Developing A Priority–Based Decision Making Mod To Evaluate Geometric Configuration Of Urban Interchanges

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Abstract

The present article involves in evaluation and engineering judgment of various geometric configurations for highway interchanges by considering substantial parameters over the discretion process. The geometric, economical and architectural criteria as the fundamental indicators are divided into related sub-indicators and the total combinations of such sub-elements from the general criterion for establishment of decision making process. Hence, this article deals with geometric configuration analysis of interchanges as a complex decision problem by the use of analytic hierarchy process (AHP) which is a structured technique to analyze complicated engineering systems. By considering an interchange as a case study in north of Tehran, the capital of Iran, the performance of the proposed method has been examined in order to select the most suitable type of interchange by forming the evaluation process of AHP and taking into account the given design and construction data. a wide range of notorious criteria and desired prerequisites are available. Owing to established the AHP model and perform the decision-making method, the Expert Choice analytical software has been utilized. The evaluation results are determined in terms of priorities for various options and their decision weights in the case study. However the presented model is able to be applied for other cases and different alternatives. As a tentative finding, using directional pattern for the case example of current work has been the optimum variant rather than parallel alternatives i.e. semi-directional and loop schemes.

Keywords: Interchange, criteria, configuration, AHP, decision making

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1. Introduction

The main purpose for construction of interchanges is to form the required accessibilities to various directions where the vehicles can move in safe conditions. In the field of road transport, an interchange is a road junction that typically uses grade separation, and one or more ramps, to permit traffic on at least one highway to pass through the junction without directly crossing any other traffic streams. Interchanges are almost used when at least one of the roads is a controlled-access highway, though they may occasionally be used at junctions between two surface streets. Construction of interchanges with different levels is probably the best way and of course the most expensive solution (Only from initial construction cost viewpoint) for traffic passage in intersecting directions. Due to increasing traffic condition of in level crossings and existent rate of accidents and also wasting the time of drivers, the necessity to establish interchanges is increasingly felt [AASHTO, 2011].

These days, especially in big cities, it is common to make grade separated interchanges instead of level-crossings and the costs are justifiable. Therefore, it is essential to know efficacious factors in terms of technical and economical ones to have better judgment about different types of interchanges. By taking engineering prospective into account and looking over the examples is being experienced by designers around the world , generally it can be predicted that safety and convenience of the passengers, aesthetic and geometric configuration, construction aspects etc. can help designers to choose the most suitable types of interchanges. It is usual, but not always the optimum option to choose the cheapest type of interchange system and designers has to consider all of influential parameters for judgment. Applying decision-making methods for evaluation of various configuration systems for urban interchanges is one of important concerns for designers, managers, contractors and related authorities in urban organizations consulting engineers companies. Increasing the numbers of interchanges, high costs of construction and necessity of optimization in civil design projects have obliged experts pay attention to such evaluation methods. Geometrical configuration of an interchange has a lot of effect upon its performance and suitable design with optimum characteristics can improve their operation. [Iranian Highway Design Leaflet 415, 2012, Urban Design Manual, 2001]

A complete interchange has enough ramps to provide access from any direction of any road in the junction to any direction of any other road in the junction. A complete interchange between two freeways normally requires eight ramps, while a complete interchange between a freeway and another road requires at least four ramps. Depending on the interchange type and various needs for providing connectivity among the lines other numbers of ramps may be used. For example, if a highway intersects with another highway containing a collector/express system, additional ramps can be used to strictly link the interchanging highway with the collector and express lanes respectively. By considering the geometric configuration, four-way interchanges, can be divided into the following types: [AASHTO 2011]

- Stack (Directional) interchange
- Cloverstack/ full cloverleaf interchange
- Turbine interchange (four-level stack interchange)
- Roundabout interchange (ramps meet at a roundabout)
- Other/hybrid interchanges (mixture of interchange types)

In this article, by taking various geometric schemes for the typical four-way interchanges into account, much effort has been carried out to present a suitable methodology of multi criterion decision- making process to find the most suitable alternative for geometric configuration of urban interchanges. Hence the main objective in this research is inclusion of the most substantial parameters for comparison of grade separated crossings (interchange hereinafter).

By considering one interchange as a case study in north of Tehran, after determination of effective factors in the decision- making approach, the parameters have been obtained in terms of qualitative and qualitative measurement criteria and their weights have been examined. By use of Expert Choice Software, all acquired data have been imported into a database for overall analysis of the alternatives and determine their priority for different choices. Finally the most suitable choice has been extracted from the hierarchical procedure. An example of highway interchange is employed to demonstrate how to use the proposed method.

2. Selection of the Optimum Interchange

Review over the history and background of current work shows that many researchers have been dealing with various design aspects of urban interchanges. In majority of previous works, various geometric configurations for the interchanges are studies based on traffic and capacity of the crossing roads [Stanek, 2009, Stout, 2008], while in some other cases, the correspondence of different topologies for geometry of interchanges evaluated and controlled by instructions in design codes and manuals. Results related to performance of various types of interchanges from an experiential point of view are also reported by Leisch, 2007. Fang et al (2005) studied specific traffic simulators in terms of their capabilities for simulating single urban point interchanges and diamond interchanges. They focused on identifying the elements that should be available in a simulator in order to evaluate a specific interchange scenario (including type, geometry, and traffic control characteristics). To accomplish this, three traffic simulators were selected by them and available data from two sample interchanges were obtained and used in the assessment of these packages.

Songa et al (1999), reported a brief introduction of diamond interchange of China and USA and compared their effectiveness. The study also focused on the discussion on the characteristics and applicability of Chinese diamond interchange. These studies mostly have dealt with the traffic and operation phenomenon in the interchange and do not consider other substantial features. Loulizi et al (2011) identified that sophisticated techniques including travel demand forecasting, microscopic traffic simulation, and evaluation of alternatives are needed to assure that a selected project is optimal. They presented a methodology to evaluate urban interchanges in developing countries which are built to replace saturated signalized intersections. The procedure was demonstrated to be easily implementable and cost-effective. This study is similarly focused only on traffic concept resolution.

There are several investigations in the literature which deal with interchange types from project management point of view. Wu et al (2009), recognized Interchange type classification as a nonlinear system. They introduced a nonlinear mapping analysis to study the process of classification by multiple attributes which express the characteristics of interchange project were directly mapped into two comprehensive indexes by data processing system. They recommend their method for its clear modeling, tangible physical significance and objective and effective judgment. Comprehensive evaluation method for interchange design scheme was built by Lin et al (2008) based on projection pursuit technique. They determined the index objective weights result directly from sample data of candidate schemes and real coding based on Accelerating Genetic Algorithm, which can deal with global optimization problem with various restriction conditions effectively. By model optimization they looked for the optimal projection directional vector. These works were mostly concentrated on project optimization and are not applicable for optimum selection of interchanges.

Some investigations focused more on the basis of urban traffic matters and overall network planning visions to evaluate interchange types. A methodology for the type selection of interchanges at expressway network planning stage was proposed by Zhao et al (2006). They considered 25 typical interchanges to be the objects of the analysis and then with the cluster analysis, all criteria analyzed for the classification. Based on the results of the cluster analysis, the 25 commonly used interchanges were classified into 6 classes, and the interchanges in each class had similar characteristics and application conditions. With the classification results, this methodology was applied in the Expressway Network Planning of one new case study for checking the applicability and practicability. Sun et al (2007), accomplished a thorough study on the outer belt freeway’s layout of a case study in China, based on the research on planning and layout of Chongqing belt freeway interchange. They proposed some opinions and proposals about several key technologies for layout planning in highway interchanges. In another work, Yang et al (2002) proposed an index system of synthetic evaluation for highway interchange plans through the synthetic analysis of the design, the construction and the using of interchanges. They established a model for fuzzy synthetic evaluation of interchange plans and then the method for practical fuzzy synthetic evaluation of interchange plans is given to choose the better or the best choice for interchange. These methods were mostly about urban planning matters with less notice to other criteria.

