GU J Sci 31(2): 381-397 (2018)

Gazi University

Journal of Science

http://dergipark.gov.tr/gujs

Multi-Criteria Evaluation by Means of Using the Analytic Hierarchy Process in Transportation Master Plans: Scenario Selection in the Transportation Master Plan of Ankara

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Article Info

Received: 26/01/2018
Accepted: 26/03/2018

Keywords

Multi-criteria evaluation
Analytic hierarchy process
Transportation planning
Transportation master plan

Abstract

The Transportation Master Plan, includes the processes of producing, election and evaluating process for scenarios that can respond to transportation problems. In this election process, a scenario should be selected by a scientific method as transportation plan from among the determined alternatives. This study explains in details how inter-scenario selection criteria are determined by using the analytic hierarchy process that is a multi-criteria evaluation method in transportation master plan implementation processes. The effectiveness of mathematical model, which is set up in the selection processes, is discussed in particular with respect to the Ankara region and the prospective estimates and results are evaluated depending on the selected alternative.

1. INTRODUCTION

Presently, developing cities face major problems in socio-economic differentiation, education, health and environment in parallel with economic development. Combined with the population growth, increase in the number of vehicles in transportation creates pressure on the transportation systems of cities and threatens the economic progress and individual life quality with its results such as the difficulty in accessing the areas in which social and economic activities of persons are carried out, traffic congestion, traffic accidents, air and noise pollution [1].

Societies are engaging in new zoning activities day by day depending on the level of their socio-economic development. Within this framework, structuring in today's cities also includes the development process of the city and control of the process as subheadings under the title of the city planning. The idea that in planning drafting, development, relationship and location use in the cities does not occur as predicted or fictionalized is often mentioned and policies, methods and strategies for overcoming this problem are discussed in the planning theory [2].

This dissonance between the planning activities and the urban development causes urban focalizations and environmental problems and emphasize the need for priority measures on the protection of the environment to be included in the urban planning discipline. The ever-growing of the environmental problems related to transportation in Turkey, as in the global scale, necessitates practice at every scale the process of urban planning that protects the nature and priorities the environmental effects [3].

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One of the important dimensions of the relationship between planning and environment is the transportation decisions that are developed in order to enable mobility between places depending on forms of land use and change. These transportation and traffic related decisions are subheadings of urban planning and land use [4].

The sustainability policy, which aims social progress and is widely applied in today's policies, also has an effect on planning and transportation policies due to its environmental consequences. Sustainability in transport policies that provides interaction between locations requires the adoption of a variety of policies, investments and practices that are relevant to many types of transportation, especially highway transportation [5].

The selection of a sustainable transport policy starts with a process in which multiple alternatives are created that can solve transportation problems in transportation plans that are integrated with the planning processes. Decisions in the transport policies that are formed by certain concepts and rules play a decisive role in urban development. Accordingly, a sustainable transport system aims to harmonize the necessities of sustainability and development [6]. At the step of preference of these transportation policies, social, economic and environmental parameters come into prominence. Due to these characteristics, the transport systems that are affected by multiple parameters entail a complicated decision-making process [7].

These decision-making processes are availed of when making a selection between the scenarios in the transportation master plans, as it is the case in the step of planning step. [8]. Important decisions on transportation are made as a result of private and public initiatives and has effects on the target area in terms of its social, economic and environmental aspects [9].

In the transportation planning processes, decision-making criteria consist of many different parameters while the financial resources of local and public authorities is a significant restrictor [10]. As a natural consequence of limited resources, institutions and organizations, which support projects capable of solving the transportation problems, are confronted with a decision-making problem that aims to find the most appropriate solution using the least amount of resources. This decision-making problem requires a multi-criteria assessment of all appropriate alternatives with social, economic and environmental criteria in the transportation planning. Practices of multi-dimensional comparison of alternatives by considering multi-criteria are often found in the literature [11].

Transportation projects are mostly widescale and therefore expensive investments. Thus, investments to be made in both intra-urban and inter-city transportation networks require critical and comprehensive decision-making processes. Critical decisions to be made during the planning of new transport systems or during the development of existing transport systems are often selected among from multiple options. The first requirement for proper selection of the type of transportation is to make a comparison among the different options. Multi-criteria evaluation methods such as multi-criteria decision making, multi-criteria decision analysis and multi-attribute decision making are used to evaluate transportation investments as properly as possible [12,13]. The main objective of the multi-criteria decision-making mechanism is to evaluate the preferred general values of the alternatives at an acceptable scale. According to Keyvan-Ekbatani and Cats [14], multi-criteria decision making on transport is naturally necessary. The processes of multi-criteria decision making present decisions of configuration and solution in the planning problems such as transportation plans [15].

