Prioritization of rail system projects by using FUZZY AHP and PROMETHEE

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Abstract

Istanbul stands out as a center with a high population density, similar to the large metropolitan areas of Europe. The traffic and population density increase in Istanbul makes it attractive for people to use the rail system for public transportation. In this study, the economic and financial evaluation of the rail system projects is made in terms of the municipality. Furthermore, the social-environmental review, public demand, and urgent needs were also considered. Thus, selecting the best alternative was evaluated for a better solution to reducing traffic congestion and meeting people's needs. MCDM (Multi-Criteria Decision-Making) techniques are often used in prioritization, ranking, and finding the best alternative. This paper used a combination of the F-AHP (Fuzzy Analytical Hierarchy Process) and the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method. Three main criteria and ten sub-criteria were used to evaluate 33 alternative projects where three experts determined criteria weights.

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1. Introduction

Istanbul is one of the most important cities in the world, with a strategic location connecting the continent of Europe and the continent of Asia. On the other hand, in Istanbul, which is among the most crowded cities in the world, population density continues to increase rapidly with economic growth (Peterson, 2017). The population of Istanbul, which was 12 million in 2006, reached 18 million in 2020. As a result of intense urbanization, economic development, and population growth in Istanbul, the number of daily trips is increasing (Ayyildiz & Taskin Gumus, 2021). On these journeys, public transportation is used extensively, as well as personal vehicles. The most preferred type of public transit is rail systems (Aydin, 2017). As a result of increasing population density and travel demand, the existing rail systems infrastructure has yet to meet the increasing travel demand.

Istanbul Metropolitan Municipality allocates most of its investment expenses to transportation systems. These transportation systems include rail, highways, sea, and parking lots. While the population accumulation settled in a narrow area develops rapidly and increases the traffic volume and demand, an extended period is required to produce the transportation sector, especially the rail system (Özdemir & Üsküdar, 2020). For this reason, there was a need

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for an integrated essential plan study, which includes dynamic investment planning and policies for transportation infrastructure in harmony with Istanbul's long-term land use plan.

Many application areas are examined in the literature with F-AHP and PROMETHEE methodology (Broniewicz & Ogrodnik, 2021). However, only one research focused on selecting intercity transport schemes on railway networks using this methodology (Stoilova, 2018). In this study, the rail system projects within the scope of the MPIT (Master Plan of Istanbul Transportation) were evaluated in terms of economic, financial, and social-environmental with the MPIT's data. The criteria set is also based on MPIT, and this set was never combined with the methodology mentioned in this paper.

In the second section, the literature review was given. In the third section, the F-AHP and PROMETHEE methods were explained. In the application part, 33 alternatives were evaluated with the proposed methods. In the conclusion and future works part, the results of this paper were summarized, and potential future works were mentioned.

2. Literature Review

Decision-making is choosing one or more available options to achieve goals and objectives (Kaya & Kahraman, 2011). Decision-making is essential in planning (Gündoğdu & Kahraman, 2019). However, many factors affect decision-making, and may not always have complete information about these factors (Norouziyan, 2022; Piya et al., 2022). Making a decision determines the procedure followed in the most measured way (Berk & Can, 2022).

Thomas L. Saaty first proposed the AHP method in the 1980s (Saaty, 1980). It could apply to problems where more than one decision-maker can evaluate while choosing or ranking from more than one alternative, MCDM problems (Eraslan, 2013). The AHP method allows the decision maker to model problems that take a complex situation in a hierarchical structure that shows the connections between the main objective, criteria, sub-criteria, and alternatives of the difficulties (Uskudar et al., 2019). The AHP method is based on pairwise comparisons (Javanbarg et al., 2012). These pairwise comparisons evaluate the importance of the alternatives-criteria compared to each other (Gumus, 2009).

MCDM methods are widely used for transport systems evaluations (Macharis et al., 2009; Stoilova et al., 2020). Jasti et al. used the F-AHP approach for integrated and sustainable benchmarking of the metro rail system (Güler, 2022; Jasti & Ram, 2019; Jasti & Vinayaka Ram, 2019). Labbouz et al. used the MCDM approach to implement a public transport line (Labbouz et al., 2008). Railroad safety is another important area combined with MCDM methodologies (Blagojević et al., 2020, 2021).

