Value Engineering Analysis in the Construction of Box-Girder Bridges

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Abstract- Bridges construction are one of the most challenging construction projects around the world as it necessitates a lot of experience, equipment, and a huge deal of money. Consequently, it is indispensable to consider appropriately how to direct the monetary total spent on such projects. Currently the selection process of bridge's superstructure construction methods in Egypt mainly depends on the experts' knowledge and experience without performing or applying a systematic procedure. Thus the made decision might not be the most suitable one as some important considerations could be neglected. Recently box-girder bridges are considered as one of the most common systems of Nile bridges constructed in Egypt and it is also widely used all over the world. There are many methods of the construction of box-girder bridges. Therefor in order to select the most appropriate construction method many factors should be well considered as site conditions, technology used, construction method characteristics and bridge physical characteristics.

In this paper, a machine learning model is developed to determine the most appropriate box-girder bridge construction method, using the Value Engineering concepts, which is used for comparing the different construction methods for achieving the required basic function after considering the main significant factors and without affecting the desired quality.

Keywords – artificial intelligence, box-girder, construction methods, machine learning, Value Engineering

I. Introduction

A. Nature of the Problem

The selection process of bridges' construction methods is based mainly on skill, knowledge and experience without having a specified reference helping in this process. Moreover there are a lot of advancements in the structural analysis and in the materials introduced new techniques and necessitated the consideration of new criteria. [1] reported that, although the existence of a wide range of construction techniques has increased design flexibility, it has increased the difficulty in selecting appropriate alternatives. Such perquisites have complicated the selection process beyond the capability of most professionals.

Hence, it is important to provide all the parties involved in the bridge construction industry with a guiding tool which evaluates different construction methods of bridges by developing an artificial intelligence decision support system applying the Value Engineering systematic job plan in order to determine the most appropriate construction method with presenting the probability of using each method.

B. Previous Work

[2] noted that the early design decisions that may exclude desirable construction methods create constructability problems. They may increase construction effort and increase construction difficulty and the risk of problems. Such inappropriate decisions are caused by the lack of flow of knowledge and expertise from contractor to designer especially under traditional management systems where responsibility for design and construction is separated. This situation is unique to the construction industry as illustrated in [3]. As mentioned in [4] it is very clear that the selection of bridge construction methods mirrors the randomness that often characteristics the construction industry.

It relies heavily on the experience, skill, knowledge and judgment of bridge engineers. This provides scope for errors in the resulting decisions in the absence of any clear formwork.
[5] stated that under Value Engineering, highway projects are reviewed and opportunities for better, less expensive means of completing the projects are analyzed. The intention is to improve project quality and productivity, foster innovation, optimize design elements, and ensure overall economic costs. [6] has observed that value engineering studies frequently result in a 10% to 30% reduction in total cost of the project and they often have a profound effect on the ultimate design.
In [7] using Value Engineering approach to low-volume road bridges selection found that the deck was found to be the highest-costing low value component, they chose it as the prime candidate for improvement the superstructure itself; therefor it was the focus of this paper.
[8] dealt with the use of value engineering principles to evaluate the selection of construction systems for major bridge projects in Egypt. The construction systems used in Egypt and their applicability under different site conditions were reviewed. The study included different construction systems and 14 bridge projects. The weighted evaluation technique was used to evaluate the construction system used for each project in comparison with other applicable alternatives. The most important criteria considered in this evaluation include construction cost, resource availability, ease of construction durability, construction progress rate, service life, design efficiency, and maintenance. Finally it was found that in six out of the 14 bridge project cases included in the study (about 43%), the construction system used was not the best alternative, based on economic and engineering considerations. It was also found that the reasons for improper selection of the construction system are thought to be fancy-to-new technology, inadequate studies concerning alternative construction systems, or contract provisions stipulating the use of a certain construction system.
In [9] selecting the suitable bridge construction method by using Fuzzy AHP approach, it was found that selecting an appropriate bridge construction method is essential for the success of bridge construction projects. The Analytical Hierarchy Process (AHP) method had been widely used before for solving multi-criteria decision-making problems as in [4] and [10]. However, the conventional AHP method is incapable of handling the uncertainty and vagueness involving the mapping of one's preference to an exact number or ratio.