One of the prominent approaches in the evaluation process of transportation investment alternatives is the "Multi-Criteria Evaluation (MCE)" method. For example, this evaluation has been used in transportation study in the city of Gaziantep in Turkey and formed the city's transport policy [16]. Another example where the method was used is the practice in Delhi, India, where a suitable transit system was determined in the design of a sustainable transport system. This practice deals with both quantitative and qualitative criteria of multi-criteria approaches in contrast with traditional decision-making processes, which are dependent only on quantitative criteria [17].

Multi-criteria evaluation mechanism includes sequencing and mathematical programming approaches. Sequencing approach is a quite simple, easy to use and plain method. Due to their inclusiveness, it is also widely preferred in the transportation field. Among the sequencing approaches, various methods such as analytic hierarchy, fuzzy sequencing, and multi-criteria sequencing are widely used [18]. The analytic hierarchy process (AHP), first introduced by Thomas L. Saaty in 1977, is one of the multi-criteria decision-making techniques used to solve decision problems [19].

AHP is a mathematical method that can assess qualitative and quantitative variables together in the decision-making process and consider group or individual priorities [20]. The concept in the core of AHP is dividing and synthesis [21]. The main feature of the AHP distinguishing it from other decision-making methods is the evaluation of all quantitative and qualitative decision variables together. Additionally, owing to its easy application, this method increasingly draws interest to itself [22]. In the AHP, the problem is structured hierarchically, and the prioritization follows this process [23]. The AHP is able to divide the problem into detailed layers in a highly efficient manner for decision-making thanks to its hierarchical structure. With AHP, information, experience, individual subjective thoughts and intuitions are put together in a specific logic framework and it is aimed to comprehend the subjective decision-making system and to make better decisions [24].

From a methodological point of view, the AHP is used as a decision-making tool in the processes of determining intra-urban transport policy, as it enables preferences and priorities to be laid and complex problems to be structured in transportation plans [25]. In these decision-making processes, the use of AHP in order to find the best solution among scenarios allows saving time and costs [26].

The AHP is used in areas such as transportation planning [27], traffic planning [28], prioritization of urban transport options, transportation route selection, planning of the most suitable rail system network, light rail system corridor and route selection [29,30]. Except for these application areas, the method is employed to solve problems such as classifying the sustainability of transport investments, evaluating the public transport fee system [31], public transport service quality analysis [32] and prioritization of public transportation companies.

In the following sections of the study, transportation master plan and implementations, how and why transportation plans are passed through which processes, multi-criteria evaluation and the place of multi-criteria decision in transportation planning process and analytic hierarchy process and method of multi-criteria decision are explained, and implementing the mentioned concepts in planning activities is evaluated through the transportation master plan of Ankara.

2. TRANSPORTATION PLANNING PROCESSES AND MULTI-CRITERIA EVALUATION

As a method developed to obtain the predictions of change in the urban transport system, the transport master plan is a long-term project in which investment, regulation and management approaches to transport infrastructure are determined [33,34]. In other words, the transportation master plan is the act of planning the analysis and evaluation of the existing situation in the urban transportation infrastructure [35], the investment, regulation and business approaches [36] and predictions obtained from the formed model [37] in location and time scales, under specific constraints, in order to form and develop the transportation system or to solve the problems by using the optimum structural and practical solution.

In this context, the transportation master plans are employed in situations where there is no high-level planning in the regions or cities and where transportation problems cannot be solved. In addition to being a valuable part of large-scale plans, planning activities in transportation systems also contribute to maintaining social, cultural and economic activities [38]. If the planning activities are not applied in a timely manner, the problems experienced in transportation systems can cause negative consequences such as air and noise pollution, traffic congestion, greenhouse gas emission, social exclusion, accidents and urban sprawl [39]. As a part of large-scale urban planning, the transportation master plans, which have the potential to find solutions to these problems, are now being used as a tool/method at urban, regional and country scales to meet the developments in transportation systems [40]. With this feature, the transportation planning process is a strategic document in which critical decisions are made at national, regional and local scales, beyond being schemes involving important transportation arteries, public transport lines or parking spaces [41].

