# Developing a Computerized Framework for Applying Value Engineering in Construction Projects

# تطوير نظام بالحاسب الالى لتطبيق الهندسة القيمية فى مشروعات التشييد

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## الملخص

يهدف هذا البحث إلى تطوير نظام بالحاسب الآلي لتطبيق منهجية الهندسة القيمية حتى يمكن استخدامها في حل المشكلات التي قد تواجهنا يوميا. يتميز هذا النظام بالسهولة والدقة والسرعة حيث تم تصميمه باستخدام برنامج ميكروسوفت إكسل وبطريقة تضمن تطبيقه في مجالات عده (الإنشاءات، المبيعات، الطاقة ...... ). يقوم هذا النظام إما بتقييم العنصر الواحد أو تقييم مجموعه من العناصر أو مقارنتها  ببعضها البعض وذلك عن طريق تعريف وتصنيف وظائف هذه العناصر أيضا يحتوي النظام على برمجة لمخطط تقنية تحليل الوظيفة (FAST diagram) بطريقة سهله وبسيطة، وتحقيق هذه الوظائف إما بأحسن الطرق أو بأقل التكلفة الكلية أو كلاهما معا (يأخذ تكلفة دورة حياة العنصر في الاعتبار LCC). ولتحقيق ذلك يتم استخدام بدائل إبتكارية بشرط عدم تأثير هذه البدائل على الوظيفة الرئيسية التي تؤديها هذه العناصر كما يقوم هذا النظام أيضا بحفظ جميع البيانات المدخلة والبيانات التى تم تحليلها ثم عرضها في تقرير مطبوع حتى تعمل كمرجع للإحتياجات المستقبلية.

تم استخدام مشروع تشييد كمثال تطبيقي للبرنامج حيث يحتوى على بدائل لتسقيف البلاطات (بلاطة تقليدية وبلاطة لاكمرية بأعماق مختلفة) وكانت نتائج التطبيق على هذا النظام أن وفرت حوالي 30 % من وقت المشروع والتي تعنى خفض في مصروفات المشروع وفى نفس الوقت يحقق الوظيفة الرئيسية والمتطلبات السياسية وأهداف الجودة.

## Abstract

This paper aims at developing a computerized system for applying the Value Engineering (VE) in construction projects. Simplified, quick and accurate system is designed to be used at any problem in normal day-to-day situations. The computerized tool is designed using Visual Basic for Application on Microsoft Excel. This system could be applied in (construction, sales, energy...). It is designed for the evaluation and comparison between one or more elements by identifying and categorizing element's functions to be achieved by the best ways. The developed system creates automatically the Function Analysis System Technique (FAST) diagram. Also, it decreases the total cost considering the life-cycle cost (LCC) analysis through innovative alternatives without affecting the basic functions. In all system applications, the VE inputs data that entered and solved is automatically stored and worked as a reference for future needs.

A real-life construction project is used as a case study involving concrete ceiling's alternatives (solid slab and flat slab with different thicknesses). The results of applying the proposed system saved about 30% of project time which means reduction in project cost and at the same time achieving the required political, performance and quality targets.

Keywords: value engineering VE, FAST diagram, life cycle cost LCC, alternative ranking, VE computerized

# Introduction

Building and construction projects usually face many problems and unexpected obstacles that lead to increased cost and may hinder their progression if there is a deficit in budget. Some of high cost items could be obtained not only at a lower cost and better quality but by using other alternatives that have the same function as the required materials and at the same time with a total cost close to or less than their original cost. Therefore, VE is coming to the forefront. It is a powerful tool used not only for combating escalating costs and improving quality but also for resolving system failures. It has become a basic requirement in the present time particularly during the world economic crisis.

The origin of VE can be traced back to the days of World War two. Its application started when there was material shortage problem in the manufacturing sector due to an increased consumption for war purposes. Responding to this serious problem, an electrical engineer named Lawrence D. Miles, working at General Electric (GE) Company, started finding ways to alleviate the material shortage problem in GE's production, focusing on functions that should be performed by the product and experimenting with alternatives to achieve the same functions without affecting quality [1].

