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Frame Work for Improving Constructability of Bridges Implementing Value Engineering Approach and Analytical Network Process (ANP) "Virtual Study"

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Abstract:

Due to the inter relationships between the erection method of construction of bridges and material behavior make the constructability of bridges more complex. Also the impact of loads accessed the problem , in addition to the environmental influences. Upon this the objective of this research is to develop decision support model to assist designers in deciding the best alternative that improve the constructability of bridge project based on the principles of value engineering. This model use super decision system by applying the analytically network process (ANP) system. The implementation of this system is carried out through integration of value engineering with the ANP. The implementation of the system developed is tested virtually. The results attained confirmed the possibility of applying this system to such studies of infrastructure and bridges, This study was be adopted with regard to the use of the same method of construction. which is "precast segmental, balanced cantilever construction (cantilever carriage system)".

Keywords: Analytic Network Process (ANP), Weighted Graph, Value Management (VM), Un Weighted Matrix, Weighted Matrix, limit matrix.

ملخص:

نظراً لتداخل العلاقة بين طريقة التشييد وسلوك المواد الداخلة في الانشاء الأمر الذي جعل قابلية إنشاء الجسور أكثر تعقيدًا. كما أدى تأثير الأحمال إلى زيادة المشكلة بالإضافة إلى التأثيرات البيئية. بناءً على ذلك، فإن الهدف من هذا البحث هو تطوير نموذج لدعم القرار لمساعدة متخذي القرار والمصممين في تحديد أفضل بديل يعمل على تحسين انشائية مشروعات الكباري بناءً على مبادئ هندسة القيمة. يستخدم هذا النموذج نظام القرار الفائق من خلال تطبيق نظام عملية الشبكة التحليلية (ANP). يتم تنفيذ هذا النظام من خلال دمج هندسة القيمة مع ANP. يتم اختبار تنفيذ النظام المطور بشكل افتراضي. أكدت النتائج التي تم التوصل إليها إمكانية تطبيق هذا النظام على مثل هذه الدراسات الخاصة بالبنية التحتية والجسور ، وتم اعتماد هذه الدراسة فيما يتعلق باستخدام نفس طريقة البناء وهي البلاطات المنفصلة سابقة التجهيز باستخدام الشدات ذات العجلات المتحركة.

الكلمات المفتاحية: الشبكة التحليلية (ANP), رسم بياني مرجح, إدارة القيمة, مصفوفة مرجحة, مصفوفة الحد.

Introduction

"The fast growth of populations has created new needs for mobility and increased the demands for constructing efficient bridges"[1]. "Department of public works, is one of the strategic objectives in particular the directorate general of highways and bridges to increase the percentage of roads, and bridges in good condition"[2]. "Bridges form an essential part of the infrastructure of a nation, facilitating its social and economic development by allowing the free movement of people and goods between remote locations"[3]. "Bridges play an important role in linking different parts of highway networks, and therefore have a great impact on the capacities of such networks"[4] . Bridges are massive structures that require large amounts of materials, skilled labor, and heavy machinery for their construction. Therefore, the decision regarding the most convenient construction system should be based on careful evaluation of all applicable alternatives, and using evaluation criteria appropriate for each project" [5,6]. There are lots of bridges that need to be analyzed, these problems will increase the length of the planning process and the results are less accurate" [7]. OQA; represented a report showed how the VE technique applied on the transportation projects. Accordance with (23-CFR part-627); state highway agencies must establish programs to assure that value engineering studies are performed on all Fedral-Aid high projects on the NHS (National Highway System) with estimated cost of $ 25 million or more and for bridge projects with an estimated cost of $ 20 million or more [8]. (Ando,2005); applied the VE (Value Engineering) as an evaluation approach for the highway improvement plans [9]. (Jingyu.,etal.,2014); Applied the VM approach (SAVE International, 2007) [10] in an actual highway construction project – the Meihe Highway project in Guangzhou, PRC to explore the feasibility of using a systematic VM, the results indicated that systematic VM assisted participants generate creative proposals, which could enhance the value of the project and help construction managers to reduce the construction period, minimize the total project cost, and reduce the construction-related risks to employees in a real situation. It was assisted that the systematic VM approach helps VM participants to pay attention to both VM techniques and the effect of human behavior [11]. Therefore, it is necessary to build an information system that can help the Public Works Department in obtaining and analyzing information on the handling of bridges infrastructure. "ANP is a method of multi-criteria analysis that can be used in the decision-making process [12,13,14,15]. The Analytic Network Process (ANP) is a multi-criteria theory of measurement used to derive relative priority scales of absolute numbers from individual judgments (or from actual measurements normalized to a relative form) that also belong to a fundamental scale of absolute numbers [16,17].

