the tendency to change the mode, preferably to public transport or bicycle. These studies have shown that the important factors influencing these decisions have socio-demographic attributes [1, 8].

3. Methods of modal split modelling

In the process of modal split modelling, as is the case with travel modelling, it is necessary to adopt assumptions regarding the scope, scale and methods of testing the analysed phenomenon. In Poland, the most commonly used approach is the approach of the two-stage journey split. In the first stage, pedestrian trips are separated from all journeys, usually with a division into trip purposes. Then, in the second stage, these trips are defined as being either car trips or trips involving collective transport.

When approaching travel modelling, an assumption should be made regarding the range of transport options that can be selected. Due to the continuous increase in the share of bicycle trips, it is recommended to extend the calculations for this mode of transport. In the case of using a two-step approach, bicycle trips should be separated in the second stage of calculations, i.e. from the pool of non-pedestrian trips, because bicycle trips are significantly longer than trips taken on foot.' However, it is possible to use alternative methods through the use of various mathematical tools (non-linear regression, discrete choice models, neural networks and others). One of the alternative methods may be the use of a multimodal logit model with the structure as in Fig. 1.

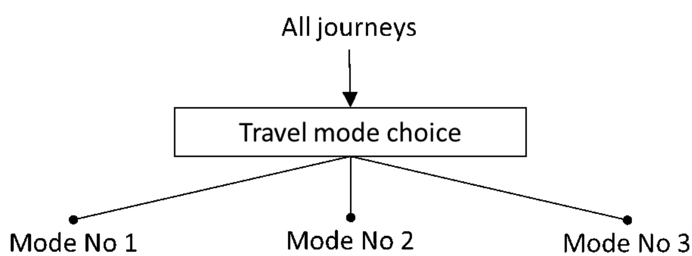

Fig. 1. Scheme of choice alternative in nested logit model approach (own study)

The disadvantage of this approach is the high sensitivity of such models to changes the attractiveness of alternatives to pedestrian modes of transport in terms of the probability of pedestrian trip choice In the case of a significant increase in the attractiveness of, for example, a car, the model would react with a significantly lower probability of choosing walking for short distance travel (up to 1 km) causing a significant deviation from values obtained by means of empirical research. Another method to limit this problem is the use of a nested logit model with the structure shown in Fig. 2. In addition to the discrete choice models, other tools can also be successfully applied, such as neural networks, which have also been analysed by the author.

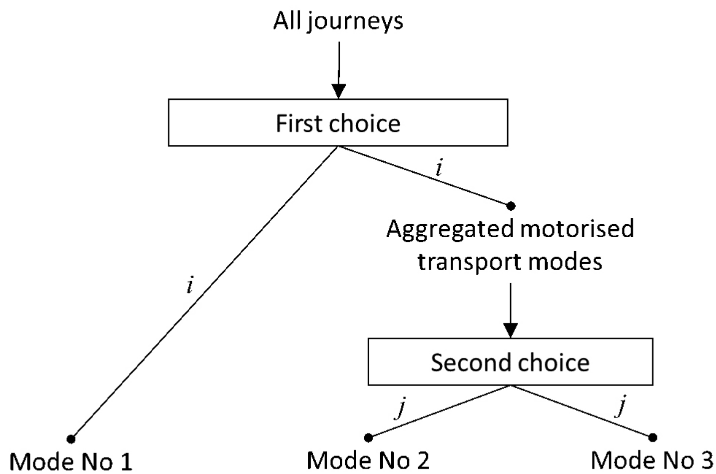

Fig. 2. Scheme of choice alternative using a nested logit model approach (own study)

4. Selection of variables

The selection of explanatory variables depends on their statistical significance and is limited by the availability of data. Factors affecting the mode choice can be divided into two basic groups [2, 4, 7]:

- easy-to-measure, which can also be quantified as they describe the elements of the analysis numerically (e.g. time, travel distance, number of vehicles in the household),
- difficult to measure, the quantification of which requires additional testing.