C. Box-Girder Bridges Construction Methods

Box girders have gained wide acceptance in freeway and bridge systems due to their structural efficiency, better stability, serviceability, economy of construction and pleasing aesthetics [11]. The most common methods of constructing box girder bridges in Egypt and in the Middle East are: Stationary False-Work (Traditional), Cantilever Carriage, Deck Pushing, Mobile Scaffolding.

II. PROPOSED ALGORITHM

[4] stated that there are around sixty experts in the bridge construction industry in Egypt, Most of the time they are the decision makers in their organizations selecting the construction methods. Hence this research is mainly based on some of those experts' opinions, knowledge and expertise with respect to a sample size formula.

According to [12] the sample size which can be convenient for this study after considering the previously mentioned experts in the bridge construction industry will be calculated from the following formula,

$$n = n^{\backslash} / (1 + n^{\backslash} / N) \qquad (1)$$

Where;
n = Sample size, N = Total population= 60, n\ = S2 / V2, V = The standard error of sampling distribution = 0.1 (As [13] recommended that a margin of error of 10% is used in many well-conceived surveys), S = The maximum standard deviation in the population elements (at confidence level of 95%), S2 = P * (1 – P) = 0.5 * 0.5 = 0.25, P = The proportion of population elements that belong to the defined class, the maximum value according to [12] is chosen at P = 0.5.
After performing the necessary calculations the required sample size is n = 18. In order to achieve this requirement twenty eight questionnaires have been sent.
There were four main objectives of this questionnaire survey:

- Obtain specific information of the decision making process to decide the most appropriate construction method.
- Find out more information about the implementation of value engineering in bridge construction industry.
- Ranking the factors affecting the criteria of choosing the most appropriate construction method for box-girder bridges in order of importance to consider each factor weight in the machine learning system.
- Setting the boundaries and limits of using each construction method.

The experts stated twenty main factors affecting the criteria of choosing the most appropriate construction method for box-girder bridges. These factors are: Span of Bridge, Height of Piers, Typical Span Number, Statical System, Breadth of the Deck, Horizontal Alignment, Soil Subsurface Condition, Existing Utilities and Diversion Cost, Nature of Crossing, Surrounding Area Nature, Land Topography, Cranes Capacity and Maneuvering, Workmanship Skills, The used Material, Time Span, Contract Type, Equipment, Kind of Tender, Human Resources, Material Cost.

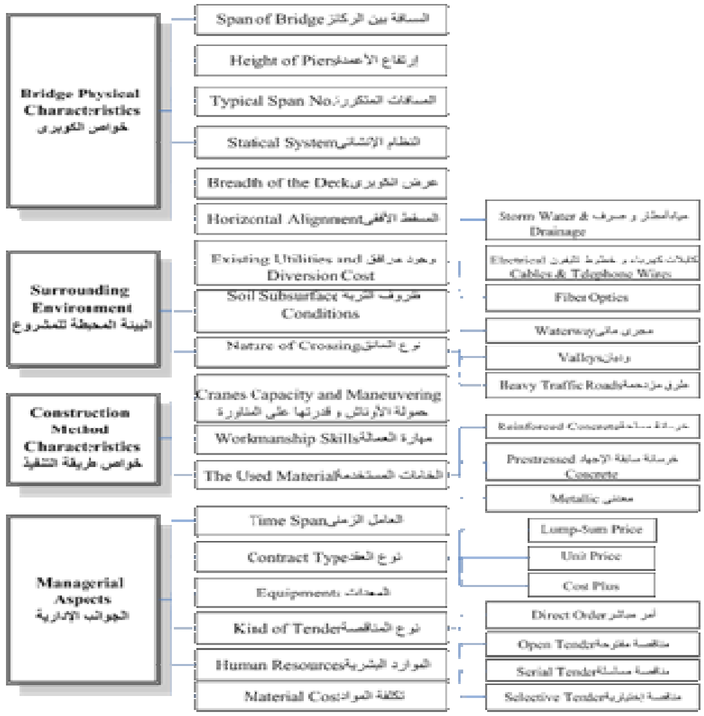

Figure 1: the factors affecting the selection of box girder bridges' construction method.

