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Integrated Framework for Proper Constructability in Bridges Using Value Engineering and Analytical Network Process 'ANP" (Analytical Study)

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Abstract: Due to recent environmental and Political requirements, and regulations of the construction industry, in which bridges is one of its important category, deciding its proper constructability is becoming vital. Therefor the objective of this research is to develop a decision model for selecting proper constructability of green bridges constructions, the model was built based on analytical network process (the ANP) soft were program, integrated with value engineering approach. For this analytical study different parameters are identified and ranked to be implemented for the decision model developed on the biases of four surveying studies conducted in this study the results of these surveying's was be analyzed by using the statically analytical program; "SPSS". Model validation and reliability is carried out using the analytical network process (ANP) for statistically analysis using case study which is a cable bridge project constructed in Egypt. ANP proves to be an effective framework for assessing readiness to adopt and facilitating TQM. The result of the study illustrate that the proper constructability alternative in green bridge concept for this determinate project is the concrete box girder type, upon this there is a cost loss of $3, 500 per square meter, equivalent to 50% losses, respect to the life cycle cost this is due to did not using the best alternate of the estimated project. upon the possibility of applying this decision model to such studies of infrastructure projects, and with respect to the results gained; it is recommend to apply 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.

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

إطار متكامل لتحسين إنشائية الكباري باستخدام الهندسة القيمية وعملية الشبكة التحليلية "ANP" (دراسة تحليلية)

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المستخلص: نظرًا للمتطلبات البيئية والسياسية الأخيرة، ولوائح صناعة البناء، والتي تعد صناعة الكباري واحدة من فئاتها المهمة، فإن تحديد النظام الانشائي وطريقة الانشاء المناسبة لها أمرًا حيويًا وهاماً. لذلك فإن الهدف من هذا البحث هو تقديم نموذج مطور لمتخذي القرار يتيح اختيار طريقة الانشاء المناسبة والمستدامة لمنشآت الكباري. يعتمد هذا النموذج على عملية شبكة تحليلية متكاملة مع نهج هندسة القيمة. يتم تحديد معايير مختلفة وتصنيفها طبقاً لنموذج القرار الذي تم تطويره لهذه الدراسة التحليلية بناءً على عدد أربع دراسات مسحية تمت على هذه المنشآت والتي تم إجراؤها في هذه الدراسة، تم تحليل نتائج هذه الاستبيانات باستخدام برنامج التحليل الاحصائي (SPSS"). يتم التحقق من صحة وثبات هذا النموذج لإجراء التحليل الاحصائي باستخدام عملية الشبكة التحليلية (ANP) وذلك من خلال تطبيقه على حالة دراسية وهي مشروع كبري مدعم بالكابلات تم إنشاؤه في مصر. أثبت هذا النموذج من خلال نتائج هذه الدراسة أنه إطار عمل فعال لمثل هذه المشروعات. كما أوضحت النتائج أيضاً أن البديل المناسب للإنشاء الكباري في حالة اعتبار نفس المحددات للحالة الدراسية مجال هذا البحث هو نظام الكمرات الصندوقية الخرسانية، وأنه توجد خسائر تقدر بحوالي (3500 دولار لكل متر مربع بما يعادل 50 % خسائر في التكاليف)، وذلك نتيجة عدم استخدام البديل الأنسب للمشروع محل الدراسة، بناءً على النتائج التي تم الحصول عليها من خلال تطبيق نموذج التكلفة على المشروع، وفيما يتعلق بالنتائج المحققة؛ يوصى باستخدام هذا النموذج وتطبيقه على دراسات أخرى في المستقبل خاصة مشروعات الكباري بكل أنواعها، مما يتيح لمتخذي القرار اتخاذ قراراتهم بما يحقق أعلى جودة دون هدر استثمارات في غير موضعها.

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

1- Introduction

"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" (Akimovs, 2012)."The fast growth of populations has created new needs for mobility and increased the demands for constructing efficient bridges" (Jingyu, Cai- jiang, Mei- yung, 2014). "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" (Imhof, 2004]. "Bridges play an important role in linking different parts of highway networks, and therefore have a great impact on the capacities of such networks" (Cai- jiang, 2008). 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". (Óskarsson, 2012). 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" (Bruce, 2017). 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 (OQA 'office of quality assurance, 2009); applied the VE 'Value Engineering' as an evaluation approach for the highway improvement plans (Ando, 2005). (Jingyu, Cai-jiang, Mei- yung, 2014)); Applied the VM approach- SAVE International, 2007- 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 (Kadoić, Ređep, Divjak., 2020). 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 (Kadoić, Ređep, Divjak., 2017). 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 (Dou, Zhu, Sarkis., 2007). "this method uses with respect to factors of perception, preference, experience and intuition" (Siamak, Fariba, Hadis., 2020). 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" (Saaty, Vargas., 2009). "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" (Saaty, Cillo., 2008).

So, and 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)".

2- Research methodology

the objective of this research is to demonstrate decision support model to assist designers in deciding proper 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. This system developed was tested virtually using a case study which is a cable bridge project constructed in Egypt. four surveying studies conducted in this study whether through: field visits to bridge site, as well as interviews with the owner which are the Egyptian Ministry of Transportation, and The Engineering Authority of the Egyptian Armed Forces of the Egyptian Ministry of Defense. Also interviews with the consultancy offices of the project, and the contractor company which is the Arab contractor company, also by making communications with many of those interested in this field and those working in it from other countries. 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)". Several highway bridges have been constructed for different purposes, such as:

A. Crossing the waterways,
B. Crossing important highway intersections,
C. Solving the urban traffic problem by constructing elevated roads over the existing roadways, and
D. Replacing obsolete bridges.

The decision regarding the most convenient system of bridge construction is dictated mainly by many factors; including the site conditions, the technology, the resources available, and the required construction period. The objective of this study is to evaluate the bridge construction systems used in Egypt. The evaluation would be based on economic and engineering analysis.

So the work of this study involved the following:

First: Information gathering process was done about the bridges generally to define the scope of study and to define which project will be a case study. Upon this phase of study; the selected project is Rawd al- Farag Bridge- The East Nile Part- which is the widest cable- stayed bridge in the world according to what was approved by the International Guinness Book of Records, it is with 67.36 meters (221 feet) wide(186). So it was chosen to apply the ANP model to it. several interviews were made with the authorities concerned with this projects type, and in the forefront was the Engineering Authority of the Armed Forces as the supervisors, also with the Arab Contractors Company, the executing company of the project.

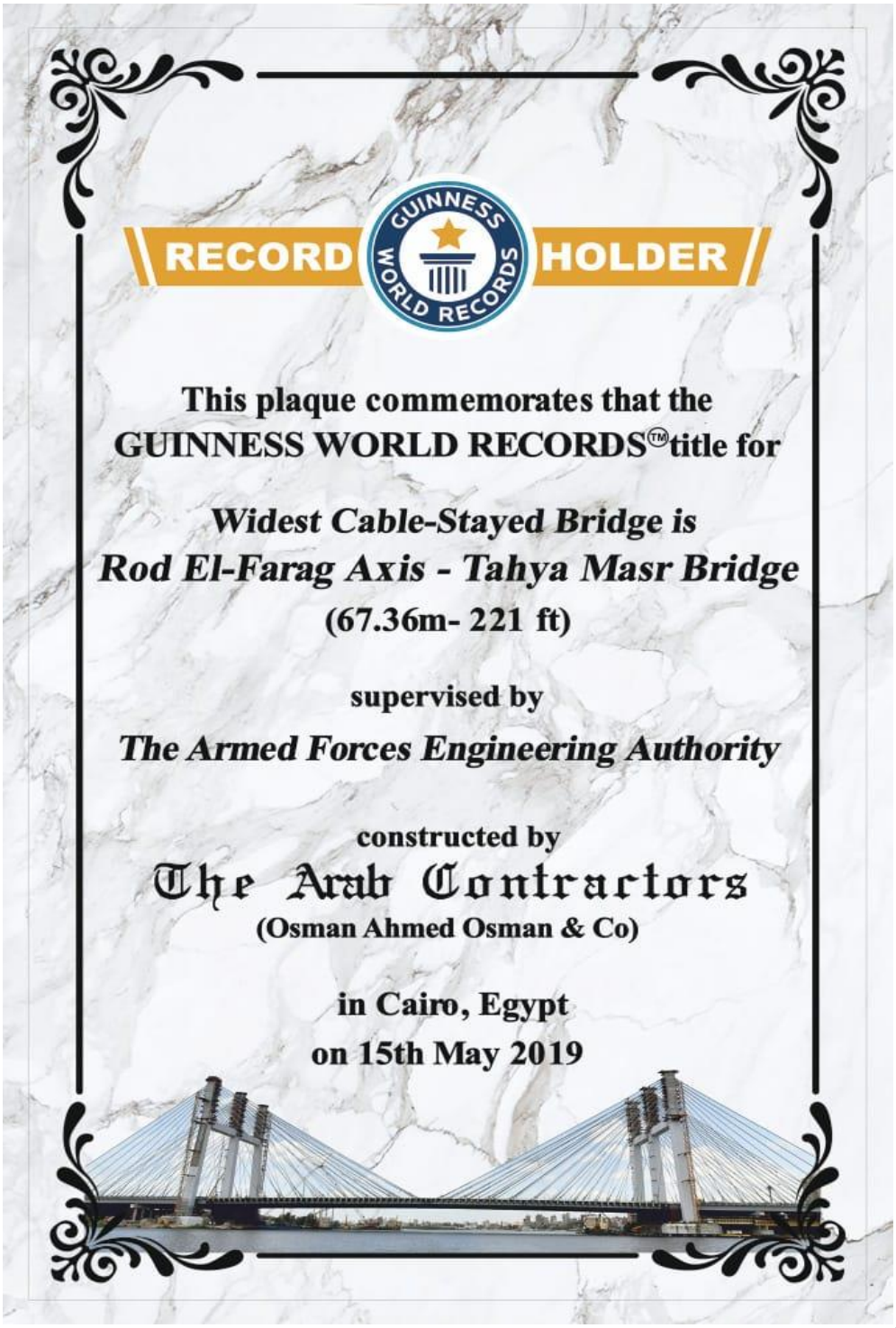

Figure (1) International Guinness Book of Records for Rawd al- Farag Bridge[25]

Second: Data collection was set about the project under study through surveying study and then analysis its results.

