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Fuzzy Analytic Hierarchal Process for Sustainable Public Transport System

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ABSTRACT

The Analytic Hierarchy Process (AHP) is a well-established methodology for tackling complex multi-criteria decision problems in practical contexts. However, like many decision-making approaches, AHP confronts certain limitations, particularly in scenarios where evaluations are fraught with uncertainty and imprecision. This study sets out to enhance the capabilities of the AHP method and provide a comprehensive evaluation of public bus transport service quality within Budapest, Hungary. To address the inherent uncertainties in real-world decision-making, the study leverages the Fuzzy Analytic Hierarchy Process (FAHP), a fusion of Fuzzy Set Theory with the traditional AHP. This novel approach equips decision-makers with a more robust framework to handle the multifaceted nature of real-world decision problems. The study is grounded in empirical data obtained through dynamic surveys, ensuring its relevance to the actual conditions experienced in Budapest. Expert evaluators, well-versed in the field, contribute their assessments to enrich the analysis. This novel FAHP approach doesn't just promise improved decision-making outcomes; it also champions simplicity and comprehensibility. Its computational efficiency streamlines the decision-making process, providing a powerful tool for evaluating public bus transport service quality, thereby offering a significant contribution to the sustainable development of Budapest's transportation system.

1. Introduction

The service quality of public transportation holds a central position in the interests of various stakeholders. Government authorities and transportation companies consider it a matter of prime concern. Simultaneously, the research community actively engages with the topic. The significance of a robust and efficient public transportation system extends beyond mere convenience. It plays a pivotal role in mitigating a myriad of challenges that plague large urban centers, such as traffic congestion, public health concerns, and environmental issues. Budapest, the capital city of Hungary, is no exception to these challenges. The city grapples with its own set of problems, many of which

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can be alleviated by enhancing passenger satisfaction and, crucially, by drawing in more riders. In this context, elevating the quality of public transportation services takes on a paramount role [1-2].

Several research endeavors have been dedicated to exploring and enhancing public transport service quality. Budapest, with its rich history and vibrant urban life, is an ideal backdrop for such studies. These efforts are integral to finding sustainable solutions that not only meet the evolving demands of a city but also contribute to the broader vision of a more efficient, environmentally friendly, and healthier urban environment [3-4].

The Analytic Hierarchy Process (AHP) stands as one of the most widely embraced methods for addressing complex decision problems. Yet, it's not without its imperfections. These limitations have spurred researchers to seek ways to augment the original AHP framework with fuzzy approaches, striving to overcome its inherent deficiencies. Various innovative applications have emerged in this pursuit, each tailored to the specific complexities and intricacies of their respective problem domains. Sun [5], for instance, developed a systematic decision support tool grounded in Fuzzy Analytic Hierarchy Process (FAHP) principles. This approach was designed to navigate the intricacies of industrial performance evaluation, offering a reliable method for finding optimal solutions. Duleba and Moslem [6], in their work aimed at improving the quality of public bus transportation in Mersin, Turkey, addressed non-efficient eigenvectors by employing optimality tests on pairwise comparison matrices. Their innovative use of Pareto efficiency led to more trustworthy and efficient results. Ghorbanzadeh et al. [7] tackled the challenge of synthesizing ratings from different rater groups, thereby avoiding the expected opposition of the public and contributing to a more sustainable transport system. They utilized the interval AHP approach, illustrating its potential in navigating complex rating scenarios. Dožić et al. [8] took a different route, applying the FAHP approach to select the most suitable aircraft types for a set of routes. Their work was underpinned by a consideration of user interests, demonstrating the adaptability of the FAHP framework. Sahin and Yip [9] introduced an integrated FAHP approach using triangular or trapezoidal numbers. This innovation was born out of a need to address consistency issues in decision matrices. Their work focused on choosing shipping technology, providing a practical application for the refined method. In the context of evaluating the optimal performance of seven bus operators in Nanjing, China, FAHP played a key role. Through techniques like normalizing scales, constructing pairwise comparison matrices based on fuzzy numbers, and optimizing scores using nonlinear programming models, the study presented a comprehensive and effective approach to the problem.

The transit system does not only used for travel, but also it considered as suitable place for doing several activities, like eating, relaxing, reading and many other activities. The purpose of the paper is to measure the most important factors related to public bus transportation in Budapest city by using the FAHP technique. The data was collected based a dynamical survey and using linguistic scale with fuzzy numbers [5]. The questionnaire survey evaluators were the experts in the related field.