The questionnaire was written in English and Arabic for more clarity as it had been sent to different nationalities. Also it had been sent to experts from all categories in the industry (owner's representatives, designers, contractors and consultants) in different countries (Egypt, Saudi Arabia and Kuwait). The questionnaire was sent to them mostly by hand and by emails in some cases.

III. Experiment and Result

A. Questionnaire Results:

Twenty eight questionnaires have been sent, fifteen of them were sent back with answers. Three of these questionnaires were incomplete in some points, but the answered points had been taken into consideration in order to make use of them as much as possible. Several phone calls were made and emails were sent for those who didn't answer the questionnaires to remind them but unfortunately to no avail. "Fig. 2" shows the rate of responses to the sent questionnaires. The questionnaires also were meant to cover the main players in the industry, as 40% of the responses received were from contractors, 40% from consultants and 20% from owner's representatives. The exact numbers are indicated in "Table 1".

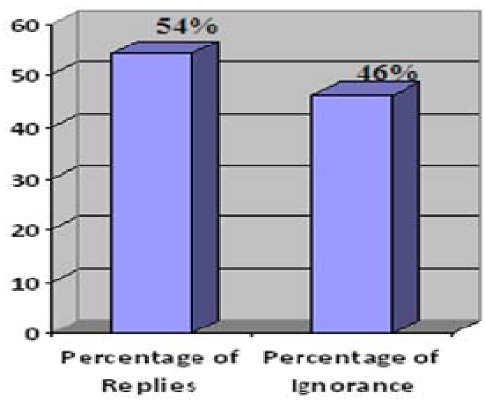

Figure 2: percentage of responses to the sent questionnaires.

Table 1: Responses sorted by profession

Profession	Number of Respondents
Contractors	6
Consultants	6
Owner's Representatives	3

The respondents who had 20 years of experience or more were 53% of the total responses, while those who had experience between 10 to 20 years were 47%.

60% of the responses were from experts working in Egypt and the other 40% were working in Saudi Arabia and Kuwait with different nationalities.

In the part asking "who decides which construction method to be used?" 73% of the respondents chose more than one person for this task, while 27% named one person to be responsible for it. The results were as follow in "Fig. 3".

53% stated that the designer should be one of the decision makers, the same for the project manager. While 47% found that it should be the consultant, 33% considered the cost estimator and the site manager and only 20% mentioned the client.

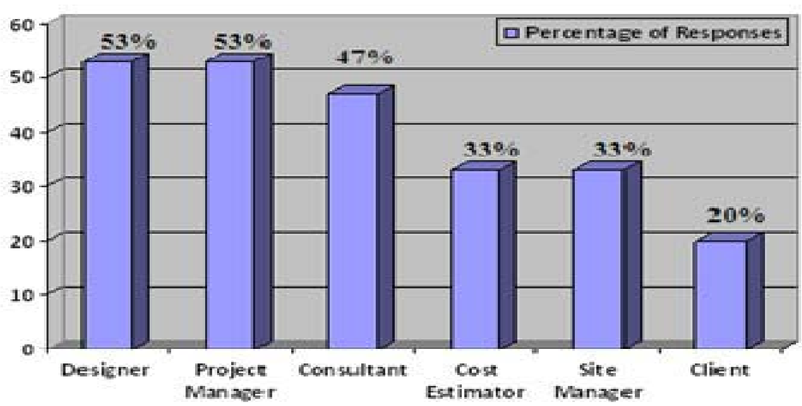

Figure 3: percentage of responses with respect to the decision makers of the selected construction method.