Taking only the economical criteria into account for evaluation of different types of interchanges, Cribbins et al (1995), examined the economical effects of controlled-access facilities in interchanges on surrounding property value. They employed techniques to isolate economical influence of highways include the use of the before-and-after method in combination with a multiple regression analysis for each period. Three case studies were chosen for investigation to estimate the influence of these facilities associated with the highway interchange construction. Land value, which is selected as the indicator of economical influence, is determined by obtaining sales prices for parcels sold in the study periods. The effects of non-highway and highway variables are estimated by utilizing a multiple regression analysis. They proved that the average unit price of property increased significantly within all sites. However, the results are established only by considering economical features.

A comprehensive and well known research as one of the most related topics to the current work, the evaluation methodology for selection of an interchange configuration presented by Mulinazzi et al (1973). They divided the evaluation process into four parts: 1) scrutinize the evaluation criteria to determine which ones are relevant; 2) estimate the initial cost of each reasonable alternative interchange design; 3) develop an effectiveness profile for each such alternative design; and 4) compare the initial cost and the effectiveness profile for each alternative design and then select an interchange configuration. They recognized specified effectiveness profile for each alternative interchange design which was is a graphical technique to show each alternative’s effectiveness rating for every evaluation criterion. It is based on the cost effectiveness approach of economical analysis and is the accumulation of several cost-effectiveness plots into a single graph. Finally they analyzed the initial cost and the effectiveness profile for each alternative interchange configuration. In the current study more economical indicators are employed for the analysis and the analysis is more comprehensive in terms of number of indicators together with their evaluation method.

Relatively similar to previous investigation, Nicholas et al (1999) developed guidelines to aid highway designers in the preliminary selection of the optimum interchange type at a location. In these guidelines, a number of sources were used to develop the guidelines. A literature survey of state engineers helped determine the methods for interchange selection. These surveys also assisted in determining the relative advantages and disadvantages of the various interchange types. Also, 10 interchanges throughout Virginia were studied in order to find their operational and safety characteristics. Extensive computer simulations of the interchange types were performed in order to determine traffic characteristics that affected operations at the interchanges. Based on all of these sources, some general guidelines for preliminary interchange type selection were created. There are also some findings in connection with various strategies for design of left-turns in the interchanges. Researches by Monajjem et al., 2011, Hadiyan, 2008, are some cases on this point. Investigating the effects of various factors on left-turn selection and their comparison are considered in these references. This study in contrast, is more applicable for the whole body of an interchange. Considering main features of the mentioned studies especially in connection with Mulinazzi et al (1973) and Nicholas et al (1999), the necessity of current research can be justified by following implications:

- Considering all the effective parameters into decision process, i.e. geometric, economical and architectural criteria. It should be noted that previous studies mostly focused on one or several specific items. Even for the case of Nicholas et al (1999), assumed criteria for decision are not comprehensive.
- Applying the knowledge and experience of interchange designers to propose well-matched design alternatives for the case study to establish selection process on well-defined variants. That is also noticeable that that the geometric design of all alternatives vigorously defined according to well established standards.
- Making comparison between geometric configurations of the whole body of an interchange system instead of concentrating only on specific or particular elements like left-turns, right-turns etc.
- Establishing integration and coherence between effective criteria in design of interchanges by distinguishing their priority level and effectiveness.
- Concentrating upon whole configuration of interchange in traffic acquisition analysis while overall traffic statistics for all routs of the interchange is considered.
- Utilizing engineering judgment to transfer all qualitative parameters as the quantitative ones. It is worth noting that all substantial criteria for the final decision are weighted and considered during the analysis.

- Importing all effective parameters into one overall database to perform decision-making plan.
- And finally utilizing an AHP based processor (Expert Choice) to evaluate the data and present the results in terms of priority levels, dynamic outputs and sensitivity degree for the items.

3. Methodology of Optimum Configuration Selection

Multiple-criteria decision-making or multiple-criteria decision method (MCDM hereinafter) is a sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments. Cost and quality are usually among the main criteria. Some measures for the quality of interchanges are typically in conflict with the cost measure. Well structuring of complex problems and considering multiple criteria explicitly, leads to more informed and better decisions. The difficulty of the problem originates from the presence of more than one criterion. There is no longer a unique optimal solution to an MCDM problem that can be obtained without incorporating preference information. The concept of an optimal solution is often replaced by the set of non-dominated solutions. This solution method has this important advantage that through the evaluation process, it is not possible to move away or sacrifice one criterion relative to other criteria which are important for the final decision. Therefore, it makes sense for the decision maker to choose a solution even from the non-dominated set. [Saaty, 2011, 2012].

There have been important advances in this field since the start of the modern multiple criteria decision making discipline in the early 1960s. A variety of approaches and methods, many implemented by specialized decision-making software, [EC, 2004], have been developed.

The Analytic Hierarchy Process (AHP hereinafter), while can be used by individuals working on straightforward decisions, is the most useful method where many criteria are investigated in complex problems, especially those with high coherence and relation between sub-criteria , involving human judgments and qualitative parameters, whose resolutions have long-term repercussions. [Saaty, 2011, 2012].

The problem of selecting the optimum alternative for the geometric configuration of interchange shall be regarded as one of the complex problems since there are many parameters which may have effect over the final decision. Therefore, in this article MCDM strategy and AHP method has been used for comparison and evaluation of various types of interchanges.

The overall procedure in this study includes several steps, namely the problem definition, search for substantial criteria, recognition of relations between indicators, AHP model establishment, specification of alternatives, analysis of the problem, evaluation of alternatives and final optimum selection. The procedure was tested on a case study where four interchange variants were proposed to a particular location in Iran. Thanks to the help from one consulting engineers company, all alternatives were preliminary designed by experienced designers in order to predict the feasible variants for construction. Once the key specifications for all alternatives were obtained, the analytic hierarchy process was used to select the best alternative among the four retained ones. AHP technique shows each alternative's effectiveness rating for every evaluation criterion.

3.1 Recognition of Effective Parameters for Decision Making Procedure

Selection of pertinent evaluation criteria is fundamental to the evaluation methodology in this research. The criteria chosen should measure differences between the alternative interchange designs. Generally speaking if no such criteria exist, then there is no difference between the alternative designs and the interchange configuration with the lowest initial cost should be selected. So the initial costs together with some other economical factors were used as the cost indicator for each alternative interchange design. A review over the literature shows following items as the key indicators for previous studies:

- The capacities, design speeds, complexities, areas required and costs of these interchanges were considered by Zhao et al (2006).
- Fang et al (2005), identified four elements as critical in simulating interchange types: (1) the capability of representation of specific geometric characteristics; (2) the capability of simulating specific signal control plans; (3) calibration needs and accuracy in comparison to field conditions and (4) the extraction of specific performance measures from the traffic simulator.
- Songa et al (1999), analyzed and compared these two interchanges for operation performance in terms of their geometry characteristics, traffic signal control and safety implication.
- Sun et al (2007), considered layout planning, grade, technical condition, type and network plan as the key indicators for the comparison of interchanges.
- Initial construction cost and land value together with some technical features in terms of travel time, fuel consumption, safety, and environmental impacts were chosen by Mulinazzi et al (1973).
- Nicholas et al (1999) considered not only projected traffic data, right-of-way needs, environmental concerns, safety, project costs but also reaching reduced costs, improved levels of service, and increased uniformity as the key indicators.