Since that moment, the concept of value has been employed in numerous countries around the world. The worldwide use of VE has attracted interest from both researchers and practitioners in studying the use of VE in construction.

By achieving the study aims, computerized system is expected to have the following advantages [2]:

**1-** It will make the VE concepts easy to apply, which in turn will encourage an increasing number of engineers to apply the VE technique to their projects.

**2-** It will reduce the human resources needed for the VE studies.

**3-** It will save time and money for projects.

**4-** It will serve as a database for keeping a record of the case studies that undergo VE analysis.

## VE Theory and Fundamental

The principles of value engineering can be applied by anyone; e.g. a systems analyst, an engineer, a shopkeeper, or a homemaker. It is often considered a management tool to control costs; but, should be understood in a broader context as a problem-solving tool that anyone can use. VE principles consist of key questions, techniques, and procedural tasks used in pursuing the objective of the VE job plan. These principles are explained, where each phase of the job plan is discussed. Certain VE techniques are applicable throughout the formal VE study [1, 2].

## Definition

Value engineering is an organized/systematic approach directed at analyzing the function of systems, equipment, facilities, services, and supplies for the purpose of achieving their essential functions at the lowest LCC consistent with performance, reliability, quality, and safety. The specific objective of VE first is to provide a means of a total cost control anywhere within a project's life cycle. This total cost control is

accomplished, basically, by identifying and separating the necessary from the unnecessary costs, removing the unnecessary costs and developing alternate means of accomplishing the required function at a lower total cost [3], [4].

## Value Engineering and the Construction Industry

Whilst VE has its origins within the manufacturing sector, its application in the construction industry has been the subject of considerable researches over the past 30 years. It was introduced into the construction industry between 1963 and 1965 when contractor clauses were added to construction contracts. In 1964, the Army Corps of Engineers began conducting VE workshops. The Bureau of Reclamation, a division of the Department of the interior, began using VE in 1966. The senate Committee on public Works held hearing on value engineering in 1967 [5].

In the early 1970s construction management (CM) was introduced. Many CM firms advocated the use of VE during the design phase. In the same year, the General Services Administration (GSA) recommended the establishment of a value engineering program on their construction projects. In 1973, GSA Public Building Services introduced the first value engineering service clauses requiring value engineering studies on their construction contracts [5], [6].

In 1974, the Bell Telephone Company (private sector) faced a raise in construction costs and there was no easy way to revenue to meet those increased costs. Not only they were pleased with the results of identifying and removing unnecessary cost, but the program provided evidence of vigorous management efforts to reduce costs in other areas to prevent the need to seek a rate increase [5], [6].

## Construction Industry in Egypt

Construction sector is one of the most dynamic sectors in countries' economy. One can judge that a country is economically booming if it has a boom in the construction industry. While the picture is generally positive elsewhere, the concept and applications of VE do not seem to be well embraced in Egypt, [7] recommended General Authority for Educational Buildings in Egypt to construct a VE department in its organization in order to apply VE studies for educational buildings. Cost rising in construction projects and delaying in time are considered the most common problems in Egypt causing a multitude of negative effects on the project. Then, the proposed system should be simplified as possible as we could to meet a lot of challenges such as difficulties in applying, lack of information, lack of time and limited resources [5], [6].