Then 80 % stated there is a specific procedure for selecting the most appropriate construction method. In the other hand 20% denied that there is a specific procedure for the selecting process. The 80% using a specific procedure mentioned some of the factors listed previously in "Fig. 1" such as nature of crossing, cost, equipment, workmanship skills, duration of the project, bridge's different physical characteristics, soil condition, the used materials, surrounding area nature and cranes capacity.

Focusing on the field of Value Engineering, 83% of the respondents reported that VE technique is being implemented in order to select the most appropriate construction method and 17% stated that they don't use it. All the 83% assured that the VE technique is being applied before constructing the project (during the first studies and in the design phase).

After that the respondents were asked about the range of savings in the project's total cost that could be achieved by implementing the Value Engineering Technique. 60% of them couldn't decide the range as it varies from a project to another, While 40% estimated that the savings are from 20 to 25%.

Only 20% of the respondents applying Value Engineering technique have a special team responsible for this task. The other 80% considered that it is the responsibility of the designer or the consultant and a few mentioned the contractor.

After answering these questions, the respondents were asked to rank the factors shown in the hierarchy which is presented in "Fig. 1" and was attached to the questionnaires from the most important (1) to the least important (N). The average rank for each level in the hierarchy was calculated. . This process is important in order to refine this hierarchy so it only includes the most important factors. Then the final average rank will be used later in the developed computer model as the weight of each factor so that the model deals with every factor in order of importance.

The main purpose of the final part of the questionnaire was for the experts to set the limits for using each construction method. As setting the limits for height of piers, span of bridge, horizontal curvature……etc. for every method. Then these data will be used as the database for the computer model.

B. Value Engineering Data Mining Software:

WEKA (The Waikato Environment for Knowledge Analysis) is the used software, written in Java and developed at the University of Waikato in New Zealand [14]. It is a workbench designed to aid in the application of machine learning technology to real world data sets. According to [15] WEKA has proved itself to be a useful and even essential tool in the analysis of real world data sets. It has also provided a flexible aid for machine learning research and a tool for introducing people to machine learning in an educational environment. The WEKA system has been applied successfully in a variety of areas including the areas of agriculture, machine learning research and education.

The WEKA system is not so much a single program as a collection of interdependent programs bound together by a common user interface. Typically these modules fall into three categories: Data set processing (which represents the Information Phase in the VE job plan), machine learning schemes (represent the Function Analysis Phase, Creativity Phase and Evaluation Phase), and output processing (represents the Development Phase and Presentation Phase).

In the current version of WEKA any output that is created by a machine learning scheme is passed back to WEKA in text form that is able to be displayed in a scrollable text viewer. This view allows text to be copied to other X applications, printed or save to a file. If the user selected external evaluation in one of the schemes that allows it then the output will be passed back as per normal but it will also be converted into the WEKA rule format and evaluated using the WEKA PROLOG rule evaluator, PREval. PREval itself takes a rule file and an ARFF file and evaluates how well the rules cover the classifications in the data file.

Then a new system is created in the next stage, a friendly user graphical interface. This graphical interface has a code linked to WEKA. This interface has been given the name IBCT as (Intelligent Bridge Construction Tool) as shown in “Fig. 4”. Then the data of the desired project should be entered in the empty slots like the project name, the project location as well as the data required for determining the bridge physical characteristics as the span of bridge, the height of piers and the horizontal alignment. The same procedure should be done in the surrounding environment and the construction method characteristics. Finally after entering all the required data, Get Appropriate Construction Method button should be selected and the most appropriate construction method will be revealed according to the WEKA results.