Third: Selection the evaluation procedure; which is by applying the value engineering procedures integrated with analytical network process (ANP).

Forth: 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.

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

1. Economic and engineering analysis of the construction systems applicable for each site conditions, and.
2. 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.

3- Data Collection Phase

The aim of this phase is to collect all the data about the project under study

3- 1- Description path of Rawd AL- Farag axis

The corridor starts from the area of Shubra in the east and extends to the west to cross the two branches of the Nile River between the island of Warraq and connects the Ring Road, the Axis of Zomor, Al- Barajil, Marioutia and Mansouriya, the industrial zone in Abu Rawash and the Alexandria Desert Road in the west and from it to the cities of Sheikh Zayed and the sixth of October, and the length of the axis is 35 km (Shubra- Alexandria Desert Road) and meets With the Dabaa axis and intersecting with the regional ring road and from it to Al Wahat Road.

3- 2- Components of the path of Rawd al- Farag axis

According to the data collected from the Engineering Armed Forces the axis of Rawd al- Farag contain the following component:

1. A concrete bridge consisting of five sectors with a total length of 15.7 km.
2. The length of the main body is 6.5 km.
3. The length of bridges (views / houses) is 9.2 km.
4. The total amount of concrete in the project 960 thousand cubic meters.
5. The total amount of iron in the project is 270 thousand tons.

3- 3- Description of the path of Rawd al- Farag axis sectors

The path of Rawd al- Farag axis consists of five main parts (sectors) according to the data from Engineering Armed Forces of Egypt.

The first sector: Shubra bridge

The structural system is: Box girder type in some parts, and precast main girder type in another parts

The second sector: East Nile bridge

The structural system is: Cable- Stayed type using precast segmental erection technique

The third sector: Al- Warraq island bridge

The structural system is: Box girder type in some pares, and precast main girder type in another parts, also some parts constructed as a slab type on piles

The fourth sector: West Nile bridge

The structural system is: Beam bridge using the cantilever carriage as a method of construction

The fifth sector: Ring intersection bridge

The structural system is: precast main girder type

4- Scope of the study

The field of study was determined by applying the previous experimental model of the ANP, on a section of the axis, which is the bridge on the Est Nile sector, as shown in 'figure 2'

Figure (2) Designed Shape of the Second Sector of Rawd al- Farag Path: East Nile Bridge [25]

4- 1- Information gathering

At this stage, the project data were collected in order to determine the parameters of the field of study. It was found that the determinates of the bridge under study are:

1. The subject bridge crosses a water channel of a total width 300m.
2. The water channel is 10m depth.
3. The navigational requirements are two envelopes each of 40m width by 10m height.
4. The site is located in Egypt and all the local market conditions apply.
5. There are no height restrictions existed.
6. No special environmental requirements were been.

4- 2- Information analysis

In this stage will apply the experimental model of the ANP on Est Nile sector of Rawd al- Farag axis with respect to the determinates of the project under study

5- The model applied

The model applied in this study is the ANP, this model consists of some of clusters, one of them is the criteria cluster; main and sub criteria also the cluster of the alternatives that may be exist for the project under study. With respect to the determinates of the study and the behavior of the project under study The model consist of the following

1. Cluster Goal with one node.
2. Clusters Alternatives with Six nodes, alternatives A1, A2, A3, A4, A5 and A6.
3. Cluster of Main Criteria with Eight nodes
4. Cluster of Sub- Main criteria with Nine nodes

The main network of the model, and objective, & clusters relationships showed in 'figures 3, 4'