3. Methodology

There are many MCDM approaches in the literature. In this paper, criteria evaluations were made with F-AHP because of the complexity of the decision-making process. However, the F-AHP approach is not efficient in large-size alternative evaluations. The PROMETHEE methodology was used to overcome this challenge for the alternative evaluation process. Both F-AHP and PROMETHEE methods are well-known methods. For that reason, the methods are explained briefly in sections 3.1 and 3.2.

3.1 F-AHP

The F-AHP is a well-known methodology frequently used in MCDM processes (Hossain & Thakur, 2021). Due to the fuzzy nature of the selection criteria and the comparison of alternatives, pairwise linguistic comparisons could be better for explaining decision-makers' expressions (Tashayo et al., 2020).

F-AHP methods are prepared in different ways by various authors from the literature. In 1985, Buckley determined the fuzzy priorities of the comparison ratios with the triangular membership function (Buckley, 1985). The linguistic measurements used in this paper for F-AHP are given in Table 1 (Kahraman et al., 2003).

Table 1. Linguistic Measurements for F-AHP

Linguistic Measurement	Fuzzy Number	Crisp Number
Equally Important (EI))	(1, 1, 1)	1
Slightly More Important (SMI)	(2/3, 1, 3/2)	3
Very Important (VI)	(3/2, 2, 5/2)	5
Very High Important (VHI)	(5/2, 3, 7/2)	7
Absolutely More Important (AMI)	(7/2, 4, 9/2)	9

3.2 PROMETHEE

The PROMETHEE method was first introduced in the 1980s by Barns and Vinckle (Brans et al., 1986). The evaluation table is the starting point of PROMETHEE, which is the method that provides a ranking of several alternatives by considering more than one criterion (Gul et al., 2017). In this table, the options are evaluated according to different criteria. We need two kinds of information in the application of the PROMETHEE method (Abdullah et al., 2019).

- Relative importance levels of the criteria considered
- Function preferences of the decision maker to compare the utility of alternatives to these criteria over each criterion.

The PROMETHEE method is called PROMETHEE I, which performs partial sorting, and PROMETHEE II, which performs complete sorting (Turcksin et al., 2011). In addition, there are six available preference functions in the PROMETHEE method (Dağdeviren & Eraslan, 2008).

4. Application and Results

The list of steps to be implemented in the paper is as follows:

1. Creation of hierarchical structure,
2. Surveying by expert decision-makers,
3. Creating the decision matrix according to the AHP method according to the survey results,
4. Completing the group decision matrix by taking the geometric mean of the decision matrices created for each questionnaire,
5. Calculating the consistency by normalizing the group decision matrix,
6. Making the decision matrix for F-AHP,
7. Calculation of local and global weights with the Buckley approach,
8. For the alternative evaluation, the PROMETHEE method was applied. Here, the global weights were used.

While creating the hierarchical structure, the data in the MPIT was used. Here, the three main criteria were used ("Economic", "Financial", and "Social and Environmental Evaluation"). There are ten sub-criteria related to these three main criteria. Thirty-three planned rail system projects would be evaluated based on these main criteria and sub-criteria. The main and sub-criteria are explained in detail below. MPIT was used while determining the main criteria and sub-criteria and the data obtained from the calculations. The hieratical structure of F-AHP is given in Figure 1.

a. Economic Indicators: The projects planned with cost-benefit analysis were evaluated economically.

Economic Internal Rate of Return (E-IRR): It has been calculated by comparing the traffic assignment results of the transportation demand forecasting model according to the construction and non-performance of these projects.

Benefit: While calculating the economic benefit of the projects, "vehicle operating cost, environmental costs (noise, emissions, water pollution), vehicle ownership cost, accident cost, and time cost" were considered.

