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Determining the Relative Importance of Indicators of Suburban Public Transport Comfort by the Method of Geometric Mean Fuzzy-AHP

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***Abstract*—Nowadays to commute by train and bus in a number of countries is preferred by population for certain distances such as suburban trips. The comfort level of passengers while travelling by public suburban transport is a combination of physical and psychological factors. In order to analyze how comfort affects the choice of transport on a global scale, a number of studies have been carried out. The indicators affecting passenger comfort include the personal space, vehicle environment, level of service, etc. Commuters with different professions and travelling purposes have different notions of comfort. Comfort influences on the choice of transport mode and because of that the main objective is to determine the criteria, which passengers apply to evaluate its level. Multi-criteria decision making is the field that deals with evaluation of indicators or situations according to multiple conflicting criteria. The methods taking into account the presence of subjective elements in passengers' preferences for decision-making have been analyzed considering Analytical Hierarchy Process (AHP) and fuzzy-AHP, which is a structured technique for organizing and analyzing complex solutions based on mathematics and psychology. Using the chosen method, multi-criteria decision has been made to determine the relative importance of indicators by geometric mean fuzzy-AHP. The opinions of practitioners, researchers, managers are considered analogously to the relative importance of indicators. A survey has been developed and conducted with commuters to find out the indicators affecting assessment of comfort and quality of public transport. The study made by a group of experts to evaluate the indicators of comfort has applied the derived geometric mean fuzzy-AHP to determine the relative importance of measurement criteria. The results of study would help to increase the comfort offered and attract more passengers to railway suburban transport taking into account the level of indicators and possibilities of their improvement.**

Keywords — geometric mean fuzzy-AHP, comfort, passenger public transport

I. INTRODUCTION

The modernization of the railway network nowadays is a result of technological development and introduction of modern rail traffic management systems such as the ERTMS (European Rail Traffic Management System). At the same time it is necessary to meet the increasing demands of passengers for comfort when traveling by rail. Passenger comfort is determined by a combination of physical and psychological factors. A comfortable environment in railway carriages would lead to higher consumption of offered service. That means that the provision of comfort is one of the necessary measures to attract more passengers. In cases where the problem of attracting passengers to a given transport mode is considered, a Logit model is applied [1][2]. It uses the specific cost of transport including the cost of trip, its change, regularity and comfort available. While the first three indicator can be easily determined, to define the offered comfort is a complex issue and depends on the conditions provided to passengers and their personal understandings of what comfort is.

In modern society comfort is a term that refers not only to living conditions, but also to learning, working, traveling, and utilization of all public goods. Moving by train as one of the oldest forms of transport is experiencing a renaissance. In a number of countries rail transport has become increasingly preferred especially at certain distances. If a year ago the accent was put on freight rail transport, nowadays the attention is focused on passengers, speed and comfort.

In the 1970s some studies established an index system affecting passenger comfort and tried to obtain the results

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of assessment by surveys or other methods. A number of factors were introduced to characterize passenger comfort including temperature, ventilation, lighting, photostimulation, length of trip, etc. Comfort is evaluated also by personal space, travel time, vehicle environment and level of service [3]. One should take into account that passengers with different professions and purposes to travel have different notions of comfort. So, the comfort rating model can be created only by dividing the entire rating coefficient into two parts: objective and subjective factors.

Multi-criteria decision making is the field that deals with evaluation of indicators or situations according to multiple conflicting criteria [4]. The authors of [5] have studied six groups of indicators such as cost, travel time, transport quality, transport means, transport services and social benefits for selection and evaluation of different routes using the fuzzy analytic hierarchy process (FAHP) and the theory of artificial neural network (ANN).

To define the optimal multimodal transport route [6][7][8] by examining criteria such as travel cost, transportation time and transport risk factors, Analytical Hierarchy Process (AHP) and Zero-One Goal Programming (ZOGP) are used. Due to analyzing the passenger preferences and decision-making for choosing a transport mode, the examined indicators determining the comfort offered by public transport have a subjective element. In this case the publications present how analytical hierarchy process (AHP) and the fuzzy logic analytical hierarchy process (FAHP) [9][10] are applied as structured techniques for organizing and analyzing complex decisions based on mathematics and psychology. That is why FAHP will be used to find out the weight of indicators determining comfort when choosing a mode of transport.

