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SPATIAL MODELLING OF THE TRANSPORT MODE CHOICE: APPLICATION ON THE VIENNA TRANSPORT NETWORK

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Abstract. A new approach for spatial modelling of transport mode choice is presented in the paper. The approach tackles the problem by considering the trade-off between subjective and objective factors. To obtain mode Preference Rates (PRs) based on subjective factors, the Analytic Hierarchy Process (AHP) method is applied. The objective factors are expressed with the journey time from any point in the map to destination according to the available transport mode choice on the specific connection. The results are presented as PRs of individual transport modes. The model is validated on the conducted the survey, with students of Vienna University of Economics and Business (WU) as a target audience. Members of different target groups (age, national, employment) decide differently regarding the transport choice, so it is better to analyse them separately. The presented model can be used for the city transport planning in any urban area. It can help promote the sustainable modes of transport in the areas that are less adjusted in sustainable manner.

Keywords: AHP, decision-making policy, GIS, students, mode choice, objective and subjective factors, transport management.

Notations

AHP – analytic hierarchy process;
CI – consistency index;
CR – consistency ratio;
GEO – geographic;
GIS – geographic information systems;
GIS-T – GIS for transportation;
OD – origin–destination;
PR – preference rate;
WU – Vienna University of Economics and Business (in German: *Wirtschaftsuniversität Wien*).

Introduction

30% of the world's population lived in the cities back in 1950's, but it is expected to grow up to 66% until 2050. Because of this fact, the United Nations have started the *United Smart Cities* – a program to develop and improve urban facilities and infrastructure to not only welcome all existing and potential residents, but also to give them a good quality of life (KPIT Technologies Inc. 2018). Recent researches show that smart transportation within the cities is a crucial element for realizing the vision of turning cities smart. In order to address this topic, many studies of human travel behaviour within the cities have been conducted in the last decades. Many of them curb the expectations of policy makers for quick and lasting changes when choosing a particular mode. Implementing policies that reduce population density and promote access to public transport may initially have a more limited impact on reducing the share of car travel (Buehler 2011; Bissell 2014). Policies that make transport alternatives more attractive turned out to work only when they are supported by measures that make cars seem less attractive. Since commuting is one of the most significant mobility practices that takes place in every city, it has arguably been given most attention in the academic world (Bissell 2014). The shift from private car travel, to public transport is the first from the list of changes that are in play when talking about promoting sustainable mobility. The shift encompasses many different measures, such as car sharing and car pooling, cycling, walking and many more (Conley, McLaren 2009; Kent, Dowling 2013).

The authors in (KPIT Technologies Inc. 2018) argue that it necessary to look beyond conventional expansion

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approaches, such as interlinking roads, upgrading constructions or introducing high-speed vehicles to make our cities more liveable. There is no shortening of the path with only investment in transportation infrastructure to address those challenges (KPIT Technologies Inc. 2018). Even more, for the effective development of public policy strategies for achieving a commuting-mode shift from cars to public transport is necessary to understand the whole range of psychological and situational factors that influence the commuter-transport choice behaviour (Collins, Chambers 2005).

The main goal of this paper is to present a new method in the field of mode choice, based on objective and subjective factors. So far, many researchers have studied the field of mode choice resulting in decision models. Studies have been done by the researches from various professions (Klöckner, Friedrichsmeier 2011), which mostly cover the issue only from particular perspectives. The studies from transportation field tend to ignore health and motivation, and the studies from health field ignore the role of competing modes of transport (Götschi *et al.* 2017).

The objective of our work is to construct a model for transport choice on the subjective PR, combined with the objective factors such as time, cost, distance, etc. Students from WU were selected for the target group due to the advantage of the students travel behaviour analysis. Whalen *et al.* (2013) claim that the mode choice of university students provides a better understanding of the populations that has a larger proportion of active commuters at a major trip-generating location. Moreover, the analysis of university students can provide a better understanding of active travel factors of the mode choice. The advantage of the proposed model is that it can be used for future transport management, since it considers the stated instead of the revealed preference, and does not require the collection of historical data. Stated preference of the people's transport mode choice is estimate from the survey where, people are asked, on how much they value different transport mode in the perspective to their habits and everyday routines. The answer is based on many different things, and it may be very different from revealed preference and their actual behaviour. In the opposite, the revealed preference method cannot be used in direct way to evaluate demand under conditions, which do not yet exist. Revealed preference method require explanatory objective or sc. engineering variables (time or cost) and cannot be used to analyse more soft or more subjective variables such a comfort, safety, convenience, etc. (Kroes, Sheldon 1988).

