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AHP - Arithmetic Mean Model on Bridge Structural System Selection

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Decision of selecting of a bridge structural system mostly is derived from, a few main "Priorities" as criteria, such as: Project cost, Construction Duration, Traffic limitation, Deck length between two piers, Passive defense capability and Maintenance costs separately. Interaction between criteria usually makes the designer not to decide in an appropriate way.

AHP i.e. Analytic Hierarchy Process, is a procedure to handle a Multi Criteria Decision Making (MCDM) problem easier. By collecting a designed questionnaire from professional expertise, analyzing data would be the next step. Analyzed and averaged data and gaining its statistical elements with a formulated spreadsheet based on AHPArithmetic Mean method lead the procedure to results.

In conclusion part, each bridge structural system compared with the others, and Consistency Provisions had been checked by the means of the AHP Consistency Index (C.I.), matrix Random Index (R.I.) and Consistency Ratio (C.R.) that act the main roll in verification of the results.

1. Introduction

The AHP process, introduced by Saaty in the 1970s, [1] has been one of the most extensively used methods for MCDM and has been extensively studied and refined since then. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, relating these elements to overall goals, and for evaluating alternative solutions. AHP has been used to solve MCDM problems in several different areas such as economic planning, energy policy, project selection, budget allocation [2], software selection [3] among other contributions there are several paper as in "Table 1".

The AHP is a general theory of measurement. It is used to derive the most advanced scales of measurement from both discrete and continuous paired comparisons in multilevel hierarchic structures. These comparisons may be taken from 1

actual physical measurements or from subjective estimates that reflect the relative strength of preferences of the experts. By physical we mean the realm of what is fashionably known as the tangibles in so far as they constitute some kind of objective reality outside the individual conducting the measurement. By contrast, the psychological is the realm of the intangibles, comprising the subjective ideas, feelings and beliefs of the individual. The

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question is whether there is a coherent theory that can deal with both of these worlds of reality without compromising either. The AHP is a method that can be used to establish measures in both the physical and human domains. The AHP has special concern with departure from consistency and the measurement of this departure, and dependence within and between the groups of elements of its structure. This is made possible by taking several factors into consideration simultaneously, allowing for dependence and for feedback, and making numerical tradeoffs to arrive at a synthesis or conclusion [4].

Authors	Contribution
Saaty (1980)	First application and implementation of AHP.
Al-Harbi (2001)	Application and implementation of AHP in project management.
Felek et al. (2002)	Application of AHP and ANP in the determination of market share in mobile communication industry and comparison of results.
Baslıgil (2005)	Application of fuzzy AHP in the software selection.
Akman and Alkan (2006)	Application of fuzzy AHP to the evaluation of performance measurement of suppliers in the automotive industry.
Chang et al. (2007)	Utilization of AHP and ANP decision models in Evaluating digital video recorder systems
Gümüs (2000)	Utilization of fuzzy AHP in the evaluation of hazardous waste transportation firms.
Wang et al. (2008)	Discussed the shortcomings of fuzzy AHP extent analysis method.
Sevkli et al. (2008)	Proposed the analytical hierarchy process (AHP) weighted fuzzy linear programming model (AHP-FLP)" for supplier selection problems

In using the AHP to model a problem, one needs a hierarchic structure to represent that problem, as well as pair wise comparisons to establish relations within the structure. In the discrete case, comparisons lead to dominance matrices and in the continuous case to kernels of Fredholm operators, from which ratio scales are derived in the form of principal eigenvectors, or Eigen-functions, as the case may be. These matrices, or kernels, are positive and reciprocal. In a real world application of the AHP the required number of such matrices is equal to the number of the weighting factors [4].

In addition, regarding that the number of the group members, there is a need for aggregation what is called the process of synthesizing group judgments. By synthesizing the particular priorities with the average weighting factors of the attributes the ultimate output is yielded in the form of a weighted priority ranking indicating the overall preference scores for each of the alternatives under study [4].

2. PROBLEM Definition

Selecting "Bridge Structural System" is the most important design part of a structure like a bridge as an infrastructure. The designing process is usually based on a Consultant Engineer's elegance. Talented engineers usually seek and choose the structural system based on the project situation in the territory of their own experiments. Thus, there may be some ignored criteria and also structural systems that may be useful for the project. This ignorance may impose much amount of expenses to the project that can be avoided in the primary steps of a civil engineering project. As it can be seen design process is an easy way to handle if a step by step procedure is provided.