In Egypt, it was discovered that the top factors affecting the percentage of cost of quality for building construction projects are project's duration, planned cost of quality, supervision team experience, project size and location, class of contractor, client type and labor skills etc. [8], [9], [10].
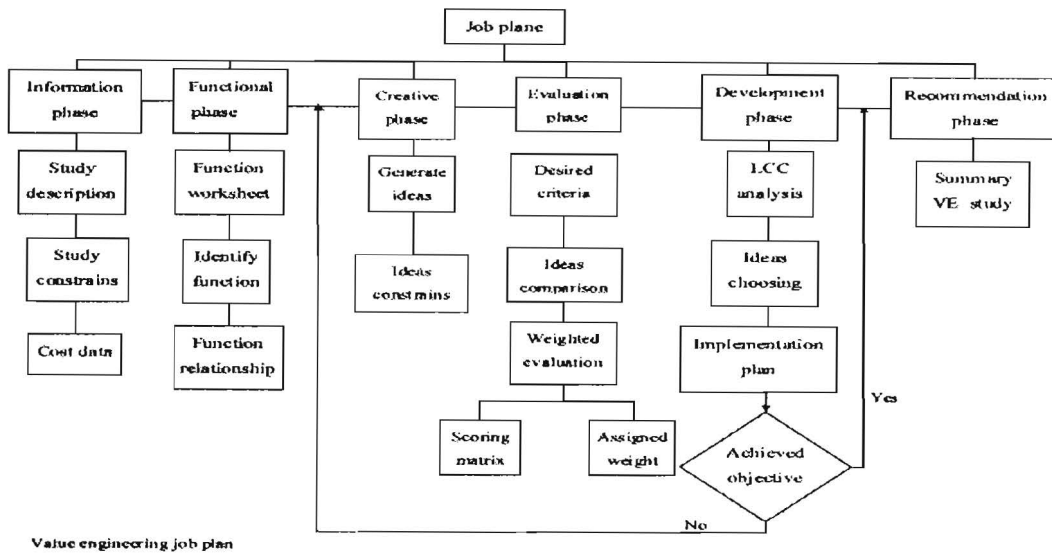
**Figure (1) VE framework**

# Research methodology

Various techniques are used in VE studies. Some studies use only five phases, whereas others may use as many as nine phases. But in the research, to avoid any discrepancy, six phases are used including the main phases of the VE job plan. These phases are the information phase, function analysis phase, creative phase, evaluation phase, development phase and recommendation phase.

# VE framework

The proposed framework of the study includes the standard phases of VE as shown in Figure 1. It shows the flowchart of the job plan (six phases) which are used throughout the whole study [11, 12].

1- Information Phase :

To understand what the project is and the improvement we hope to see. It is required to identify the study description and objectives. Good scoping and good description are the starting point for accurate results. In the construction field, the scope of a project includes not only the structure but also other items as site preparation, demolition landscaping, provisions for future expansion and parking. It is important to understand not only what you study, but why. Some restrictions which are also placed in the scope must be defined such as site location, building orientation, project duration, aesthetics (matching existing facilities), or existing structures or utilities that are being affected by the new construction.

The cost model used in this framework breaks down any element into two components:

- The quantity of each item.
- The unit cost for these items and then calculating the initial total cost.

The unit cost consists of any present payment such as material, transport, labor....etc, in order to own a specific item. Also the total cost is described as "initial" because there

are future costs as "operation and maintenance costs" regarding the life cycle cost.

The typical outcomes from the information phase are: items identification (i.e., determination of specific items which continue throughout the whole study), quantity, unit cost, the initial total cost for each item and the worth of that item. Worth is defined as the least cost required to perform the item's basic function which could be accomplished, basically, by removing the unnecessary costs such as project overhead, number of unwanted labors, profit percentage .......etc. then comparing the total unit cost to the worth of the basic function. Based on experience in comparing cost, cost-to-worth ratio greater than 1.5 usually indicates possibilities for costs within this item [13].

**2- Function Analysis Phase.**

The methodology of FAST is deceivingly simple while the application is difficult and requires a change in thinking habits. To overcome this difficulty in application, FAST is created in the current development by asking a set of logic questions after developing a "function relationship-FAST diagram" by asking the question, "What does it do?" Each function should be expressed in two words – an "active verb" and a "measurable noun".

In this stage, the difference between developing FAST diagram for the whole project and for a specific item should be recognized. It is important to know that developing FAST diagram for whole project achieves good understanding of all project functions, then accurate

determination of the most effective items to be under study.

Focusing in functions, there are two types of functions: Basic Functions "BF" and Secondary Functions "SF". BF is the specific work that the project /item is designed to accomplish. Secondary functions are classified as: Required Secondary Functions "RSFs" (that support the BF and make it happen or happen better) called also Critical Path Functions "CPFs"

- Functions that are happening at the same time with RSF but not critical
- One time function that happens only one time in the whole project
- All time functions that happen and are repeated during the project
- Out of scope functions called "Assumed Function" and "Higher Order Function HOF" but these functions are necessary to ensure a good scoping and understanding for the project.