It is observed that the transportation planning activities, which are performed in order to solve transport problems in urban areas and to predict the future change of the system, has undergone various methodological changes compared to the historical planning activities. The first studies in the field of transportation planning are the road regulation activities carried out in the beginning of the 20th century. As a result of technological and economic development, the increase of motor vehicles and urban transportation mobility has given rise to transport problems. In order to find solutions to these problems, transportation planning studies have focused on household surveys and censuses that have revealed the texture of urban travelling in 1920s and 1930s. In the following years, the cities' increasing transportation mobility, which had increased with the city expansion, was attempted to be solved by way of developing the transportation infrastructure, be the problems caused by city expansion and the increase in the number of vehicles which reinforced each other could not be solved. In the 1950s, with the bringing into use of the US federal fund for urban development [42], new studies were performed as regards transport planning in cities such as Detroit and Chicago. Among these studies, the Detroit Metropolitan Area Traffic Survey the journey investment rate was established on the basis of land use category for each zone and a six-step process involving data collection, forecasting, target identification, preparing the network recommendations, testing proposals, and evaluation stages was attempted. The effects of transportation planning study in Chicago are the same as those in Detroit. These two studies have significantly changed the implementations of transport planning in developed countries, particularly in the USA [43].

With the influence of related studies, with mathematical models using data from field studies in the years 1950-60, it was forecasted that how the changes made at any point in the system affected other points, and future transportation demand. This traditional approach, which forms the basis of transportation planning processes, had the potential to produce more systematic and multivariate results in the 1970s through the integration of mathematical models into computer technology. In today's transportation planning studies, with the influence of technological developments, computer package programs are used frequently [33].

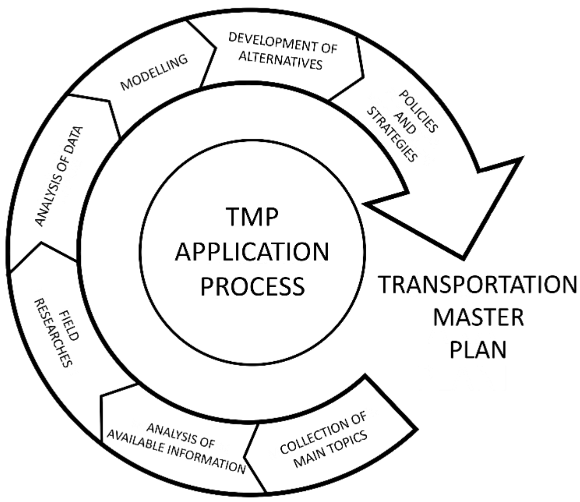

Figure 1. *Implementation processes of transportation master plans*

Within the context of the development of transport planning activities, transportation master plans with large-scale strategic documents include the main topics of collection and analysis of available information, field researches, analysis of data, modeling, development of alternatives and determination of policies / strategies; Figure 1. With the information obtained during the implementation step of the plan, transportation demands and problems / deficiencies are determined for the current and target year.

Scenarios are created by using these evaluations and solution alternatives including scenario-specific goals, objectives, policies and recommendations are developed.

The transportation master plan begins to study with the collecting of available information, including assessments that involve the social, physical, demographic, economic and transportation aspects of the target area [44]. In the process of gathering existing information, a study is started to obtain new information for the data which should be used in planning but not obtained from existing information. This step includes survey studies on transportation in general. Except the surveys, measuring of journey times, pedestrian counting, speed delay and parking survey are other studies that form the data sources. Additionally, in the step of the collection of existing and new information, the digitized current road network must be prepared within the scope of the study if the current network cannot be obtained from the local government. After collecting the data required for the target area, this information is analyzed at the level that will be an input for the journey transportation demand forecasting model. Following this step, the journey transportation demand forecasting model is produced by using computer aided technical software.

Depending on the journey transportation demand forecasting, a four-stage model is established. As the first step, in the generation/attraction models created based on socio-economic parameters, journeys is classified according to their purposes and daily journey calculations are made. Estimated journeys with the generation attraction model are divided between the regions where the journeys are estimated to take place. It is in this manner that the journey prediction model in which the starting and ending matrices are created for each journey purpose is formed. This stage is followed by the development of a type of distinction model which evaluates how many of the estimated voyages between regions are made by which type of vehicles on the basis of the estimated transport infrastructure and vehicle ownership. While these studies continue, the journey matrices are estimated at the end of model studies. In the third step, the urban and intercity freight and transit passenger traffic is transferred to the model in a certain way and the matrix representing these parameters is obtained. All these matrices are loaded on the model with the assignment model of the journey to the relevant road and public transportation network [44]. In the final step, testing and iterations are carried out until the consistency between the model and the desired state is brought to the intended level. This step, also called calibration, prepares the model in order to predict the target year [45].