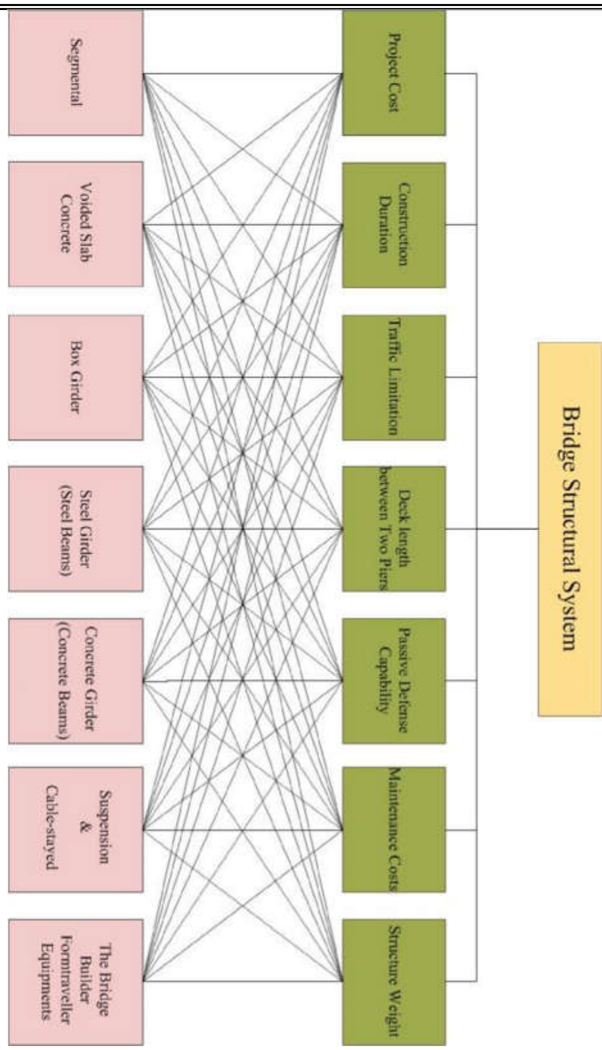
The Problem Model

The problem has a hierarchy with three levels which are discussed in this section. The overall objective is placed at level 1, criteria at level 2 and the decision alternatives at level 3. The main objective ere is the selection of the most suitable consultant for the sample company. The criteria to be considered in the election are Project cost, Construction Duration, Traffic limitation (especially in urban zones), Deck length between two piers, Passive defense capability and Maintenance costs. According to these decision elements, the hierarchy for the problem is presented in "Figure 1".

The Definition of Criteria

Among all criteria for a bridge design Project cost, Construction Duration, Traffic limitation (especially in urban zones), Deck length between two piers, Passive defense capability and Maintenance costs have been elected to consider in questionnaires:

Project cost: The ability to estimate the influences of the project schedule, resources, and risk items on cost, i.e. one of the most important item of a project. Meanwhile for the best comparison the expense of mobilization is ignored. **Construction Duration**: The construction duration arising from critical path in which duration for items of work or activity in sequence cannot be reduced further



Traffic Limitation (especially in urban zones): All traffic (Cars, Peoples and etc.) limitations that urban areas have during construction duration.

Deck length between Two Piers: The distance between two piers of a bridge.

Passive Defense Capability: Passive defense capability is a bridge structural system characteristics capability in defense without weapon i.e. in design process.

Maintenance Costs: Cost result the care and services for the purpose of maintaining equipment and facilities in satisfactory operating condition by providing for systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects.

Maintenance, including tests, measurements, adjustments, and parts replacement, performed specifically to prevent faults from occurring.

Structure Weight: The weight of the structure (Piers, Abutments, Deck) in relation with the surface that the structure can provide can act an important role in seismic capability of the structure.

Decision Alternatives

There are different Decision Alternative can be elected for this research. Among them there are7 different Bridge Structural System had been chosen that are [6]:

Segmental: As its name implies, a segmental bridge is a bridge built in short sections (called segments), i.e., one piece at a time, as opposed to traditional methods that build a bridge in very large sections. The bridge is made of concrete that is either cast-in-place (constructed fully in its final location) or precast concrete (built at another location and then Transported to their final location for placement in the full structure).

These bridges are very economical for long spans (over 100 meters), especially when access to the construction site is restricted. They are also chosen for their aesthetic appeal [5]. There is a sample of this in "Figure 2".