II. MATERIALS AND METHODS

In decision making theory, the analytic hierarchy process (AHP) is a mathematically based technique for organizing and analyzing complex decisions developed by Saaty [10][11][12][13]. This method is used to calculate qualified priorities of a given set of alternatives by a scale based on decision maker's judgement. It emphasizes on the importance of decision maker's intuitive judgments and consistency in comparing alternatives in decision-making process. The strength of this approach is that it organizes tangible and intangible factors in a systematic way and offers simple structuring of problems and a possibility of decision making. The relevance of using AHP is based on the fact that this technique allows involvement of individuals in decision making based on evaluating not only numerical, but also intangible factors [14] [15] [16].

When using FAHP, the problem is presented in a hierarchical structure through conditional elements (experts, criteria, subcriteria and alternatives). The specific goal is to be able to assess the weights of examined indicators using the opinion of a group of experts. The experts are selected by specialists as their number should be between 5 and 10. Each expert has to rate the competence of other participating experts and the examined criteria (according to a selected scale) using triangular fuzzy numbers [17]. The solution for determining the weight of indicators is derived using the geometric mean FAHP. The geometric mean is considered an appropriate rule for aggregating individual judgments. The main reason is that the geometric mean method can preserve the reciprocal property in a combined pairwise comparison matrix. The main steps in FAHP are as follows:

- Assessment of the importance of alternatives made consistently (for each level of the hierarchy) using pairwise comparison;

Experts make their selection in the form of assessment for each alternative under examination. The importance of indicators is individually measured by each expert. Pairwise comparison matrices with triangular fuzzy elements are used to derive the weights from a matrix and calculate the sequence of information about the preferences of decision makers.

It is why these pairwise comparison matrices should be created for each expert separately. They are the expert's assessment of the selected indicators relative to each other. To construct such matrices, it is necessary to compare the assessments of different indicators and determine the values according to triangular fuzzy numbers. The matrix should be structured in the following way [18]:

$$X = \{x_{ij}\} = \begin{bmatrix} 1,1,1 & (l_{12}, m_{12}, u_{12}) & \dots & (l_{1n}, m_{1n}, u_{1n}) \\ (u_{12}^{-1}, m_{12}^{-1}, l_{12}^{-1}) & 1,1,1 & \dots & (l_{2n}, m_{2n}, u_{2n}) \\ \dots & \dots & \dots & \dots \\ (u_{1n}^{-1}, m_{1n}^{-1}, l_{1n}^{-1}) & (u_{2n}^{-1}, m_{2n}^{-1}, l_{2n}^{-1}) & \dots & 1,1,1 \end{bmatrix} \quad (1)$$

To find the priority features of main indicators, the fuzzy values for each indicator are determined using the following formulas derived from formula 1:

$$\begin{bmatrix} \left(\sqrt[k]{(\prod_{j=1}^{k} l_{1j})}, \sqrt[k]{(\prod_{j=1}^{k} m_{1j})}, \sqrt[k]{(\prod_{j=1}^{k} u_{1j})} \right) \\ \left(\sqrt[k]{(\prod_{j=1}^{k} l_{2j})}, \sqrt[k]{(\prod_{j=1}^{k} m_{2j})}, \sqrt[k]{(\prod_{j=1}^{k} u_{2j})} \right) \\ \dots \\ \left(\sqrt[k]{(\prod_{j=1}^{k} l_{nj})}, \sqrt[k]{(\prod_{j=1}^{k} m_{nj})}, \sqrt[k]{(\prod_{j=1}^{k} u_{nj})} \right) \\ \sum_{i=1}^{n} \sqrt[k]{(\prod_{j=1}^{k} l_{ij})}, \sum_{i=1}^{n} \sqrt[k]{(\prod_{j=1}^{k} m_{ij})}, \sum_{i=1}^{n} \sqrt[k]{(\prod_{j=1}^{k} u_{ij})} \end{bmatrix}$$

$$= \begin{bmatrix} \text{Average}\,(\tilde{l_1}, \tilde{m_1}, \tilde{u_1}) \\ \text{Average}\,(\tilde{l_2}, \tilde{m_2}, \tilde{u_2}) \\ \dots \\ \text{Average}(\tilde{l_n}, \tilde{m_n}, \tilde{u_n}) \end{bmatrix} = \begin{bmatrix} M_1 \\ M_2 \\ \dots \\ M_n \end{bmatrix} =$$

$$= \begin{bmatrix} \frac{M_1}{\sum_{i=1}^{n} M_i} \\ \frac{M_2}{\sum_{i=1}^{n} M} \\ \dots \\ \frac{M_n}{\sum_{i=1}^{n} M} \end{bmatrix} = \begin{bmatrix} W_1 \\ W_2 \\ \dots \\ W_n \end{bmatrix} \quad (2)$$