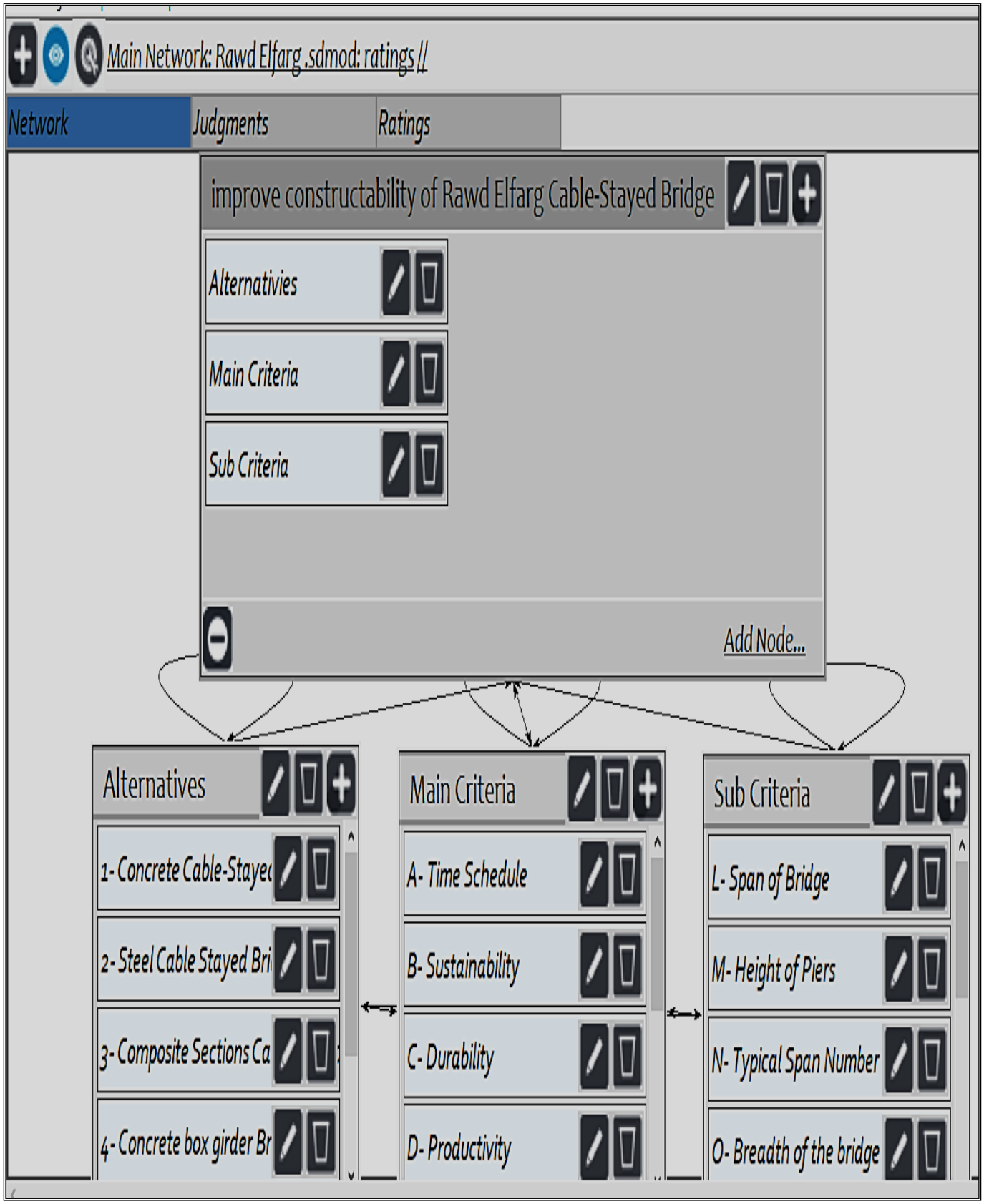

Figure (3) Main network

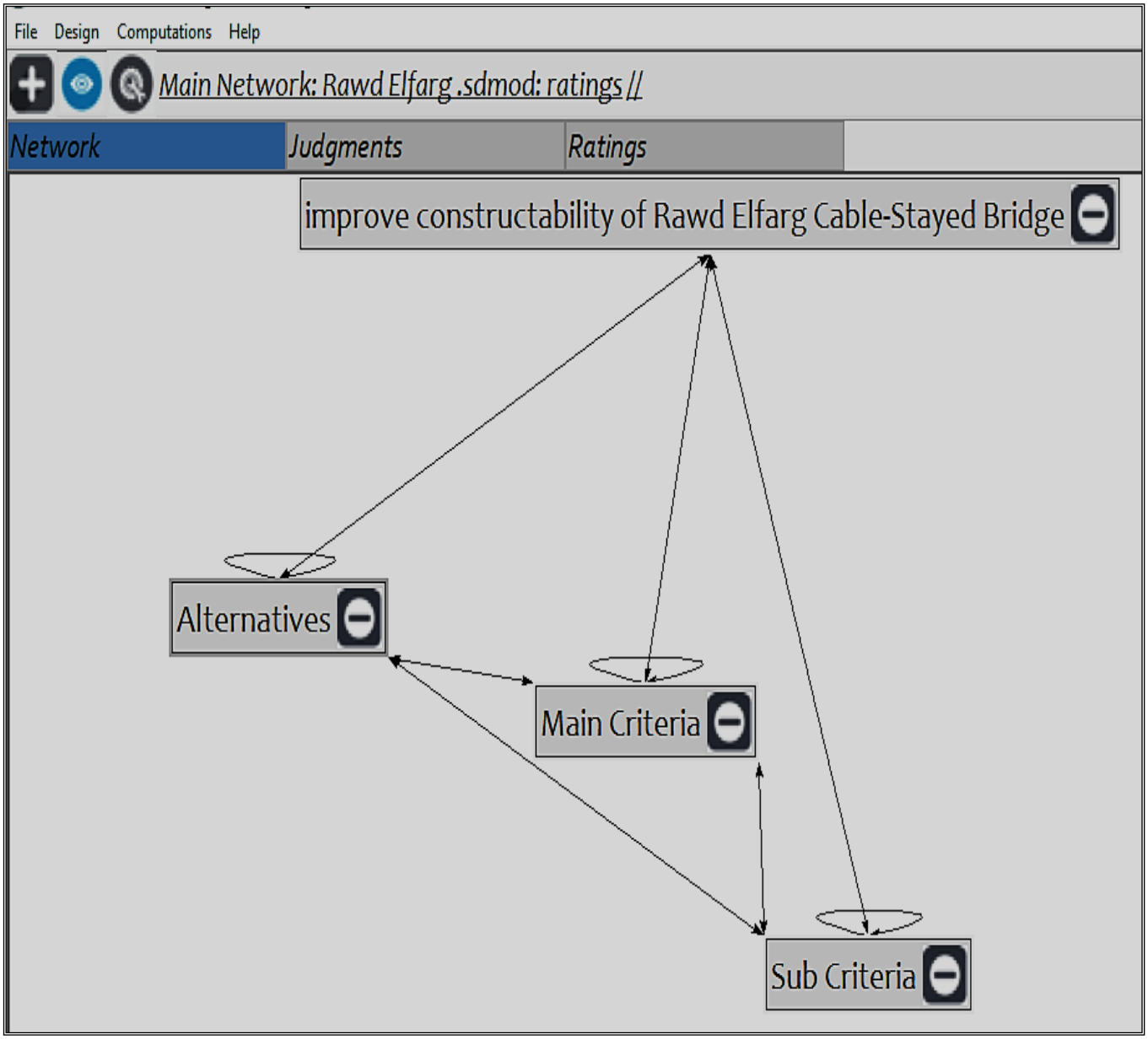

Figure (4) Objective & clusters relation ships

5- 1- Cluster design

a. ***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.

b. ***Cluster of main criteria:*** The main criteria of that scoped study are as in the following table, these criteria was studied through a surveying study to identify and rank it, that as in 'table 1'

Table (1) The main criteria of study

ID	Criteria	Ranking	IID	Criteria	Ranking
A	Time schedule	10	EE	Safety	9
B	Sustainability	9	FF	Secure requirement	8
C	Durability	9	TT	Surrounding Area nature	6
D	Productivity	8	ZZ	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 the 'figure 5

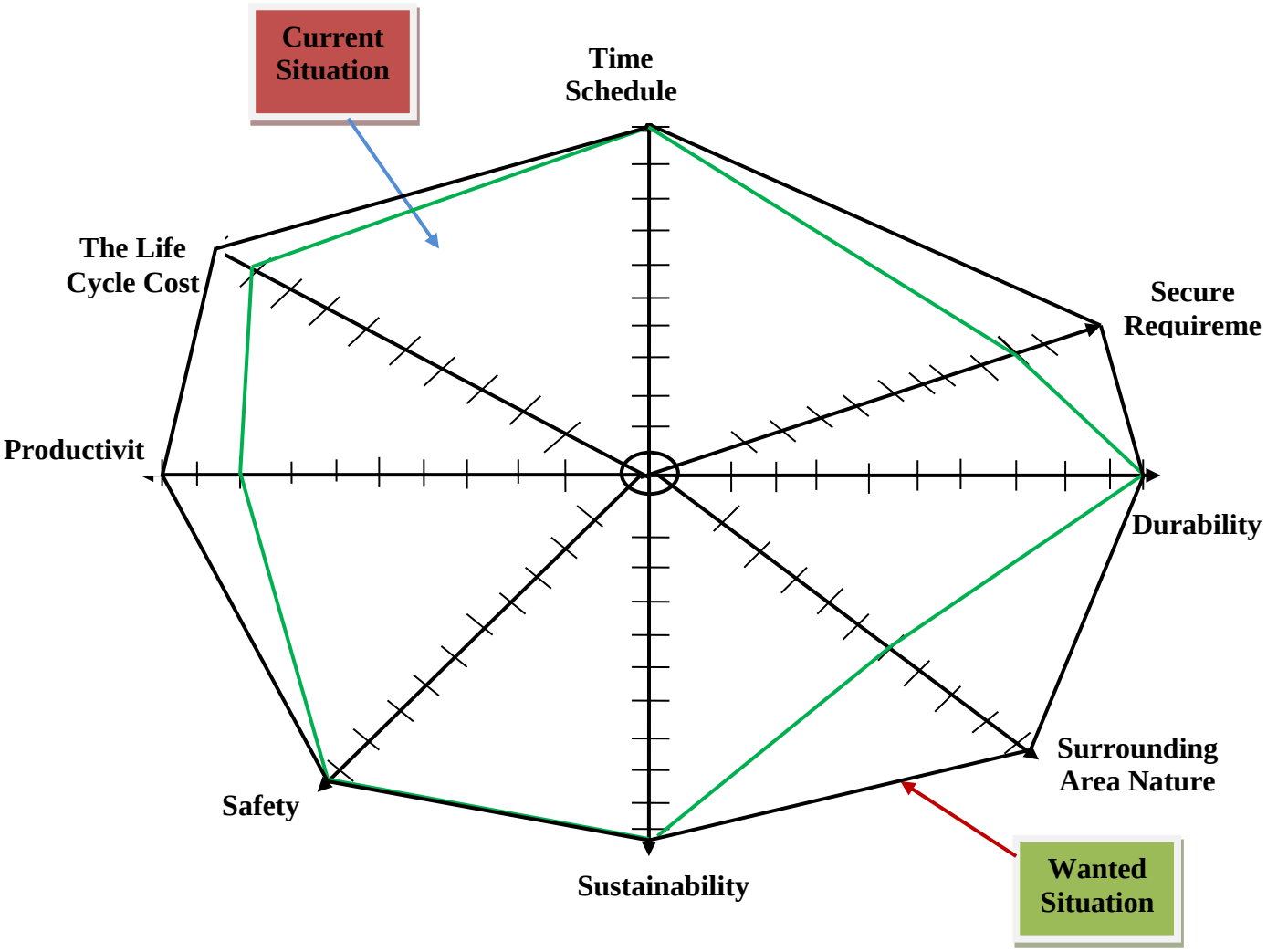

Figure (5) Quality model for construction projects [24]

c. ***Cluster of sub- main criteria:*** Also through a surveying study was be done to identify and rank it, the sub- main criteria of this scoped study are as in the '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		

d. Cluster of alternatives: As a speculative phase, with a brain storming technique, some of interviews was done with all of stake holders there may be with interest with this type of project as a surveying study whatever with owner authorities, consultant's offices, as well as contractor's companies; as the results obtained from analysis these questionnaires responds found that: the namely widely used bridges systems as alternatives for scoped study were as following;

1. Cable stayed bridges, and
2. 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:

1. Concrete bridges,
2. Steel bridges, and
3. 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.

In another round of questionnaire was make a surveying to study these alternatives by comparing there each with others to rank it. Then as a last round of questionnaire was made an survey to study the alternatives with the criteria –main and sub main ones- each of alternatives with the criteria respectively.

6- Analysis process

In the first; was studying pairwise comparisons on node level, then studying the Pairwise comparisons on a cluster level, which contain two comparisons the first one is compare three clusters of criteria with respect to the goal, and the second is comparing three clusters of criteria with respect to the

alternatives. The following step is; calculating the limit matrix, and in the last; the proposals of The ANP upgrades as the final results of the study.

6- 1 Pairwise comparisons on node level.