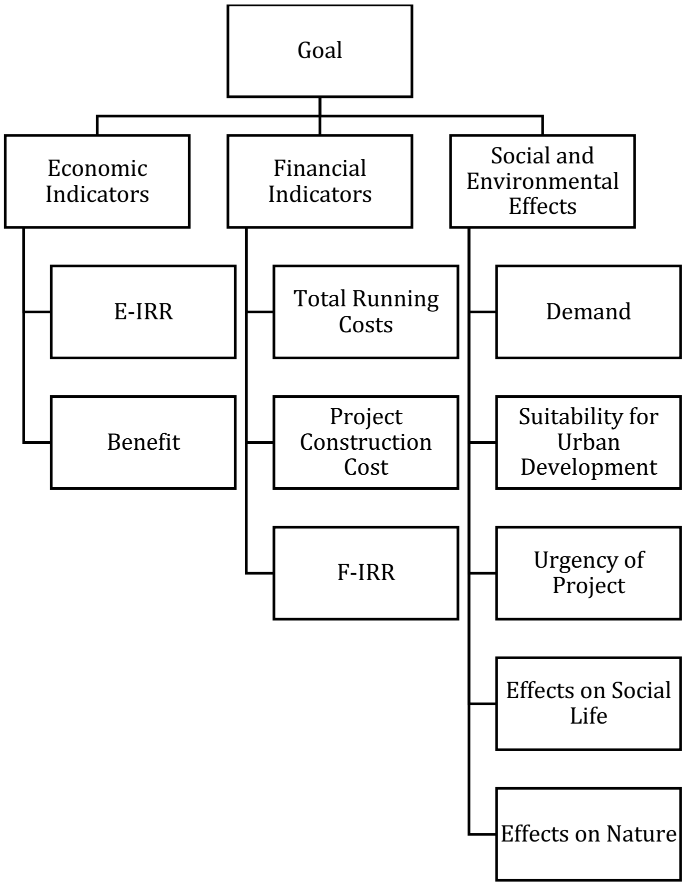

Figure 1. The hieratical structure of F-AHP

b. Financial Indicators: Income-generating projects such as maximum rail system projects were evaluated financially by comparing cash inflows (ticket fees collected) and cash outflows (construction, operation, and maintenance costs).

Total Running Costs: Maintenance and operating costs are "variable" expenses and vary according to the type of system and depend on the service volume of the rail system. These costs include energy, vehicle line, maintenance, rent, personnel, etc. constitute expenses. To estimate maintenance and operating costs, Expenses per service volume such as train-km, passenger-km, and the number of passengers, employees, or trains are used.

Project Construction Cost: The cost of the rail system project varies according to specific and local conditions. The unit cost in this study; include construction cost, electromechanical costs, and vehicle cost.

Financial Internal Rate of Return (F-IRR): The profitability of a project is measured by the financial internal efficiency ratio without considering the distribution of benefits.

c. Social and Environmental Effects: In this section, the projects; Within the framework of the laws and regulations in force, natural and cultural assets have been evaluated for their environmental impact in case they are in sensitive areas such as the Bosporus front and back view area, water basins, and in cases where expropriation is required, social and environmental assessments have been made. The sub-criteria are Demand, Suitability for Urban Development, Urgency of Project, Effects on Social Life, and Effects on Nature. The alternative rail system projects are shown in Table 2.