Selected objects in the current work cover relatively all of the indicators which are introduced in the literature. The main criteria and sub-criteria for comparison of geometric scheme in the interchanges in this study are shown in Figure 1. As can be seen in this figure, the most important factors for comparison of interchanges are divided to three categories i.e. geometric, economical and architectural criteria which any of them has some several sub-criteria in behind.

By technical criteria as the main geometric indicator, different topologies for geometry of interchanges evaluated. All of the technical indicators are measurable and can be represented by particular values. Economical criterion is the second category of indicators in this research. The economical criterion was selected here includes some of the uncertainties associated with the calculation of road-user costs. By the way the results of one case study are used as an example in this research. Several estimative criteria are also combined and named as aesthetic criterion as the third category of indicators.

Safety as one of the important indicators (as considered by Mulinazzi et al (1973), Nicholas et al (1999) and Songa et al (1999)), is considered indirectly in this research. Total length of conflict or weaving traffic in connectors has been considered as a sub-criterion for geometric design indicator (see Table 1) in which the safety in operation can indirectly be addressed. Other geometric specifications like radius of curves and design speed are indirectly related to safety issues in performance of interchange. In order to apply long-time serviceability of the interchanges, a sub-criterion namely maintenance cost has been employed for the economical indicator (see Table 1) by which life cycle benefits can be addressed. The brief abbreviation for any criteria which is illustrated in the figure has been used hereinafter.

3.2 Establishment of the AHP Model

The hierarchical process for the decision making goal among possible options in configuration of interchanges is including different levels that are shown in the diagram of Figure 2. As can be seen there, the first level of hierarchical process is the main purpose of the

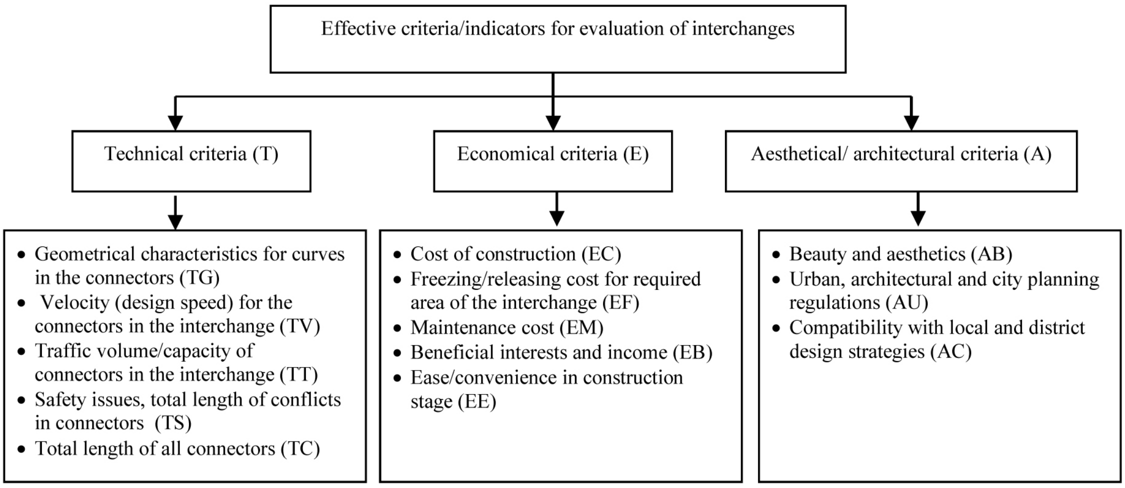

Figure 1. Substantial criteria/indicators and their sub-criteria in comparison to various types of interchanges

analysis which is preparing the optimum decision for the problem. After distinction of main criteria, the authors recognized several sub-criteria as the second layer beneath the main parameters and then established the AHP algorithm. Hence the level two of the AHP process is recognition of the effective factors on decision- making process (technical, economical and aesthetical indicators) together with their sub-indicators (totally 12 items as TG, TV etc.). Definition of the main sub-criteria is according to Figure 1. The last level of hierarchy is the possible options (alternatives) for the configuration of the interchange which shall be determined specifically for any highway interchange. In this diagram four alternatives have been considered as the options for the selected case study.

3.3 Recognition of Qualitative and Quantitative Parameters

Distinction between qualitative and quantitative parameters is an essential part of decision- making problem. The method for determination of equivalent weights for qualitative/descriptive parameters has important effect on the final results of AHP problem. As can be seen in various sub-indicators of Figure 1, it is not possible to evaluate all parameters with quantitative factors. Owing to this end, relative importance and weight relevant to each parameter has been determined using two general procedures:

- Quantitative calculation for the items which can be measured by specific values
- Qualitative estimation by using questionnaires for the items which cannot be measured by particular values

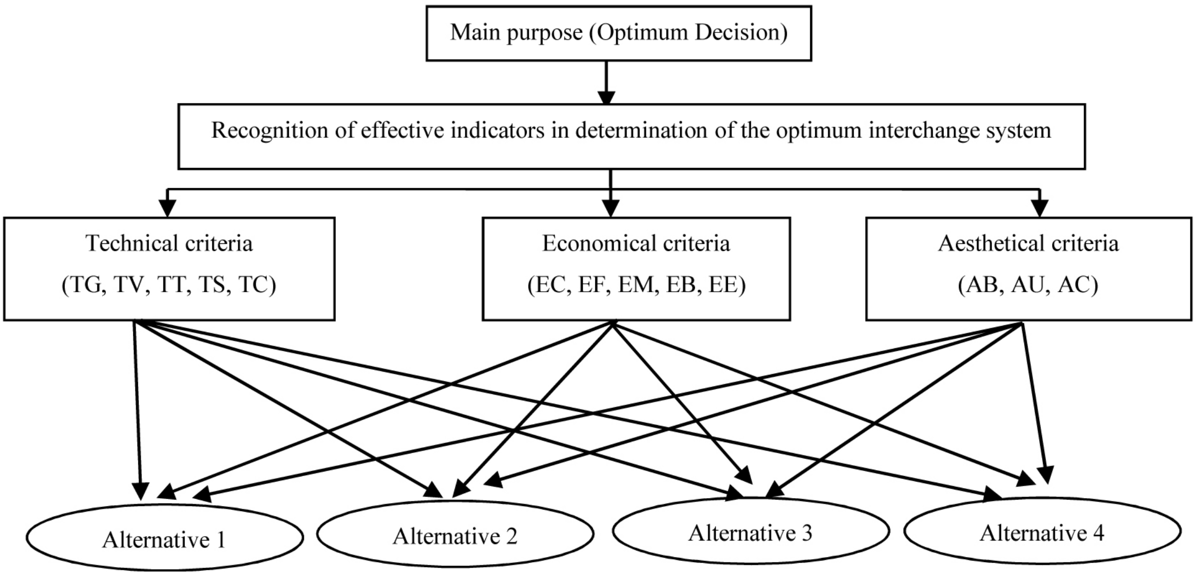

Figure 2. Hierarchical model for evaluation of possible options in interchange configuration

The results of comparison for all estimative criteria in this work were obtained by engineering judgment through questionnaire gathering process.