In this step was created the unweighted super- matrix. It is a square matrix of all nodes in the decision- making problem and contains local priorities. of the project under study "Rawd al- Farag Path: East Nile Bridge". This was performed through comparison relationships in the node level for:

1. Alternatives
2. Main criteria
3. Sub- main criteria
4. Sub- Sub criteria

a. The comparison of alternatives: The final results of comparing varies alternatives in node comparison level as in 'figure 6'

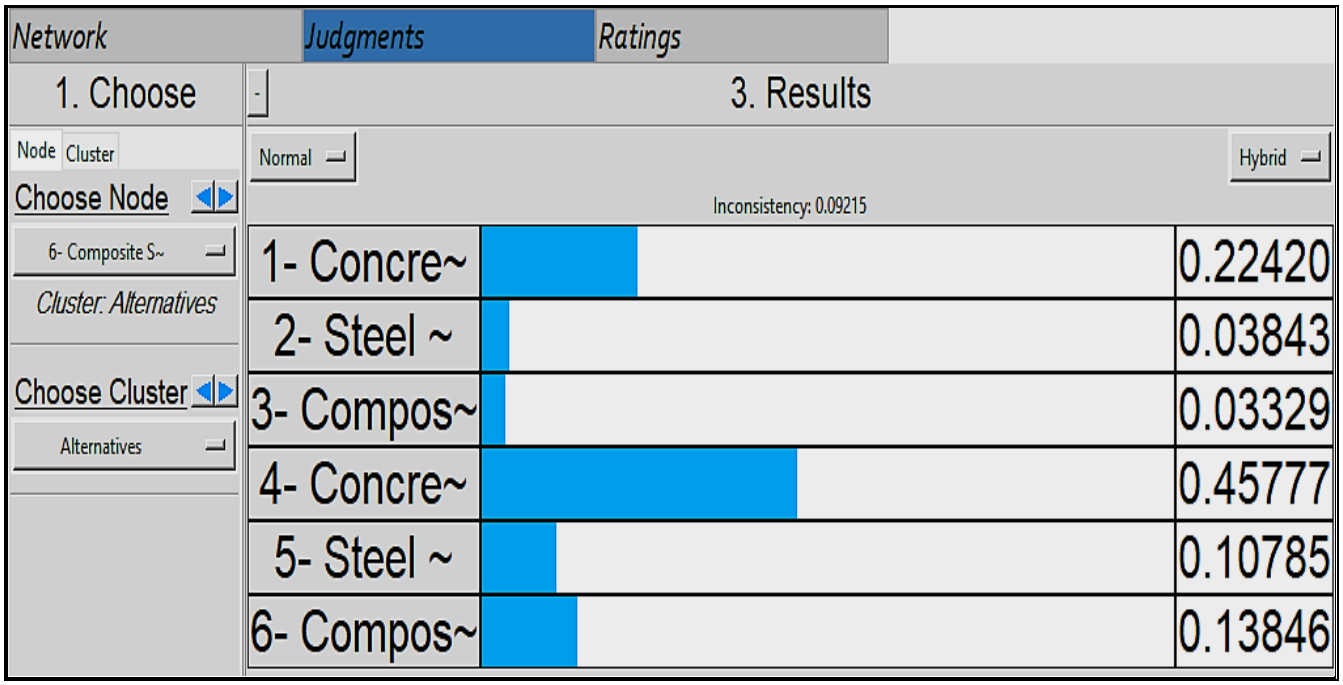

Figure (6) Final results of varies alternatives in node comparison level

b. The Comparisons of main criteria: The final results of comparing different main criteria in node comparison level as in 'figure 7'

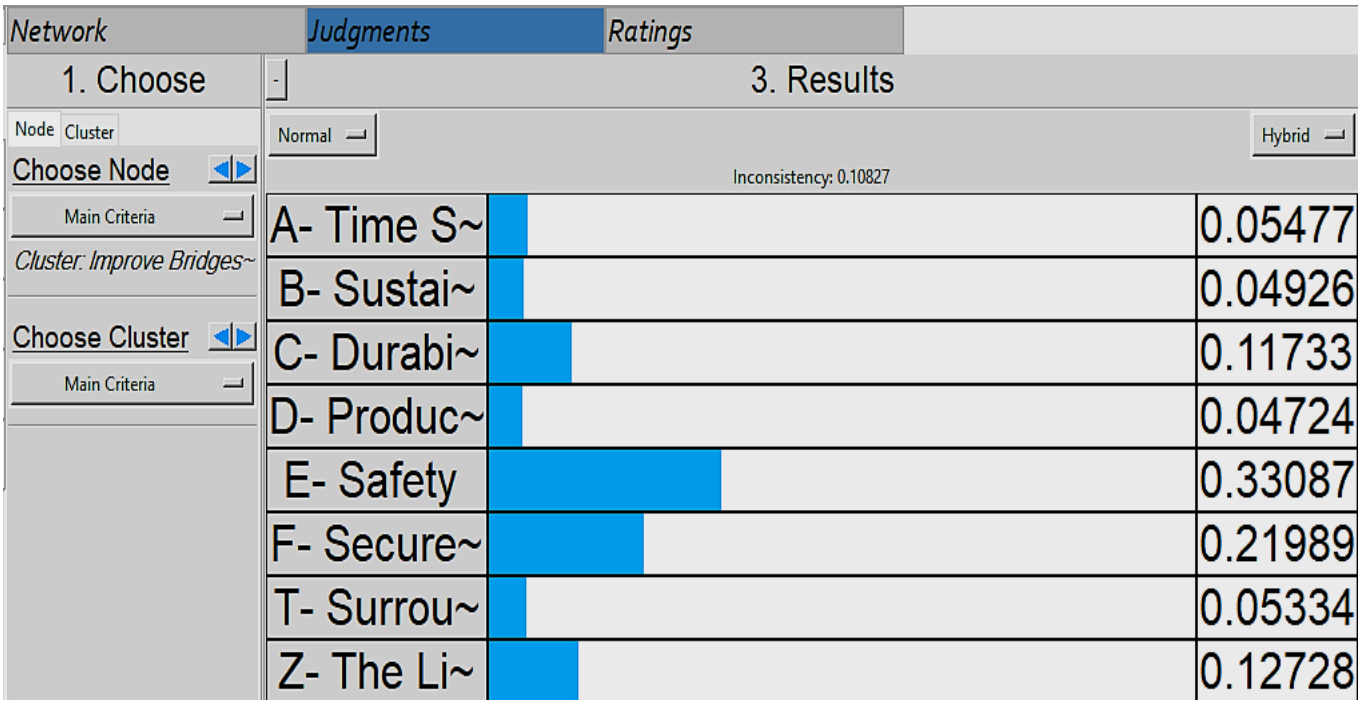

Figure (7) The unweighted super- matrix for main criteria

c. ***The comparisons of sub criteria:*** The final results of comparing different sub criteria in node comparison level as in 'figure 8'

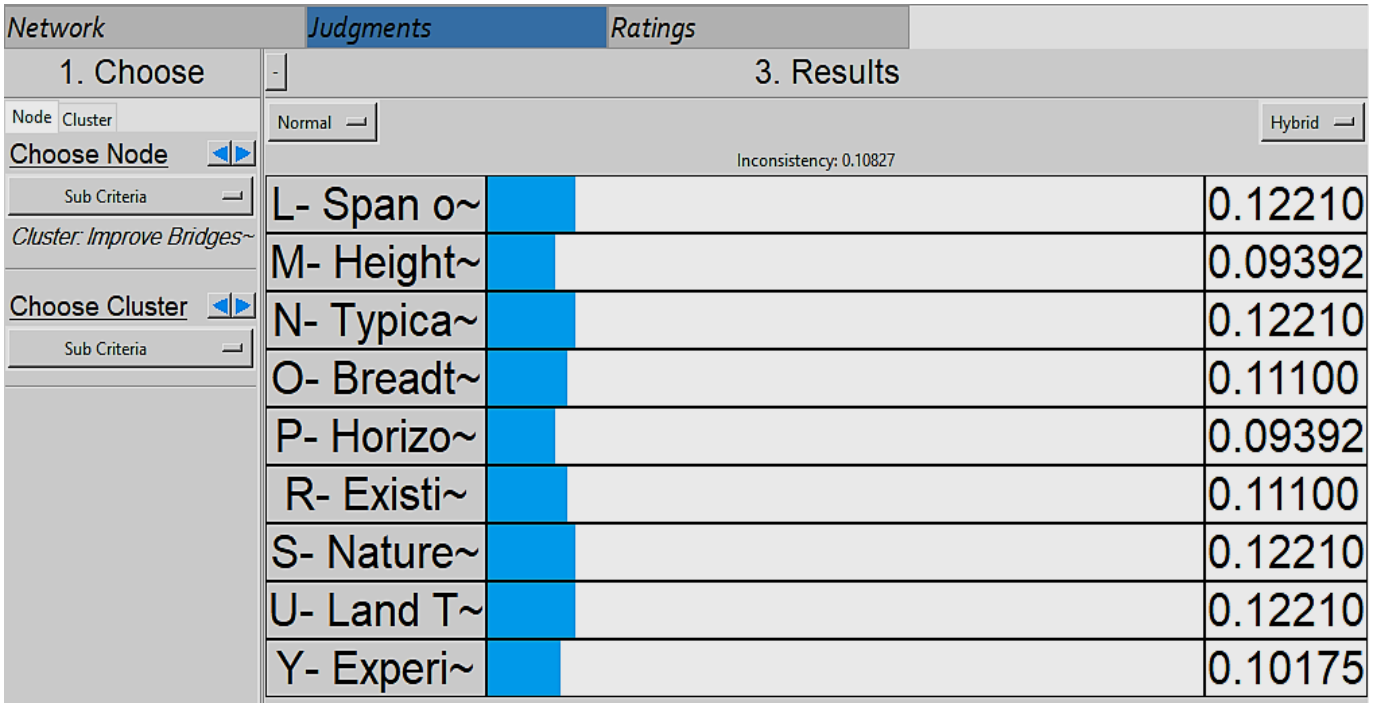

Figure (8) The unweighted super- matrix for sub- main criteria

6- 2 Pairwise comparisons on a cluster level:

In this step was convert the unweighted matrix into the weighted super- matrix to achieve this, we have to do the following comparisons:

a. Compare three clusters of criteria with respect to the goal.

b. 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 14' show the comparisons of alternatives in the cluster level comparison, 'Figure 15' comparisons of main criteria in the cluster level comparison, and 'Figure 9' comparisons of sub criteria in the cluster level comparison

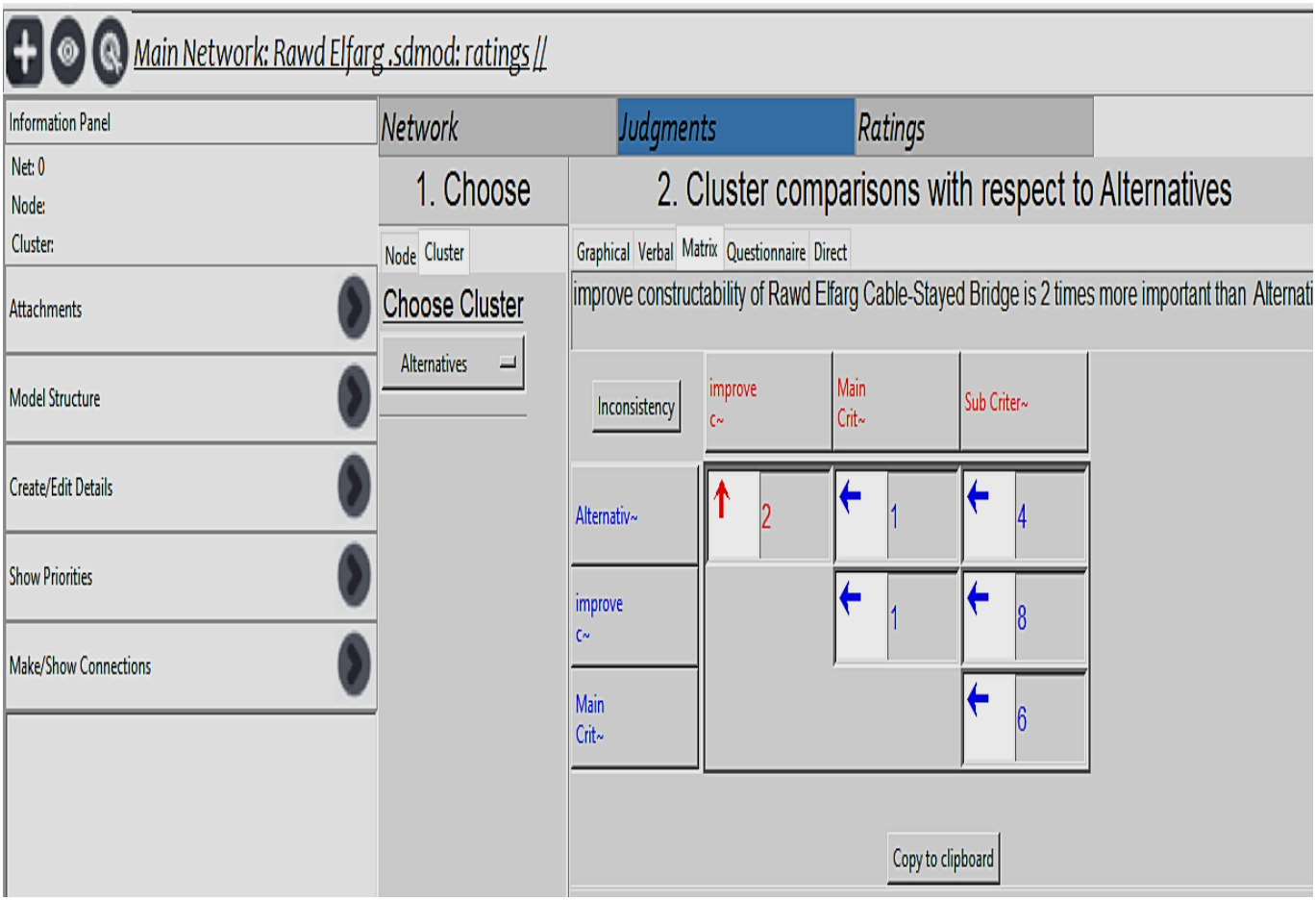

Figure (9) Comparisons of alternatives in the cluster level comparison

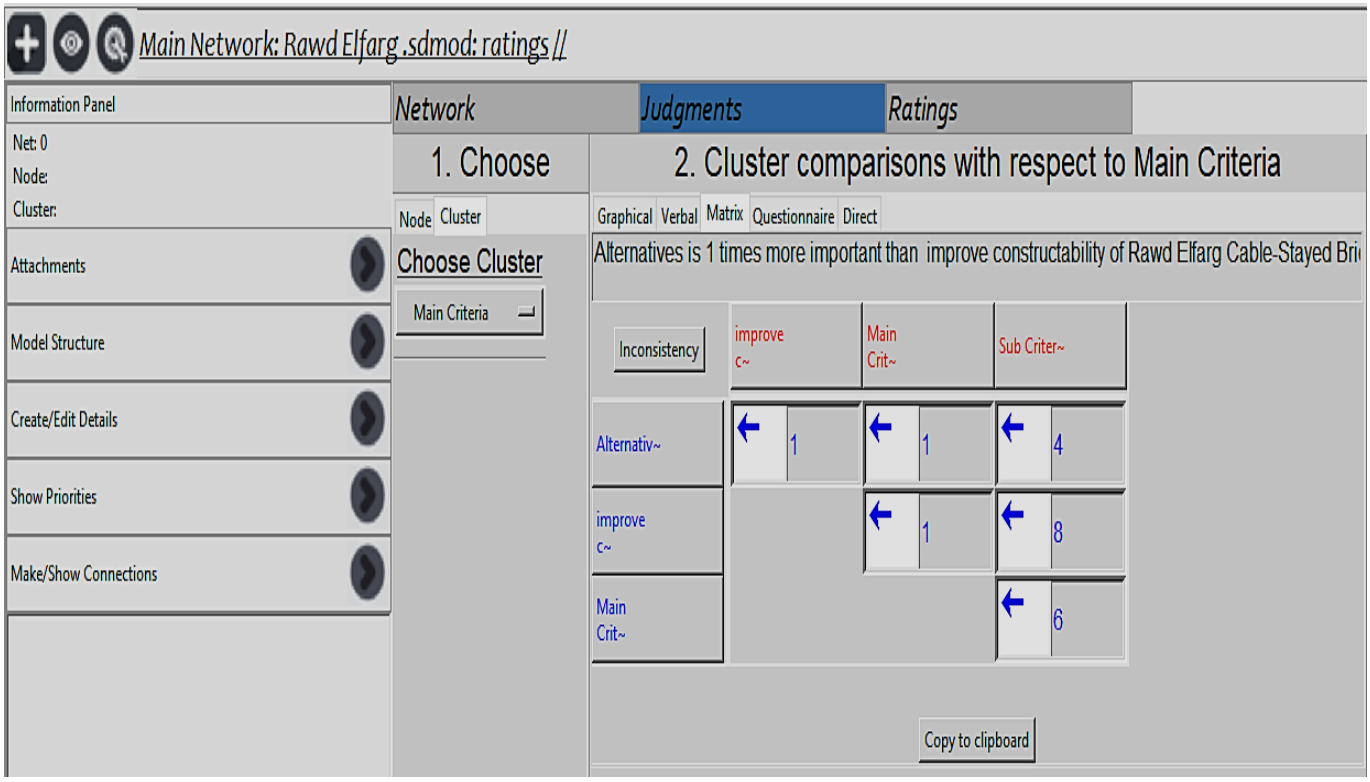

Figure (10) Comparisons of main criteria in the cluster level comparison

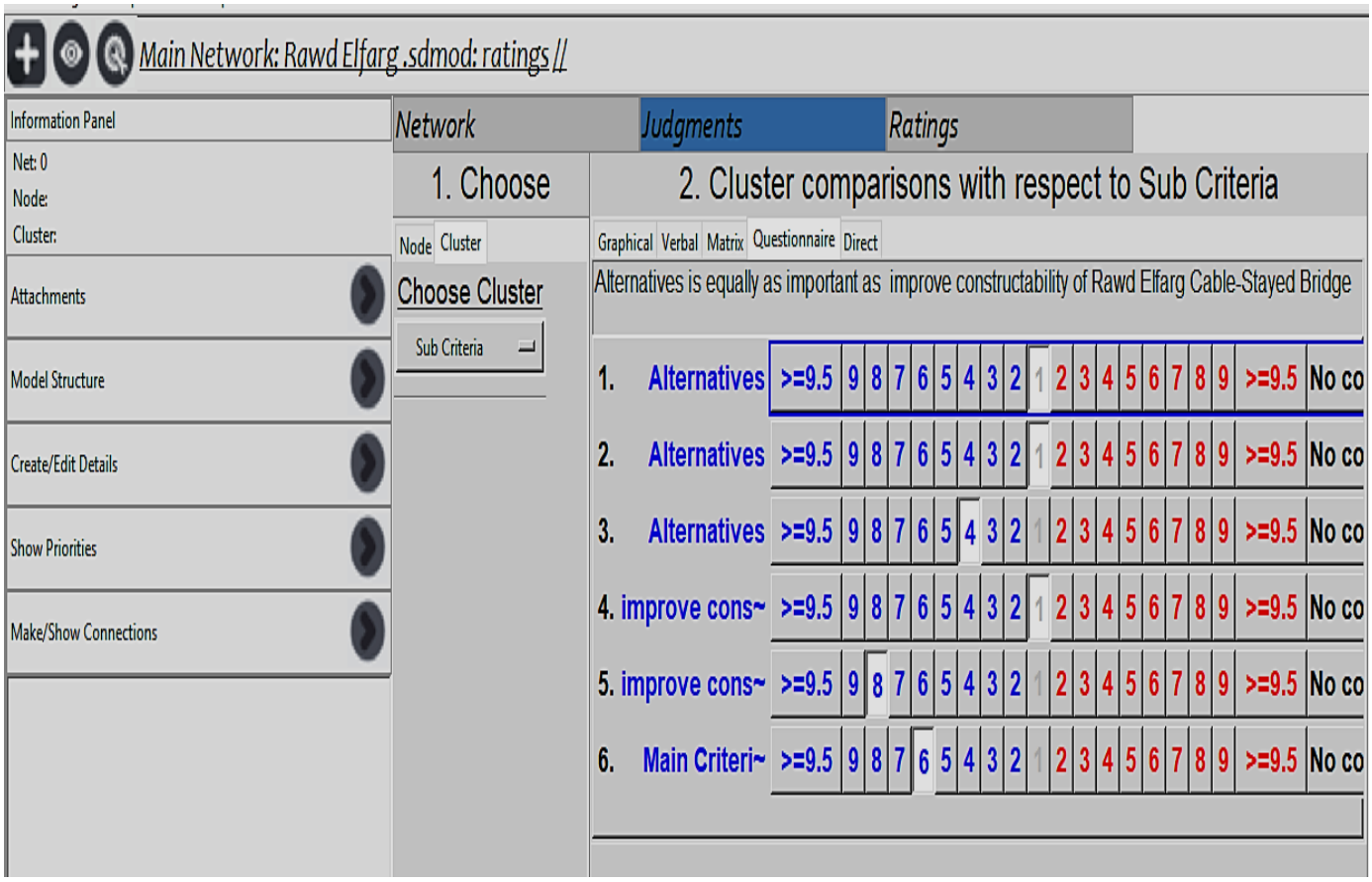

Figure (11) Comparisons of sub criteria in the cluster level comparison

6- 3 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. Which is expresses the results of the study that will be shown briefly in the next chapter.

6- 4 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. As following, where 'figure 12 showing the overall synthesized priorities for the alternatives, and 'figure 13' shows; priorities for columns rating system:

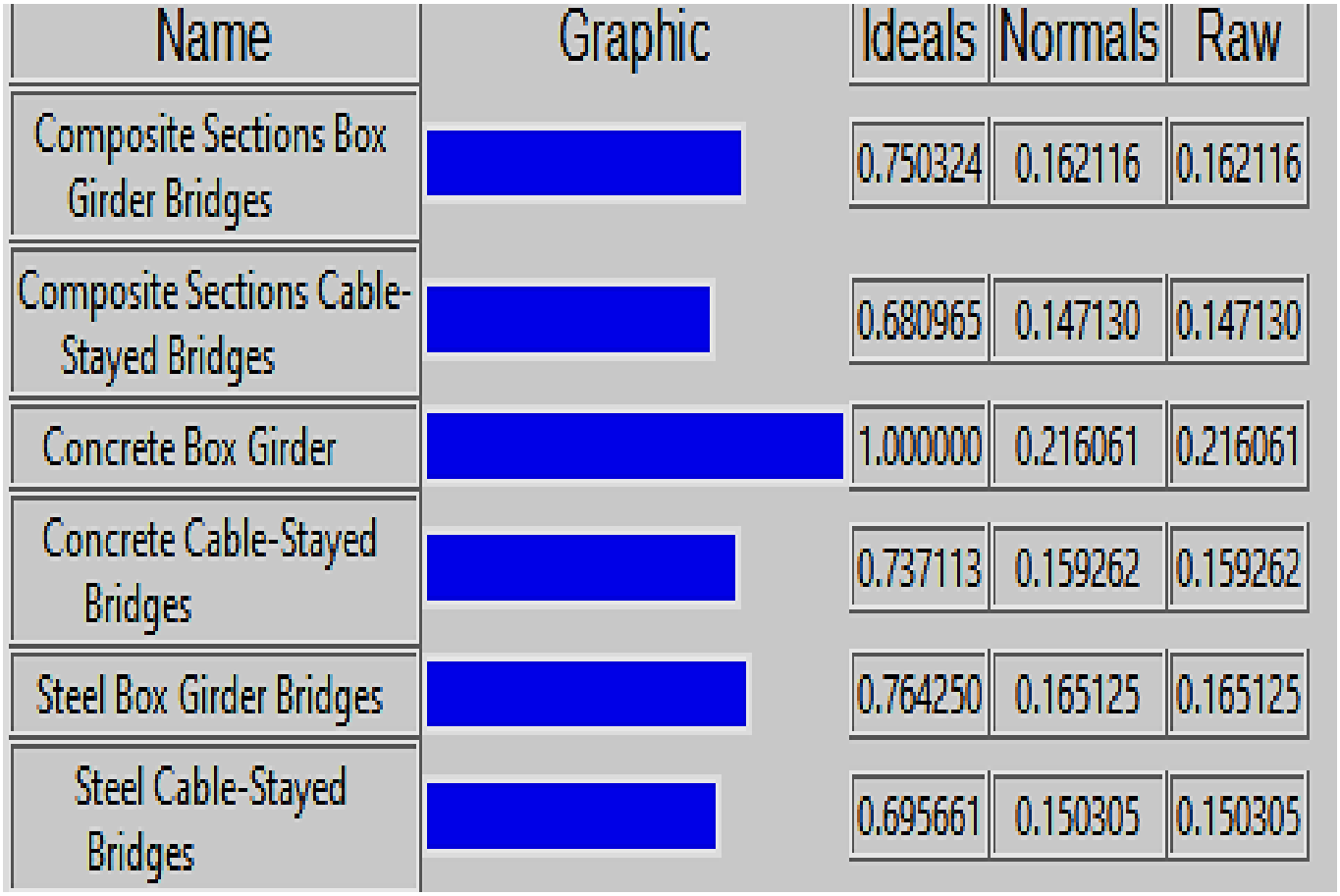

Figure (12) The overall synthesized priorities for the alternatives

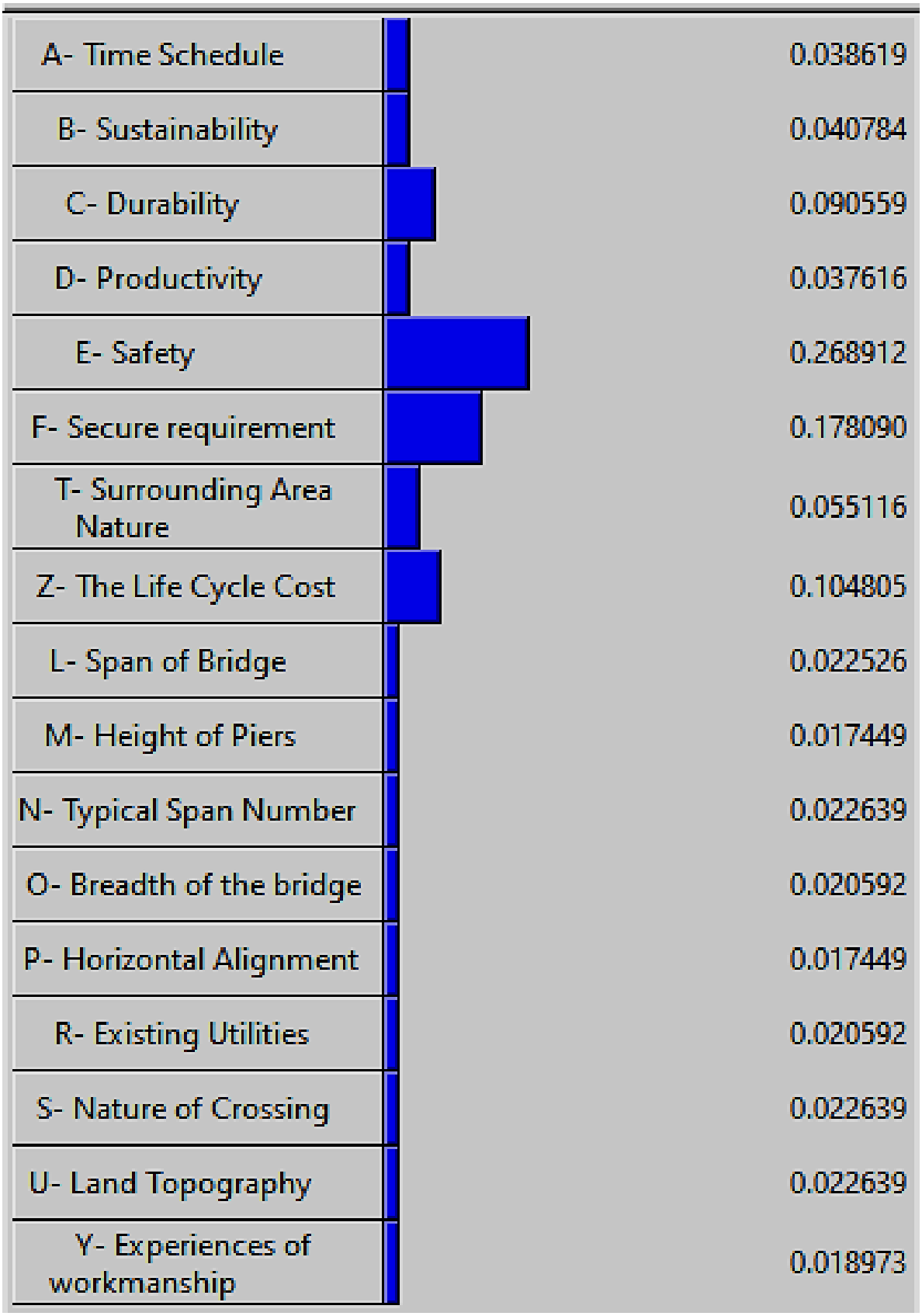

Figure (13) priorities for columns rating system

Next step is the finally ones, which is the final report that is in two main categories

The first one is: The top level part

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.

The second part is: The bottom level

Network with ratings information, 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.

7- 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 the following table

1. The best alternative is the concrete box girder
2. The rank of all different alternative was as in 'figure 14'
3. The final out puts of ANP model for the results shown in the next figures