Figure 2: The Sadr Elevated Expressway, Under Construction (2012),Tehran, IRAN

Voided Slab Bridge: A hollow core slab, also known as a voided slab or hollow core plank, is a precast slab of prestressed concrete typically used in the construction of bridges deck and also floors in multi-story apartment buildings. The slab has been especially popular in countries where the emphasis of home construction has been on precast concrete, including Northern Europe and socialist countries of Eastern Europe. Precast concrete popularity is linked with low-seismic zones and more economical constructions because of fast building assembly lower self-weight (less material), etc.

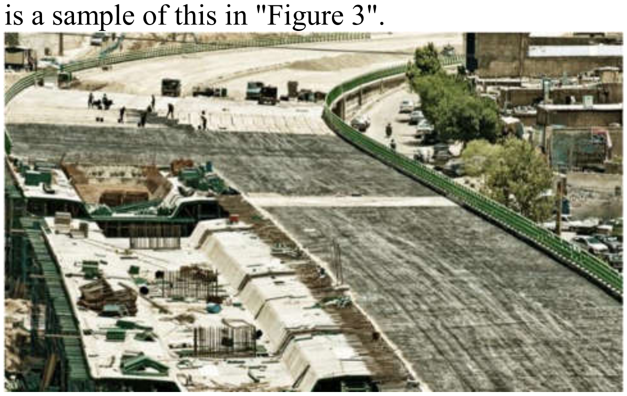
The precast concrete slab has tubular voids extending the full length of the slab, typically with a diameter equal to the 2/3-3/4 of the slab. This makes the slab much lighter than a massive floor slab of equal thickness or strength. Reduced weight is important because of transportation cost and less cost of material (concrete). The slabs are typically 120 cm wide with standard thicknesses between 15 cm and 50 cm. The precast concrete I-beams between the holes contain the

Steel wire rope that provides bending resistance to bending moment from loads.

Slabs are usually produced in lengths of about 120 meters. The process involves extruding wet concrete along with the pre-stressed steel wire rope from a moving mold. The continuous slab is then cut by big diamond circular saw according to the lengths (and width) required on blueprint. Factory production provides the obvious advantages of reduced time, labor and training.

To meet modern standards (both hollow-core and massive slab) of soundproofing the floor needs to be covered with a soft floor covering that is able to dampen the sound of footsteps. An alternative is to use a thin "floating" slab of

Concrete insulated from the voided slabs [5]. There is a sample of this in "Figure 3".



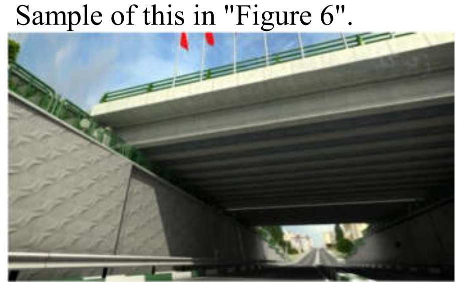
: A box girder bridge is a bridge in which the main beams comprise girders in the shape of a hollow box. Box Girder The box girder normally comprises either prestressed concrete, structural steel, or a composite of steel and reinforced concrete. The box is typically rectangular or trapezoidal in cross-section. Box girder bridges are commonly used for highway flyovers and for modern elevated structures of light rail transport. Although normally the box girder bridge is a form of "Beam Bridges", box girders may also be used on cable-stayed bridges and other forms [5]. There is a sample of this in "Figure 5".

Steel Girder (Steel Beams): A girder bridge, in general, is a bridge built of girders placed on bridge abutments and

.foundation piers. In turn, a bridge deck is built on top of the girders in order to carry traffic

A rolled steel girder bridge is made of I-beams that are rolled into that shape at a steel mill. These are useful for spans between 10 meters and 29.5 meters. Rolled steel girders are practically available with a web height of up to one meter forms [5] . There is a sample of this in "Figure 6".

Concrete Girder (Concrete Beams): A concrete girder bridge is made of concrete girders, again in an I-beam shape. The concrete girders can be either pre-stressed cast concrete or post-tensioned girders. Concrete girder bridges are best for spans between 10 meters and 50 meters. Pre-stressed, precast concrete girders are readily available [5]. There is a Sample of this in "Figure 6".



Suspension & Cable-stayed: A cable-stayed bridge is a bridge that consists of one or more columns (normally referred to as towers or pylons), with cables supporting the bridge deck.

There are two major classes of cable-stayed bridges: In a harp design, the cables are made nearly parallel by attaching them to various points on the tower(s) so that the height of attachment of each cable on the tower is similar to the distance from the tower along the roadway to its lower attachment. In a fan design, the cables all connect to or pass over the top of the tower(s).

