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Research Article

Transportation planning with analytic hierarchy process and goal programming

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ABSTRACT

Transportation planning process, which requires a multi-criteria decision making a very specific decision, is one of the most important issues of metropolitan cities. There are many projects in the field of rail systems in Istanbul and some of these projects are monorail projects. Through this way, urban transportation is supported by various types of public transportation. However, it is not possible to allocate the resources to all projects at the same time. This is affected by several criteria, especially by limited budgetary constraints. In this study, monorail projects were evaluated in accordance with urban needs of Istanbul and the planning was done under three different budget scenarios. The analytic hierarchy process (AHP) was used in the evaluation process of the projects and the goal programming (GP) model was used for the selection process. As a result, the selection of the monorail projects planned for Istanbul was made.

1. Introduction

Transportation planning is an important issue to be focused on due to the growing population, the expanding city borders and the resulting traffic intensity. For a regular and good transportation, it is essential to make planning by taking into account a long process and all factors. However, unforeseen circumstances arising later can cause disruptions or revisions in planning.

In Istanbul, with its population approaching 15-16 million, urban transport projects have an important place among the other investment areas. Urban transportation is the main of the issues that are emphasized. In this field, with various transportation types and projects, many investments are made, planned and designed. Various projects are being put forward to improve the quality of life in the urban areas, such as purchasing new transportation vehicles, constructing rail system projects, projects for supporting the infrastructure, speeding up environment friendly investments, investments in culture, arts, tourism, health, social services, youth sports and education. Transportation investments are at the beginning of all these investments, and a large budget is allocated to this field.

With their high capacities, diverse rail systems, such as metro, tramway, light rail system, form the main backbone of the urban transportation. Monorail systems emerging in response to changing transportation needs have also taken its place among these rail systems.

In this study, regarding the budget constrain, selection of the most suitable projects was made among the monorail projects planned for Istanbul.

The paper consists of six sections. In the 2nd section of this study, the monorail systems are explained. While the AHP is briefly explained in the 3rd section, a brief expiration of the GP and its literature review are presented in the 4th section. Section 5 provides a solution to the established mathematical model. The summery of the study and concluding remarks are presented in the 6th Section.

2. Monorail

The Monorail is a fast, comfortable and environmentally friendly system that travels along its own route by being isolated from vehicle traffic. Monorail has applications in the urban transportation. However, it is newly included in transportation planning in our country, and has taken its

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place in urban transportation with its various advantages.

There are some academic studies about this subject in the literature. Çankaya [1] investigated the applicability of monorail for Kocaeli province in his study. Hamurcu [2] determined the most suitable route for monorail alternative projects planned for Ankara. Çalis [3] compared the characteristics of the monorail transport system with other transport systems. Division [4] conducted an application study for Adıyaman province. Tarighi [5] assessed the applicability of the monorail for the campus in terms of financial, technical and social perspective. In their studies, Ghafooripour et al. [6] examined the countries having metro and monorail applications, and evaluated the feasibility and cost effectiveness of those applications for developing countries. Das et al. [7] evaluated the effectiveness of the transportation system in terms of user satisfaction and made suggestions. Marathe and Hajian [8] talked about the ideal use of monorail in urban transportation in terms of economy, safety and environmental awareness. Zhang, et al. [9] estimated the population around Kitakyushu monorail and estimated the usage of monorail stations. Liu et al. [10] pointed out the advantages and disadvantages of monorail systems by comparing the conventional rail transport systems with the monorail system. In his study, Timan [11] emphasized that metropolitan cities would be a suitable solution for the traffic problem. He [12] referred to the properties of the straddle type monorail system and noted that the popularity of this system increased day by day. Gür et al. [13] and Taş et al. [14], made selections among different monorail projects in terms of capacity, vehicle and route for Ankara. Taş et al. [15], determined the monorail line type among three alternatives.

3. Analytic Hierarchy Process

The Analytical Hierarchy Process (AHP) is a multi-criteria decision-making method developed by Saaty. The AHP is an effective method in the decision making process because it can be understood and applied easily by decision makers [16]. The implementation steps are:

Step 1. Determination of the problem.

Step 2. Determination of the objectives of the problem or consideration of all actors, objectives and its outcome.

Step 3. Identification of the criteria for evaluation

Step 4. Structuring the problem in a hierarchy of different levels constituting goal, criteria, sub-criteria and alternatives.

Step 5. Comparing each element in the corresponding level and calibrate of them on the 1-9 Saaty scale.

Step 6. Performing calculations to find the maximum Eigen value, consistency index (CI), consistency ratio (CR).

