Chapter 4

Evaluation of Rail Transportation Stops Efficiency in Antalya by Applying Intuitionistic Fuzzy TOPSIS Analysis

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Abstract

Ensuring comfort, safety, security, and accessibility in public transportation (PT) systems is essential for promoting equitable access and inclusivity, especially within urban rail networks. This study evaluates the efficiency of tram stops in Antalya's urban rail system by employing an application of multi-criteria decision-making (MCDM) method, Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Intuitionistic Fuzzy TOPSIS) analysis. The research focuses on the first tram line in Antalya, examining its stops in central areas. Evaluations encompass various aspects including comfort, safety, security, and accessibility. Particularly, comfort levels are assessed based on the availability of amenities surrounding tram stops. Safety is evaluated by analyzing the density and proximity of bus stops, while security measures consider street lighting adequacy. Additionally, accessibility for disabled individuals is examined, particularly regarding the presence of stairs. This investigation centers on the Antalya tram line as a case study, comprising 16 stops, thereby presenting 16 alternatives for analysis. Three experts participate in the evaluation process, deploying four established criteria. Results indicate variations in efficiency among stops, with recommendations provided for improvement. By addressing critical factors and utilizing MCDM methods, this research contributes to enhancing PT services in Antalya, fostering a more efficient and inclusive urban transit system.

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1. Introduction

Comfort, safety, security, and services for disabled people are principal in public transportation (PT), particularly in urban rail systems and their stops, for ensuring equitable access and inclusivity. Providing comfortable seating, spacious layouts, and accessible amenities not only enhances the travel experience but also promotes independence for disabled passengers. Safety measures such as clear signage, tactile paving, and platform barriers mitigate risks and ensure a secure environment. Lighting, surveillance cameras, and existence of security staff contribute to the regular and disabled passenger security. Furthermore, services such as boarding assistance and passenger information systems make trips or journeys easier for disabled individuals. They can reduce barriers to mobility and participation in urban life. By making these aspects prioritized, urban rail systems can create an inclusive PT network that fulfills the needs of passengers, thus a more accessible urban infrastructure is obtained.

Comfortable PT enhances the experience for passengers. A smooth journey reduces stress and makes commuting more relaxed. Moreover, it positively affects passengers' mood, especially for daily commuters. Besides, comfortable PT systems can lead more ridership. People are more likely to choose PT over other modes of transportation if they feel comfortable and the services are convenient and reliable. Increased ridership leads to greater efficiency in traffic by reducing congestion and greater sustainability by decreasing environmental pollution. Ensuring safety in urban rail systems and their stops is essential for protecting the passengers. Accidents or crashes in PT contribute to injuries or fatalities, such as physical harm and emotional distress. In this way, prioritizing safety measures helps prevent such occurrences and supports a sense of security, because safety concerns can damage public confidence in PT systems. Otherwise, they may opt for alternative modes of transportation or even avoid travel. Therefore, maintaining safety standards inspires trust in the reliability of urban rail systems and encourage greater ridership. Moreover, security measures help protect passengers from threats such as vandalism and assault. By implementing surveillance systems, security personnel, and access controls, urban rail systems create a safer environment for passengers to commute. Thus, an effective security presence in PT systems improves public confidence in the safety of PT. When passengers feel secure in their travel, they are more likely to use PT. Thus, increased ridership and reduced traffic congestion can be observed.

This study focuses on investigating the tram line and its stops located in the rail systems of Antalya city in Türkiye. Specifically, this research takes into account the first of the four tram lines in the city and the stops in the central areas of the city. The analysis covers various aspects related to these tram stops on the tram line. Firstly, the study assesses the comfort degree by considering the availability of amenities such as cafes, restaurants, buffets, and markets in the vicinity of the stops. Furthermore, safety is evaluated by dealing with the density of bus stops near the tram stops in order to understand the overall safety for commuters. Security aspects are also studied by acknowledging the presence of street lighting adjacent to the tram stops, which contribute to a secure environment for PT users. Moreover, the study addresses the accessibility for disabled individuals by examining the presence of stairs at and around the tram stops. In this manner, we utilize the Intuitionistic Fuzzy TOPSIS method, one of the most contemporary multi-criteria decision-making (MCDM) approaches, to identify the best and worst-performing stops along the tram line.