Socio-economic parameters are projected to the future and loaded into the model and the model is re-run for the target year in order to determine the problems that can be encountered in the target year in advance and to take measures. Large-scale transportation and infrastructure projects that are planned to be completed until the target year are examined with parameters such as target year network, traffic volume, network capacity and public transport capacity, and shortcomings and bottlenecks are determined. In summary, within the scope of the transportation master plan studies in which estimated the transport demands, spatial data processed in the demographic and GIS environment are utilized [46].

Predetermination of expected problems in the target year helps to develop and test different alternatives involving various transportation solutions. In order to overcome the current and future shortcomings and bottlenecks identified in the transportation master plan study, alternative solutions are produced under the scenario name, in which different types of approaches are effective. In order to overcome the current and future shortcomings and bottlenecks identified in the transportation master plan study, alternative solutions are produced under the scenario name, in which different types of approaches are effective [47].

The scenario aims to rationally approach the encountered or potential problems in a city and to develop solution alternatives on the basis of the resource management criterion. Every scenario that is targeted to be realized also produces transportation projects for the approach that it depends on. Due to limited resources, it is possible to select and apply the only one of the developed scenario alternatives. Therefore, a decision-making process must be applied in order to make a choice between the scenarios. The decision-making process, which refers to the process by which a decision maker performs a selection, sequencing or classification within the available options [48], is carried out by decision makers in two ways. The first of these methods is the intuitive decision making which has the potential to produce an effective result in a short time; and the other is a more scientific method, the mathematics-based analytical decision making method. The analytical decisions are preferred not only due to the fact that they have a data-based ground compared to intuitive decisions, but also that they are separable to more meaningful sub-sections in the solution of problems [49]. In analytical decision making, decision makers use mathematics-based methods to develop a decision rule and they ensure defining the decision options, and can scientifically select the scenario among the scenarios or options. Some of the methods used to make mathematical modeling in decision making are simple additive weighting, weighted product, value/benefit function based and pairwise comparative advantage approaches [24, 50]. Table 1 displays the advantages and disadvantages of the mathematical models used in the decision making step in relation to transportation problems.

The solution of the decision problem is usually achieved by comparing and evaluating a number of alternatives [51, 52]. To this end, multi-criteria approaches [53], which have a rich content in defining, designing, and evaluating decision problems [53], can enable multiple measures used in the selection of scenarios to be considered together as harmonious, active and consistent [54].

Table 1. *Mathematical models that is used to solve transportation problems [55]*

Methods	Advantages	Disadvantages
Analytic Hierarchy Process (AHP)	Easy to use; scalable; hierarchy structure of it can easily adapt to problems with many dimensions	Establishing inter-criteria relationships can lead to inconsistencies
Electre	It can take account of the uncertainties	Strong and Weak aspects may not be directly identified
Promethee	Easy to use; it does not require the assumption that the criteria are proportional	It cannot provide a clear method for attributing weight
Smart	It is simple; enables the decision maker to make less effort; it can allow any weighting process	The procedure may not be appropriate given the operational framework

The transport master plan is a strategic document that identifies and predicts the current and future situation of the transport system, taking into account many different variables, and develops and chooses multiple scenarios to solve the encountered or probable problems. As there are multiple parameters affecting the social life in the accommodation unit, there is a necessity to make an evaluation among these parameters when making a choice between the scenarios. The analytic hierarchical approach, which produces successful results for the multi-criteria evaluation problems encountered in different areas, is explained by the mathematical model in the following section and is used as the decision making method in transportation planning in the following section.

3. THE ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP), which shows a rapid increase in the use of the decision theory in recent years, is an alternative to solution of complex problems, it becomes a more preferred method as the number of decision-making criteria increases [56].

The AHP used in the case where the decision hierarchy can be defined contains the following four main steps for the decision problem applied:

1. Structuring the decision problem
2. Pairwise comparison
3. Weight and comparison consistency
4. Addition of weights [57]

The step in which determined the decision points and factors that affect the decision points is a process that the problem is separated to the sub-problems hierarchically, which allows the decision making problem to be more easily understood and evaluated. The AHP allows decision makers to model complex problems in a hierarchical structure depending on the relationship among the main objective of the problem, criteria, sub-criteria and scenarios. Figure 2.