If the CI, and CR are satisfactory, decision is taken based on the normalized values; otherwise, the procedure is repeated till these values lie in a desired range.

4. Goal Programming

The GP is one of the many models which have been developed to deal with decision-making problems related to the multiple objectives. While the decision-maker is seeking the best solution among a set of feasible solutions, this model allows taking into account simultaneously many objectives [17]. GP is first described by Charnes and Cooper [18]. Today, GP is one of the most widely used multi-criteria decision making techniques. Regarding this technique, which has been applied in various fields, Romeo, Scnieederjans and Tamiz's studies showed that it had more effective application areas. [19-23]. AHP and GP are used separately as well as they are used together. Table 1 shows the jointly use of AHP-GP. At the same time, for detailed information about the methods, these studies can be reviewed. In the classical formulation, it takes the following form:

Ω: feasible set

X_j : the input variables representing

g_i: goal leves

d_i^-, d_i^-: the positive and the negative deviations

Minimize

$$\sum_{i=1}^{p} d_i^+ + d_i^-$$

Subject to

$$\sum_{j=1}^{n} a_{ij} X_j + d_i^- - d_i^- = g_i, \quad i = 1 \ldots\ldots p \qquad (1)$$

$$X \in \Omega$$

$$d_i^-, d_i^- \geq 0, \qquad i = 1 \ldots p$$

Table 1. Jointly use of AHP -GP in the literature

Author	Year	Method	Decision Problem
Özcan et al. [24]	2017	AHP-GP-TOPSIS	Maintenance planning
Gür et al. [25]	2017	AHP-GP	Transportation planning
Gül and Eren [26]	2017	AHP-GP	Logistics
Wichapa and Khokhajaikiat [27]	2017	Fuzzy AHP-GP	Location selection
Chi [28]	2016	AHP-TOPSIS-GP	Supplier selection
Hamurcu ve Eren [29]	2015	AHP-GP	Transportation
Lin et al. [30]	2015	AHP-GP	Contractor company selection
Memarian et al. [31]	2015	AHP-GP	Water resources management
Ünal and Eren [32]	2015	AHP-GP	Staff scheduling
Özder et al. [33]	2015	TOPSIS-GP	Supplier selection
Karaman and Çerçioğlu [34]	2015	AHP-VIKOR-GP	Investment project selection

Table 2. Alternative projects

Route	Line of Route	Type	Distance (km)	Number of Wagon	Cost (Million US$)				
					Operation and maintenance costs	Km/ maintenance costs	Build+ M&E	Wagon cost	Total
M1	XXX	Monorail1	5,8	26	4	0,71	145	44,1	189
M2	YYY	Monorail2	7,7	33,2	5	0,71	92,4	56,4	149
M3	ZZZ	Monorail1	8,6	33,9	6	0,71	103,2	57,6	161
M4	CCC	Monorail1	3	28,4	2	0,71	36	48,3	84
M5	BBB	Monorail2	11	48,8	7	0,68	132	82,9	214
M6	DDD	Monorail2	3,5	46,3	3	0,73	42	78,7	121
M7	SSS	Monorail	69,3	135	49	0,71	831,6	365,5	1.197

5. Application

In this study, project selection was made for monorail which is an alternative public transportation system planned by Istanbul Metropolitan Municipality in order to improve urban transportation.

The Istanbul Transportation Master Plan was taken into consideration to determinate the alternatives. The planned seven monorail projects and their costs, lengths and number of wagons are shown in Table 2 [35]. The evaluation criteria also are shown in Table 3.

Literature review and expert opinions were used to determine the criteria related to the AHP method. Gerçek et al. [36] used 4 main criteria and 16 sub-criteria to evaluate the rail transportation network for Istanbul. Piantanakulchai [37] evaluated highway routes by using 6 main criteria and 34 sub-criteria. Brunner et al. [38] took into consideration the demographic, social and environmental factors in their analysis made for the determination of public transport routes and selection of station locations.

Table 3. Determined evaulation criteia

Criteria	Sub-criteria	Description
Economy	Constraction cost Operation cost	Includes construction costs of the projects
Environmental impact	Land structure Sensetive area	The impact of the projects on the environment
Social impact	Access to employment areas Access to education areas Population rate Access to housing Accessibility	Improvement of urban transportation
Engineering	Extensible Travel time Integration Demand level	The ensuring sustainability

Kim et al. [39] established a spatial decision support system to identify the most suitable corridor for high-speed trains. Their evaluation criteria were engineering, environment and population. The selection of project is one of the difficult decision processes of managers and transportation planners. In the literature, there are a lot of academic studies about selection of monorail projects [40-42]; selection of transport projects [43-45]; route selection [46-47], determination of mass transport type [48-50].