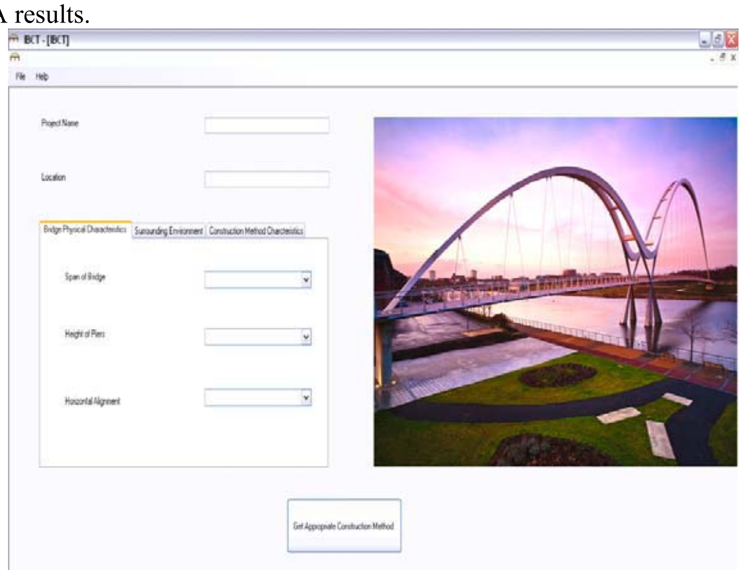

Figure 4: the friendly user graphical interface IBCT.

C. Evaluation Phase of the System

This evaluation is made to determine the usability and functionality of the system and it will be applied on Tima Bridge project.

- Project Name: Tima Bridge over the Nile.
- Location: in Tima city, Sohag governorate, Egypt.
- The Owner: General Authority for Roads, Bridges and Land Transport (GARBLT).

- The Contractor: General Nile Company for Roads and Bridges (NC).
- Consultants: Consulting Engineering Office (owner's consultant), Nile Engineering Consulting Office (NECB) (contractor's consultant), Arabian Group Office (quality control consultant).

➢ Main Features of the Project:

The project is a box-girder bridge over the Nile in Tima city, Sohag governorate, Egypt. The length of the bridge is around 14.5km, 1.1km of it has two main navigational vents with width 120m and two secondary navigational vents with width 70m. There is a 0.32km of the project crossing a railway and Assiut-Sohag agricultural highway, and the project also contains 25 industrial works.

➢ Testing the System:

Long bridges cross sites of different nature thus resulting in differences of height, span, land topography, obstacles, soil condition, etc. Therefor this project will be divided in two parts. The first one is the part crossing the Nile and the second is the one crossing the highway.

i. The Part Crossing the Nile:

The required information is collected after studying the drawings and the site nature, and then this information is registered in IBCT. IBCT shows that the most applicable construction method according to Value Engineering principles in this case is "Cantilever Carriage" the same method used in the real site.

ii. The Part Crossing the Highway:

The same steps were performed again but with the new information of this part. The model predicted the accurate and precise construction method in both cases as the system chose the traditional method "Stationary False-Work" as the most appropriate method for this part and this is the same method used in the real site.

The PREval screen in WEKA shows the time required to build the model, the system predictions for each construction method, percentages correctly classified, percentages incorrectly classified, percentages classified by multiple rules and not classified at all, as well as confusion matrices. "Fig. 5" shows the analysis for Tima Bridge crossing the Nile using Naive Bayes classifier. The higher probability is given to the Cantilever Carriage Method (the same results appeared in the IBCT). The results will change according to the used classifier. As in "Fig. 6" the used classifier is Multi Layer Perceptron (Neural Network), so it provides different probabilites as shown. Despite the changes, the same choosen construction method is remained.