One of the basic factors that probably influences the travel mode choice is the income per household member. Unfortunately, this data is difficult to obtain; therefore, it is necessary to find alternative factors describing the status of the trip maker and the situation describing the conditions that affect the decision on choice of travel. When analysing comprehensive traffic research conducted in Polish cities, it is possible to include many factors characterising the user, the performed journey and the journey origin and destination points in the mode choice modelling. Such factors include:

- factors describing a user:
  - car availabilty,
  - mobility,
  - age,
  - education,
  - number of children,
- factors describing the jouney:
  - distance,
  - travel time by bicycle,
  - travel time by car,
  - perceived journey time by collective transport,
  - waiting time for public transport at the first stop of the journey,
  - number of transfers in public transport,
  - share of rail transport trips in total time of a single journey,
- factors describing journey origin or destination:
  - direct rail transport availability,
  - paid parking zones,
  - density of population.

5. Model examples

The research conducted by the author has shown that it is possible to include additional variables in mode choice modelling and most of the above-mentioned variables show statistical significance in selected trip purposes. The research was carried out using discrete choice models. These were nested logit models including four modes of transport: pedestrian, bicycle, individual transport, collective transport. The basis of the research were the latest comprehensive traffic researches for selected large cities: Gdansk, Cracow and Warsaw [10, 11, 14].

The example factors that may influence the mode choice which were presented in the previous section can be used to more accurately calculate the modal split in the four-stage travel modelling process. For this purpose, it is necessary to formulate multifactor models, in which for each of the analysed modes of transport *m* should be defined the utility function U_s^m, depending on the situation s, described by selected factors and accounting for the random variable ε_s^m which allows to include the individual user's preferences and subjective perception of utility in the model.

$$U_s^m = V_s^m + \varepsilon_s^m \tag{1}$$

where:
U_s^m – the general utility of the travel mode *m* in situation *s*,
V_s^m – the measurable utility of the travel mode *m* in situation *s*, factoring in the variables applied in the model, selected by an analyst,
ε_s^m – a random variable with a logistic distribution, mapping values not included in the utility and individual factors characterising a particular user.

A typical utility function (measurable) used in logit models takes a linear form (2); however, it is possible that some variables are functions of a non-linear form in cases when it is justified and significantly affects the result of the model.

$$V_s^m = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n \tag{2}$$

where:
β_n – function parameters,
x_n – function variables.

Based on the utility of each of the travel modes *m* thus determined, it is possible to calculate the probability of its selection for the journey in the situation *s*. The following equation is used for this purpose in standard bimodal and multimodal models:

$$P_s^m = \frac{e^{\mu U_s^m}}{\sum_m e^{\mu U_s^m}} \tag{3}$$

where:
P_s^m – the probability of choosing a travel mode *m* in situation *s,*
U_s^m – the utility of a mode *m* in situation *s,*
μ – the model scale parameter.

In the case of more complex models which include nested logit models, it is necessary to use the product of probabilities to calculate the probability of selecting one of the alternatives:

$$P_{ij} = P_i \times P_{j/i} \tag{4}$$

where:
P_{ij} – the probability of choosing a travel mode 'j' from the group of transport modes 'i',
P_i – the probability of choosing an alternative 'i',
$P_{j/i}$ – conditional probability of choosing an alternative 'j' from a branch 'i'.

The application of the above relationship in the analysed case requires defining the general utility of non-pedestrian travel modes , which depends on the particular utility of these non-pedestrian travel modes (bicycle, individual transport, collective transport):

$$U_{NP} = \frac{1}{\mu_j} \log\left(\sum_{i \in j} e^{\mu_j U_{ij}}\right) \tag{5}$$

Therefore, the above relationship defining the probability of the mode choice in the nested model takes the form:

$$P_{ij} = \frac{e^{\mu_j U_{ij}}}{\sum_{i\in j} e^{\mu_j U_{ij}}} \cdot \frac{e^{\mu_i\left[\frac{1}{\mu_j}\log\left(\sum_{i\in j} e^{\mu_j U_{ij}}\right)\right]}}{\sum_{j=1}^{m} e^{\mu_i\left[\frac{1}{\mu_j}\log\left(\sum_{i\in j} e^{\mu_j U_{ij}}\right)\right]}} \tag{6}$$

where:
U_{ij} – the utility of the mode 'j' from the group of transport modes 'i',
μ_i, μ_j – the model scale parameter.