"this method uses with respect to factors of perception, preference, experience and intuition" [18]. Also with respect to value management and value engineering procedures, where ANP represent the value engineering phases 'function analysis'. ANP incorporate assessments values and personal values into one logical way" [19,20]. "Decisions are determined by a single number for the best outcome or by a vector of priorities that gives an ordering of the different possible outcomes. We can also combine our judgments or our final choices obtained from a group when we wish to cooperate to agree on a single outcome" [21].

Research methodology

The work of this study involved the following:

First: A set of determinants that represent the field of study were developed for the type of bridges to be studied, and this model was applied to it as a virtually study, and therefore; the results of this study are based on those determinants. the following scenario of the bridge inputs considered:

- The subject bridge crosses a water channel of a total width of maximum 400m.
- The water channel is of a max depth of 10m.
- The navigational requirements are two envelopes each of 40m width by 10m height.
- The site is located in Egypt and all the local market conditions apply.
- No height restrictions apply.
- No special environmental requirements apply.

Second: Selection the evaluation procedure. By applying the value engineering procedures.

Third: Determination of evaluation parameters. They were first determined for the construction bridges, and then for the construction systems as the average values for the bridges constructed with each system.

Forth: Analysis and evaluation of scoped data. Two types of evaluation were made. They were:

Economic and engineering analysis of the construction systems applicable for each site conditions, and Economic and engineering analysis of the used construction system in comparison with the other applicable system for each bridge.

The analysis led to basic conclusions concerning the construction system recommended for each site condition, and whether the used system was the optimum choice for each bridge .

Model design

ANP is a multi-criteria process to measurement, that used to derive relative priority scales of absolute numbers from individual judgments (or from actual measurements normalized to a relative form) that also belong to a fundamental scale of absolute numbers. This procedure contain some of clusters with interior nodes for each cluster, all nodes were linked with others, to pairwise comparisons on node level. this step create the unweighted super-matrix. also all clusters were linked in upper stage of connection to partorize the criteria and give each one of them rank this is through Pairwise comparisons on a cluster level. The goal of this step is to convert the unweighted matrix into the weighted super-matrix after this Calculating the limit matrix. In this step, the weighted matrix is multiplied by itself as long as all of its columns become equal. This is how we get the final priorities. After this step, the sensitivity analysis is performed. Then were upgrade the ANP. next step is the finally one which is the final report that is in two main categories that as will show through this research.

The goal of this model of decision making respect to the scope of this study is to select the best alternative among six alternatives. These six ones that obtained from the pre study stage and from the information gathering, and creativity of VE procedure. -The information gathering was by developing four questionnaires- this model contain the following:

Cluster goal with one node.

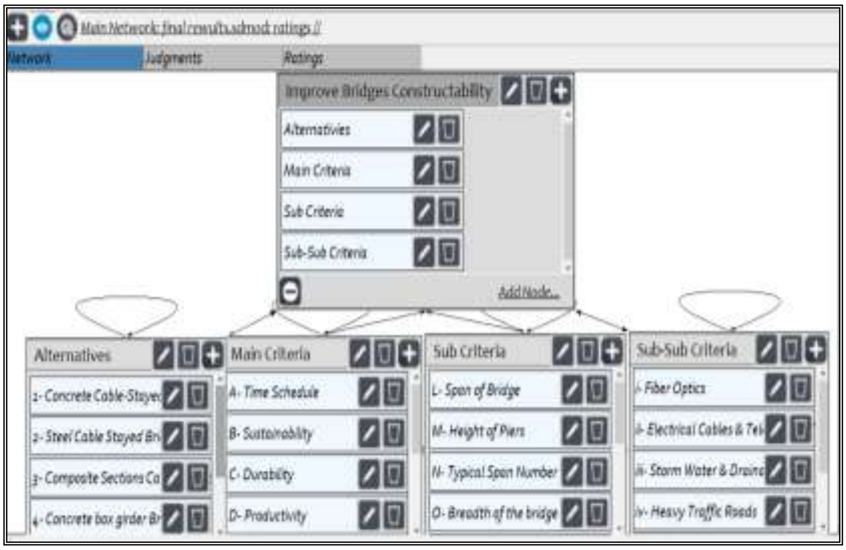
Cluster of main criteria with eight nodes (A, B, C, D, E, F, T, Z)

Cluster of sub-main criteria with nine nodes (L, M, N, O, P, R, S, U,Y)