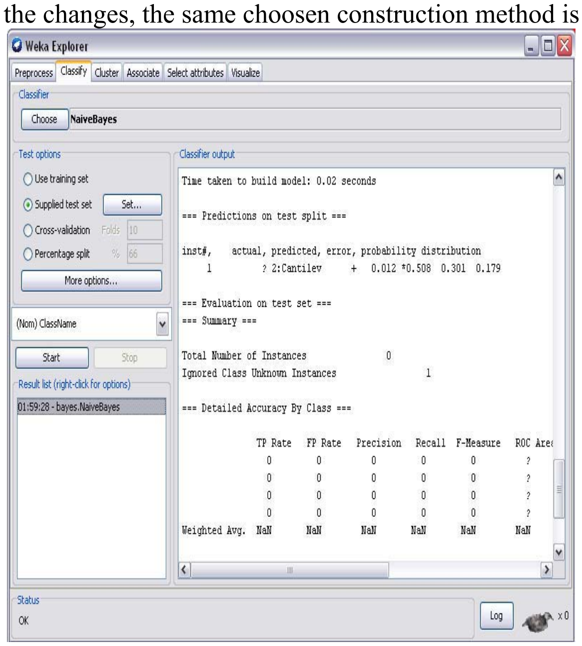

Figure 5: The PREval screen showing probabilities of each construction method (using Naive Bayes classifier).

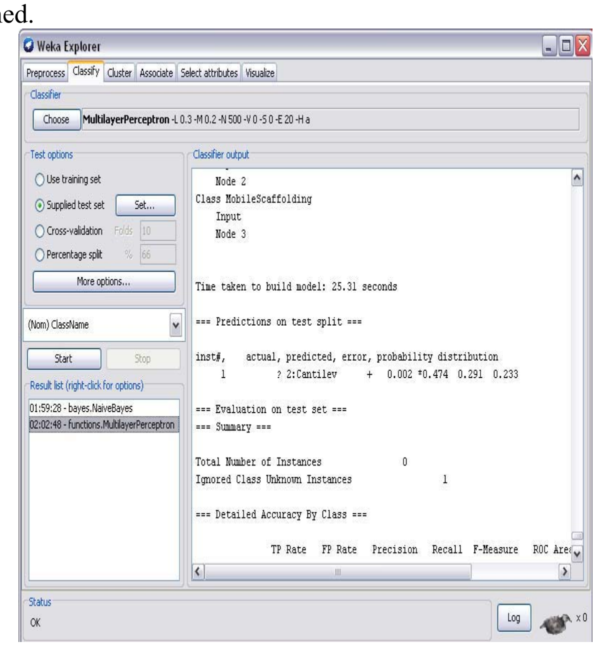

Figure 6: The PREval screen showing probabilities of each construction method (using Multi-Layer Perceptron (Neural Network)).

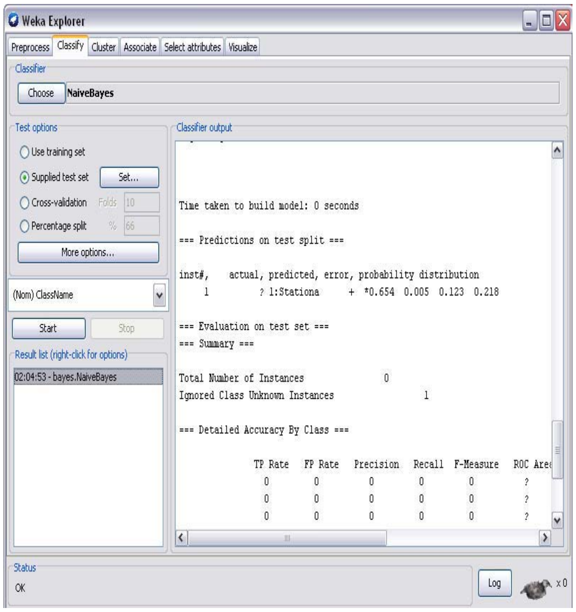

Figure 7: The PREval screen showing probabilities of each construction method (using Naive Bayes classifier).