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 alternatives ranking

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

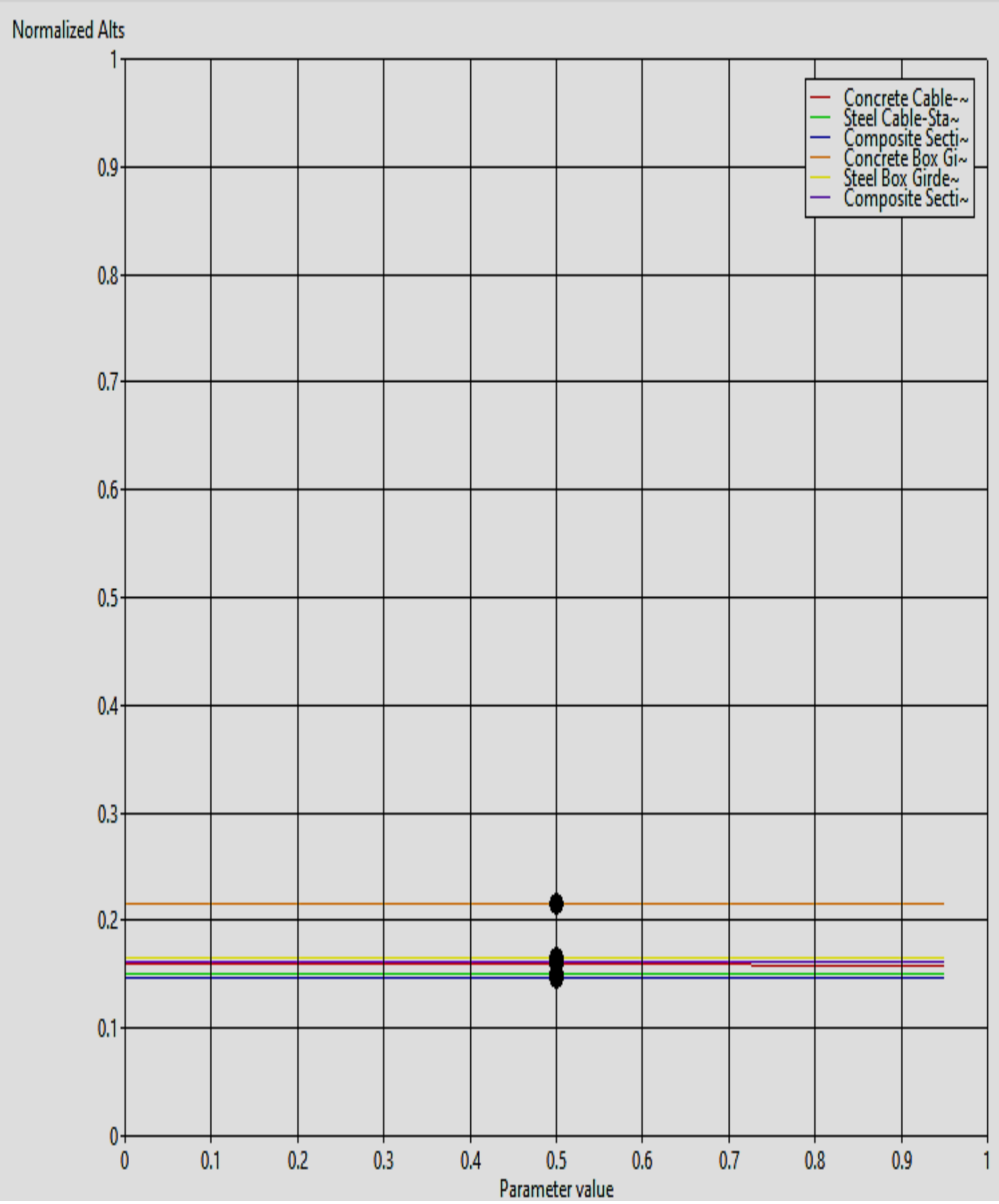

Figure (15) Plotted sensitivity for final results

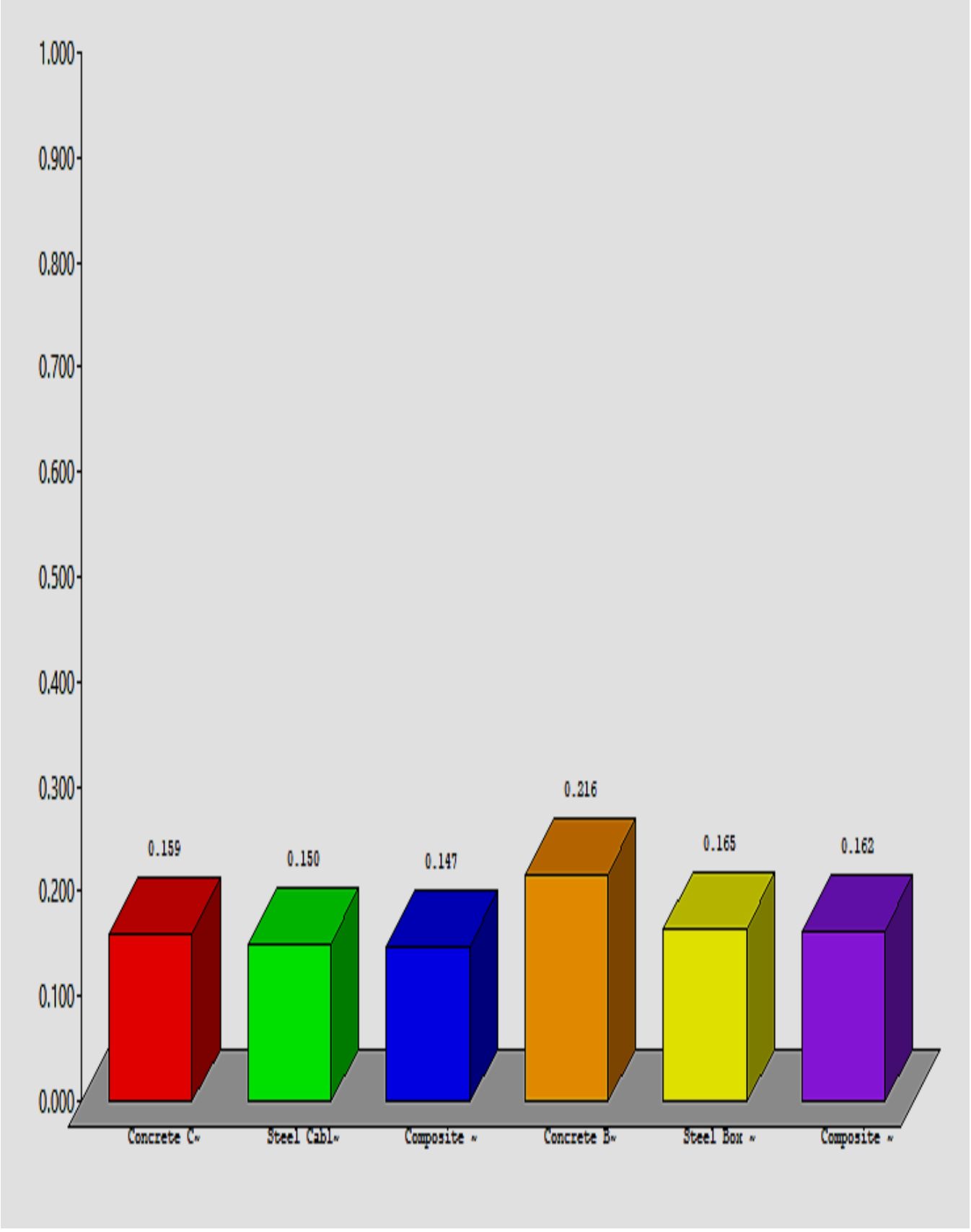

Figure (16) Bar chart sensitivity for final results

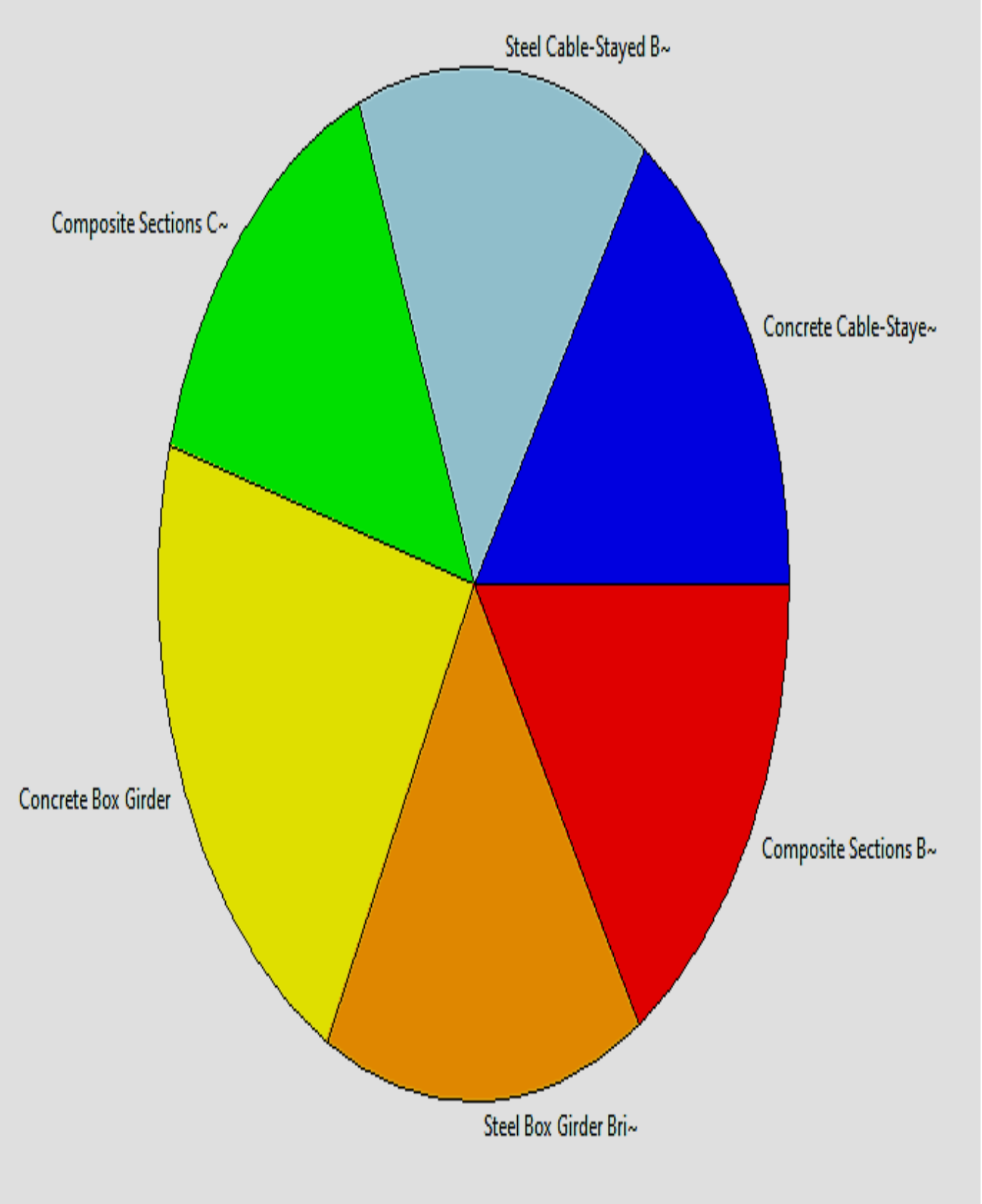

Figure (17) Pie chart sensitivity for final results

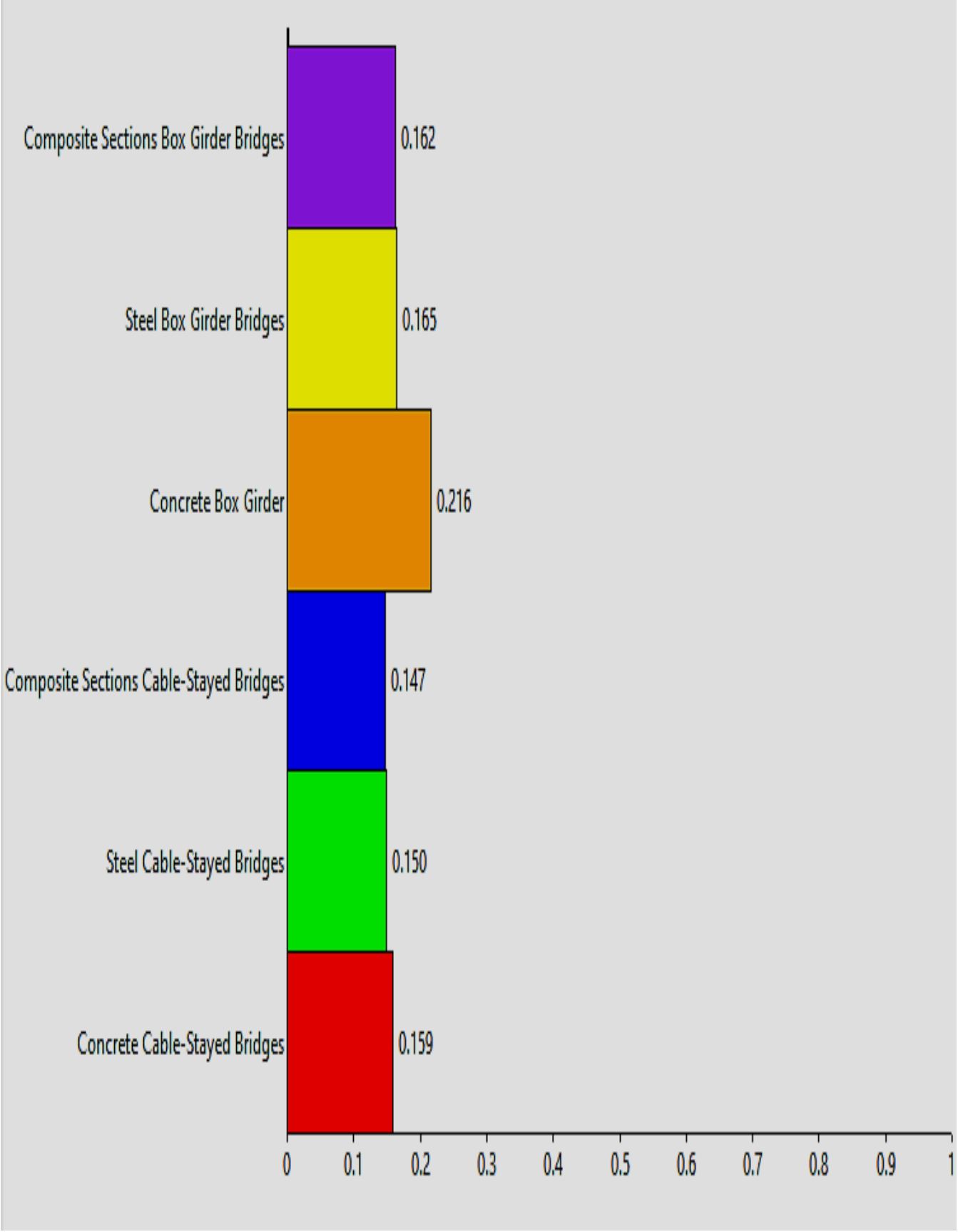

Figure (18) Horz bar chart sensitivity for final results

This ANP model proves to be an effective framework for assessing readiness to adopt and facilitating TQM. In this research, we gave an overview of the ANP method with a detailed illustration of the steps that we find crucial in the ANP, and which are often still not understood by users. Conducting the ANP is a time- consuming activity, and some steps are very challenging. Therefore, we proposed two upgrades of how to automatize some parts of the ANP to be less complex and more appropriate for users.

The final results of this study prove that;

1. The best alternative is the concrete box girder type, in case of the project have the same determinants and criteria of this study.
2. The possibility of applying this system to such studies of infrastructure and bridges, and its applicability for any scope, and any type of projects.
3. 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
4. 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.

8- Conclusion and Recommendation

Upon the results gained that the concrete box girder is more effective than cable- stayed one- this is for this determinate project- . The cost of square meter in case of using cable stayed bridge is approximately estimated by 7000 $/ m2, but for concrete box girder approximately estimated by 3500 $/ m2 –this is upon the data of the experts of this field opinion- . That mean there is loses estimated by 4000 $ for each square meter by a percentage of lost money considered by 50 %.

So It is recommend; 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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