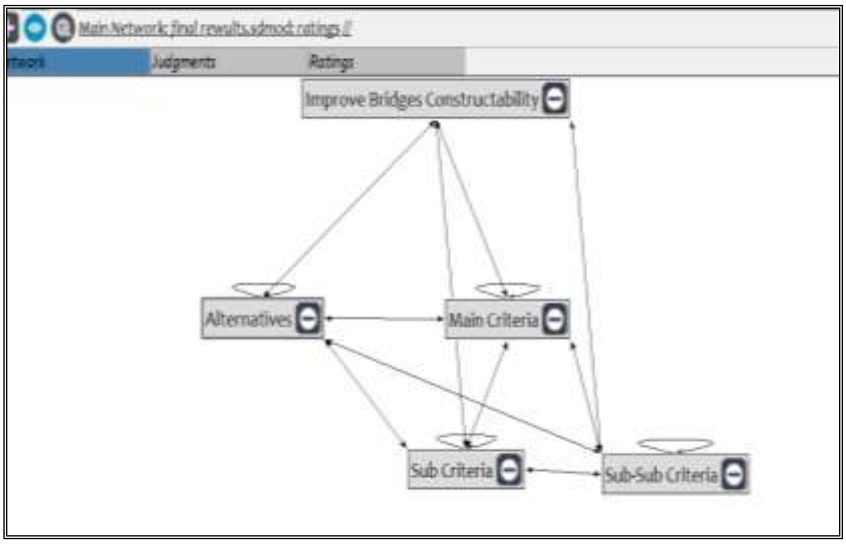
Cluster of sub-sub-main criteria with six nodes (i, ii, iii, iv, v, vi)

Cluster Alternatives with six nodes, alternatives A1, A2, A3, A4, A5 and A6.

'figure 1' shows the main network of the ANP model, also 'figure 2' illustrate the objective, & clusters relationships.



'Figure 1': Main network of ANP model



'Figure 2' Objective, & clusters relationships

3.1. Cluster design

Cluster of goal

This cluster is; the objective of the study of this research based on the scope of the study that defined in the pre study stage as VE procedure, this objective considered the only node of this cluster. also from pre-study stage of the VE procedures and with respect to the experience were determined both of main criteria, and sub-main criteria, also sub-sub main criteria. This is as will show in the following parts of this study.

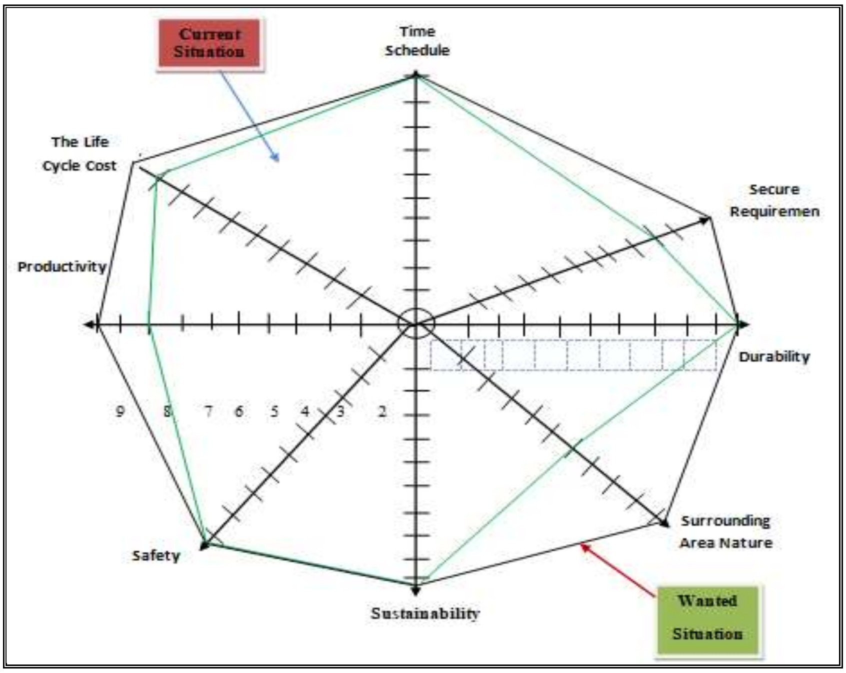
Cluster of main criteria

The main criteria of that scoped study are as in 'table 1'

'Table 1': The main criteria of study

ID	Criteria	Ranking	ID	Criteria	Ranking
A	Time schedule	10	E	Safety	9
B	Sustainability	9	F	Secure requirement	8
C	Durability	9	T	Surrounding area nature	6
D	Productivity	8	Z	The life cycle cost	9

The objectives of any VE study is to achieve the maximum quality with optimizing cost so our target in this research is to achieve the maximum for all the parameters which are considered the criteria of the VE study as shown in 'figure 3'



'Figure 3' Quality model for construction projects

3.2.3 Cluster of sub-main criteria

The sub-main criteria of this scoped study are as in 'table 2'

'Table 2' The sub-main criteria of study

ID	Criteria	ID	Criteria
l	Span of bridge	R	Existing utilities
m	Height of piers	S	Nature of crossing
n	Typical span number	U	Land topography
o	Breadth of the bridge	Y	Experiences of workmanship
P	Horizontal alignment		

Cluster of sub-sub main criteria For nature of crossing, and existing utilities criteria there have a sub criteria; The nature of crossing may be one of:

- Heavy traffic roads
- Waterway
- Valleys., Also the existing utilities may be one of:
- Fiber optics
- Electrical cables & telephone wires
- Storm water & drainage.