In this study, all functions could be recognized by sequentially answering "How questions" to make a right relationship between the whole project/item functions. Also any missing functions could be recognized then it will be easy to create FAST diagram.

**3- Creative Phase**

The creative effort is directed toward the development of alternatives to accomplish the basic functions. The advantages and disadvantages of each of the ideas are listed without any constrains "in terms of value only". The typical outcomes from the creative phase are developing alternatives.

**4- Evaluation Phase**

Specific criteria must be defined to meet the main objectives of the project. Scoring matrix, assigned

weights and feasibility ranking will be used in the framework. The typical outcome from evaluation phase is the ranking for alternatives (including the original design) and then choosing the preferred alternatives.

5- Development Phase.

After choosing the best alternatives (in terms of value), a total cost analysis is necessary to make a real comparison among the selected alternatives and then calculate LCC. LCC is described by the American Institute of Architect as any technique that allows assessment of a given solution, or choice among solutions, on the basic of considering all relevant economic consequences over a given period of time or life cycle [5].

Total cost consists of the initial costs and all future costs including operation which calculate the expected costs "income/outcome" for the item/alternative. In this study, LCC is calculated as the present worth (PW) of all costs. Equations 1 and 2 show the present worth factor (PWF) for both fixed and annual costs respectively [14]:

$$PWF\ fixed = 1 / (1+r)^n \qquad (1)$$

$$PWF\ annual = [(1+r)^n - 1] / (1+r)^n \qquad (2)$$

Where, n is the year number and r is the discount rate.

6- Recommendation Phase

The next step is summarizing the VE study for the original and proposed alternative. Recommendations are essentially a challenge to the original design. It is perhaps one of the hardest steps in the VE job plan. Describing advantages/disadvantages, reasoning,

and compliance with standards and requirements are also necessary [15].

# Computerized VE system

The computerized system is designed using Visual Basic for Application on Microsoft Excel program. Upon execution of the VE system, the main user interface screen is displayed as shown in Figure (2) which has six buttons "ADD NEW PROJECT", "OPEN PROJECT", "OPTIONS", "ABOUT", "MANUAL" and "CONTACT ME".
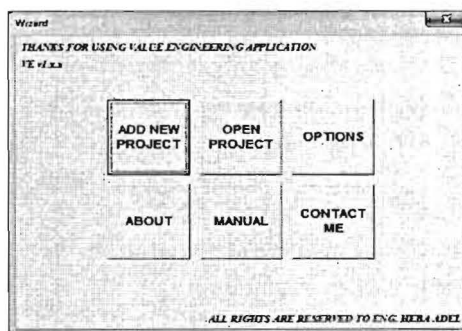


Figure (2) Main user interface screen

### Information phase

The user can start new project by clicking on "Add New Project" button or open an existing project which has been stored before by clicking on "Open Project" button. In this case, the window shown in Figure (3) appears to start the first phase of VE (the information phase) which is summarized in two windows: "General Information" window and "Item Information" window. In the general information window, the user enters the required data for the project under study as: project name, project title, project location, and date of the study.

**Figure (3) General information**

Also, a basic function for the project is required in this window. Also extra information is required about the people who will study and approve the VE recommendations.

After then, item information window appears. Users start to input the main items affecting the study and expressing these items by names and IDs "each of them cannot be duplicated". Then the user writes in the description text box, in details, all conditions related to the item and also writes constrains, advantages and disadvantages of that item in the comment box.

In this window, the screen is divided into two main parts, an input data on the left side and an output data on the right side as shown in Figure (4). In the left side, the user enters the main requirement data for the information phase (item description, item constrains and cost data) and then determines the main items affecting the study. The user writes all required data for cost analysis as unit cost, quantity, and the unit of the item and then, estimates the worth of that item without affecting its function. The determination of worth should be compared with the item's cost and the system will calculate the value of (Total Cost (TC) / Worth (W)) ratio to show the opportunity for large cost reduction for all items.