One of the model examples accounting for additional factors is a model using variables: travel distance (DIS), travel time by bicycle (TT0r), travel time by individual transport (TTC), perceived journey time by collective transport (PJT), car availability (CAR), paid parking zones at the origin or destination (PARK) and direct availability of rail transport (RA). Based on statistical analyses, the following utility functions have been formulated for this model:

$$V_P = \beta_{10} + \beta_{11} \cdot DIS \tag{6}$$

$$V_R = \beta_{20} + \beta_{21} \cdot TT0r$$

$$V_{TI} = \beta_{30} + \beta_{31} \cdot \frac{TTC}{PJT} + \beta_{32} \cdot CAR + \beta_{33} \cdot PARK$$

$$V_{TZ} = \beta_{40} + \beta_{41} \cdot RA$$

The parameter values of the above functions were determined for each of the analysed cities for each of the seven basic trip purposes. Examples of parameter values for the 'from home to work' purpose are presented in Table 1.

Table 1. Parameters of the utility functions of the model example

Data from:	σ2	μ1	μ2	β_{10}	β_{11}	β_{20}	β_{21}	β_{30}	β_{31}	β_{32}	β_{33}	β_{40}	β_{41}
Gdansk	0.428	1.000	2.380	1.790	-0.920	0.218	-0.036	-0.402	-0.287	2.150	-0.241	0.000	0.196
Cracow	0.408	1.000	9.540	-0.270	-0.424	-0.202	-0.005	-0.133	-0.048	0.439	-0.036	0.000	0.029
Warsaw	0.436	1.000	1.710	0.418	-0.605	-0.943	-0.022	-1.590	-0.398	2.670	-0.315	0.000	0.319

Statistical analysis of the above model example, accounting for all trip purposes, indicates good and very good fit between the results and empirical values. The coefficient σ2, depending on the purpose of the trip, takes values in the range 0.32-0.48 for each of the analysed cities, which is a significant increase in the quality of the model in comparison to the model using only variables of distance and travel time, where σ2 is 0.22-0 35.

To the example presented above, similar studies have been conducted for various combinations of factors for each of the trip purposes using the results of comprehensive traffic studies from the above three cities. Based on the studies conducted in this manner, it has been found that the most important variables affecting the mode choice decision are the distance (particularly in the case of short journeys up to 1 km) and car availability. In the case of very short trips (up to 1 km), there is an increased probability of the choice of walking (Fig. 3). With the increase in travel distance, the probability of alternative mode choices (bicycle, car and public transport) increases. For long journeys (over 20 km), there is an increased probability of choosing a car.

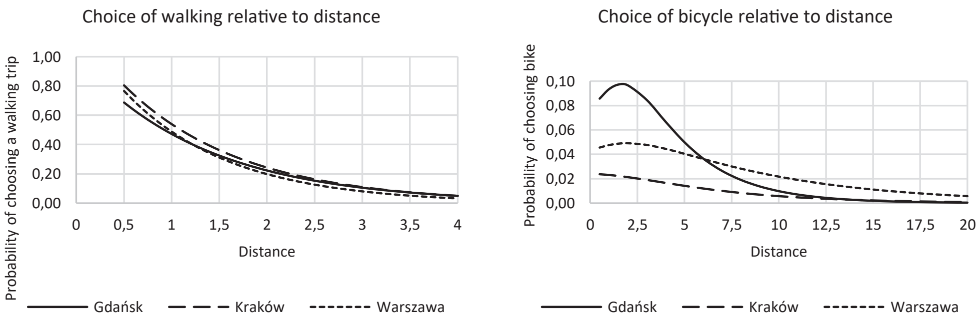

Fig. 3. Distribution of the probability of choosing walking and bicycle trips (own study)

With an increase in the availability of a car in a household, the probability of choosing this mode significantly increases. In addition, in regions with direct access to rail transport, there is an increased probability of choosing public transport (Fig. 4).