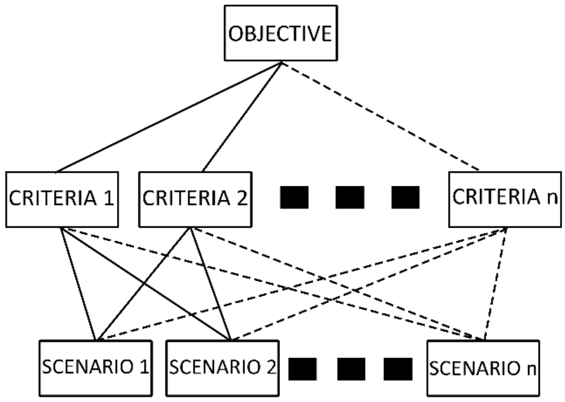

Figure 2. *AHP structure*

The AHP relies on a one-to-one comparison of decision points on a decision hierarchy, using a pre-defined comparison scale, both in decision-affecting factors and in the importance values of decision points in terms of these factors [58]. As a result of this comparison, the importance difference in decision points converts the percentage distribution of decision points [59].

When AHP is used in the decision making process, firstly the criterion, sub-criteria and options that form the problem are determined and the comparison step is started. Following this process, comparative judgments and bilateral comparisons, which are considered the basic and most important processes of the AHP, are determined [24, 60]. The comparative judgment between the scales is made by a survey or interview, preferably face-to-face, with experts directly concerned with the topic under study. Since the data obtained from the AHP depend entirely on the pairwise comparison judgements of the individuals, it should be preferred that these persons are expert in the field or are moderately knowledgeable so that the results are consistent. Depending on the comparison judgements, the superiority, judgement or pairwise comparison matrices are generated in the AHP and through these matrices, judgements are converted into numerical values [61]. The number of rows and columns of the inter-criterion comparison matrix equals the number of criteria, see Equation 1.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

When components are determined in the comparison matrix, the importance scale of the criteria in comparison to each other is used. With this scale, the criteria are compared with each other in the binary system, in such a way that numerical results can be obtained and, the matrix components are determined [62]. The components on the diagonal of the matrix take the value 1 because it contains the result of comparison with the criterion itself [63].

The comparison matrix shows the importance levels of the criteria in comparison to each other within a certain logic. In order to determine the weight of the criteria within the whole, in other words, to determine the percent importance distribution, column vectors constituting the comparison matrix are used and the *B* column vectors with *n* components, *n* being the number of criteria, are formed. While *B* column vectors are obtained, Equation 2 is used.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

The *B* column vectors obtained by dividing each component in the comparison matrix by the sum of the other components in the current column are combined to form a matrix *C* with $n \times n$ dimension. Using the obtained matrix *C*, the percentage distribution of importance, in other words the weight matrix, showing importance levels of the factors in comparison to each other, is obtained. In this step, the arithmetic mean of the line components in the *C* matrix is taken, and the *n* dimensional weight vector, *w*, is calculated using Equation 3. [64].

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \quad (3)$$

The AHP has a consistent systematic in terms of its mathematical model and the consistency of the weight vector obtained is naturally dependent on the consistency of the comparison between the criteria made by the decision maker. Therefore, the consistency ratio (*CR*) is calculated with a mathematical model in which the comparison matrix and the weight vector are used so as to measure the consistency of the comparison ratios [65]. In this step, firstly the *D* column vector is obtained by multiplying the *A* matrix and *w* vector, and thereafter the base value *E* of each criterion is obtained by the division of the corresponding elements of the *D* and *w* column vectors to one another. The arithmetic average of these basic values is used to calculate the basic value of the comparison, λ, and the coherence indicator (*CI*) is obtained using Equation 4.

$$CI = \frac{\lambda - n}{n-1} \quad (4)$$

After the coherence indicator is obtained, the consistency rate (*CR*) is calculated by dividing the coherence indicator by the standard adjustment coefficient, called the random indicator (*RI*), Equation 5. If the ratio obtained is greater than 0.10, the comparison of decision makers is inconsistent and it is necessary to return back to this step [66].

$$CR = \frac{CI}{RI} \quad (5)$$

If the decision makers' assessment is consistent, the comparison of the alternatives step is proceeded with. In this step, the alternatives are evaluated by numeric data according to each criterion, and the numerical values in each criterion are standardized by dividing by the largest data of that line. These values, which are standardized, are converted into a matrix depending on the number of criteria and alternatives. $n \times m$ dimensional matrix *S*, multiply by the weight vector w using Equation 6 and total weight factor ratio, *SR*, for each alternative is obtained.

$$SR_m = \sum_{i=1}^{n} S_{im} w_i \quad (6)$$

The ratio of the total weight factor obtained for each alternative allows the evaluation of alternatives depending on the determinated criteria.