The proposed method was partially already implemented for choosing appropriate ports for goods carrier (Kramberger *et al.* 2015, 2018) and for choosing appropriate airports for leisure or business transport (Button *et al.* 2018). As it can be seen in the following literature review, it seems that the proposed method presented in this paper fills the gap from existing research as it takes into the account the subjectively measured factors and objectively measured factors. In none of the research, the authors use a graphical representation of the mode choice results. The model presented in this paper has an advantage to present a sophisticated map of transport choice in the selected area. The model is demonstrated based on the Vienna City transport network.

The rest of the paper is organized as follows. First is the brief literature review, tackling three main topic. The second part contain the description of methodology used and the third is the presentation of data and results, of which the most important is the final map of Vienna transport mode choice and fourth part is the conclusion of our research.

1. State of the art

Since most of the previous research in the field of transport mode choice is based on different influence factors, it is important to know which these factors are. Rodríguez and Joo (2004) separate decision factors on mode-specific factors, individual factors and environmental factors. In mode-specific factors authors have considered the cost of the specific mode, travel time and waiting time. Characteristics of participants are included in the group of individual factors, while population density, land-use, marked street crossing and street connectivity belong to the group of environmental factors. Unlike Rodríguez and Joo (2004), Zhou (2012) identifies 6 classes of factors to use in the study of mode choice:

- »» individual or specific factors (included socio-economic and demographic);
- »» psychological factors (like attitudes of each participants);
- »» mode-specific factors (comfort of individual mode);
- »» trip characteristics (specific to the each mode);
- »» built environment and urban form factors (density and intersections);
- »» presence of travel demand management measures (parking cost).

From the literature review we can conclude that most frequently used factors are travel time and travel distance (Ewing *et al.* 2004; Mitra *et al.* 2010). On the other hand, Danaf *et al.* (2014) found out that student would choose public transport instead of car in the case of parking cost increase, transit travel time decrease and cost decrease.

One of the more recent research of the students' mode choice made by Mehdizadeh *et al.* (2019) shows that among others factors, seasonal variation also has an impact.

The gap in the reviewed research is in compliance with mostly one type of factors: only subjective or only objective. The first research that combined both groups is done by Wang and Liu (2015). The subjectively and objectively measured factors are integrated into the same regression model to compare their importance as predictors for mode choice.

There is a wide range of literature, which deals with the mode choice and many different methods used. Table 1 presents a review of the methods used in the transport mode choice literature.

We can see from the Table 1 that some authors use basic statistical methods like descriptive statistic to capture travel patterns of students. Among the more sophisticated methods, the most commonly used method is multinomial logit model or its modification.

In the field of transport research appeared GISs relatively late, only in the late 1980s (Thill 2000). Namely, the transport sector has become very multidisciplinary that time and GISs have positioned themselves as an ultimate technology for the integration of information (Thill 2000). The contribution of GIS to transport research subsequently grew during the 1990s (Loidl *et al.* 2016). Since the beginning of the 21st century, innovation paths influenced GIS in transportation research: the situation has flipped from data scarcity to a deluge of sensors and data streams, policy is forced to move to smarter traffic management, and a paradigmatic shift to activity-based and micro-scale transport models (Loidl *et al.* 2016). In our research, network model of GIS is relevant to represent topologically connected linear entities, i.e. roads, public transport routes, bike lanes and footpaths, which influence the mode choice. In view of this, we speak about GIS-T, which represent one of the most important applications of GIS (Miller, Shaw 2001, 2015).