In this research some factors including velocity, traffic volume, geometrical characteristics etc., are measurable in quantitative form. Therefore they have been determined by numeric values for the case study. Some other factors including aesthetical and environmental conditions are not measurable by means of numerical quantities. Hence the people's judgment methodology has been employed for them. In the other word, in order to find equivalent quantities for these parameters, people's judgments (experts and professional engineers in this field) have been considered to reach the qualitative priority of the factors by converting the results of descriptive estimation to quantitative forms. [Razi, 2010, Monajjem et al., 2011].

Once needed for any of the estimative parameters, several professional highway designers at Hexa consulting Engineers, Iran, contributed for filling the judgment questionnaires. The general method for one of the estimative parameters is explained in section 5.3 and similar procedure is utilized for the others.

3.3 Steps of the AHP Methodology

Figure 3, is presenting the general algorithm of AHP method which is being employed in this research for evaluating the various types of interchanges and recognizing the optimum case. Based on this chart, the prerequisite quantities in AHP analysis have been extracted in the first layers and after description of coherence between parameters, the analytical process has been established in the middle part and finally evaluation of different geometric variants of interchanges has been appraised at the end. The model parameters and assumptions are described for each indicator in the following sections.

4. Case Study

The methodology of AHP evaluation must be applied on objective cases and examples with clear and visible specifications to calculate numerical weights and priorities. This is due to the natural and intrinsic basis of the AHP approach. In order to determine the final alternatives for the problem and find the priority of all effective indicators in the analysis, the algorithm of Figure 3, has been implemented upon one case study in North-East of Tehran, Iran. The urban interchange between Shahid Zeinoddin and ImamAli highways in Tehran has been selected due to the availability of required data for the analysis and also enough area/ space for construction of various alternatives for interchange without any limitation or restriction. All of the initial data for this study has been prepared by Hexa CE, 2010 and Tehran Traffic, 2008. The statistical traffic volume of all the directions in peak hour for this interchange is reported according to the information received by Tehran Municipality

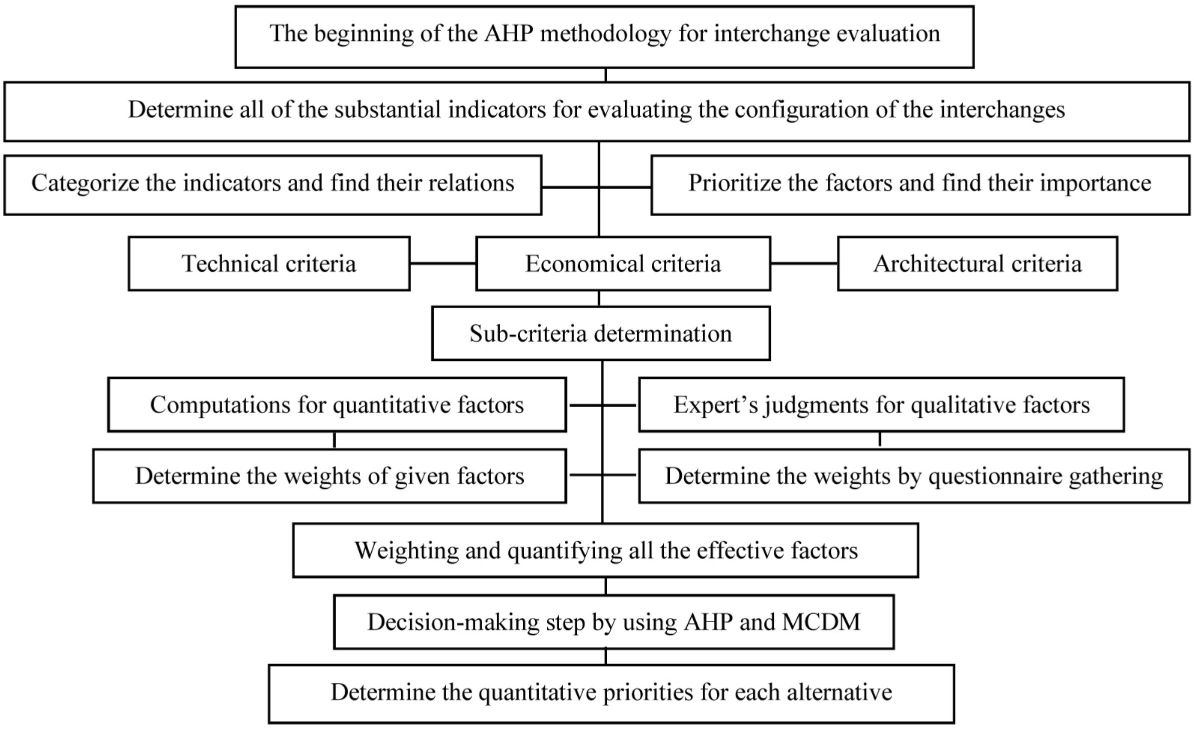

Figure 3. The general algorithm of AHP method for evaluating various types of interchanges

Comprehensive Traffic Studies Company. The amount of traffic volumes for period of 7:30 A.M. to 8:30 A.M. can be observed in Figure 4. An aerial photo of the existing situation in this interchange is also presented in this figure.

4.1 Alternatives for the Case Study

In order to determine the components of the last layer in AHP model, (See Figure 3) possible and feasible alternatives for the interchange's geometric design configuration in this case study have to be specified. As can be

Figure 4. Shahid Zeinoddin – ImamAli interchange, Left: Traffic distribution statistics, Right: Aerial photo of the existing situation [Hexa CE, 2010]

seen in Figure 4, (right), the interchange in the existing status has an arrangement of four cloverleaf or complete cloverleaf patterns. According to the design studies by the consulting engineers company, except for the existing scheme, several other alternatives for geometric configuration of this interchange can be considered. [Hexa CE, 2010]. Therefore the main options for the configuration of this interchange can be sown as the alternatives in Figure 5. In order to manifest the specification of these four alternatives, a preliminary geometric design has been accomplished for them by means of well-established standards and experienced highway interchange designers. [Razi, 2010]. AASHTO 2011, Leaflet 415, 2012 (Iranian code mainly based on AASHTO with some calibration for Iran) and Urban design manual, 2001 are employed as the main references by which the design process accomplished and the key specifications for the alternatives were obtained. Schematic configuration of these feasible alternatives depicted in Figure 5.