4. DETERMINING THE SCENARIOS IN THE TRANSPORTATION MASTER PLAN OF ANKARA AND THE AHP

The city of Ankara to which AHP is applied in this study is an important junction point intersecting the wheel and rail transport system due to the facts that Ankara is the Turkey's capital city and it is located in the center of the country [67]. Ankara Transportation Master Plan (AUAP), as one of the most important requirements of the Master Plan of The Capital City of Ankara targeting the year 2023, aims to determine Ankara's location and importance in terms of transportation in Turkey, to identify the city's transportation problems by having regard to the metropolitan areas and immediate environment of the city and to secure visioning in order to solve the problems and to direct and manage the investments. The AUAP prepared by the Ankara Metropolitan Municipality’s Department of Transportation and the Gazi University's joint service protocol includes the detailed calculations and the process staging of the transportation plans prepared with scales changing between 1 / 50.000 and 1 / 100.000 in the period of 2013-2038.

The AUAP targeting the year 2028 and visioning 2038, supports the development of the city's metropolitan area in a concentrated structure which is public transportation oriented. In the light of the principle of sustainability, it renders the infrastructural, organizational and fundamental decisions with respect to the transportation system by bearing in mind the present and future transportation behaviors. In this context, the plan establishes an effective and secure urban transport system within the framework of accessibility principle, which prioritizes human mobility instead of vehicle mobility in the context of the sustainability and compositionality principles. Depending on the purpose and vision of the study, there are principles in the plan that focused on integrating land use and transport planning processes in urban transport, prioritizing humans instead of vehicles, prioritizing integrated planning, ensuring social justice, ensuring economic and financial efficiency, and regarding health, safety and environmental impacts. These principles determines the principal objectives in line with principles so as to ensure the development of policies and strategies [68].

The AUAP is to establish a hierarchical model that moves from the main objectives to the sub-objectives and from the sub-objectives to the strategies. After completing the hierarchical process, projection studies are started. Projection calculations in which predictions are made about the future state of the city in terms of its population, vehicle and employment, use different mathematical approaches. These projections are converted into the projection models in order to be used in the scenario. Following the projections which are made respectively on population [69], vehicle [70-71], employment and housing areas, alternative scenarios are envisaged while the transportation model is established.

In the AUAP study, there are two different types of assignment studies one of which includes inputs related to the available data on the existing network while the other includes projections and information with respect to the target year. These assignments are the private vehicles and public transport assignments. Scenario evaluations are produced according to the data obtained from these assignments [72].

Four different scenarios are studied within the plan which are as follows: The current situation scenario (S1) including transportation investments targeting the construction of the transportation network with existing road and public transportation routes, the highway development scenario (S2) involving the existing public transport routes and existing, under construction and future highways, the rail system scenario (S3) involving the existing highway and rail system as well as under construction investments and the mixed system scenario (S4) formed by the proposed railway system network which is integrated into the existing highway and railway system in the transportation network. By using projections and model studies, it is possible to make critical determinations about the four scenarios.

According to the Current Situation Development Scenario (S1), if the transportation system is not intervened, the scenario cannot meet the city's road network transportation demand [68,73]. More investment to the road system become compulsory as the demand cannot be met [71]. If this scenario is chosen, it is seen that there occurs congestion in the urban road network and the quality of service decreases. Besides, even if the use of public transportation increases in proportion to the population projection, the expected number of public transport journeys in the target year cannot be reached.

The Highway Development Scenario (S2) forms the road development model by the potential of the public transportation journey. The new road network, which should be added to meet this potential, also brings environmental problems. Assignment studies made within the scope of this scenario show that private vehicle journeys have increased in time, while public transportation journeys have decreased. The proposed new highway network in this scenario increases the number of private vehicles by creating its own potential and reduces the potential for public transportation passengers. When the highway development scenario is selected, energy consumption and emission levels increase compared to other scenarios.

The Rail System Scenario (S3) aims to increase the number of public transport journeys in the total journeys. In accordance with this purpose, it envisages a transportation plan in which the rail system is upgraded and the wheeled system is enhanced. This transportation planning also includes an optimization study for the rail and wheeled system, in which the assignment results are interpreted on different routes. With the contribution of this optimization study, significant increases in public transport journeys are observed. When this scenario is implemented, important generation-attraction areas within the city are connected to each other, the journey service is provided more comfortably and in a short time, and the number of private cars on the roads where traffic congestion is experienced is decreasing. However, when the results of the assignments are examined, it is established that even though the aim is met in public transport journeys, the problems related to the city's private vehicle traffic cannot be solved.