Table 1. Review of methods used in the literature in the field of transport mode choice

Used methodology	Reference
Descriptive statistics	Boyd *et al.* (2003); Delmelle, E. M., Delmelle, E. C. (2012); Shannon *et al.* (2006); Uttley, Lovelace (2016)
Chi-square	Wilson *et al.* (2018)
Logistic regression	Collins, Chambers (2005); Wilson *et al.* (2018)
Multilevel logistics regression	Ko *et al.* (2019)
Multinomial logit model	McKelvey, Zavoina (1975); Müller *et al.* (2008); Eluru *et al.* (2012); Ding, Zhang (2016); Ermagun, Samimi (2018); Nasrin (2020); Obaid, Hamad (2020)
Mixed multinomial logit model	Eluru *et al.* (2012)
Multinomial conditional logit model	Rodríguez, Joo (2004); Nguyen-Phuoc *et al.* (2018)
Finite mixture multinomial logit model	Xiong *et al.* (2019)
Cross-nested logit model	Rodríguez, Joo (2004)
Bayesian binomial multi-level regression model	Fitch *et al.* (2016)
Hierarchical tree-based regression model	Zhan *et al.* 2016

2. Methodology

In order to efficiently model the spatial distribution of transport mode choice in the large city, we introduce the methodology based on the trade-off between measurable costs and subjective decision-making factors (Figure 1). The methodology relies on the assumption that people do not only decide based on objectively measurable factors, but also take into account subjective, personal factors, when deciding. The methodology takes into account the idea that a particular group of people, for example, students of some university or visitors to opera etc., have similar attitude or similar habits and everyday routines. So the transport mode choice may be very different, depending on whether the subjects go to the opera or to listen a lecture at the university, i.e. because of that, we propose that the transport mode choice modelling is more efficient when it targeted at a certain group of people, with the similar attitudes and the common goal of their travel.

Let us assume that a travelling individual, starts his journey at start point S_i with the destination at point D. That individual can chose between four different modes of transport or combinations of them, according to his personal preferences. The modalities considered in our survey are walking, biking, car transport and public transport. The decision made is usually a trade-off between measurable costs and subjective decision-making factors. The proposed method use the time C_t or cost C_{EUR} as a measurable costs and stated preference about transport mode choice expressed with PR. The preferences about the transport mode are estimated using the AHP method (Saaty 1980). The AHP method based on a subjective assessment of multiple alternatives compared to multiple criteria. The criteria are organized into a hierarchical structure. Subjective assessment is made for each level of criteria and alternatives by one or more decision-makers (Popović *et al.* 2018).

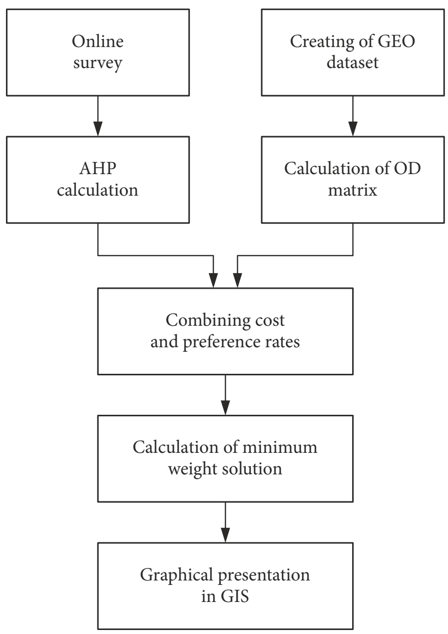

Figure 1. The steps of methodology

2.1. Survey and AHP calculation

The method takes into consideration several things like: perception, intuition, rational and irrational, etc. The main task of the methodology is a comparison of pairs of alternative solutions during which all alternatives are compared to each other and a decision-maker. It expresses the level of preference towards one alternative in relation to another according to the criteria the decision-maker finds important (Saaty, Vargas 2012).

In our case, the results the AHP method are so called PRs of certain transport modes, which represent the stated preference about transport mode choice. On the following figure, the set of alternatives and set of criteria considered in our research are shown (Figure 2).

The goal was to rate the existing alternatives of students' transportation to the university according the most important factors of influence. First, three factors of influence were identified:

- convenience covers changing weather conditions, autonomy of the chosen alternative of transport, time to relaxation on chosen mode or doing something else on the trip;
- the ecological aspect covers the emissions caused by transport mode and self-awareness of environmental issues of the participants;
- accessibility and interchanges covers access time, frequency of particular services, waiting time for transport, number of interchanges between the journey and flexibility of transport mode.

In the next step, the four alternatives of transportation mode were introduced. Students can commute by car (alone or in a group), by bicycle, they can walk, or use public transport (bus, u-bahn, s-bahn). In the final analysis, we have split the public transport usage into two groups. Each of them was combined with other transportation modes depending on the mode selected to arrive at the station.