**Figure (4) Item information**

In this stage, a basic function for item is one of the most important data in order to ensure that the user gathers all information about that item and at the same time it is the first step for the second phase "function analysis phase". It is easy to select the stored functions (verbs and nouns). The "Add New" ✚ button to add any other functions to the stored functions. In case of huge number of verbs and nouns that may be useless in the study, filtering for verbs and nouns is available to make it easy to find the desired function.

For more details about the project, attaching any file that relates to the project/item (drawings /calculation file/jpg file) is possible in the proposed system. The user clicks on the "Attach File" ⌗ button, the open file dialog will appear to upload the attached file. In this case, new directory will appear in the directory text box to view this attachment just click on the "View Attachment" ⊙ button to open the attachment if existed for the selected item.

After entering the main items data, just click on the "Add" ✚ button to add this item which will appear in the right side as an input data. Adding any number of items and items' alternatives is available. All inputs will be checked and saved before adding any other items and if there is an error at any input, an

error message will appear from the "Helper". The user can modify or remove any item by clicking on "Edit" ✐ or "Remove" ✚ buttons respectively. After entering all items, it is time to know what item is affecting the total cost. The user can click on "Create Cost Chart" 📊 button to show a bar diagram for all items which show all items' names and their costs. Finally the user can get back to the wizard by clicking the "Wizard" ✎ button or press "Next" ▶ to go to the second phase of VE and create FAST Diagram.

## Function analysis phase

After proposing different alternatives, creating FAST diagram is available also to whole project, the entered items or items' alternatives.

To start FAST creation, just click on "Create FAST Diagram" ◄ button (Figure 5) and some questions about the project functions are asked.
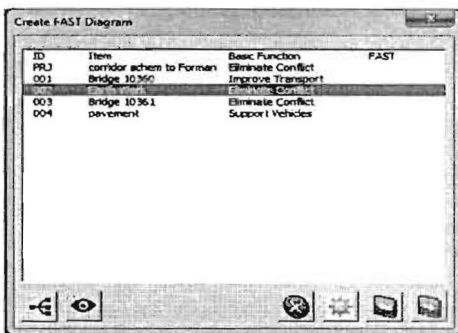


Figure (5) FAST diagram screen

The first window in FAST is a basic function (BF) confirmation or modification for the functions that has been defined in the information phase (Figure 6). The system allows the user to add any number of items, alternatives and functions for each item.

The logic way to create the FAST is by asking "HOW" question (How is "function" actually accomplished or

proposed to be accomplished) that guides the user to determine all CPFs (left to right direction). "WHY" question for the 1$^{st}$ RSF is a HOF determination (is the function explaining the reason for performing the basic function) as shown in Figure (7).
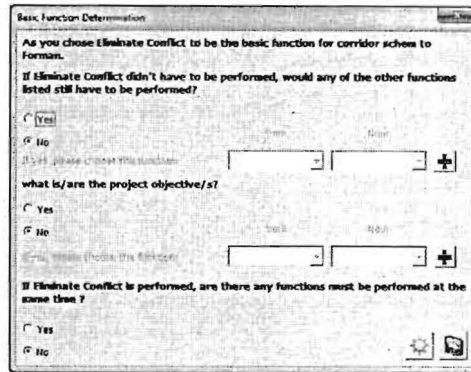


Figure (6) Basic function confirmation screen
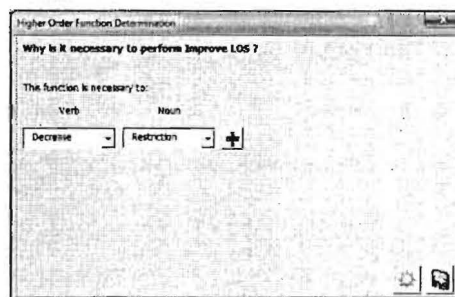