2. Literature Review

Sustainable urban mobility stems from the need to create environmentally friendly, socially inclusive, economically livable and healthier cities for current and future generations [10,11]. Attempts to identify sustainable transportation alternatives face major challenges [12]. Multi-criteria decision making (MCDM) problems are used to solve these difficulties. Sarkar, Chakraborty and Biswas [10] proposed a new version of type-2 Pythagorean fuzzy set for sustainable transport system selection. The benefit of using T2PFS in MCDM is that the membership and non-membership values of each argument are represented by Pythagorean fuzzy numbers rather than fuzzy numbers or intuitive fuzzy numbers. It was created using two MCDMs depending on the developed aggregation operators and TOPSIS. A case study has been avaluated and solved to demonstrate the application potential of the proposed method for sustainable transportation system selection in India. The result revealed that electric cars will be the most sustainable vehicles in India in the future. At the same time, Yücesan et al. [11] The importance of creating more sustainable urban transportation is now ever more. It is one of the sustainable urban transport indices (SUTI) developed by the United Nations (UN). SUTI has a large pool of criteria to assess the mobility sustainability of cities. However, considering the criterion weights equally and ignoring the uncertainties in expert opinions is a significant disadvantage. A new integrated approach for SUTI evaluation, including the best-worst method (BWM), multi-objective optimization with ratio analysis (MOORA), and MOORA plus fully multiplicative form (MULTIMOORA) method, has been improved and applied. To handle fuzzy linguistic approximations, the use of BWM has been implemented in the framework of interval type-2 fuzzy (IT2F) sets. The results show that the proposed approximation provides both a more scientific perspective and the possibility to perform sensitivity analysis on criterion weights. In addition, Sarkar et al. The deployment of decision support systems developed in [12] is to irradiate users' demands and help make perfect policy decisions considering the current situation. The q -rank orthodouble fuzzy set (q –ROFS) is a generalization of "intuitive fuzzy sets (IFSs)" and "Pythagorean fuzzy sets (PFSs)" that state unclear data more efficiently. Addressed MCGDM issues using Heronian mean (HM) and DH q -ROF data. The concept of "DH q -ROFS)" was introduced to explain human hesitation. Frank t -norm and t -conorm based DH q -ROF HM (DH q -ROFFHM) operator proposed a solution to MCGDM problems. Moreover, Senapati et al. [13] proposed that postal operators It offers a new strategy for the implementation of the concept of shared mobility, where they use common networks of units and serve as service providers. To solve this challenge, an advanced decision support model based on Aczel-Alsina association operators and power operators in an intuitionistic fuzzy (IF) environment has been improved. In addition, Bouraima et al. [14] suggested a multi-criteria method for sustainable transportation by conducting an assessment of existing operational railway systems in West Africa. They submited the interval coarse stepwise weight evaluation ratio analysis-joint consensus solution (IR-SWARA-CoCoSo) model. Cope with uncertainty and the interval rough SWARA method has been examined to enable the use of interval rough numbers (IRNs). Also Rajak, Parthiban et al. [15] presents a model for judgement of transportation sustainability performance. The model addressed dimensions such as Economic Sustainability, Social Sustainability, Environmental Sustainability and Transportation System Efficiency. Moreover Gandhi and Kant [16] propose sustainable performance measurement of the iron freight transportation industry. An application has been made to Indian Railways. It suggests an index-based sustainable performance evaluation frame using the global fuzzy analytic hierarchy process (SF-AHP) and fuzzy logic-based approach. The findings show a sustainability index of 16.1141 for HR, close to "fairly high sustainable" performance. Furthermore Makarova et al. [17] proposed a study on the possibility of improving the sustainability of the public transport system through the implementation of the management system. The testing of the recommended method was implemented using the Naberezhnye Chelny example. Also Antunes et al. [18] put forward research to fill the gap in the literature on both the uncertainty of innovation and Research and Development (R&D) expenditures on pollutant emission performance and designing and contemporaneously discovering the mightys of MCDM. A new TEA-IS model was developed to analyze the 14-year road transportation sustainability performance criteria of the Chinese province. Hybrid DEA-TOPSIS model was used. It has been concluded that TEA-İŞ's discriminatory power is good. There is high synergy in Chinese provinces in terms of sustainable road transportation. Additionally, Ngossaha et al. [19] aimed to provide a frame that allows the selection of the most environmentally friendly policy. For this, they proposed an integrated approximation to turn to account the sustainability of the current transportation system design depending on the policy formulation problem. It has been shown that commutual conflicts that may occur between indicators can be reduced with this model, which is depending on a holistic view of the transportation system. In addition, the policy formulation problem considered to validate the proposed model also emphasized the flexibility of fuzzy AHP. Dahooie et al. [20] proposed a new portfolio matrix for decision-making to identify IoT applications in the urban transportation sector for future investments depending on two dimensions of the effect on sustainable development (SD) and the feasibility of implementing IoT using a new hybrid multi-criteria decision-making dealing. Seventeen IoT applications in urban transportation were identified. The improved Fuzzy Cognitive Map (FCM) - Best Value Method (BWM) method was used to designate the relationship between SD criteria and IoT challenges and calculate their significance. Büyüközkan, Feyzioğlu, Göçer [21] also turn to account different public bus technologies as urban transportation alternatives. A series of criteria regarding sustainability have been established so that expert opinion can be included in the model environment. Expert opinion was got relating to the sustainability of vehicle options according to each criterion. Since meeting a single criterion is not sufficient to draw significant conclusions, dependencies between decision criteria were taken into account in the evaluation to find compromise solutions. To solve this problem, an aggregation method based on Intuitive Fuzzy Choquet Integral (IFCI) and Group Decision Making (GDM) techniques is proposed. TOPSIS (Order Preference Technique Based on Similarity to Ideal Solution), which is a fuzzy pairwise comparison measure definition method, and 2-sum Choquet integral were used to define the parameters in IFCI. An integrated performance evaluation frame (PAF) based on competitive priorities for sustainable freight transport (SFT) systems has been developed in Pathak, Shankar, Choudhary [22]. A combined approach come out of fuzzy group decision making, fuzzy evidential reasoning approach, and the concept of inevitable utility was used to turn to account the critical success factors of PFT in the basis of four competitive priorities. In terms of performance score, PAF concluded that logistics professionals are the most competitive PFT system facilitators. Pamucar et al. [23] also pay regard to metadata, which is the integration of four alternative physical and digital spaces into a virtual universe: automatic driving algorithm testing for training autonomous driving artificial intelligence, public transport operation and safety, traffic operation, and sharing economy applications to achieve sustainable transportation. These alternatives are evaluated according to thirteen sub-criteria grouped under four main headings: efficiency, functioning, social and health, legislation and regulation. A new Rough Aczel-Alsa (RAA) function and Ordered Priority Approximation (OPA) method are used in the evaluation model. Metaverse technology has made it probable e to evaluate the impact of transportation systems on traffic from many perspectives. Ayadi et al. [24] also proposed an approach with economic, environmental, social, political and spatial dimensions that help freight transportation actors in evaluating sustainability, with a vision that takes into account the characteristics of the city.