Having the following ranking of effect on the weighting of the criteria that as shown in 'table 3'.

'Table 3' Ranking for "the sub-sub main criteria"

ID	Criteria	Ranking
i	Fiber optics	20 %
ii	Electrical cables & telephone wires	18 %
iii	Storm water & drainage	12 %
iv	Heavy traffic roads	21 %
v	Waterway	18%
vi	Valleys	11 %

Cluster of alternatives

As a speculative phase; The namely widely used bridges systems as alternatives for scoped study were as following;

Cable stayed bridges, and Box girder bridges. Although, there are many types in bridge construction, there are three types of bridge construction that are widely used across the world; these are:

Concrete bridges,

Steel bridges, and Composite sections bridges

By combining the above-mentioned bridge types and systems, result the following 6 bridges alternatives:

A1. Concrete cable stayed bridges

A2. Steel cable stayed bridges

A3. Composite sections cable stayed bridges

A4. Concrete box girder bridges.

A5. Steel box girder bridges.

A6. Composite sections box girder bridges.

Analysis of ANP outputs

Comparisons on node level.

In this step create the unweighted super-matrix. It is a square matrix of all nodes in the decision-making problem and contains local priorities. This be performed through comparison relationships in the node level for:

- Alternatives
- Main criteria
- Sub-main criteria
- Sub-sub criteria

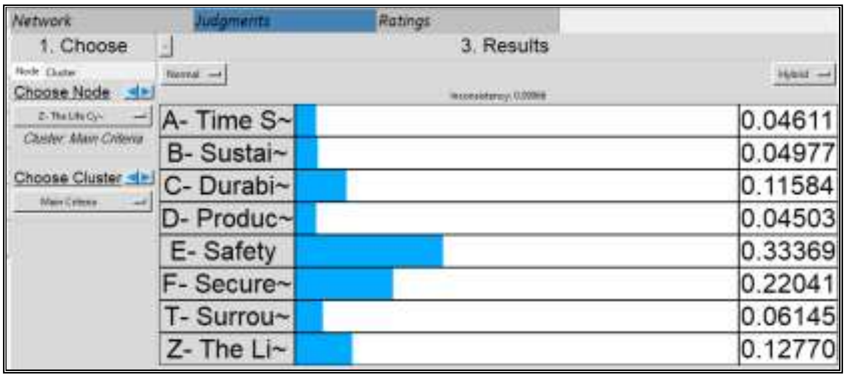
The Comparison of alternatives

The final results of comparing varies alternatives in node comparison level as in 'figure 4'

'Figure 4' Final results of varies alternatives in node comparison level

The comparisons of main criteria

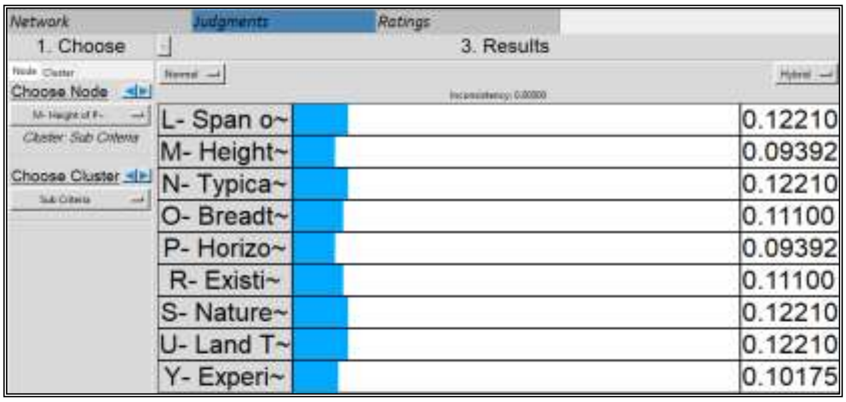
The final results of comparing different main criteria in node comparison level as in 'figure 5'



'Figure 5' Final results for node comparisons of main criteria in node level comparison

Comparisons of sub criteria in node level comparison

The final results of comparing different sub criteria in node comparison level as in 'figure 6'



'Figure 6' Final results for node comparisons of sub- main criteria in node level comparison.