Table 2. List of Alternatives

#	Project Name	#	Project Name
1	Üsküdar - Çekekoy	18	Taşdelen - Tuzla
2	Bakırköy - Beylikdüzü	19	Ataşehir Havaray
3	Bakırköy - Bahçelievler - Bağcılar	20	Kadıköy - Sultanbeyli
4	Kabataş - Beşiktaş – Şişli - Giyimkent - Bağcılar	21	İkitelli - Habipler
5	Yenikapı - Bakırköy	22	Silivri - Gümüşyaka
6	Haliç Area	23	Sultançiftliği - Arnavutköy
7	Yenibosna - İkitelli	24	Tuzla Tramvay Sistemi
8	Şişhane-Kulaksız - Cemal Kamacı	25	Maltepe Havaray
9	Bağcılar - Halkalı	26	Hisarüstü Raylı Sistemi
10	Tekstilkent - İstoç-Olimpiyatköyü - Ispartakule	27	Silivri - Selimpaşa Havaray
11	Kartal D100 - Kartal IDO	28	Kadıköy - Kazlıçeşme
12	Sabiha Gökçen Havaalanı - Formula 1	29	Soğütlüçeşme - Kazlıçeşme
13	4.Levent-Gültepe - Celiktepe	30	Soğütlüçeşme - Gayrettepe
14	Besiktaş - Sarıyer	31	Bostancı - Kazlıçeşme
15	Ispartakule - Beylikdüzü - Avcılar	32	Ünalan - Mecidiyeköy
16	Ispartakule - Kıraç - Büyükçekmece - Silivri	33	Soğütlüçeşme - Incirli
17	Üsküdar - Beykoz		

The local weights of the main criteria were evaluated and given in Table 3.

Table 3. Local and Global Weights of Criteria and Sub Criteria

Main Criteria	Weight	Sub Criteria	Local Weight	Global Weight
Economic Indicators	0,4916	E-IRR	0,6475	0,3183
		Benefit	0,3525	0,1733
Financial Indicators	0,2272	Total Running Costs	0,4315	0,0980
		Project Construction Cost	0,3183	0,0723
		F-IRR	0,2502	0,0568
Social and Environmental Effects	0,2812	Demand	0,2127	0,0598
		Suitability for Urban Development	0,2323	0,0653
		Urgency of the Project	0,2053	0,0577
		Effects on Social Life	0,1617	0,0455
		Effects on Nature	0,1880	0,0529

It is seen that the Economic Indicators criterion is the most important, with a rate of 49%. The Financial Indicators criterion's weight is 23%, and the "Social and Environmental Effects" weight is 28%. The sub-criteria of the Economic Indicators criterion, E-IRR, was found to be 65%, and the Benefit was 35%. When the local weights are evaluated according to the importance levels of Financial Indicators, Total Running Costs are 43%, Project Construction Costs are 32%, and F-IRR is 25%. It has been seen that the local weights of the Social and Environmental Effects sub-criteria are approximately distributed to each other. The Demand was 21%, the Suitability for Urban Development was 23%, the Urgency of the Project was 21%, the Effects on Social Life were 16%, and the Effects on Nature were 19%. According to this evaluation, the E-IRR, with a global weight of 31%, will significantly prioritize rail system projects among all sub-criteria. The rail system projects to be ranked as a result of the evaluations made with PROMETHEE are given in Table 4.

Table 4. The Results of PROMETHEE

Rank	Alternative	Phi	Phi+	Phi-
1	İkitelli - Habipler	0,5886	0,6174	0,0288
2	Yenikapı - Bakırköy	0,4144	0,4432	0,0288
3	Kabataş - Beşiktaş - Şişli - Giyimkent - Bağcılar	0,2583	0,3342	0,0759
4	Bakırköy - Bahçelievler - Bağcılar	0,2425	0,2782	0,0356
5	Tekstilkent - İstoç - Olimpiyatköyü - Ispartakule	0,1615	0,2093	0,0478
6	Ispartakule - Kıraç - Büyükçekmece - Silivri	0,1034	0,2033	0,0999
7	Haliç Area	0,0397	0,1674	0,1277
8	Şişhane - Kulaksız - Cemal Kamacı	0,0357	0,1814	0,1458
9	Bakırköy - Beylikdüzü	0,0298	0,1485	0,1188
10	Üsküdar - Çekmeköy	0,0240	0,1324	0,1084
11	Kadıköy - Sultanbeyli	0,0141	0,1159	0,1017
12	Sultançiftliği - Arnavutköy	0,0096	0,1152	0,1056
13	Ataşehir Havaray	0,0069	0,1312	0,1243
14	Taşdelen - Tuzla	0,0039	0,1288	0,1249
15	Bağcılar - Halkalı	0,0003	0,1067	0,1064
16	Yenibosna - İkitelli	-0,0008	0,0980	0,0988
17	Hisarüstü Raylı Sistemi	-0,0196	0,1188	0,1384
18	Tuzla Tramvay Sistemi	-0,0275	0,1220	0,1496
19	Bostancı - Kazlıçeşme	-0,0277	0,1396	0,1673
20	Kartal D100 - Kartal IDO	-0,0338	0,1346	0,1684
21	Söğütlüçeşme - İncirli	-0,0356	0,1000	0,1356
22	Söğütlüçeşme - Gayrettepe	-0,0487	0,0830	0,1317
23	Ünalan - Mecidiyeköy	-0,0581	0,1154	0,1735
24	Maltepe Havaray	-0,0720	0,1073	0,1793
25	Söğütlüçeşme - Kazlıçeşme	-0,0934	0,0788	0,1722
26	Sabiha Gökçen Havaalanı - Formula 1	-0,1129	0,0907	0,2036
27	Kadıköy - Kazlıçeşme	-0,1154	0,0940	0,2094
28	4. Levent-Gültepe - Çeliktepe	-0,1213	0,0866	0,2080
29	Silivri - Gümüşyaka	-0,1837	0,0550	0,2387
30	Ispartakule – Beylikdüzü - Avcılar	-0,1931	0,0567	0,2499
31	Üsküdar - Beykoz	-0,2036	0,0445	0,2481
32	Beşiktaş - Sarıyer	-0,2429	0,0425	0,2854
33	Silivri - Selimpaşa Havaray	-0,3427	0,0266	0,3693