3. Methodology

The study at hand has a pivotal goal – to delve deep into the intricate world of service quality criteria for public transportation. This involves a hierarchical structure of fifteen criteria neatly organized into two levels, as beautifully illustrated in Figure 1. The first level comprises the primary criteria concerning public transport service quality, namely Approachability, Directness, Reliability, Time availability, and Speed. Meanwhile, the second level dives into the sub-criteria that provide more granular insights into each primary criterion. In order to effectively address this multifaceted task, the Fuzzy Analytic Hierarchy Process (FAHP) approach takes center stage. This approach serves as the compass to navigate through the myriad criteria and rank them based on their importance in the realm of public transport service quality. It's a methodology that's proven its mettle and adaptability in various decision-making scenarios. The heart of the matter is the assessment conducted by experts in the field, who lent their knowledge and judgment to evaluate the survey. These assessments are anything but ordinary; they're cast in the intriguing form of fuzzy numbers. These fuzzy numbers, initially defined by Gumus [25], serve as a powerful tool for representing and handling the inherent uncertainties and vagueness that often accompany real-world data. The application of these fuzzy numbers to public transport service quality criteria creates a dynamic and nuanced perspective that goes beyond rigid, crisp numbers.

For those who like to get down to the nitty-gritty details, the mathematical equations underpinning this process are as clear as day, largely following the formulations defined by Sun [5]. While it's important to note that fixed costs are a known factor in this study, the primary focus is unerringly centered on issues related to service quality. This focused approach ensures that the investigation drills deep into what truly matters in the context of public transport, ensuring a comprehensive evaluation of service quality aspects that can lead to tangible and impactful improvements.