Compared to other bridge types, the cable-stayed is optimal for spans longer than typically seen in cantilever bridges, and shorter than those typically requiring a suspension bridge. This is the range in which cantilever spans would rapidly grow heavier if they were lengthened, and in which suspension cabling does not get more economical, were the span to be shortened [5]. There are samples of this in "Figure 7" and "Figure 8".

Figure 7: Abdoun e, Construct (20), Amm n, Jord h

Figure 8: Javadieh Constructed 1), Tehran,

The Bridge Builder Form-traveler Equipment's: The "Bridge builder" form-traveler system is NOT a bridge design system but because of its useful characteristics in urban areas especially in urban zone, authors consider it as a one of the choices for a client to check.

This Equipment (Form) was invented in 1970 and today it is acclaimed for enhancing the cost-effectiveness of bridge projects world-wide. The system is lightweight, versatile and easy to assemble and operate. Rolling forward on rails, the system can be reset quickly and easily [5]. There is a sample of this in "Figure 9".

APPLICATION

The problem of selecting the most adequate consultant is systematically considered by the decision makers of the project under analysis. As its name implies Analytic Hierarchy Process, considers the problem in a hierarchical way. At the top of the hierarchy there is a goal that is affected only by decision criteria, which are on the second level in hierarchy and, at the bottom of the hierarchy there will be alternatives, which are only affected by sub-criteria (if there are no sub-criteria (like this model), alternatives are affected by main-criteria). After defining the relative importance of all the decision criteria via pair-wise comparisons, the results of the pair wise comparisons are represented in a comparison matrix. The Scales of Relative Importance are simply follows "Figure 10" rules.

Most Important	Important	Equal Importance	Less Important	Least Important
3	2	1	0.50=1/2	0.33=1/3

In the first step by taking advantage of professional experts and getting back a designed questionnaire, and gaining raw data from them, the mean Criteria Matrix among all experts can be found below in "Table 2", that shows the comparison matrix for the criterion defined as the goal. It results from the analysis of the relative weight among all the possible combinations of decision criteria.

Then the normalization of this matrix is necessary in order to find the relative weights of all the decision criteria. The normalization process requires dividing the elements of each column by the sum of the elements of the same column.

Up to this point, decision criteria were compared and their relative weights calculated.

It is obvious that filling out this matrix by the experts is just because of the research aims; as this matrix should be complete and fulfill the client opinion about all criteria that will satisfy his needs. However experts' opinion is a useful index to calculate different points of views between experts and clients. Also among those experts, there are a few that handle a client situation in a company.

So far, comparison and weighting of decision criteria were handled. Now it is time to compare all the decision alternatives with respect to each decision criteria; it can be handled by using 7 different Tables like "Table 3" to gain each of them. "Table 3" is an example of Comparison Matrix with Decisions.

After evaluating all the decision alternatives with respect to the decision criteria the calculation of weights for each decision element in AHP is complete. All the weights will be ready to start the analysis. According to these weights, the composite weight for each consultant is calculated and consultants are ranked based on their composite weights.

Table 2: Criteria Comparison Matrix; filled by MCDM Experts

	Project Cost	Construction Duration	Traffic Limitation	Deck Length	Passive Defense	Maintenance Costs	Structure Weight
Project Cost	1.00	1.67	1.25	2.67	1.92	1.92	2.67
Construction Duration	0.60	1.00	1.39	1.83	1.83	1.72	1.92
Traffic Limitation	0.80	0.72	1.00	2.50	1.92	1.83	2.67
Deck length	0.38	0.55	0.40	1.00	1.39	0.64	1.17
Passive Defense	0.52	0.55	0.52	0.72	1.00	1.31	1.64
Maintenance Costs	0.52	0.58	0.55	1.57	0.77	1.00	2.17
Structure Weight	0.38	0.52	0.38	0.86	0.61	0.46	1.00

Table 3: Project Cost Comparison Matrix with Decisions

Project Cost	Segmental	Voided Slab	Steel Girder	Box Girder	Concrete Girder	Suspension & Cable stayed	The Bridge Builder Form-traveler Eqp.
Segmental	1.00	0.53	0.75	0.75	0.53	1.63	0.88
Voided Slab	1.89	1.00	1.42	1.42	1.17	2.50	2.00
Steel Girder	1.33	0.71	1.00	1.17	0.97	2.21	1.63
Box Girder	1.33	0.71	0.86	1.00	0.69	2.24	1.65
Concrete Girder	1.89	0.86	1.03	1.44	1.00	2.24	1.90
Suspension & Cable-stayed	0.62	0.40	0.45	0.45	0.45	1.00	0.69
The Bridge Builder Form-traveler	1.14	0.50	0.62	0.60	0.53	1.44	1.00

In the next step, by comparing and completing all matrixes, normalization and calculation of each matrix there will be to matrixes. First; the matrix of Decisions-Criteria that result from calculation of its own matrix, "Table 4". Second Matrix; is the matrix of the Criteria weights (Importance), as in "Table 5".