Comparisons of different sub-sub criteria in node level comparison

The final results of comparing different sub-sub main criteria in node comparison level as in 'figure 7'

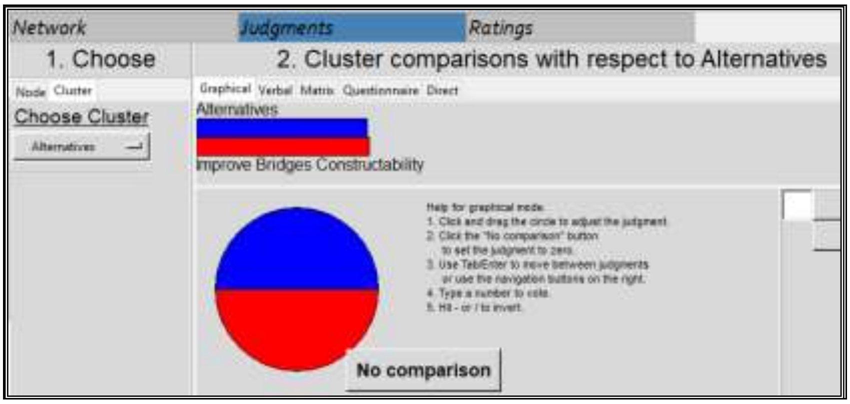
'Figure 7' Final results for node comparisons of sub- sub main criteria in node level comparison

Comparisons on a cluster level

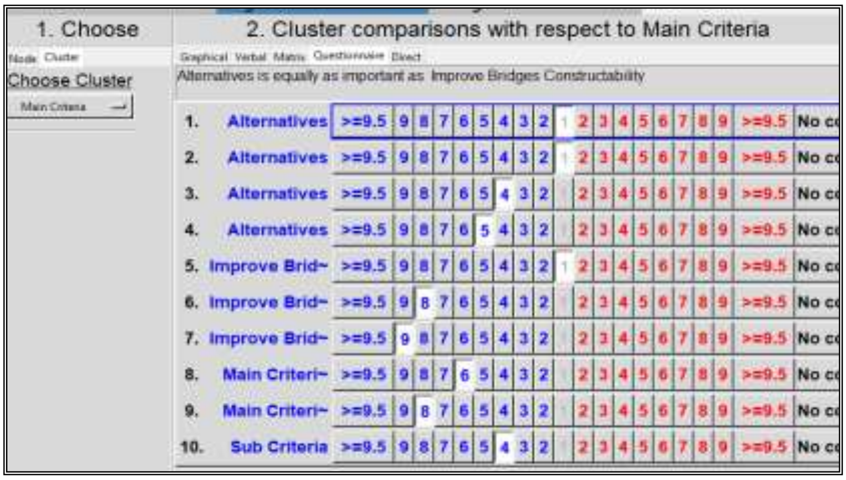
The goal of this step is to convert the unweighted matrix into the weighted super, for this step, we have to do the following comparisons:

- Compare three clusters of criteria with respect to the goal.
- Compare three clusters of criteria with respect to the alternatives.

In the next part will show the comparisons of the three clusters in the cluster comparison level, 'figure 8' shows the comparisons of alternatives in the cluster level comparison, 'figure 9' shows the comparisons of main criteria in the cluster level comparison, and 'figure 10' shows the comparisons of sub criteria in the cluster level comparison, in the last 'figure 11' shows the comparisons of sub-sub criteria in the cluster level comparison.