5. Establishment of Matrices at Different Levels

As the general style of AHP approach, the pair

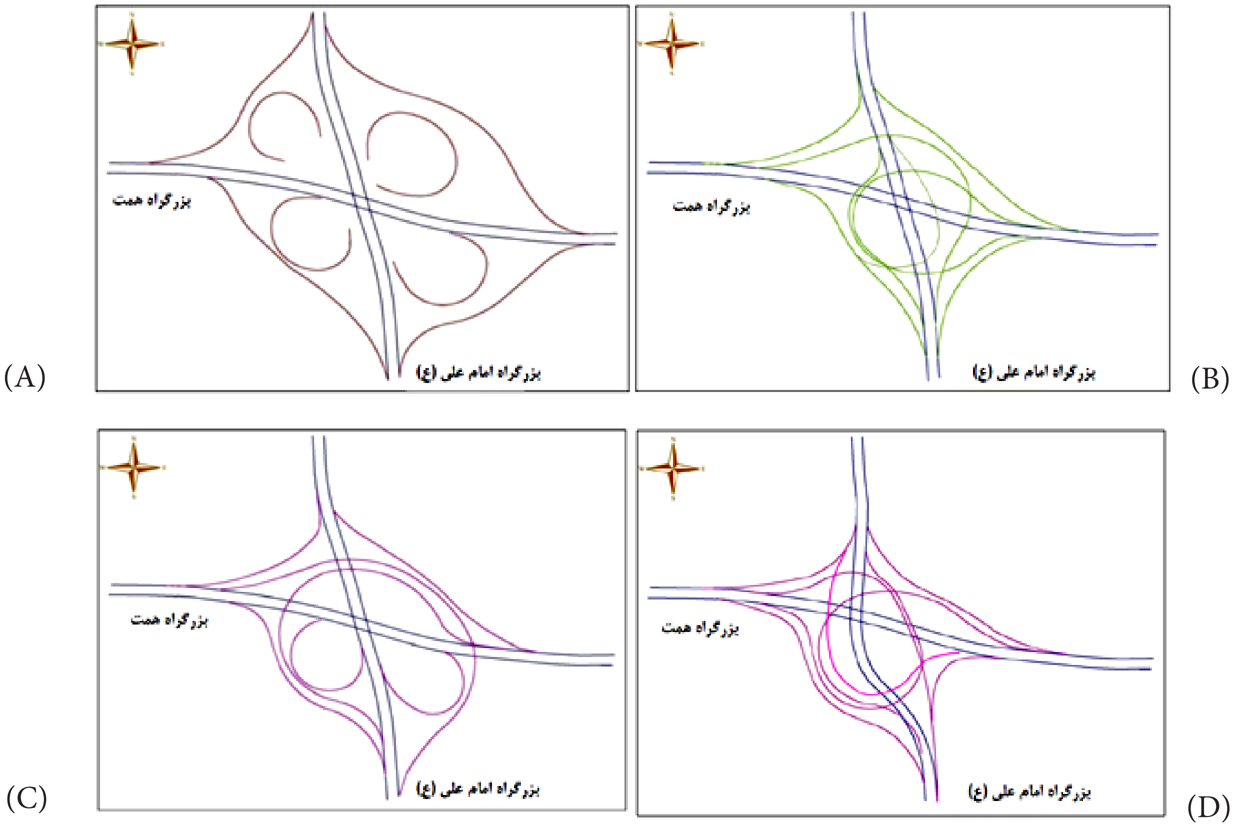

Figure 5. Four feasible alternatives for geometric configuration of the interchange (ImamAli-Shahid Zeinoddin)

A) Full cloverleaf sketch- existing state, B) Semi-directional sketch

C) Semi-directional, semi-cloverleaf sketch D) Full directional sketch comparative matrices in different levels of the problem are to be determined step by step. This evaluation is performed over the four variants in the case study and comparative results presented in the following sections:

5.1 Evaluation of Technical Criteria

Owing to determine the priorities of various alternatives regarding to the technical criteria (See sub-indicators in Figure 1), geometrical specifications for the alternatives has been extracted based on their preliminary design. The summary of technical characteristics of the alternatives in the case study is presented in Table 1.

Evaluation of the options in regard to technical criteria is performed by applying following approaches and assumptions:

- TG, TV, TT, TS, TC are defined in Figure 1.
- Geometrical design factor (TG) has been obtained by combination of curve radii in the connectors. In order to find a suitable indicator for comparison, average value for all curves in connectors were considered. For this parameter the total number of curves in the connectors was regarded and the average radius of curves determined.
- For the velocity parameter (TV), by considering the indicative charts for correlation between speed-radius and super-elevation in connectors, [AASHTO, 2011], corresponding values for the speed are determined and then the average design speed for the whole connectors has been determined. This index has been determined for all variants and reported in Table 1.
- In order to obtain traffic volumes in the connectors (as the TT index in the geometric criterion in Figure 1), correlation tables for speed-capacity relations in connectors [AASHTO, 2011], have been employed. These tables are obtained based on sophisticated equations for traffic volume in connectors and can be applied as a simplified method to determine equivalent traffic volume (p.c.v/h) for any assumed speed. Then the volumes for all connectors have been added up and the total traffic index is determined in Table 1.
- In order to determine the amount of weaving length in connectors (as the TS sub-indicator), the overall length of connectors with waving traffic situation has been considered. Then the distances are added up to reach the total length

Table 1. Characteristic specifications of different alternatives (in regard to technical criteria)

Alt. No.	Abbreviation Explanation	TG Geometric radius of curves in connectors (m)	TV Average design velocity of in connectors (km/h)	TT Total traffic volume in connectors (p.c.v/h)	TS Total length of conflict (Safety) in connector (m)	TC Total length of all connectors (m)
1	Full cloverleaf	53	46.00	10440	280	2467
2	Semi-directional	116	68.02	12060	153	825
3	Semi-directional-cloverleaf	92	60.68	12440	229	1173
4	Full directional	145	76.05	13600	142	785

of conflicts in all variants.

- To achieve the last parameter (total length of all connectors as the TC), total values of connector's lengths are added up.
- These indexes separately determined for all variants and reported in Table 1.

By applying above comparative analysis, the third level matrices relating to the technical criteria can be written as the Table 2. Any array value in the matrices is obtained by dividing corresponding values of two pair alternatives.

As an example, the array value which is located in the second row and third column of TG matrix (2.19), is counted by dividing the quantity of 116 over 53 as the corresponding values for alternative 2 and 1 respectively. The rest of arrays are counted similarly.

An important point which is noticeable in Table 2 is the remarks + and – for the sub indicators TG, TV, TT, TS, TC. These remarks show the increasing/descending rate of priority value against the indicators for any variant. As indicated in this table, all indicators beside TS have only one remark (+ or –). For the TS indicator the inverse matrix is also calculated and written in the table. The reason is that for the TS indicator, the objective behavior of the model is in the reverse manner. This means that if any alternative has a lower value in total length of conflict, it physically has better safety condition. That is why the value is inversed in the tables. For the other parameters, the physical behavior is correspondent to the changing rate of values. Therefor the original matrices are being used.

5.2 Evaluation of Economical Criteria (Quantitative indicators)

It should be noted that in this part of the re-

Table 2. The pair comparison matrices for different alternatives regarding to geometrical criteria (TG, TV, TT, TS, TC)

		Alt.1	Alt.2	Alt.3	Alt.4
	TG(+)	53	116	92	145
Alt.1	53	1.00	2.19	1.74	2.74
Alt.2	116	0.46	1.00	0.79	1.25
Alt.3	92	0.58	1.26	1.00	1.58
Alt.4	145	0.37	0.80	0.63	1.00

		Alt.1	Alt.2	Alt.3	Alt.4
	TV(+)	46.00	68.02	60.68	76.05
Alt.1	46.00	1.00	1.48	1.32	1.65
Alt.2	68.02	0.68	1.00	0.89	1.12
Alt.3	60.68	0.76	1.12	1.00	1.25
Alt.4	76.05	0.60	0.89	0.80	1.00

		Alt.1	Alt.2	Alt.3	Alt.4
	TT(+)	10440	12060	12440	13600
Alt.1	10440	1.00	1.16	1.19	1.30
Alt.2	12060	0.87	1.00	1.03	1.13
Alt.3	12440	0.84	0.97	1.00	1.09
Alt.4	13600	0.77	0.89	0.91	1.00

		Alt.1	Alt.2	Alt.3	Alt.4
	TS(-)	280	153	229	142
Alt.1	280	1.00	0.55	0.82	0.51
Alt.2	153	1.83	1.00	1.50	0.93
Alt.3	229	1.22	0.67	1.00	0.62
Alt.4	142	1.97	1.08	1.61	1.00