In order to get the data to perform AHP calculation we have set up a web-based survey to collect the information on the traveller's preferences about given alternatives and socio-demographic information (gender, age, and distance from home to the faculty). To enhance the survey we have performed live interviews at the WU nearby public transport station. The survey was conducted among the students of WU during January 2020.

The respondents were asked to evaluate importance of the previously defined decision factors. According the AHP methodology, we use pairwise comparison questions. The survey consisted of one question, which compares the stated factors, and three questions in which comparison of alternatives have been made. For example: Please, think about the decision factor CONVENIENCE. For which mode transport is more important for you when compare the following pairs? (Table 2) (1 – both factors are equally important, 3 – one is moderately more important, 5 – one is strongly more important, 7 – very strongly more important).

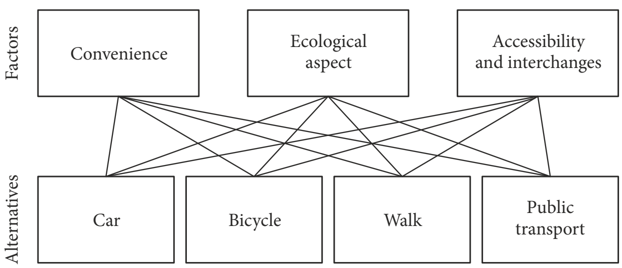

Figure 2. The set of criteria and the set of alternatives

The students were asked to evaluate decision factors with the comparison of all possible pairs from three chosen factors. Each of respondent was evaluating the 6 pairs of factors on 7 grades Likert-scale proposed by Saaty (1980).

From each individual response, related to the focus of the topic, we constructed a judgement matrix of pairwise comparisons. The pairwise comparison was done to determine the relative importance of the factors. Afterwards the geometric mean of all constructed matrices was calculated for each question in order to get the combined judgement matrix. Saaty (1980) claims that the geometric mean is the most appropriate method, because of its ability to provide the homogeneity, unanimity and reciprocal properties. The formula used for calculate geometric mean is:

$$\left(\prod_{i=1}^{n} x_i\right)^{\frac{1}{n}}, \quad (1)$$

where: n – represents the number of independent answers for one judgements; x_i – represents the value of independent judgement.

We get the united judgement matrixes for all three factors and alternatives in the form (Saaty 1980):

$$S = \begin{bmatrix} 1 & s_{12} & \dots & s_{1n} \\ \frac{1}{s_{12}} & 1 & \dots & s_{2n} \\ \dots & \dots & \dots & \dots \\ \frac{1}{s_{1n}} & \frac{1}{s_{2n}} & \dots & 1 \end{bmatrix},$$

where: S – united judgement matrix; S_{in} – independent answer for one pairwise comparison (on the interval 1…7).

From united judgement matrixes, the normalized matrixes were calculated.

For all normalized matrixes, the CRs were calculated with the help of (Saaty 1980):

$$\lambda_{\max} = \sum_{j=1}^{m} \frac{(S \cdot v)_j}{m \cdot v_j}; \quad (2)$$

$$CI = \frac{\lambda_{\max} - m}{m-1}; \quad (3)$$

$$CR = \frac{CI}{RI}, \quad (4)$$

where: $\lambda_{\max}$ – normalized matrix; m – represents the number of independent rows in the matrix; v_j – an eigenvector.

Since every CR, were <0.1, it implies that the respondents' evaluation about mode choice factors preference is consistent.

The final PR were calculated from the arithmetic mean of the individual rows in normalized matrixes:

$$\overline{F} \cdot \overline{A}_i, \tag{5}$$

where: $\overline{F}$ represents the vector of arithmetic mean of the individual factors; $\overline{A}_i$ represents the vectors of alternatives (i = walk, bike, car, bus).

2.2. Creating of GEO dataset and OD cost matrix calculation

ArcGIS for Desktop 10.6.1 software with *ArcGIS Network Analyst Extension* was used to perform the transportation network analysis (ESRI 2021). This allows us to solve the shortest path problem for finding the best route from the starting points to the destination. Our georeferenced transportation database was created using the *Intermodal Transport Reference System of Austria* (ODÖ 2021), containing all the traffic routes entered by the GIS partners. A mesh of 250×250 m cell size was created over the Vienna area. Each cell was assigned a center point representing a student's commute origin point (Figure 3), resulting in 6648 origin points. The OD cost matrix was computed using Dijkstra's algorithm (Dijkstra 1959), with the destination point being represented by the target university.