The Economic Indicator values significantly affect the determination of the "İkitelli - Habipler" project as the best solution. Economic Indicators, one of the main criteria, had the most significant effect, with a rate of 49%. The fact that the most effective values in the sub-criteria included in this evaluation belonged to the "İkitelli - Habipler" line played a significant role in making this project the best alternative. The reason for the low economic costs of this line is that it is a tram line. Since there is no need for a large station design, such as any underground work or a large transition area on the tram line, its cost and operating expenses are meager.

According to the results, the "Silivri - Selimpaşa" rail system line is the worst alternative. After all, the financial liability is high in economic and financial criteria such as construction cost and operating expenses. In addition, the low population in the districts where the line is planned to be built and the lack of traffic density naturally show that there is no general demand or urgent need. For this reason, it seems normal to consider this line the worst alternative.

5. Conclusion and Future Works

In the age of technology, people or institutions want to make the right decision while making decisions. The decision-making process is an essential process that people and institutions frequently encounter at every moment. Decisions taken individually in our daily lives, investments, and projects by institutions are a part of this process. This process has always been a difficult one. Because there are many criteria when choosing, it may require choosing among many alternatives. When faced with such a situation, scientific methods must be used to reach the best result or prioritize it. Scientists have found and developed many decision-making methods to assist in such decision-making processes.

This study discusses the prioritization of the planned rail system projects in Istanbul. In this study, the F-AHP method and the PROMETHEE method were used in an integrated manner. The most important reason for using the two methods in an integrated way is to make the most of these methods and to bring us more accurate results.

In this research, the critical criteria mentioned in MPIT were used. The alternatives were evaluated with the three main criteria and ten sub-criteria. In addition, the hierarchical structure was created accordingly. These criteria and hieratical structure could be used for other railway evaluation papers.

Thirty-three planned rail system projects are the subject of this study. These projects were evaluated with a questionnaire of four expert DMs working in IBB. The classical AHP method was used for consistency controls in the first step. According to the results of the evaluation, it was seen that the DMs' evaluations were consistent. Then, local and global weights were calculated with the Buckley approach, one of the Fuzzy AHP methods. Finally, local and global weights were evaluated using the PROMETHEE approach for each criterion and sorted according to net priority values according to positive and negative priority values.

Different methods could be used for future studies, and the results could be compared. Furthermore, the proposed railway evaluation approach could be applied in other cities.

Conflicts of Interest

The authors declared that there is no conflict of interest.

Contribution of Authors

This study is based on the Ömer Ramadan's master's thesis. Dr. Yavuz Selim ÖZDEMİR is the thesis supervisor.

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