This study offers an approach to examining the first tram line and its stops within Antalya's urban rail systems. It focuses specifically on consideration of comfort, safety, security, and accessibility aspects. By employing advanced decision-making methods such as the Intuitionistic Fuzzy TOPSIS, this research reveals the performance of tram stops. The results will offer recommendations for augmenting the quality of PT services in the city.

The following sections contain a literature review alongside an explanation of the methodology applied in this study. Methodology part is followed by the presentation of the application including criteria explanations and the case study presentation. Subsequently, the results and findings are discussed before the recommendations. Finally, the study is concluded with remarks and suggestions for the case and potential research.

2. Literature Review

Several studies investigated aspects influencing passenger comfort in rail transit systems in urban areas. For example, Nordin et al. (2016) examined factors such as noise, vibration, and coach design. They gathered feedback from rail transit passengers from many rail lines. Mohammadi et al. (2020) proposed a model for assessing comfort levels during rail transportation trips, while Ma et al. (2020) utilized longitudinal acceleration data and passenger feedback to measure riding comfort in a large city subway. Roncoli et al. (2023) introduced a pattern for on-board comfort degree, utilizing passenger counting and vehicle location data. Moreover, many researchers such as Kici-ski and Solecka (2018), Li et al. (2019), Zhang et al. (2020), and Görçün (2021) applied MCDM methods to assess the change of urban PT systems. These works considered several criteria including comfort to evaluate different scenarios. However, none of these studies explicitly addressed comfort at rail transit stops, particularly in terms of amenities or facilities available in their vicinity. This research gap in the literature emphasizes the need for further research to address the comfort features at rail transit stops.

Furthermore, various studies inspected safety characteristics within urban rail transportation systems. For instance, Brons et al. (2009) investigated the 'access-to-the-station' component of rail trips on passenger satisfaction. Also, they explored the interaction between PT service features. Abenoza (2018) explored factors such as travel and bus stop features that influence travelers' safety observations. Additionally, Kici-ski and Solecka (2018) and Görçün (2021) applied MCDM methods to assess different scenarios for urban PT systems, integrating safety measures. Also, Cheng et al. (2015) introduced an MCDM model for computing transfer efficiency between rail stations and bus stops. However, as far as we know, none of these studies specifically address safety concerns at rail transit stops concerning their proximity to bus stops, indicating a gap in the literature that requires further investigation.

In addition, Fan et al. (2016) found that basic amenities like benches and shelters play a crucial role in reducing perceived waiting times at rail stops and stations. Murray and Feng (2016) highlight the positive impact of public street lighting services on promoting transportation, including rail PT. Furthermore, Badiora et al. (2020) investigated concerns regarding personal security in PT facilities and explored measures to enhance the sense of personal security. However, based on our knowledge, none of these studies specifically address security concerns at rail transit stops, particularly regarding the quantity of street lamps or street lighting.

Several studies have examined aspects about the conditions for disabled people passengers in urban rail transportation stops or train stations considering the steps or stairs in them. For example, Sze and Christensen (2017) observed an increase in PT usage following the implementation of accessible designs aimed at improving facilities such as stairs and elevators for disabled individuals. However, stairs remain a significant challenge for many disabled PT users (Seriani et al., 2022; Stjernborg, 2019). While Cheng et al. (2015) developed an MCDM model to assess transfer efficiency for urban rail stations and their connected bus stops, their analysis did not specifically address the needs of disabled PT users in relation to stairs. Similarly, Ghosh and Ojha (2017) assessed passenger satisfaction with platform-based amenities, including the presence of stairs, without focusing on disabled passengers' perspectives. Despite existing facilities for disabled passengers at rail transit stops, considerations for the conditions surrounding these stops are lacking, to the best of our knowledge.

3. Methodology

In this study, intuitionistic fuzzy TOPSIS method is used as Boran et al. (2009) introduced. In the following the main steps of the method are provided by assuming $Alt = \{Alt_1, Alt_2, \ldots, Alt_m\}$ are the alternative sets and $Cr = \{Cr_1, Cr_2, \ldots, Cr_m\}$ are the criteria set:

Step-1 starts with the decision-makers' weights which are defined. We assume that the decision group takes *l* number of decision makers. Decision-makers' importance is made clear using linguistic expressions or phrases and intuitionistic fuzzy numbers (Atanassov & Stoeva, 1986). Later, the weighting of *k* th decision-maker is acquired.