The OD matrix presents the times needed for travel from start locations S_i to the faculty U for each of the alternatives for transport:

$$OD = \begin{bmatrix} C_t\left(S_1, U\right)_{walk} & C_t\left(S_2, U\right)_{walk} & \ldots & C_t\left(S_n, U\right)_{walk} \\ C_t\left(S_1, U\right)_{bicycle} & C_t\left(S_2, U\right)_{bicycle} & \ldots & C_t\left(S_n, U\right)_{bicycle} \\ C_t\left(S_1, U\right)_{car} & C_t\left(S_2, U\right)_{car} & \ldots & C_t\left(S_n, U\right)_{car} \\ C_t\left(S_1, U\right)_{public} & C_t\left(S_1, U\right)_{public} & \ldots & C_t\left(S_n, U\right)_{public} \end{bmatrix},$$

where: n = 6648; C_t represents the time value [min].

2.3. Calculation of the trade-off

In this stage, the values of subjective factors gained from AHP and measured cost (times/distances) are combined and the final solution is calculated as follows.

Combining cost and PRs

Combining cost (C_i – final cost for specific mode i (i = walk, bike, car, bus)) and PRs (PR_i – preference rate of individual alternatives i (i = walk, bike, car, bus)) give us the trade-off between measurable costs and subjective

Table 2. The example of survey question

First alternative	7	6	5	4	3	2	1	2	3	4	5	6	7	Second alternative
Walk														Bicycle
Walk														Car
Walk														Public transport
Bicycle														Car
Bicycle														Public transport
Car														Public transport

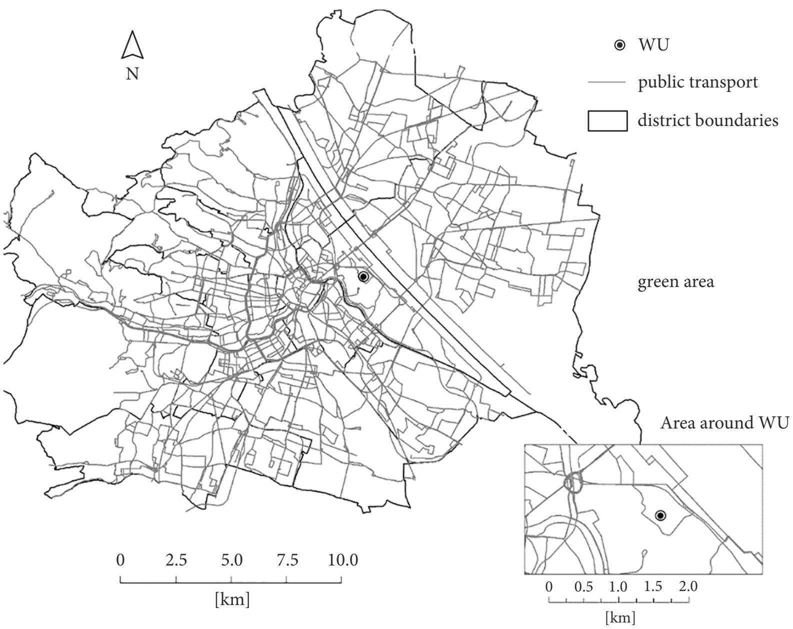

Figure 3. The map of Vienna

decision-making factors. The trade-off is expressed by the equation:

$$C_{walk} = \frac{1}{PR_{walk}} \cdot C_{t\_walk} \tag{6}$$

and the same way for other modalities $\left(C_{bike}, C_{car}, C_{bus}, C_{public}\right)$ as well, where: C_{t_walk} – time spent walking on specific route.

Calculation of minimum weight solution

The purpose of the next step is to find the

$$\min\left(C_{bike}, C_{car}, C_{bus}, C_{public}\right). \tag{7}$$

Among the previously calculated values for the individual journey from each possible point S_i within the selected geographical area to the destination.

Graphical presentation of the results

The winning modality for each point S_i assigned it to the spatial area of the same transport mode. A regular grid is used to present results of mode choice with every cells sized 250×250 m. Every cell has its own mode choice number and the cells with the same number were joined into a polygon of the same colour. The final solution of transport choice is seen on the map (Figure 4).

3. The data and calculation

3.1. Demographic data

WU Vienna is an international university established in 1898 in Vienna, the Capital City of Austria. Around 22 thousand students studying there and 27% of total student population (more than 1000 students every year) are international students, coming from 110 countries around the world (WU 2021). Most of the participants in our survey are male (54%), aged between 22 and 25 years.