Table 4: The matrix of Decisions-Criteria

	Project Cost	Construction Duration	Traffic Limitation	Deck Length	Passive Defense	Maintenance Costs	Structure Weight
Segmental	0.1092	0.1805	0.1805	0.1715	0.0971	0.1205	0.1518
Voided Slab	0.2100	0.1352	0.1028	0.0962	0.1896	0.2086	0.1019
Steel Girder	0.1636	0.1472	0.1620	0.1071	0.1761	0.1607	0.1777
Box Girder	0.1501	0.1430	0.1599	0.1128	0.1735	0.1607	0.1942
Concrete Girder	0.1884	0.1482	0.1541	0.0825	0.1527	0.1459	0.1178
Suspension & Cable-stayed	0.0746	0.1152	0.1158	0.2381	0.0984	0.0812	0.1381
The Bridge Builder Form-traveler	0.1042	0.1307	0	0.1917	0.1126	0.1224	0.1185

Table 5: The matrix of the Criteria weights (Importance)

Segmental	**0.2322**
Voided Slab	0.1819
Steel Girder	0.1911
Box Girder	0.0939
Concrete Girder	0.1084
Suspension & Cable-stayed	0.1180
The Bridge Builder Form-traveler Eqp.	0.0744

Results

To analyze the problem, via AHP approach, it is necessary to multiply "Table 4" matrix to "Table 5" matrix. As it can be seen, the "Table 4" matrix is 7×7 and "Table 5" matrix is 7×1, then without any mathematical problem the result matrix will be 7×1, as in "Table 6" and "Figure 11". By ranking it in "Table 7", the result will be much more tangible.

Table 6: Result Matrix

Segmental	**0.1449**
Voided Slab	0.1548
Steel Girder	0.1571
Box Girder	0.1542
Concrete Girder	0.1505
Suspension & Cable-stayed	0.0303
The Bridge Builder Form-traveler Eqp.	0.1253

Table 7: Ranked Result Matrix

1	Steel Girder	**0.1571**
2	**Voided Slab**	0.1548
3	**Box Girder**	0.1542
4	**Concrete Girder**	0.1505
5	**Segmental**	0.1449
6	**The Bridge Builder Form-traveler Eqp.**	0.1253
7	**Suspension & Cable-stayed**	0.0303

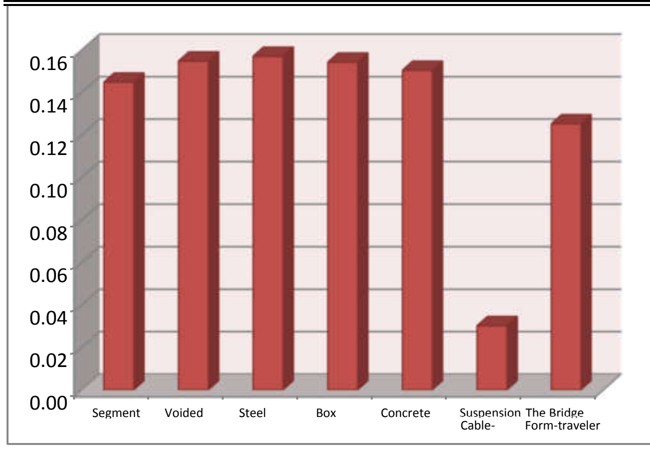


Figure 11: Table 6 Result Matrix Figure

Conclusions

In this paper after fulfilling all AHP principles with arithmetic mean approach we got to 2 main matrixes that both of them lead us to the Result Matrix "Table 7". The results show that the highest scored Bridge Design System is Steel Girder with the score of 0.1570 and

Voided Slab, Box Girder, Concrete Girder, Segmental, Bridge Builder Form-traveler Equipment's and Suspension & Cable- stayed are follow ups. This shows that with the default Criteria Comparison Matrix; filled temporary by MCDM Experts and other seven matrixes for each criterion, the designed AHP software lead us to above hierarchy for the case study of Tehran interchanges Bridge Design System.

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