Figure (7) higher order function determination screen

After entering the HOF, the next windows are for adding the rest critical functions as shown in Figure (8). In this window, users are asked the "How" question to get the next RSF that are located in the critical path. For every critical function in the RSF, user will be asked five questions. The first is to determine the next RSF. The second and third questions will be asked to confirm the new selected function (i.e., this selected function is important for the preceded function and allow it to

happen or happen better". The fourth question is asked to determine the functions that happen at the same time with the preceded selected function. The last question is to determine if there are other RSFs. Users are allowed to add any number of functions to each item but at least five RSFs is required for the program to build the FAST. By adding process for all RSFs until the answer is an out of scoping answer, this means that the selected function becomes the "assumed function".
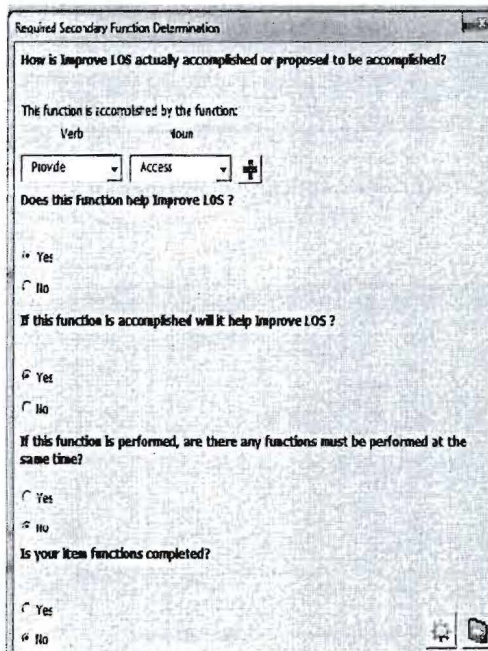


**Figure (8) RSF determination**

In this case user will choose also "Yes" as an answer for the last question. The upper three questions shown in Figure (9) will be deactivated.

Now questions for the above critical path functions are asked "One time function, all time functions and Project objectives functions" as shown in Figure (10). Just the user clicks on next button, FAST diagram will be created as shown in Figure (11) in its formal view. If the user created the FAST

diagram before, the word "Created" will appear and the diagram could be viewed by clicking the 👁 button.
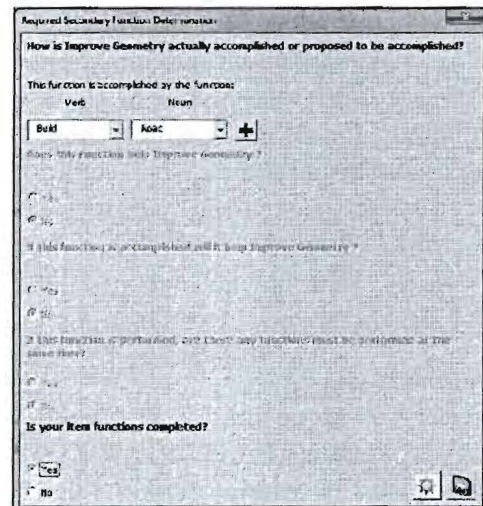