The Mixed System Scenario (S4) aims to keep the traffic intensity at an acceptable level and advocates that the mutual development of the rail and wheel transportation network is necessary to prevent the increase of the individual vehicle rate. One of the main purposes of the scenario is to expand and increase the use of the public transportation system. The assignment results of this scenario indicate that public transport journeys increase in the city center, public transportation times are shortened, emission levels reduce significantly and volume/capacity ratios decrease. These results directly contribute to reducing energy consumption in the transport system and improving urban transportation and quality of life.

As in other transport planning studies, the AUAP selects a single scenario to be implements due to economic constraints. The AHP (Analytic Hierarchy Process) method, which is one of the multi-criteria decision-making methods, is applied in this step since this selection requires to be preferred one of the scenarios through multi-criteria evaluation.

The AHP method, as stated in the previous section, begins with the step in which the criteria determined in order to make a selection among the alternatives are evaluated by the experts. The plan is assessed according to economic and environmental six criteria, depending on the purposes, objectives, policies and strategies in principle and is established a proportional relationship among the criteria. The criteria in question are cost of journey, cost of investment and access time in terms of economy and air pollution, noise pollution and energy consumption in terms of the environment. In the comparison matrix and weight matrix in which these criteria are compared with each other, the obtained values follow the given order.

The journey and investment costs, which are two of the economic criteria which are taken as basis for the evaluation, are obtained by calculating the consumption of fuel, number of passengers and the access time by using the model which is dependent on projection of each scenario [68]. The highest value in terms of the journey costs is found in the existing development scenario in which the increase in the number of private vehicle and consequently fuel consumption is the highest while the lowest values are found in the mixed system development scenario that reduces fuel consumption and overall transportation costs by successfully attracting the private vehicle passenger to public transport. When scenarios are examined in terms of investment cost, since it does not include any investment decision, the mixed system development scenario comes out with the highest cost since the existing development scenario includes at least both rail and highway proposals together. The access time, which is the third of the economic criteria, is calculated by model assignment results [68]. According to these calculations, the longest access time is in the current situation development scenario in which increase in the number of vehicle and traffic intensity are the highest while the shortest access time is the rail system development scenario, which plans to arrange transport mobility with a railed public transport network.

Air pollution, one of the environmental criteria, is calculated by way of multiplying the distance per vehicle by the emission value produced by the vehicle in question [68]. According to the values obtained by the relevant calculation method, the highest level of air pollution is observed in the highway development scenario and the lowest level is found in the mixed system scenario. Another environmental criterion, noise pollution, is calculated by using the decibel type, which is the sound intensity produced by the vehicle types in the urban traffic [68]. As the result of this calculation, it is seen that the mixed system scenario produces the least noise due to the density of subway system network which is designed underground, while the highway development scenario suggesting wheel transportation solutions produce the most noise. The final criterion used for environmental assessment is the energy consumption. In the process of calculating this criterion, a calculation is made by considering the parameters such as fuel consumption per travel and journey distance of public transportation systems [68]. As the result of this evaluation, it is seen that the most energy consumption is in the rail system scenario and the least consumption is in the current system development scenario.

As a result of the pairwise comparison of the criteria made by the experts, the inter-criterion comparison factor matrix, *A*, is obtained.

$$A = \begin{bmatrix} 1.000 & 1.800 & 0.357 & 0.435 & 2.100 & 2.400 \\ 0.556 & 1.000 & 0.526 & 0.417 & 2.300 & 1.900 \\ 2.800 & 1.900 & 1.000 & 0.526 & 3.200 & 3.200 \\ 2.300 & 2.400 & 1.900 & 1.000 & 3.400 & 2.100 \\ 0.476 & 0.435 & 0.313 & 0.294 & 1.000 & 2.300 \\ 0.417 & 0.526 & 0.313 & 0.476 & 0.435 & 1.000 \end{bmatrix} \tag{7}$$

After obtaining the comparison factor matrix, *B* column vectors are calculated to determine the percent significance of the weights by dividing each component by the sum of the components in its column. The significance percentage distribution, which shows the importance values of the factors in comparison to each other and which is in other words the matrix *C* that will provide the source for the weight matrix, is found by combining the *B* column vectors.