Thus weight vectors Wi for different factors and subfactors have been obtained. Then it is necessary to determine the consistency index using comparison matrix **A** [19]. If the result is completely consistent, then **A** (before normalization) has the following property:

$$A.\bar{\omega} = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \frac{w_1}{w_3} & \dots\dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \frac{w_2}{w_3} & \dots\dots & \frac{w_2}{w_n} \\ & & \dots\dots\dots & & \\ \frac{w_i}{w_1} & \frac{w_i}{w_2} & \frac{w_i}{w_3} & \dots\dots & \frac{w_i}{w_n} \\ & & \dots\dots & & \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \frac{w_n}{w_3} & \dots\dots & 1 \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \dots\dots\dots \\ w_i \\ \dots\dots \\ w_n \end{bmatrix} = \lambda_{max}.\bar{\omega} \quad (3)$$

where $\bar{\omega}$ is the eigenvector of λ_{max}. In [20] it is proved that A is of perfect consistency if $\lambda_{max} = n$ or $\lambda_{max} \geq n$. Therefore it is determined according to [21].

$$\lambda_{max} = \frac{\sum_{i=1}^{n} \lambda_i}{n} \quad (4)$$

$$\lambda_i = \left\{ \sum_{j=1}^{n} \left(\frac{l_{ij+} m_{ij} + u_{ij}}{3} . w_j \right) \right\} / M_i \quad (5)$$

Then consistency ratio CR is determined by dividing the value of consistency index (CI) with the value of random index (RI). The value of the consistency index (CI) is derived from equation (6), and the size of RI is taken from *Table* [22] depending on the number of indicators "n":

$$\text{CI} = \frac{\lambda_{max} - n}{n-1} \quad (6)$$

Depending on the size of CR, it can be proceeded to accept the ranking of alternatives, since the solutions are relatively consistent. The authors of most references assume that the value of CR <= 0.10 but the value of CR < 0.2 in source [23] is assumed to be maximally tolerant, so it is used in this specific study.

- The general and local priorities of compared indicators are evaluated sequentially (for each level of the hierarchy).

In cases where indicators with corresponding subfactors are defined, they are evaluated for each level separately. Then each element in the level adds its weighted values and its general or global priority is obtained.

- Determining the weights of experts and the final weights of indicators

The weights for experts is determined in a similar way as in this case n=k=t is equal to number "t" of participating experts. After that a matrix is compiled where the weight of each indicator is determined as a weighted average.

III. Results and Discussion

One of the methods for collecting information about the real situation of traveling in public suburban transport is to conduct a survey. The survey related to this study was carried out completely online by using Google Forms, which provided feedback from passengers travelling in public suburban transport in regard with their assessment of comfort and service. The information collected was used to summarize seven indicators (I) of comfortable travel [22]: I1 – hygiene in the vehicle, I2 – air conditioning, I3 – passenger space, I4 – level of service by staff, I5 – digital services, I6 – connections with other modes of public transport, I7 – adherence to the schedule.

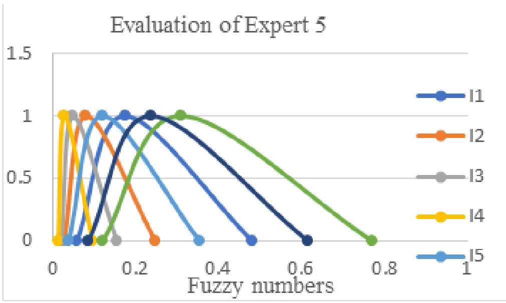

Figure 1. Presentation of evaluation of indicators by Expert 5 as fuzzy numbers.

The selected indicators were evaluated by a group of five experts (E) occupying various positions in management and organization of passenger traffic and having over twenty years of experience (Fig. 1).

Having presented the evaluation of each expert as a matrix of fuzzy numbers, a computational procedure was developed in Excel from MS Office package to determine the weights of indicators using the formulas derived for average geometric FAHP and the assessment of CR adequacy (Table 1).