Then, for step-2, we basically create an aggregated intuitionistic fuzzy decision matrix according to the attitudes of decision-makers. In order to generate an aggregated intuitionistic fuzzy decision matrix at the group of decision-making process, all specific choice perceives must be united into a group judgement or opinion. This is accomplished utilizing the intuitionistic fuzzy weighted averaging (IFWA) operator (Xu, 2007).

In step-3, the criteria weights are determined. All factors may not be considered equally important. To achieve the grades set of importance, all individual or specific decision-makers' opinions on the value of each criterion must be combined. Therefore, the decision-maker gives an intuitionistic fuzzy number to each criterion. Later, the weightings of each criterion are then determined using the IFWA operator.

In step-4, the aggregated weighted intuitionistic fuzzy decision matrix is established. Once defining the criterion weightings and the aggregated intuitionistic fuzzy decision matrix, the aggregated weighted intuitionistic fuzzy decision matrix is produced using the assessment method of Atanassov and Stoeva (1986).

In step-5 and step-6 we get intuitionistic fuzzy positive-ideal solution and intuitionistic fuzzy negative-ideal solution, and we compute the separation measures, respectively. Normalized Euclidean distance measurements are used to determine the separation between options in an intuitionistic fuzzy set. The separation measures are then decided for each alternative from intuitionistic fuzzy positive-ideal and negative-ideal solutions.

In step-7, we define the relative closeness coefficient to the intuitionistic ideal solution. The relative closeness coefficient between an alternative and the intuitionistic fuzzy positive-ideal solution is established. Finally, in step-8, the alternatives are sorted or ranked in an order based on the relative closeness coefficients of the options or alternatives.

4. Application

4.1. Criteria Identified

Comfort, safety, security, and services for disabled people are considered in this study, especially focusing on specific criteria. The total number of cafes, restaurants, markets, and buffets is designated as the comfort criterion. Additionally, the number of bus stops nearby the tram stops is specifically assigned as the safety criterion. Moreover, while street lamps or street lights are considered for the security criterion, the number of steps around the tram stops is regarded as a criterion for assessing conditions for disabled people.

4.1.1. Comfort Criterion

In urban transit systems, the comfort criterion encompasses various factors contributing to passengers' overall travel experience. Specifically, the presence and accessibility of amenities such as cafes, restaurants, markets, and buffets are designated as important indicators of comfort (Aksoy, 2022). They provide passengers opportunities for relaxation and refreshment during the PT journeys. By evaluating the availability of these amenities at transit stops and stations, transportation planners and policymakers can measure the level of comfort provided to passengers. Moreover, enhancing the provision of such amenities contribute to a more enjoyable and satisfying travel experience, thereby encouraging greater utilization of PT services. Therefore, such PT facilities or services are considered a positive criterion.

4.1.2. Safety Criterion

Tram stops inherently incorporate traditional safety features such as overpasses, pedestrian crossings, elevators, escalators, signalized intersections, and guardrails. Therefore, assessing tram stops solely based on these measures may not be pertinent for assessing safety. However, the proximity of bus stops to tram stops emerges as a distinctive criterion for evaluating safety, given its potential impact on passenger accessibility and intermodal connectivity within the transportation network (Hess, 2012; Kaszczyszyn & Sypion-Dutkowska, 2019). Evaluating this criterion can provide valuable understandings into enhancing safety and facilitating smooth transfers for commuters. As a result, such PT infrastructure or services are viewed positively.

4.1.3. Security Criterion

While the presence of security personnel at tram stops can represent a fundamental security measure, its uniform implementation across all tram stops renders it less suitable for being an individual criterion for security assessment. Nevertheless, the density of street lamps or street lighting in the vicinity of tram stops can be accounted as a critical factor for evaluating security at the tram stops (Cao & Duncan, 2019; Loukaitou-Sideris, 2012). Assessing the criterion of the number of street lighting around the tram stops provides understanding of the illumination degrees and visibility at tram stops. Thus, criminal activities can be deterred and overall security can be enhanced within the urban PT. Therefore, considering the effectiveness of street lighting systems around tram stops is essential for the security assessments. Thus, such PT services can be considered as a favorable criterion.

4.1.4. Accessibility for Disabled People Criterion

The accessibility issues for disabled individuals should be included in evaluating the rail transportation stops efficiency, because the presence of stairs and steps in the vicinity of stops brings challenges for disabled people by obstructing their mobility (Müller et al., 2022; Naami, 2019). Therefore, the consideration of conditions surrounding rail transit stops is vital to identify barriers to accessibility. By inspecting the presence of stairs and steps, transportation authorities can identify areas to enhance accessibility for disabled passengers. Addressing such concerns promotes inclusivity and equitable access to PT for all members of society. Therefore, such transportation infrastructure environment, the more stairs or steps the more obstacles for disabled PT users, can be considered as a negative criterion.