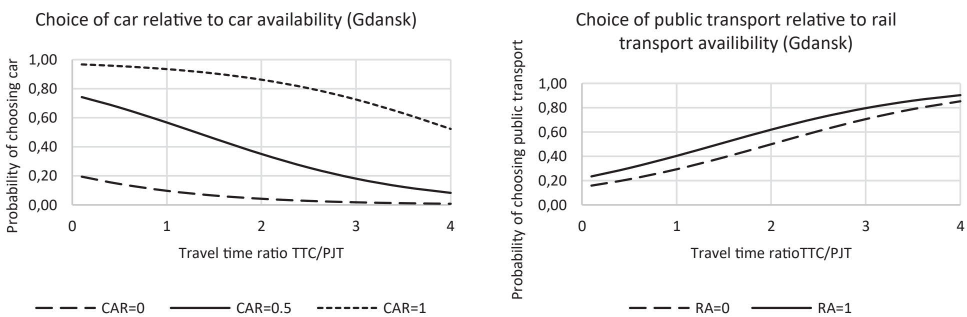

Fig. 4. Distribution of the probability of choosing a car and public transport (own study)

The other factors mentioned in the previous section also have a significant impact on the mode choice, but to a much lesser extent than the availability of a car. With the increase of mobility, age, and the number of children in the household, the probability of choosing a car trip increases. At the same time, with the increase in population density, as well as in the case of paid parking zones or the possibility of using rail transport, the probability of choosing collective transport increases.

6. Qualitative variables

In addition to the above-mentioned easy-to-measure factors, the travel mode choice is also influenced by difficult to measure factors related to the quality of travel and transport policy. The significance of the impact of factors related to the soft actions of transport policy on the mode choice has been emphasised in many foreign publications [4, 7]. Soft factors are factors that are related to the user's individual perception of travel and the standard of the transport system. It is believed that the importance of quality factors in the travel mode choice will grow over time due to changes in social standards and income [3]. In Poland, the importance of factors related to transport policy is also becoming more and more significant due to the introduction of ever-increasing restrictions on road transport by cities, while at the same time, striving to increase the attractiveness of the public transport offer.

Accounting for the qualitative factors in travel mode choice modelling is a complex issue. To investigate the potential impact of selected soft actions, the author conducted heuristic studies with the participation of national scientific experts specialising in travel modelling and transport policy. The results obtained showed that such activities as: a) an increase in comfort of public transport travel (new vehicles, more seats, etc.); b) tariff and ticketing integration; c) extended access to information on the functioning of public transport (travel planners, real dynamic timetable, etc.), d) educational campaigns promoting ecological modes of transport and active mobility; may reduce the probability of choosing a car trip by approximately 4% (in the scale of all four modes of transport).

The obtained results of the study can be used as a starting point for further research into the impact of qualitative factors on the travel mode choice. These factors can be used at the stage of travel forecasting to produce various development scenarios related to the transport policy of cities. Additional factors can be included in the mode choice model by extending the utility functions of selected modes by additional qualitative variables with the calibrated parameters of the model.

7. Summary

The modal split model is an important stage in travel modelling and knowledge in this field is important for examining the impact of various activities and investments on changes in traffic within the transport network of cities and for implementing an efficient transport policy in cities. The conducted research has shown that the most important factors influencing the mode choice are travel distance and car availability. However, other factors (listed on the fourth page of this article) also significantly influence the probability of choosing particular modes of transport.

The method of modal split modelling presented in this paper with factors showing a different degree of dependence on the probability of choosing a given mode of transport may be used in travel modelling. Taking into account these and the additional ones listed in chapter 2 and other factors may have a positive effect on the quality of the model. In addition, it allows to:

- the opportunity to develop and analyse scenarios for the development of the city and its transport system;
- improvement to the calibration process of the travel model due to a greater diversification of transport regions in terms of the modal split;
- conducting analyses and forecasts taking into account factors significantly affecting the mode choice;
- the taking into account changes in transport behavior of travelers, resulting from various external factors, including transport policy for forecasting states;
- the opportunity to develop scenarios in order to predict the effects of transport policy.

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