TABLE 1. MATRIX OF THE EVALUATIONS OF EXPERT 5 AND THE FINAL RESULT

Evaluation	I1	I2	I3	I4	I5	I6	I7	W_i	λ_i
I1	1,1,1	1,3,5	2,4,6	3,5,7	1,2,4	1/5,1/3,1	¼,1/2,1	0.17	7.37
I2	1/5,1/3,1	1,1,1	1,2,4	1,3,5	¼,1/2.1	1/7,1/5.1/3	1/6,1/4,1/2	0.08	7.12
I3	1/6,1/4,1/2	¼,1/2,1	1,1,1	1,2,4	1/5.1/3.1	1/8,1/6,1/4	1/7,1/5,1/3	0.05	7.91
I4	1/7,1/5,1/3	1/5.1/3.1	¼.1/2.1	1,1,1	1/6.1/4.1/2	1/9.1/7,1/5	1/8,1/6,1/4	0.04	6.27
I5	¼,1/2,1	1,2,4	1,3,5	2,4,6	1,1,1	1/6,1/4,1/2	1/5,1/3,1	0.12	6.49
I6	1,3,5	3,5,7	4,6,8	5,7,9	2,4,6	1,1,1	1,2,4	0.29	7.48
I7	1,2,4	2,4,6	3,5,7	4,6,8	1,3,5	¼,1/2,1	1,1,1	0.25	7.24

With the number of indicators n=7, the following indices are obtained: CI = 0.021, RI=1.32 and CR=0.016. The value of CR shows us that we can accept the assessment of the indicators. To obtain the final value, the weight of each indicator has to be determined as a weighted average (Table 2).

TABLE 2 FINAL VALUES OF THE WEIGHTS OF INDICATORS

	E1	E2	E3	E4	E5	Weight I
I1	0.14	0.19	0.21	0.30	0.17	0.19
I2	0.06	0.04	0.08	0.10	0.08	0.07
I3	0.03	0.09	0.08	0.05	0.05	0.06
I4	0.14	0.19	0.14	0.30	0.04	0.16
I5	0.06	0.09	0.21	0.03	0.12	0.10
I6	0.28	0.19	0.08	0.045	0.29	0.19
I7	0.28	0.19	0.21	0.18	0.25	0.23
Evaluation of Experts	0.29	0.16	0.20	0.16	0.19	
						1

IV. CONCLUSIONS

In the recent years the ticket prices in railway transport have been lower for ordinary and suburban trains than the prices for coaches to the same destination and much less than expenses when travelling by car. Despite that there has been a constant outflow of passengers using railway transport, and because of that it is important to determine the indicators that affect comfort of passengers [22][24]. The study has given priority to accuracy of keeping timetables of vehicles on routes – 22.9% but it is due mainly to the number of repairs and rehabilitations of track sections as well as to frequent damages of rolling stock (locomotives or carriages).

The percentage of other factors acting on comfort are as follows: providing "Connections with other types of public transport" – 18.95%, "Hygiene in vehicles" – 19.43%, "Level of service by staff" – 15.6%, availability of air conditioning in rolling stock – 7.2%, provision of space for a passenger – 5.8% and "Digital services" – 5.76%. By determining the weight of indicators, we can assess the level of comfort depending on the type of rolling stock, accurate keeping to traffic schedule and urban mobility, and last but not least the courtesy of service staff (of different carriers).

The model developed to determine the weight of indicators using FAHP geometric mean is completely original and reflects the mathematical formalization of adopted systematic approach of decomposition and synthesis. The mathematical formula for aggregating individual assessments in FAHP has been derived using geometric mean and consistency ratio CR. The described method for determining the comfort indicators allows to determine their weight without returning them for re-evaluation by experts. Although the indicators and their weights have changed over the years, the method developed with Excel files makes the process of factor determination more rapid. The use of Artificial Intelligence (AI) [25] would facilitate not only the speed, but also accuracy with determining the indicators.

Analyzing the results obtained, it is possible to influence on the transport flows attracting more passengers to a given mode of transport by improving the services offered and the indicators that are of lower value. Using a Logit model, it is possible to investigate the distribution of passengers to a given destination depending on the change in comfort indicators or the specific price elements of each transport mode.

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