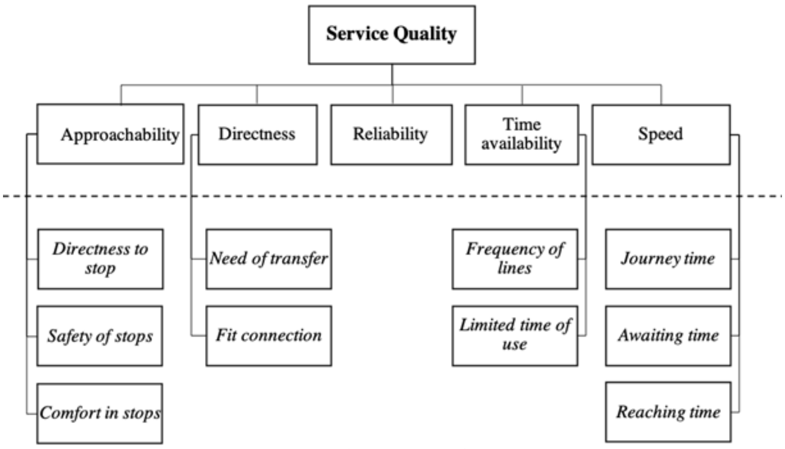

Fig.1. The hierarchical structure of public bus transport service quality [26]

Table 1
Scale of triangular fuzzy number (TFN) with different importance.

Fuzzy number	Linguistic	Scale of fuzzy number
9	Perfect	(8, 9, 10)
8	Absolute	(7, 8, 9)
7	Very good	(6, 7, 8)
6	Fairly good	(5, 6, 7)
5	Good	(4, 5, 6)
4	Preferable	(3, 4, 5)
3	Not bad	(2, 3, 4)
2	Weak advantage	(1, 2, 3)
1	Equal	(1, 1, 1)

In general, the following steps can be highlighted as the main steps when ranking the criteria based on the FAHP approach;

Step 1: Defining the criteria and setting up the hierarchical structure of the complex problem**.** In this initial step, the key criteria for your decision-making process are defined and organized into a hierarchical structure. This hierarchical structure helps you understand the relationships between the main criteria and the sub-criteria, providing a clear framework for your decision model.

Step 2: Constructing the pairwise comparison matrices based on the hierarchical structure. Once the criteria are established, this step involves creating pairwise comparison matrices. These matrices allow experts or evaluators to compare the importance or preference of one criterion over another within the hierarchy. It's a critical process to quantify these relationships.

Step 3: Preparing the questionnaire survey. The next phase involves designing a questionnaire or survey that captures input from relevant stakeholders, experts, or decision-makers. This survey should be well-structured to collect preferences, judgments, and ratings related to the criteria and alternatives under consideration.

Step 4: Checking consistency. Consistency checks are vital to ensure the quality of the data collected. These checks verify that the judgments provided in the pairwise comparisons are logical and consistent. Inconsistencies can impact the reliability of the decision model and may require revisions.

Step 5: Aggregation by fuzzy geometric mean. In this step, the fuzzy geometric mean is applied to combine the data from the pairwise comparisons. Aggregation aims to synthesize the input data, taking into account both the importance of criteria and their relationships.

Step 6: Deriving the weight vectors of the aggregated pairwise comparison matrices. Weight vectors are generated from the aggregated data. These weight vectors represent the relative importance of each criterion in the decision-making process, helping you allocate priorities.

Step 7: Conducting the final weight scores. Using the weight vectors, final weight scores are calculated for each criterion. These scores provide a quantitative representation of each criterion's significance in the decision model. The criteria with higher scores are deemed more important.

Step 8: Sensitivity analysis. Sensitivity analysis evaluates how robust your model is to variations or uncertainties in the input data or weights. It helps in understanding how small changes can affect the final decision outcomes, ensuring the reliability and stability of your decision-making process.

Each of these steps plays a crucial role in multi-criteria decision-making, particularly when dealing with complex problems. It's a systematic approach that enhances transparency and aids in making informed decisions based on both qualitative and quantitative data.
For aggregating the evaluators weight scores, the fuzzy geometric mean was employed [27].