3.2. Weights calculation

The calculated priority weight for each factor is presented in Table 3. A detailed explanation of methodology, which gave us the results is given in Section 2.

It can be seen that the most important factor for the students is convenience, which has the highest priority weight. The second most important is the ecological aspect and third accessibility and interchanges when deciding for transport mode for commuting to the university. After performing of pairwise comparison for all alternatives from the perspective of individual decision factors the local weights were calculated $\left(\overline{F}\right)$ (Table 3).

If the participants would decide about transport mode choice only based on individual alternatives, walking would most likely to be chosen. The arrangements of the alternatives arithmetic means are the same for all three factors. It appears that participants in our survey prefers active transport mode.

The global weights for individual mode alternatives were calculated from local weights of alternatives matrix (Table 4) multiplied by factor weights and ranking matrix (Table 3). The matrix is presented in Table 5.

Because of the similar factor weights' values, the arrangements in Table 5 remains the same comparing the arrangement in Table 4. Consequently, so is the arrangement of the final PR, calculated by Equation (5), presented in Table 6.

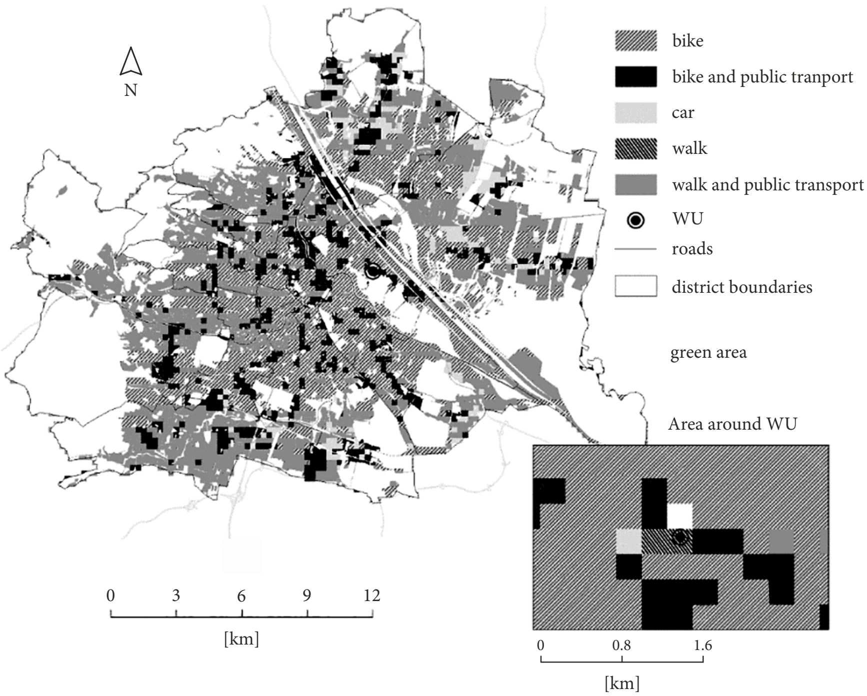

Figure 4. Mode choice in the Vienna

Table 3. Factor weights and ranking matrix $\left(\bar{F}\right)$

Factor	Priority weight	Rank
Convenience	0.3626	1
Ecological aspect	0.3398	2
Accessibility and interchanges	0.2976	3

Table 4. Arithmetic means of alternatives' matrix $\left(\bar{A}_i\right)$

Criteria	Walking	Bicycle	Car	Public transport
Convenience	0.3516	0.2793	0.1846	0.1845
Ecological aspect	0.4443	0.3043	0.1350	0.1163
Accessibility and interchanges	0.3334	0.2707	0.2026	0.1932

Table 5. Global weights of alternatives' matrix

Criteria	Walking	Bicycle	Car	Public transport
Convenience	0.1275	0.1013	0.0669	0.0669
Ecological aspect	0.1510	0.1034	0.0459	0.0395
Accessibility and interchanges	0.0992	0.0806	0.0603	0.0575

Table 6. PR for selected alternatives

Alternative	PR	Rank
Walking	0.3777	1
Bicycle	0.2853	2
Car	0.1731	3
Public transport	0.1639	4
Joint modes		
Bike and public transport	0.2246	
Walking and public transport	0.2708	

The most popular mode of transport among the participants is walking. The second is the bicycle and the third one is the car. The least popular is public transport. PRs were used in the calculation to get the winning modality – Equations (6) and (7). After calculation of joint transport (calculated with the average of public transport and previously used alternative) the public transport became more popular than car, but still less popular than walking and bicycle.