4.2. Case Study

The case study concentrates on examining the tram line within the urban area of Antalya as mentioned earlier. The tram line contains 16 stops totally that can be turned into 16 alternatives for the application. In addition, three experts are involved in our process. Moreover, four criteria about comfort, safety, security, accessibility for impaired passengers are established for the analysis. Utilizing Intuitionistic Fuzzy TOPSIS methodology, this research provides an assessment of tram stops in Antalya and their performance. The outputs will demonstrate the strengths and weaknesses of the tram stops.

Also, they will facilitate recommendations for improving the quality of PT services in the city center. Accordingly, while Table 1 shows Fuzzy linguistic descriptors and intuitionistic Fuzzy numbers employed in this study, Table 2 indicates the linguistic terminology for evaluating the importance of decision-makers involved in the research and the related criteria described. Additionally, in the context of linguistic terminology for rating alternatives using Intuitionistic Fuzzy TOPSIS, the descriptors and abbreviations in Table 3 are utilized. Related descriptors and their corresponding intuitionistic Fuzzy numbers allow for an assessment of alternatives in the evaluation process.

Table 1. Fuzzy linguistic descriptors and Intuitionistic Fuzzy numbers (Boran et al. 2009)

Fuzzy linguistic label	Abbreviation	Intuitionistic Fuzzy number		
		μ	í	ð
Very Important	VI	0.90	0.10	0.00
Important	I	0.75	0.20	0.05
Medium	M	0.50	0.45	0.05
Unimportant	U	0.35	0.60	0.05
Very Unimportant	VU	0.10	0.90	0.00

Table 2. Linguistic terminology for assessing the significance of decision-makers and criteria

Decision-makers	Importance	Intuitionistic Fuzzy number			Weight of decision-maker	
		μ	í	ð		
DM1	VI	0.90	0.10	0.00	0.90	0.406
DM2	I	0.75	0.20	0.05	0.79	0.356
DM3	M	0.50	0.45	0.05	0.53	0.238
				Sum	**2.22**	**1.000**

Table 3. Linguistic terminology for rating the alternatives

Fuzzy Linguistic Descriptor	Abbreviation	Intuitionistic Fuzzy Number		
		μ	í	ð
Extremely Good	EG	1.00	0.00	0.00
Very Very Good	VVG	0.90	0.10	0.00
Very Good	VG	0.80	0.10	0.10
Good	G	0.70	0.20	0.10
Medium Good	MG	0.60	0.30	0.10
Fair	F	0.50	0.40	0.10
Medium Bad	MB	0.40	0.50	0.10
Bad	B	0.25	0.60	0.15
Very Bad	VB	0.10	0.75	0.15
Very Very Bad	VVB	0.10	0.90	0.00

Table 4 provides a sample of linguistic terminology for rating the alternatives based on the criteria discussed earlier, indicating the diverse perspectives of decision-makers when rating alternatives. What stands out are the varied ratings allocated to each option or alternative by different decision-makers, highlighting the subjectivity characteristic in the evaluation process. Some alternatives receive consistent ratings across decision-makers, while others demonstrate considerable inconsistency.

Table 4. Sample of linguistic terminology for rating the alternatives according to the related criteria

Alternatives	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**
Alt_1	MB	B	MB	MG	MG	F	F	MB	B	VB	VB	VVB
Alt_2	MG	MG	F	F	F	F	MG	F	MB	F	MB	B
Alt_3	MB	B	MB	F	F	F	G	MG	MG	MG	F	B
Alt_4	F	F	MB	MG	MG	F	VG	G	G	MG	F	B
Alt_5	F	F	F	F	F	F	MG	F	F	VVB	VVB	VVB
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Alt_{16}	G	MG	MG	VG	G	G	VG	VG	VG	F	MB	B

Table 5 indicates the relative closeness coefficient C_i^* and the ranking of options or alternatives based on separation measures S^* and S-. Also, it illustrates that even slight differences in separation measures can significantly influence the overall ranking of alternatives.