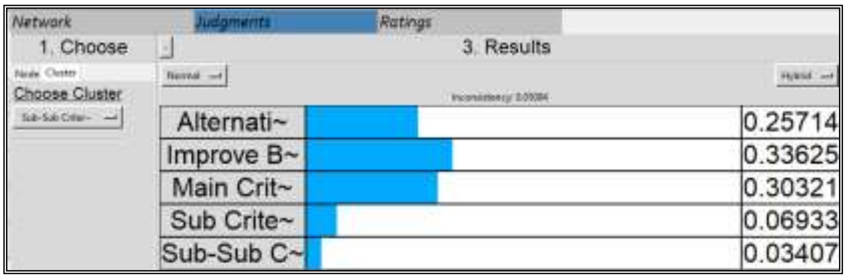


'Figure 8' The comparisons of alternatives in the cluster level comparison



'Figure 9' The comparisons of main criteria in the cluster level comparison

'Figure 10' The comparisons of sub criteria in the cluster level comparison



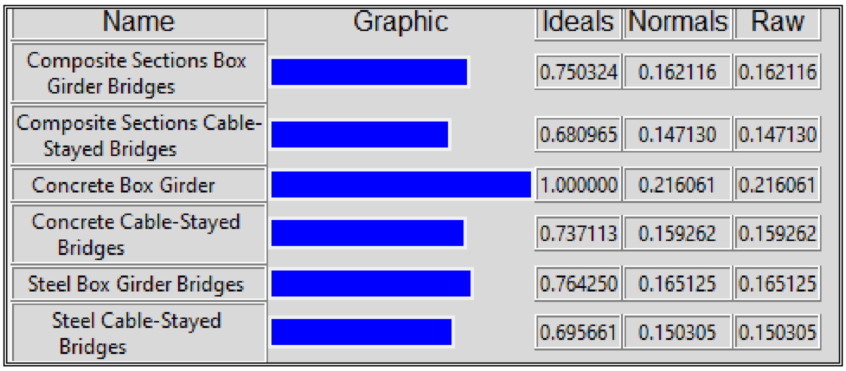
'Figure 11' The comparisons of sub-sub criteria in the cluster level comparison

The limit matrix

In this step, the weighted matrix is multiplied by itself as long as all of its columns become equal. This is how we get the final priorities. After this step, the sensitivity analysis is performed, to obtain the final upgrade of the proposal.

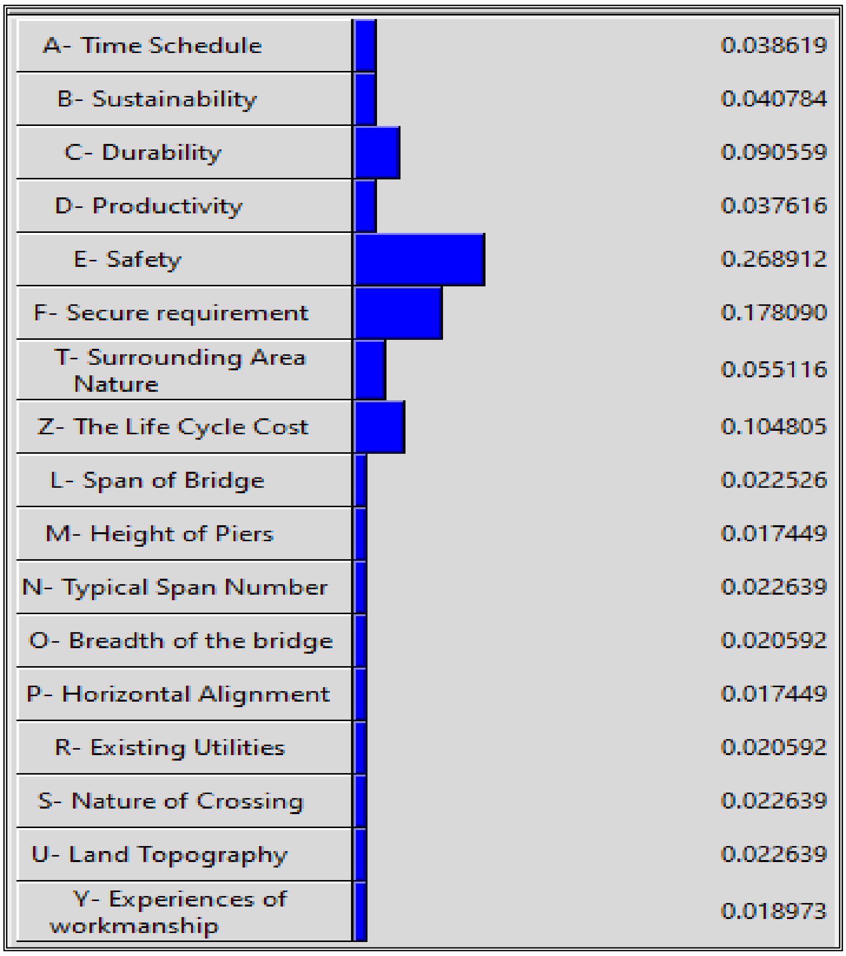
Proposals of the ANP upgrades

In this ANP upgrade, local priorities in terms of dependencies between criteria are calculated automatically. The main advantage of this approach is that the total implementation process takes less time. The second upgrade is related to applying the concept of compatibility between interdependent matrices in the ANP. By using this approach, the process of calculating the priorities of criteria with respect to alternatives can be shortened, this As in 'figure 12' which shows the overall synthesized priorities for the alternatives, and 'figure 13' Priorities for columns rating system



Name	Graphic	Ideals	Normals	Raw
Composite Sections Box Girder Bridges		0.750324	0.162116	0.162116
Composite Sections Cable-Stayed Bridges		0.680965	0.147130	0.147130
Concrete Box Girder		1.000000	0.216061	0.216061
Concrete Cable-Stayed Bridges		0.737113	0.159262	0.159262
Steel Box Girder Bridges		0.764250	0.165125	0.165125
Steel Cable-Stayed Bridges		0.695661	0.150305	0.150305

'Figure 12' The overall synthesized priorities for the alternatives



'Figure 13' priorities for columns rating system

Next step is the finally one which is the final report that is in two main categories.