$$C = \begin{bmatrix} 0.132 & 0.223 & 0.081 & 0.138 & 0.169 & 0.186 \\ 0.074 & 0.124 & 0.119 & 0.132 & 0.185 & 0.147 \\ 0.371 & 0.236 & 0.227 & 0.167 & 0.257 & 0.248 \\ 0.305 & 0.298 & 0.431 & 0.318 & 0.273 & 0.163 \\ 0.063 & 0.054 & 0.071 & 0.093 & 0.080 & 0.178 \\ 0.055 & 0.065 & 0.071 & 0.151 & 0.035 & 0.078 \end{bmatrix} \tag{8}$$

In this step, the arithmetic mean of the line components in the *C* matrix is calculated and the weight vector, *w*, is calculated using the Equation 3.

$$w = \begin{bmatrix} 0.155 \\ 0.130 \\ 0.251 \\ 0.298 \\ 0.090 \\ 0.076 \end{bmatrix} \tag{9}$$

Prior to making a final decision about the scenarios, the consistency of the expert opinions, which has been used in the step of calculating the weight of the evaluation criteria, is calculated. When the consistency is calculated, the matrix *A* is multiplied by the vector *w* to obtain the vector *D*, and thereafter the basic value *E*, which is obtained from the division of the corresponding elements of vectors *D* and *w* by each other, is found. By averaging the components of vector *E*, the basic value for comparison, λ, is found, and the consistency ratio is obtained using Equation 4 and Equation 5. The consistency constants related to the answers given by the experts in the step of determination weights of the criteria within the scope of the AUAP are as in Table 2.

Table 2. *Consistency indicator constants*

λ	*CI*	*RI* (constant)	*CR*
6.32	0.06	1.24	0.05

With this result, it is seen that comparison ratios among the criteria are consistent. In this step, the unit costs of each scenario are calculated based on the criteria and these unit costs are standardized according to the highest cost in the criterion line, Table 3.

Standardization is used to find the total weights of the scenarios by putting into calculation the standardized scenario costs with the weight vector. The total weight factor ratio, *SR*, for each alternative is obtained by multiplying the standardization matrix and the weight vector by using Equation 6, see Table 4.

Table 3. *Standardized scenario costs*

	S1	S2	S3	S4
Journey Cost	0.99	1.00	0.87	0.84
Investment Cost	0.00	0.18	0.85	1.00
Access Time	1.00	0.88	0.40	0.42
Air Pollution	0.95	1.00	0.80	0.63
Noise Pollution	0.97	1.00	0.64	0.54
Energy Consumption	0.93	0.94	1.00	0.96

Table 4. *Total weight factor ratio for the scenarios*

	S1	S2	S3	S4
SR	0.84	0.84	0.73	0.67

The AHP method used in the scenario selection of the AUAP provides an evaluation according to the criteria of journey cost, investment cost and access time, air pollution, noise pollution and energy consumption for Ankara city. When the results of these evaluations are examined, it is seen that the economic criteria are more dominant in decision making than the environmental criteria and the mixed development scenario is less costly in total and preferable than the other scenarios. Besides, as a natural reflection of air pollution and traffic congestion caused by private vehicle ownership, which is one of the major problems in the city's existing transport system, the weight of air pollution and access time take a dominant role in comparison to the other criteria [68].

5. CONCLUSION

Transportation planning studies are being used more and more every day in order to produce a high-scale solution to increasing urban transportation problems in developed and developing countries. In order to overcome the decision-making problems encountered in these transportation planning processes, it is necessary to develop techniques that enable selection in decision-making mechanisms in which multi-criteria play a decisive role. Based on quantitative and qualitative criteria, the AHP method, which can manage this decision-making process, can be used in the areas of transportation and transportation planning in which expert opinions and experiences are often availed of. The AHP, which is one of the methods that can be used to compare alternatives in transportation planning, is examined in detail in the scope of the study and it is applied in the selection of the AUAP scenario. The results show that the most appropriate alternative to the economic and environmental criteria is selected in line with the principal objectives of the transportation master plan.

ACKNOWLEDGMENTS

The authors would like to extend their thanks the editors, referees and industrial experts for their valuable contributions to the present study. This study was supported by the data of the Project on the Transportation Master Plan of the Ankara Metropolitan Area and Its Immediate Surroundings carried out between March 5, 2013 and May 30, 2014 on the basis of the agreement signed between Ankara Metropolitan Municipality and Gazi University.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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