Table 5. Relative closeness coefficient C_i^* and the ranking of alternatives

Alternatives	S^*	S -	C_i^*	**Ranking**
Alt_{16}	0.193	0.324	0.627	1
Alt_7	0.193	0.302	0.610	2
	0.249	0.295	0.542	3
⋮	⋮	⋮	⋮	⋮
Alt_3	0.315	0.174	0.356	14
Alt_9	0.341	0.154	0.312	15
Alt_6	0.376	0.129	0.256	16

5. Results and Discussion

Results indicate that Alt_{16} exhibits the highest efficiency in the ranking, followed by Alt_7 and Alt_{15}, which demonstrate the second and third highest performances among the other tram stop alternatives, respectively (Table 5). Conversely, Alt_6 displays the lowest efficiency in the ranking, with

Alt_9 and Alt_3 showing the second and third lowest performances based on the relevant criteria. Broadly speaking, the rankings demonstrate the relative performance among the trams stop alternatives evaluated in the tram line in Antalya. Particularly, Alt_{16} secures the top ranking, indicating its superior performance according to the evaluation criteria. On the other hand, Alt_6 ranks the lowest, suggesting areas for improvement or concerns regarding its suitability. Moreover, Alt_7, Alt_{15}, Alt_5, and Alt_{14} achieves a relatively high ranking, indicating its competitive performance compared to other alternatives. The rankings provide an overview of the strengths and weaknesses of each tram stop, aiding decision-makers in identifying optimal choices for further consideration in the context of the evaluated criteria.

Since this study adopts critical factors such as comfort, safety, security, and accessibility at tram stops, they should be considered carefully. Especially, the number of amenities for refreshment at the vicinity of trams stops for comfort, the amount of the bus stops near the stops for safety, the number of street lighting around the stops, and the number of steps at or near the tram stops should be taken into account for measuring the performance of the efficiency of the tram stops. Decision-makers, stakeholders or policy makers should pay attention to such features of the tram lines and stops. In this case, especially, the alternatives or the trams stops Alt_6, Alt_9, Alt_3, Alt_2, and Alt_{13} should be improved based on the related criteria in this study.

6. Conclusion

In conclusion, this study adopts a broad investigation into the tram line and its stops within Antalya's urban rail systems, with a specific focus on the first tram line and its stops located in the city center. Additionally, the research examines several areas critical to the operation and PT user experience of the tram stops.

In this manner, the assessment of comfort, one of the four criteria, considers amenities such as cafes, restaurants, buffets, and markets in the vicinity of tram stops and signifies the comfort degree for commuters. Secondly, safety is evaluated by examining the density of bus stops next to the tram stops and their proximity to tram stops. The number of them is assumed to indicate the effectiveness of safety measures for passengers. Thirdly, security aspects are addressed through an exploration of the number of street lighting around tram stops. Therefore, the prominence of well-lit environments for passenger security can be highlighted. Furthermore, this study considers the accessibility challenges faced by impaired people. In this way, the presence of stairs and their abundance at and around tram stops is our concern particularly, because they create barriers to access the PT services for disabled individuals. Therefore, such accessibility concerns point out the need for accessibility improvements in order to ensure inclusivity in PT systems.

The research identified the best and worst-performing and the most effective and the least effective tram stops by applying the Intuitionistic Fuzzy TOPSIS method. According to the results obtained, Alt_{16}, Alt_7, Alt_{15} emerged as the top performing tram stops, while Alt_6, Alt_9, Alt_3 exhibited the lowest efficiency based on the criteria and the opinions of the experts. Thus, the strengths and weaknesses of the tram line and its stops are revealed which guides decision-makers in identifying and determining the locations for improvement in terms of transportation infrastructure and operations.

Besides, while this study addresses many essential characteristics of tram stops for enhancement, a couple of limitations also exist. For example, the results are mainly based on the expert perceptions, the technique or the methodology applied, and a number of aforementioned criteria. Moreover, the examination engaged in Antalya city's first tram line only in the urban area of the city. However, such limitations deliver many opportunities for future academic studies. For instance, future studies could involve increasing the number of experts and thus their variety of opinions and also expanding the number of criteria with subcriteria. Furthermore, employing a couple of techniques for the application and comparing their outputs could enhance the evaluation.

Last but not least, this study contributes to the development of PT services in the rail transit system of Antalya by taking into account critical factors such as comfort, safety, security at the trams stops, and accessibility to them in disabled individuals' eyes. By operating modern MCDM methods and providing actionable recommendations, this research can foster a more efficient and inclusive urban PT system, especially the rail transit, for the residents and visitors of Antalya.

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