		Alt.1	Alt.2	Alt.3	Alt.4
	TS(+)	280	153	229	142
Alt.1	280	1.00	1.83	1.22	1.97
Alt.2	153	0.55	1.00	0.67	1.08
Alt.3	229	0.82	1.50	1.00	1.61
Alt.4	142	0.51	0.93	0.62	1.00

		Alt.1	Alt.2	Alt.3	Alt.4
	TC(-)	2467	825	1173	785
Alt.1	2467	1.00	0.33	0.48	0.32
Alt.2	825	2.99	1.00	1.42	0.95
Alt.3	1173	2.10	0.70	1.00	0.67
Alt.4	785	3.14	1.05	1.49	1.00

search, comparative evaluation has been the main focus of the estimation. Therefore the process is not much sensitive whether the price assumptions are accurate. This means that even if the assumptions changes, the comparative matrices will offer little change since their comparison rates is relatively unchanged. However evaluation of the alternatives in relation to economical indicators has been performed based on the following assumptions and approaches regarding to the price estimation:

- The approximate cost of construction and implementation of one line highway is 2,200,000,000 Iran Rial (IR hereinafter) per Kilometer (km).
- The approximate cost of construction and implementation of two line highway is 3,500,000,000 IR per km.
- In order to estimate the overall construction price of interchange for any alternative, total price of bridge structures and highways together with the price of connectors have been considered. The values are reported in Table 3.
- To obtain an overall estimation about the price of highways and connectors, all connectors have been considered as equivalent two way highways (by reducing their lengths to reach equivalent quantities) and total length of highways is reported in Table 3.
- The approximate cost for building every square kilometer of the bridge is around 10,000,000,000 IR.
- Total amount of bridge surface for any alternative is obtained by determining the length of bridges and multiplying them to their widths. These values are indicated in Table 3.
- The approximate cost for repair and maintenance in the duration of project's operation is assumed around %6 cost of primary construction.
- The approximate cost of land possession near the interchange area is assumed around 5,000,000 IR.
- To calculate the possession area for any alternative, the overall area of the interchange has been determined and then available area (unoccupied state area without private owner) has been deducted from that to reach the net releasing price.
- Summary of estimative price information for the alternatives is presented in to Table 3. The three last columns of this table are representing the overall cost of construction, area freezing and maintenance of the interchange for different variants. These values have been used for pair comparison among options.

By considering the above estimations, comparative matrices of the alternatives relative to economical indicators (EC, EF, and EM) are determined as the data in Table 4.

The array values are obtained the same as previous matrices. As an example the array which is located in the second row and third column of EC– matrix (1.48), is counted by

Table 3. Cost of construction and maintenances of different options (relative to economical criteria)

Alt. No.	Surface of all bridges (m2)	Equivalent Length of highways (km)	Approximate area possession (m2)	EC Overall construction cost (Million IR)	EF Overall area freezing cost (Million IR)	EM Overall maintenance cost (Million IR)
1	2850	4.2	1385	2997	693	180
2	4350	2.4	630	4434	315	266
3	3450	3.3	810	3566	405	214
4	4150	2.1	580	4224	290	253

Table 4. The pair comparison matrices for different alternatives regarding to economicalal criteria (EC, EF, and EM)

		Alt.1	Alt.2	Alt.3	Alt.4
	EC(-)	2997	4434	3566	4224
Alt.1	2997	1.00	1.48	1.19	1.41
Alt.2	4434	0.68	1.00	0.80	0.95
Alt.3	3566	0.84	1.24	1.00	1.18
Alt.4	4224	0.71	1.05	0.84	1.00

		Alt.1	Alt.2	Alt.3	Alt.4
	EC(+)	2997	4434	3566	4224
Alt.1	2997	1.00	0.68	0.84	0.71
Alt.2	4434	1.48	1.00	1.24	1.05
Alt.3	3566	1.19	0.80	1.00	0.84
Alt.4	4224	1.41	0.95	1.18	1.00

		Alt.1	Alt.2	Alt.3	Alt.4
	EF(-)	693	315	405	290
Alt.1	693	1.00	0.45	0.58	0.42
Alt.2	315	2.20	1.00	1.29	0.92
Alt.3	405	1.71	0.78	1.00	0.72
Alt.4	290	2.39	1.09	1.40	1.00

		Alt.1	Alt.2	Alt.3	Alt.4
	EF(+)	693	315	405	290
Alt.1	693	1.00	2.20	1.71	2.39
Alt.2	315	0.45	1.00	0.78	1.09
Alt.3	405	0.58	1.29	1.00	1.40
Alt.4	290	0.42	0.92	0.72	1.00

		Alt.1	Alt.2	Alt.3	Alt.4
	EM(-)	180	266	214	253
Alt.1	180	1.00	1.48	1.19	1.41
Alt.2	266	0.68	1.00	0.80	0.95
Alt.3	214	0.84	1.24	1.00	1.18
Alt.4	253	0.71	1.05	0.84	1.00

		Alt.1	Alt.2	Alt.3	Alt.4
	EM(+)	180	266	214	253
Alt.1	180	1.00	0.68	0.84	0.71
Alt.2	266	1.48	1.00	1.24	1.05
Alt.3	214	1.19	0.80	1.00	0.84
Alt.4	253	1.41	0.95	1.18	1.00

4434/2997. Also again the + and – remarks are presented for the economicalal matrices. The reason of this presentation again relied on the nature of all EC, EF, and EM indicators which act in the reverse manner i.e. as the value is rising, the indicator quality index is descending.

5.3 Evaluation of Economical Criteria (Qualitative indicators)

As the Figure 1 shows, there are two estimative parameters in the economical indicator category which cannot be obtained in the quantitative form. As explained in section 3.3 people's judgment are employed for these indicators. Table 5 indicates the general arrangement of the questionnaire forms which are utilized for this aim. As indicated, only the arrays in the top-right side of the matrices were needed to be filled by the experts. By explaining the general overview of the matrices to the engineers, they were asked to fill the quantitative forms exactly based on the normal matrices in the AHP method. To matrices of beneficial interests (EB) and convenience in construction stage (EE) are shown in this table. People clearly realized that if they need to state a better situation for pair arrays, they need to use values over than one and if they want to judge about the lower quality, values less than one have to be provided. People who admitted to fill the forms were instructed about the methodology of the work and have had competent knowledge about intersection design phenomena.

20 experts are chosen as the reference people for filling these forms and their opinions extracted separately. Then the results imported to a spread sheet database and after slight filtering, their averages are computed. Afterward, the average degrees of priority for any sub-indicator are determined and the matrices extracted. Table 6 shows the filled EB and EE matrices based on the expert's opinion.

5.4. Evaluation of Aesthetical/Architectural Criteria

The same as previous section, the results of evaluation regarding aesthetical/architectural criteria have been obtained by questionnaire gathering and expert's decision as they are qualitative factors. By employing the same approach, comparative matrices of the results against aesthetical/architectural factors have been presented in Table 7.