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \tilde{a}_{i3} \otimes \tilde{a}_{i4} \otimes \tilde{a}_{i5})^{1/n} \quad (1)$$

$$\widetilde{w}_i = \tilde{r}_i \, [\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5]^{-1} \quad (2)$$

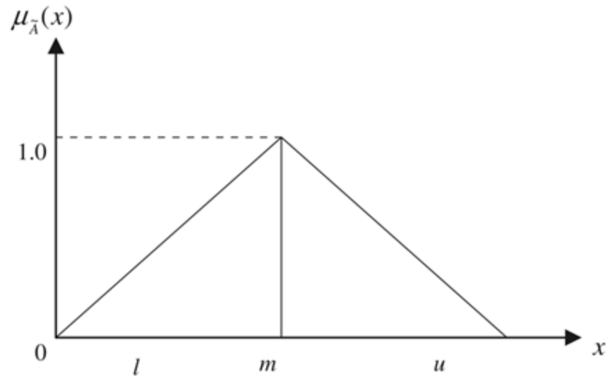

Fig. 2. The membership functions of the triangular fuzzy number

3. Results

The research has been made to estimate the situation of Budapest's public bus transportation system service quality. As a methodology, the FAHP approach was conducted. Ten experts in the relevant field were participated in the questionnaire survey. The number of participants evidently not statically representative however the MCDM provides a deeper insight based on pairwise comparisons than simple statistical survey [28]. The survey was done in 2018.

Table 2
The definitive weight scores.

Level 1		**Level 2**	
Service Quality		*Approachability*	
Approachability	0.149	Directness to stop	0.599
		Safety of stops	0.192
		Comfort in stops	0.219
		Directness	
Directness	0.108	Need of transfer	0.236
		Fit connection	0.764
		Time availability	
Time availability	0.178	Frequency of lines	0.354
		Limited time of us	0.646
		Speed	
Speed	0.2374	Journey time	0.376
		Awaiting time	0.273
		Reaching time	0.371
Reliability	0.3776		

The hierarchical structure for evaluating the criteria provides a clear understanding of their relative importance in the decision-making process. At the first level, the "Reliability" criterion was identified as the most significant factor that needs improvement. This indicates that ensuring the consistency and dependability of public transportation services is a top priority for enhancing service quality. Following closely in importance were the criteria of "Speed" and "Time availability." These criteria also hold substantial weight in the decision-making process, suggesting that passengers highly value the efficiency and timeliness of public transport services. Improvements in these areas can significantly contribute to overall service quality. In contrast, the "Directness" criterion was ranked as relatively less important at this stage. This implies that while direct routes and minimizing transfers are desirable, they might not be as critical as reliability, speed, and time availability in the eyes of the experts. These rankings serve as a valuable foundation for making informed decisions on how to allocate resources and efforts for improving public transportation service quality. They highlight where the most substantial improvements can be made to meet the expectations and preferences of passengers effectively.

Table 3
The overall scores for public bus transport service quality criteria.

Level 1			Level 2		
Criteria	Final Score	Rank	Criteria	Final Score	Rank
			Directness to stops	0.0895	3
			Safety of stops	0.0288	9
			Comfort in stops	0.0328	8
			Need of transfer	0.0256	10
Approachability	0.1493	4	Fit connection	0.0825	5
Directness	0.1081	5	Frequency of lines	0.0638	7
Time availability	0.1799	3	Limited time of use	0.1161	1
Speed	0.2374	2	Journey time	0.0902	2
Reliability	0.3776	1	Awaiting time	0.0648	6
			Time to reach stops	0.0881	4

The “Limited time of use” was the most important issue in the second level, followed by “Journey time”, “Directness to stops” and “Time to reach stops”, while the last important issue was the “Need of transfer”.

4. Conclusions

This study provides a comprehensive analysis of how improvements can be made in the public bus transport system, with a particular focus on using fuzzy dynamic analysis to yield more reliable and robust outcomes. The study underscores the critical importance of enhancing service quality to meet the evolving needs of passengers and to attract potential new riders. The central finding of the study is the paramount importance of "Reliability" in the eyes of transportation experts. This criterion is identified as the most critical factor in improving the public bus transport system. Enhancing reliability would have far-reaching and positive effects on all other criteria within the system. It serves as a linchpin for ensuring passenger satisfaction and operational efficiency. Conversely, the "Directness" criterion received a lower ranking when compared to the other criteria. While it remains essential, it may not require as immediate and substantial attention as "Reliability." The recommendations stemming from this research provide valuable insights for decision-makers, particularly in Budapest's public transportation authority (BKK). The results should be considered in the development of future strategic plans to attract more passengers and increase overall passenger satisfaction.

For future studies, it's advisable to include the direct input of passengers and those who do not currently use the public bus transport system. This can be achieved by soliciting their feedback through questionnaire surveys. This more comprehensive approach can offer deeper insights into the specific requirements of both passenger and non-passenger groups, further refining strategies for improving the public bus transport system.

Author Contributions

Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, H.K.Y.A.-Z., and M.K.; supervision, H.K.Y.A.-Z. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement
Data will be made available on request.

Conflicts of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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