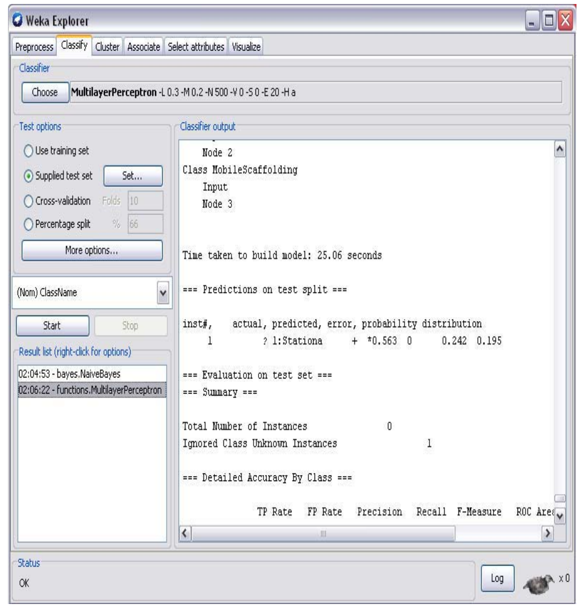

Figure 8: The PREval screen showing probabilities of each construction method (using Multi-Layer Perceptron (NN)).

The same analysis is performed again but in the part over the highway, and the results are as presented in "Fig. 7". The higher probability is given to the Stationary False-Work Method (the same results appeared in the IBCT). In "Fig. 8" the used classifier is Multi Layer Perceptron (NN), so it provides different probabilites as shown. And again inspite of the changes, the same choosen construction method is remained.

IV.CONCLUSION

A. *Conclusions and Advantages:*

1. 20% of the respondents didn't have a specific procedure for the selection process and even the respondents who have one couldn't specify this procedure. This fact reflects the randomness which may occur in the construction industry without good planning.
2. The selection process is highly affected by the bridge physical characteristics (span of bridge, height of piers and horizontal alignment), surrounding environment (surrounding area nature, soil subsurface conditions, nature of crossing and land topography) and to a less extent by construction method characteristics (cranes capacity and maneuvering, accessibility and the used material).
3. 83% of the respondents reported that they implement the Value Engineering technique in the process of selecting the most appropriate construction method, which is higher than the percentage mentioned by [10] as it was stated that only 30% of the respondents claimed that they implemented the Value Engineering technique in selecting the most appropriate construction method. It means that the awareness of applying Value Engineering technique has increased.
4. All the respondents agreed that the Value Engineering technique should be applied in the very beginning of the project through the preliminary studies and in the beginning of the design phase.
5. The respondents assured that there is a significant amount of savings due to applying the Value Engineering in the range of 20% to 25% of the project total cost.
6. 53% of the respondents were aware that the designer and the project manager should select the bridge construction method, while only 33% mentioned the cost estimator which is alarming.
7. Most of the respondents admitted that they don't perform an organized Value Engineering job plan as supposed.
8. It is obvious that the Value Engineering technique still not being applied properly as 100% of the respondents who claimed applying the VE technique stated that they mainly depend on their own previous experience in choosing the most appropriate construction method, which is very confusing.
9. Only 20% of the respondents mentioned that they have a specialized team for implementing the VE technique. Therefor it could be concluded that there is a problem in considering the VE as a separate task.

10. The computer model in this research proved to be precise, accurate and user friendly by providing a tool for selecting the most appropriate construction method for box-girder bridges by applying the VE principles.
11. The proposed computer model is flexible enough as it enables editing and reentering any registered data, also it allows the user to perform different classification methods to have enough comparison results for any project.

B. Limitations and Recommendations for Future Studies:

In order to complete the work done in this research, some more topics may be fulfilled:

1. Extend the current research to include new advanced construction methods which are not yet used in the Middle East.
2. Implementing the Value Engineering technique for other materials like steel bridges.
3. Improve this model to content other different bridge cross sections.
4. Upgrading the research to include the substructure as well (foundations, piers and bearings). This will be more helpful in deciding the most appropriate construction method.
5. Adding cost calculations also can be an important addition to this study.
6. Extend this model to contain more factors will give more credit to the selected construction method.
7. Performing this study but with using other machine learning systems and comparing the results would be more helpful for bridge construction decision makers.

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