<u>The first one is: the top level part</u>

This is a report for how alternatives fed up through the system to give us our synthesized values. The alternative rankings in this part are in the previous figure.

<u>The second part is: the bottom level network with ratings information</u>

The alternatives for this network are found in the ratings system. The totals we get for the alternative priorities for this network come from the ratings system.

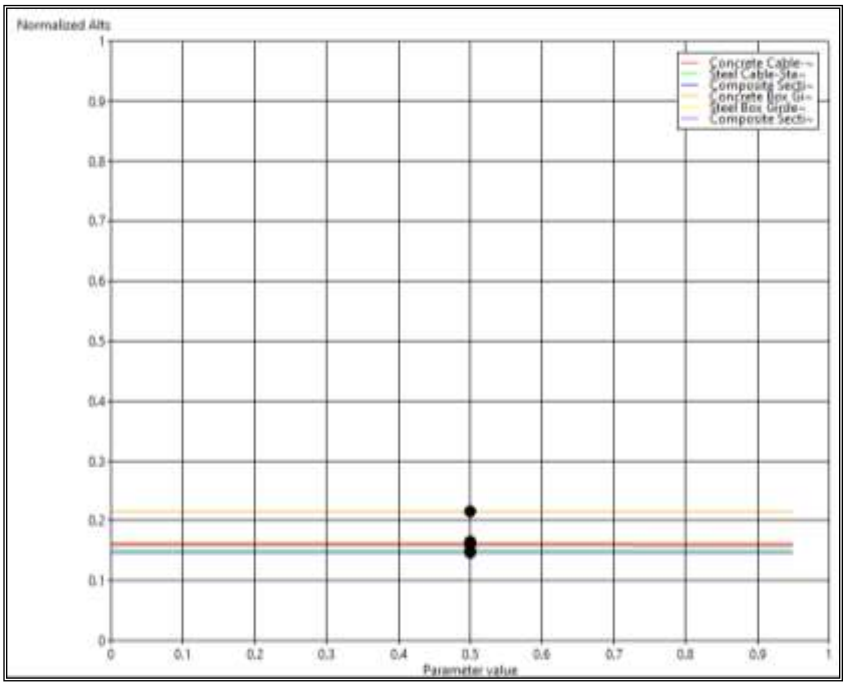
- **Results and discussions**

Based on the function analysis phase of VE, and VE procedures using the analytically net wok process; resulted that the final ranking of all different alternative was as in 'figure 14'

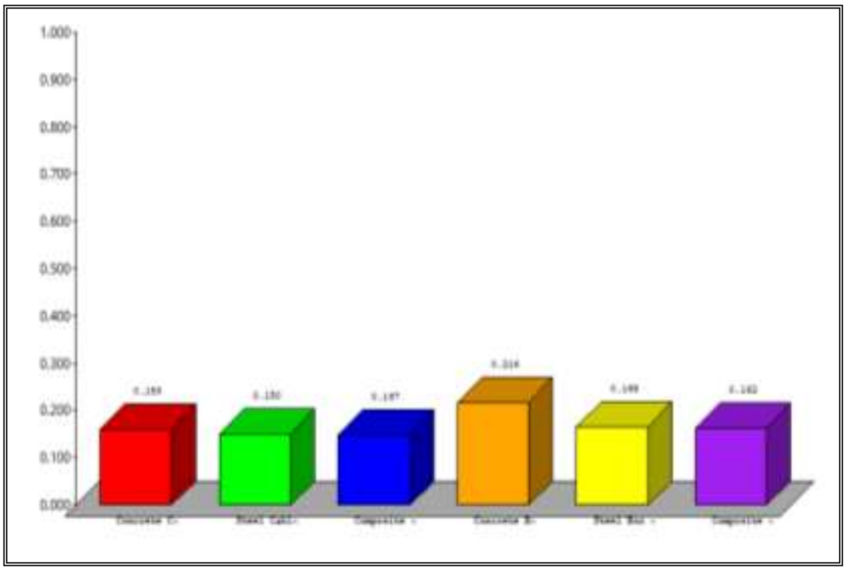
Graphic	Alternatives	Total	Normal	Ideal	Ranking
	Composite Sections Box Girder Bridges	0.1621	0.1621	0.7506	3
	Composite Sections Cable-Stayed Bridges	0.1472	0.1472	0.6813	6
	Concrete Box Girder	0.2160	0.2160	1.0000	1
	Concrete Cable-Stayed Bridges	0.1593	0.1593	0.7373	4
	Steel Box Girder Bridges	0.1651	0.1651	0.7645	2
	Steel Cable-Stayed Bridges	0.1503	0.1503	0.6959	5