3.3. Mode choice map

The about winning modality data was combined on the final map of Vienna presented on the Figure 4.

Figure 4 presents the areas with the specific modes choice in Vienna. The areas coloured white represent the actual areas of the city where population density is too low to have a significant influence on the transport situation in Vienna. Still, most of that area falls to public transport with walking. It is apparent that the mode choice areas are very fragmented. Walking area occupies the smallest area of the Vienna (0.03% of its entire surface).Very few and small areas primarily choose car as their mode of transport to the university (3.34% of Vienna surface). As is seen, the car is the primary mode choice in the areas, where connections to the public transport is not common. The second biggest area (the size of 32.99% of Vienna) is the cycling area. In addition, the biggest is public transportation area (regardless of mode transport to the public transport station) – 83.71% of Vienna surface.

Public transportation occupies the biggest area despite its unpopularity as found in the subjective part of research. The reason could be in the Vienna's public transport network, which is quite extensive and offers frequent and reliable transportation. Because of the good connections, the time, used with the public transport was the lowest and the fact that the final PR for separated modes is calculated based on the high rates of walking and cycling.

Perhaps unexpected, the results of AHP analysis shows that walking is the most popular transport mode, but it covers the smallest part of the city area. On the other hand, the least popular transport mode according the AHP analysis is public transport, despite the fact that it covers the biggest area of the Vienna City. It should be mentioned, that the final decision depends not only on the AHP results, but on the time needed from S_i to the faculty as well. The times needed for walking are definitely longer than times needed with other transport modes, so other modes are preferable in final minimum weight – defined by Equation (7). According to the OD cost matrix, public transportation turned out to be the fastest way to travel in most areas of Vienna, so a large area coverage with that mode of transport is expected.

Conclusions

This paper presents a new approach to understand the travel mode choice decision and can be very helpful in the process of urban transport regulation in cities around the world. Based on the comprehension of the mode choice on individual areas of the city it is possible to organize and improve the transportation and all of belonging infrastructure in an adjustable way to the city residents. The method includes two types of data: (1) the subjective, which give the insight into peoples' view on transport modes, and (2) the objective, which include the data about measurable components of the travels and the existing infrastructure. The subjective data are analysed based on group AHP method, which means that all of the participants make their own decisions, that there are no consultation among them and that the individual results are consolidated later (Jankovič, Popović 2019). The proposed model can be used for future transport management, since it considers the stated instead of the revealed preference, and does not require the collection of historical data. It is enough that the subjective stated preferences of the peoples transport mode choice are gained from surveys and objective measurable components are estimated depending on experience or using GIS tools as journey times/cost cannot be calculated in the areas where the transport network does not yet exist.

The method is tested in the Vienna's geographic, demographic and transportation data, where the students of the University were chosen for the test group. The method can be tested in any city and any group of people who are involved in similar activities. The first results of the method are PRs for the specific transport mode, which could be used for other analyses and traffic management decisions in the city. The results reveal that the most popular way for travelling to the university is by walking, the second one is by cycling, the third one in by car and the last one is public transport. This classification could be the result of the distance distribution of the participated students. Most of the participants live in the surrounding area of the college and can easily walk or cycle to the classes.

The final map reveals that students choose the more sustainable transport mode. The results are similar to the survey in which Haslauer *et al.* (2015) note that despite the fact that the 75% of people in Vienna own the personal car, 75% of them use public transportation.

Inner areas of Vienna primarily use the bicycle for transport mode. Such a big share in our results is expected, due to the fact that Vienna has 1400 km of bicycle paths along with 121 bicycle rental stations (Wien Info 2021).

In the future, we will analyse the revealed preference as well and compare the results from this paper to the revealed preference in order to see the gap between a real scenario in Vienna and the scenario as is shown in our analysis. On this basis, comparison improvements of the traffic infrastructure can be done. With the help of our results the city government can adopt measures to completely adjust the traffic to the Vienna inhabitants. Further, a detailed study on the impact of the stated preferences and means to increase their impact on the final decision will be done.

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