5.5 Matrices for First and Second Levels of AHP

Table 5. Typical questionnaire forms used for economical qualitative indicators

EB	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Alt. 1	1	--?--	--?--	--?--
Alt. 2		1	--?--	--?--
Alt. 3			1	--?--
Alt. 4				1

EE	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Alt. 1	1	--?--	--?--	--?--
Alt. 2		1	--?--	--?--
Alt. 3			1	--?--
Alt. 4				1

Table 6. The pair comparison matrices for different alternatives regarding to economical criteria (EB, EE)

EB	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Alt. 1	1.00	1.17	1.21	1.05
Alt. 2	0.85	1.00	1.53	1.46
Alt. 3	0.83	0.66	1.00	1.17
Alt. 4	0.95	0.69	0.85	1.00

EE	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Alt. 1	1.00	0.79	0.99	1.26
Alt. 2	1.27	1.00	1.83	1.02
Alt. 3	1.01	0.55	1.00	1.00
Alt. 4	0.80	0.98	1.00	1.00

In the case for determining other pair matrices for AHP process, (which are all qualitative factors hereinafter) the comparative analysis of different variants has been provided by the expert’s judgment method as the comparative relations between them cannot be straightly evaluated by measured quantities. By applying the same methodology of previous sections, the comparative pair matrices for the first and second level of the AHP process have been written following tables. Table 8 indicates the typical questionnaire forms of the evaluation among the importance of various indicators together with the result of average values with obtained by interpreting 20 separate questionnaires. Table 9 is also reporting the equivalent comparative matrices for the mutual importance relations of all sub-indicators against each other. The results of this table are also obtained by getting average values from questionnaire forms.

Table 7. Pair comparison matrices of different variants relative to aesthetic indicators

AB	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Alt. 1	1.00	0.86	0.56	1.58
Alt. 2	0.90	1.00	0.58	0.99
Alt. 3	0.83	1.18	1.00	1.12
Alt. 4	1.14	0.91	1.08	1.00

AU	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Alt. 1	1.00	1.20	0.81	1.32
Alt. 2	0.83	1.00	0.80	0.69
Alt. 3	1.24	1.25	1.00	1.20
Alt. 4	0.76	1.46	0.83	1.00

AC	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Alt. 1	1.00	1.08	0.89	1.71
Alt. 2	0.90	1.00	0.78	1.10
Alt. 3	0.83	1.18	1.00	0.98
Alt. 4	1.14	0.91	1.08	1.00

Table 8. Left: Typical questionnaire forms, Right: Matrix of the first level of comparison against the main indicators

Criteria	Technical	Economical	Aesthetic
Technical	1.000	--?--	--?--
Economical		1.000	--?--
Aesthetic			1.000

Criteria	Technical	Economical	Aesthetic
Technical	1.000	1.202	2.217
Economical	0.832	1.000	1.582
Aesthetic	0.451	0.632	1.000

Table 9. Matrix of second level of comparison for all sub-indicators

Indicators	TG	TV	TT	TS	TC	EC	EF	EM	EB	EE	AB	AU	AC
TG	1.000	1.153	1.019	1.264	0.743	-	-	-	-	-	-	-	-
TV	0.867	1.000	0.833	1.618	0.995	-	-	-	-	-	-	-	-
TT	0.981	1.201	1.000	1.712	1.048	-	-	-	-	-	-	-	-
TS	0.791	0.618	0.584	1.000	0.661	-	-	-	-	-	-	-	-
TC	1.345	1.005	0.954	1.514	1.000	-	-	-	-	-	-	-	-
EC	-	-	-	-	-	1.000	0.795	2.227	1.827	2.882	-	-	-
EF	-	-	-	-	-	1.258	1.000	2.451	4.608	4.049	-	-	-
EM	-	-	-	-	-	0.449	0.408	1.000	1.542	1.942	-	-	-
EB	-	-	-	-	-	0.547	0.217	0.649	1.000	0.920	-	-	-
EE	-	-	-	-	-	0.347	0.247	0.515	1.087	1.000	-	-	-
AB	-	-	-	-	-	-	-	-	-	-	1.000	0.324	0.487
AU	-	-	-	-	-	-	-	-	-	-	3.087	1.000	1.016
AC	-	-	-	-	-	-	-	-	-	-	2.054	0.984	1.000

6. Results of the AHP Analysis

The Expert Choice software which is an analytical data processor product based on the AHP method has been employed to combine the input data in an AHP database and make process over the results. After importing all obtained data (matrices for different levels of AHP process) Expert Choice utilized to store all data and make the final decision based on the priority of the alternatives upon the main target criterion. Acquired results of evaluation for the current case study have been imported into this software and the results of overall comparison among the alternatives with different factors have been extracted in Figure 6. In the other word, obtained values of prioritization matrices entered into the software all in the matrix-form and this software classified the results based on all parameters. Then the last priority analysis has been performed by considering weighting levels of all indicators and sub- indicators over the whole model.

7. Interpretation of the Results

The Expert Choice software has the ability to prepare arbitrary reports for decision making

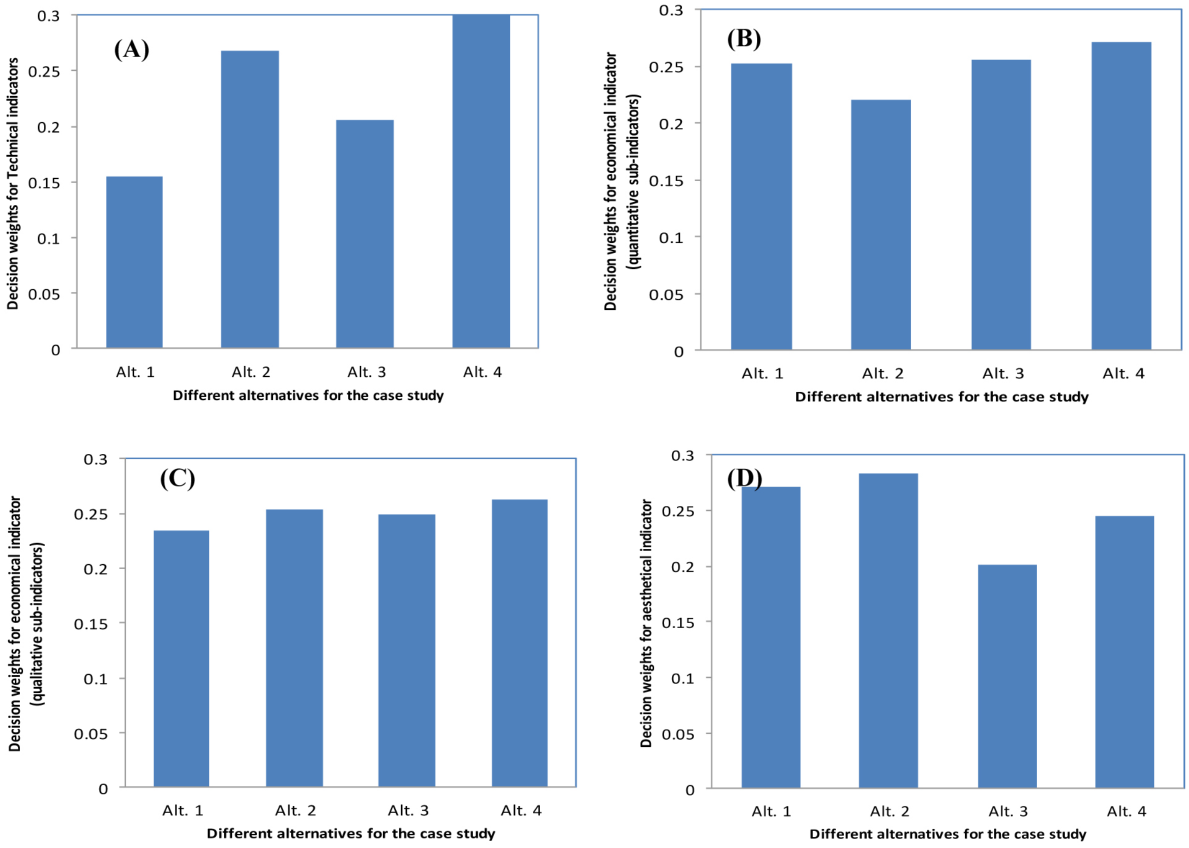

Figure 6. Overall results of AHP modeling (priorities for the alternatives in the case study) based on A) Technical criteria, B) Economicalal criteria (quantitative sub-indicators), C) Economical criteria (qualitative sub-indicators), D) Aesthetic criteria

[EC, 2004]. Practical results can be obtained by selecting required criteria in the final evaluation stage to acquire comparative diagrams of evaluation among different alternatives. As Figure 6 indicates, the decision making results have reported for any of main criteria (technical, economical and aesthetic criteria based on the definitions in Figure1). Therefore one can be able to make decision by taking any of these criteria separately into account or by selecting a combination of them. The overall decision diagram of this study is presented in Figure 7 for the main judgment goal which basically includes all sub-indicators of the AHP model.