'Figure 14' The Alternative Rankings

This ANP model give us a very good chance to achieve different plotted shapes of the results as in the following figures



'Figure 15' Plotted sensitivity for final results



'Figure 16' Bar chart sensitivity for final results

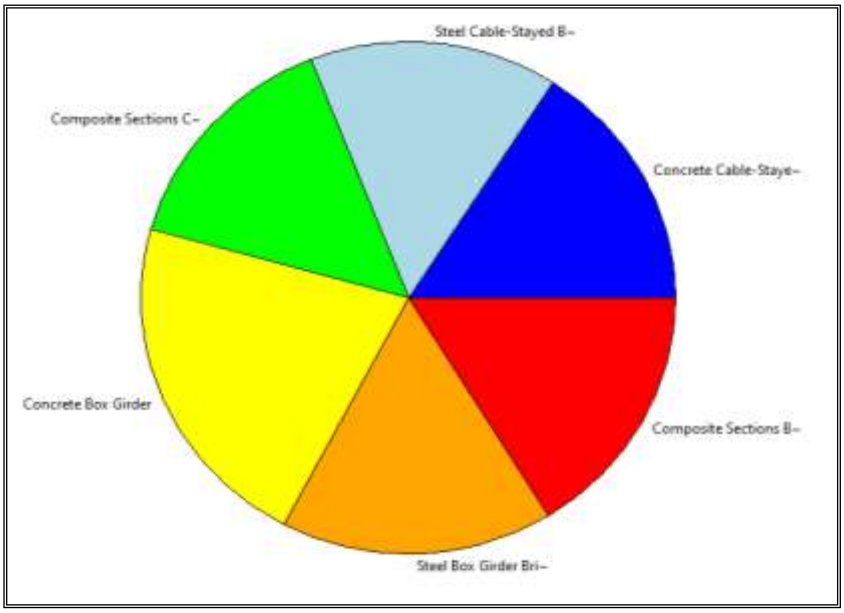
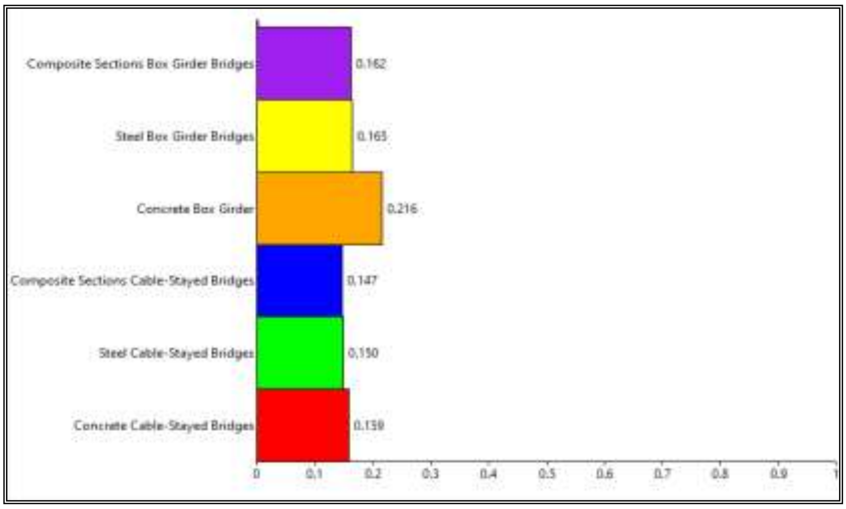


Figure 17' Pie chart sensitivity for final results



'Figure 18' Horz bar chart sensitivity for final results

<u>The final results of this study improve that</u>

The best alternative is the concrete box girder type, that based on the determinants and criteria of this scoped study as a virtually study.

The possibility of applying this system to such studies of infrastructure and bridges, and its applicability for any scope, and any type of projects.

The efficiency of this applied model in feasibility studies for projects of various kinds, whether national or private, larger or smaller. which means its high efficiency in reducing the areas of unnecessary costs by choosing the best alternative commensurate with the limitations of the field of study, which allows decision-makers to choose the best alternative among the available alternatives and what Commensurate with the objective of the project under study

The question of Why ANP?!!! Answered by the capability that achieved as a result of this study, and its widely used to solve various issues in the real-world due to the consideration of complex and interrelated relationships between decision elements and the ability to apply quantitative and qualitative attributes simultaneously. Also proves to be an effective framework for assessing readiness to adopt TQM and facilitating TQM, and VE.

- **Conclusion and recommendation**

From the results of this research it is found; the necessity of applying the ANP model with respect to VE procedures to bridges projects of all kinds and their determinants, as well as all other construction projects, especially national ones, in future studies, which allows decision-makers to make decisions that aim at the highest quality without any waste in unnecessary costs.

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