**Figure (9) Assumed function determination Screen**
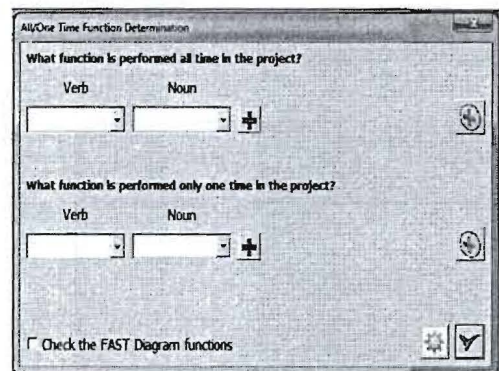


**Figure (10) All/one time function**

**Evaluation Phase**

Now it is time to start the Evaluation phases by ranking different alternatives. The proposed system weights each alternative against eight criteria and then compares criteria to each other using three relative importance: major, medium, and minor with score of 3, 2 and 1 respectively.
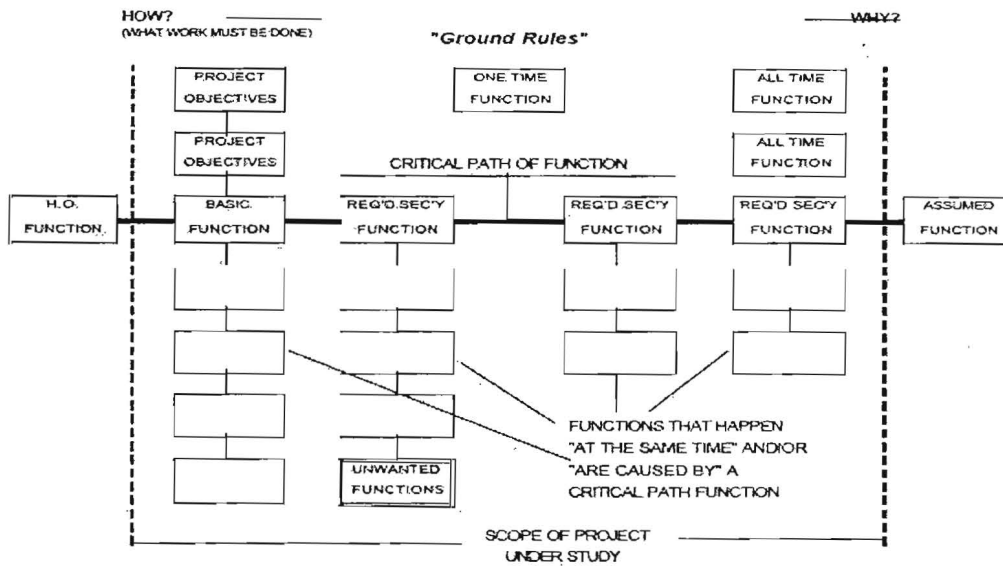
**Figure (11) FAST diagram development**

In this process, a window is presented to describe the meaning of each given number. The result of this phase will appear as shown in Figure (12) and will be done as shown in Figure (13).
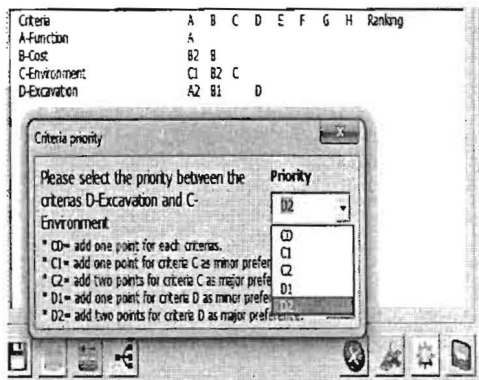


**Figure (12) Weighting process**

# Case Study Project

The developed VE system is implemented on a real-life case study project to experiment its applicability and ease of use.

**Project Description and Challenges**

This project is concerned with the national housing projects in Egypt and located in the vicinity 27, fifth District, New Damietta, Egypt. The project is for constructing 3180 residential units for youth housing. Government entrusting 106 buildings to the Arab Contractors company, each building is 478 m$^2$ with five stories and each story is divided into six units. In this project, available company's resources are limited and management has faced a problem in constructing all buildings in time. In this project, it is found that foundation and skeleton acts about 58 % of total elements in project, meaning that it is the most important elements. The structural system is solid slabs "SS" and isolated footing "IF" for foundation. Steel percentage for solid slabs is about 135 kg/m$^3$ which higher than the normal and close to that of flat slab systems. As such, VE is focused on slab design alternatives.

```
- Ranking Calculations
  Weight %                        4    10   2    4
  (1) Bridge 10360                1    2    1    1
                                  4    20   2    4            30
  (01/01/2013) culvert 1          5    3    1    2
                                  20   30   2    8            60
  (02/01/2013) fill vally         1    4    2    1
                                  4    40   4    4            52
  (03/01/2013) narrow bridge 2    1    4    3    2
                                  4    40   6    8            59

  Conclusion:
  ------------
  1- 01/01/2013-culvert 1
  2- 03/01/2013-narrow bridge 2
  3- 02/01/2013-fill vally
  4- 1-Bridge 10360 (Original)

                                  Calculations list
```
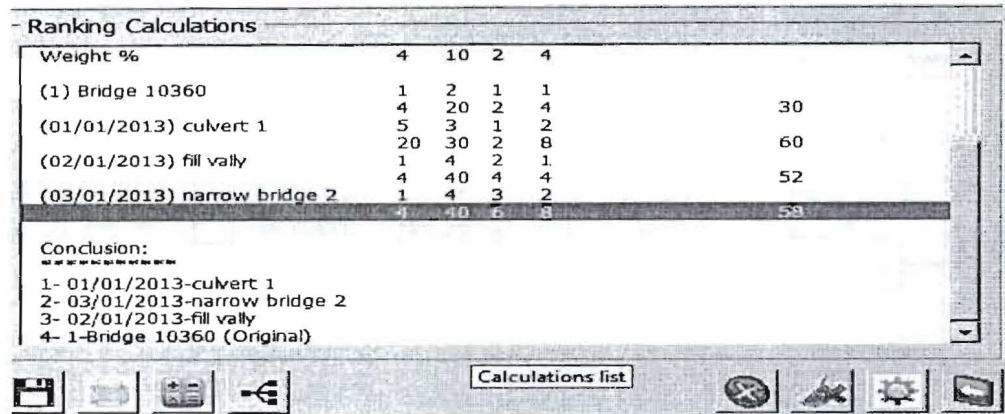
**Figure (13) Alternatives ranking screen**