After evaluation and counting of final weights for each decision alternative in the case study, the priority of various geometric configurations for the interchange has been identified as shown in Figure 7.

By looking at the results of AHP evaluation, several interpretations from the figures can be picked up:

- Although the full cloverleaf sketch has been regarded as the existing configuration for the mentioned case study, this figure visually demonstrates that alternative 4 (Full directional sketch) has obtained better overall weight (around 25% more than existing sketch) while totally taking the technical, economical and aesthetic factors into account. Indeed the analysis helps to better identify the effectiveness of various factors and indicators.
- From the results in Figure 6 and 7 it can be

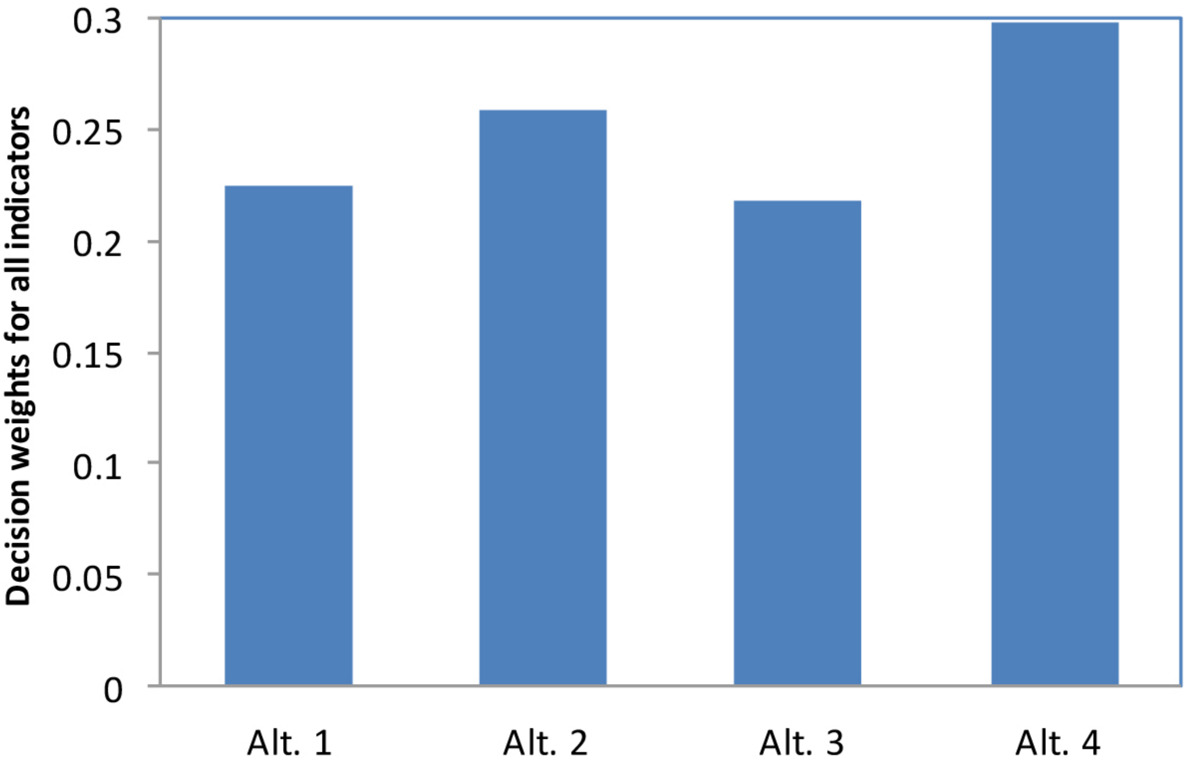

Figure 7. Final weights for the configuration alternatives of the case study

perceived that the overall comparative evaluation of the alternatives against the whole model is very close to the results of comparison for only the technical indicator (see the overall trends of Figure 6A and 7). This can prove that technical criteria have had magnificent effect to govern even the whole model.

- As shown in Figure 6 (B and C), the results of economical criterion separately presented for qualitative and quantitative sub-indicators to see their differences. From these figure it is worthy to notice that the results of comparison for qualitative sub-indicators have only slight changes among the alternative in contrast to the sensible differences for quantitative ones. This matter shows that the experts as the main input for the qualitative evaluation had not had serious distinction among the alternatives in this regard.
- As a parallel outcome, the aesthetic factor has had fewer or very slight effects on the final priority of Alt.4. This is because of the fact that the most weighted alternative in the final decision diagram has obtained the highest decision weights regarding to the technical and economical viewpoints as the governing indicators corresponding to the values in Figure 6. The reverse results of aesthetic indicator could not be able to change this trend.

Once the priority becomes clear for various alternatives, the finance source and financial restrictions can be managed in a better way to enhance the performance of the interchange system. For instance in the case study of this research, one can estimate an alternative of full directional as the most expensive alternative and remove it unconsciously from the final sketch for the interchange selection. But the analysis showed that from an overall point of view, this alternative is more efficient although it ranked worse related to the economical indicator.

8. Conclusion

In this paper, an AHP based method for evaluation of different configurations for the interchange design is developed. To reach this goal, overall strategy and process of decision making for the problem is introduced. The selection method for doing a comparative examination of this research was multi criteria decision method that in this paper established for highway interchanges by identification of the analysis process and determination of required parameters. Simulation is conducted by using an AHP based software namely Expert Choice followed by a descriptive process to adjust appropriate values related to any indicator/criterion. The most distinguished results of the study shall be concluded as:

- A decision making strategy was developed for evaluation of interchange by which all possible configurations can be examined. The idea of applying all influential parameters into the judgment process was the main new feature of the work which is leaded to better estimation for the functionality of the alternatives.

- In the case study of ImamAli - Zeinodin interchange, the AHP analysis was performed and the process of MCDM is established over the selected alternatives. The final weight results showed that the alternative of using full directional ramp pattern is the most suitable option by taking all effective parameters into account. Weights of priorities for different alternatives for the case study are shown in the results of the analysis.
- The model is practically able to consider all of the technical, economical and architectural factors, and take their weights into account for the final decision. The most important advantage of the introduced process of this paper is the ability to simultaneously investigate the influence of all important parameters and observe their weights over the decision outcome. Performing sensitivity analysis over the influential factors under main criteria and finding their effects on the final decision weights in the case is an ongoing research in this field. Investigation over other case studies of interchanges to find an overall decision making strategy for a typical interchange is another field for further researches. This study can provide engineers a starting point to begin their analyses over various alternatives and the engineers will most efficiently serve the needs of a certain area in order to determine which interchange configuration is the optimum variant for construction. The procedure which is reported in this study was established based on a case study where four interchange alternatives were proposed to a particular location in Iran. Buy the way, taking the general methodology of this research into account, it is possible to implement the same approach for the other cases.

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