In Figure 1, the decision hierarchy for weighting of alternatives are shown. The results of the AHP method are given in Table 4. Then, the mathematical model is given, and the solution results are shown in Table 5.

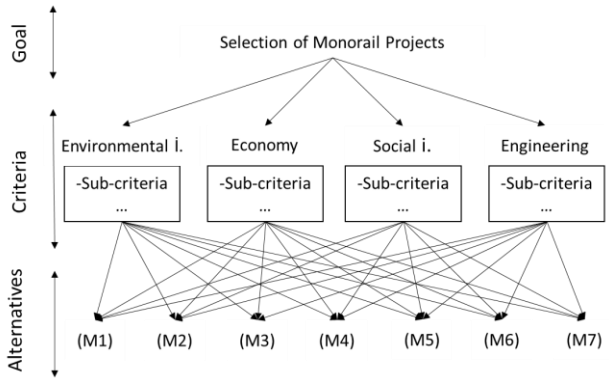

Figure 1. Decision hierarchy for AHP

Table 4. AHP important weights

Projects	The important weights of projects	Ranking
M1	0,1842	4
M2	0,2046	2
M3	0,0731	5
M4	0,1963	3
M5	0,0675	6
M6	0,2514	1
M7	0,0227	7

Goal Programming model:

M_i: Selected monorail projects(I=1,2,…..7)

d_i=deviation variables(d_i^- and d_i^+)

Objective function:

Min Z

$Pl_1 (d_1^- + d_1^+ + d_2^- + d_3^+)$

$Pl_2 (0{,}1842d_4^- + 0{,}2046d_5^- + 0{,}0731d_6^- + 0{,}1963d_7^- + 0{,}0675d_8^- + 0{,}2514d_9^- + 0{,}0227d_{10}^-)$

Constraints:

$189M_1+149M_2+161M_3+84M_4+214M_5+121M_6+1.197M_7+ d_1^- + d_1^+$ =Scenario A-B-C (Constraint of budget)

$5{,}8M_1+7{,}7M_2+8{,}6M_3+3M_4+11M_5+3{,}5M_6+69{,}3M_7+ d_2^- + d_2^+ = 108$ (Access to the farthest distance)

$4M_1+5M_2+6M_3+2M_4+7M_5+3M_6+49M_7+d_3^- + d_3^+=1$ (Minimum operation and maintenance cost)

$M_1 + d_4^- = 1$(Selection of project M_1)

$M_2 + d_5^- = 1$(Selection of project M_2)

$M_3 + d_6^- = 1$(Selection of project M_3)

$M_4 + d_7^- = 1$(Selection of project M_4)

$M_5 + d_8^- = 1$(Selection of project M_5)

$M_6 + d_9^- = 1$(Selection of project M_6)

$M_7 + d_{10}^- = 1$(Selection of project M_7)

$M_1+M_2+M_3+M_4+M_5+M_6+M_7=1$(Selection of only one project)

$M_j = 0$ veya 1; j=1, 2, …7

Table 5. Selected projects

Projects	AHP Ranking	Budget Scenario (Million US $)		
		200	500	5.000
M1	4	---	---	---
M2	2	---	---	---
M3	5	---	---	---
M4	3	x	---	---
M5	6	---	x	x
M6	1	---	---	---
M7	7	---	---	---

Goal programming model is solved with the IBM ILOG program. In Table 5, it is seen that the M4 project is selected under the $ 200 million budget constraint and the M5 project is selected under the $ 5,000 million budget constraints.

6. Conclusions

In the study, the monorail projects planned for Istanbul urban transportation was selected by using AHP and goal programming together. Three budget scenarios were used in the evaluation. These projects was planned for the next years. Urban transportation planning is one of the most important issues of the metropolitan cities.

The importance of urban transportation is emphasized and new projects are put forward to improve the traffic.

Because of inclusion of various factors in the evaluation process and desire to achieve various goals, the analytical models are needed. Within the defined evaluation criteria and constraints, these methods provide appropriate and correct results for the decision makers. For future studies, various decision making methods such as ANP-TOPSIS can be used. Dynamic programming model can be put forward. At the same time, fuzzy logic can be included in the decision process.

Increasing the number of criteria by allowing more projects to be assessed in the same model will also increase sensitivity in taking more beneficial results. Usage of resource is important for public institutes and in the decision process including various constrain. So, in this area analytic models can also be used.

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