## Project Analysis

The project is analyzed and the main items are identified as shown in Figure (14). The quantities and Steel percentages for the main items are calculated (Tables 1 and 2). Analyzing a given item means that determining each factor affecting that item in order to finish a specific work.

The unit cost for a given item is dependent on different factors based on the construction method used, technical specifications and available resources. For example, concrete unit cost for SS depends on (steel percentage, steel shape, concrete amounts and the used formwork). If changing the design to FS, this unit cost will differ.
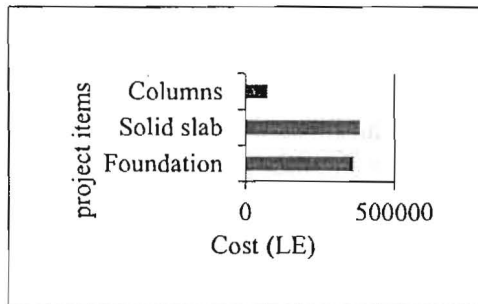


**Figure (14) Cost analysis**

**Table (1) Steel percentages for main items**

| Items | Steel percentage (kg/m$^3$) |
|---|---|
| R.C for IF | 80 |
| R.C for columns | 190 |
| R.C for SS | 130 |

**Table (2) Concrete quantities for slabs and columns**

| Element | Quantity (m$^3$) |
|---|---|
| Ground floor columns | 31 |
| Ground floor slab | 79 |
| First floor columns | 21 |
| First floor slab | 79 |
| Second floor columns | 18 |
| Second floor slab | 79 |
| Third floor columns | 17 |
| Third floor slab | 79 |
| Fourth floor columns | 14 |
| Fourth floor slab | 79 |
| Total concrete quantity/building | 496 |

Commonly, FS cost is higher than SS without taking value considerations. The challenge is how to make balance between cost and performance.

After defining all project data, an evaluation report as shown in Figure (15) is presented to the user showing the final results with considering the most preferred ideas and justifying the selection for the appropriate solution to be applied. The preferred idea is using FS system and RF (achieving value and cost targets) with changing the formwork type to use the available sets of the metal formwork. Then, the total savings consists of:

- Time savings that result from changing formwork type that affect the direct cost of renting cars, equipment and engineers and labors' salaries.

- Owning new formwork: as the renting is more expensive than buying one even if the contractor will spend more money at the moment, but it will save money in the future.

- The flexibility gained from using FF in terms of good looking and the ability to use the floor space to perform different functions.

## Conclusions and Recommendations

In this paper, a computerized system for applying value engineering is presented. The proposed system is flexible that can accommodate various types of projects in various fields. Furthermore, the computerized system is beneficial to promote the sustainable development of many fields especially in the housing industry then, improve the standards of living. The creation and addition of value is the fundamental meaning of an industry, meanwhile it is the nature of keeping competitiveness of an industry, and so optimizing the allocation of resources is required the reasonable value creation and distribution to achieve the optimal social welfare.

The developed system uses user-friendly interfaces to facilitate its use. A real-life case study project is present to in order to show the ability of the developed system to present solutions to real-life projects.

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Figure (15) VE study report