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Quantifying of Highways Safety Impacts during the Value Engineering Process

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ABSTRACT

Coincide with the Egyptian government trend in the last period for the improvement of the highway network in Egypt and its eagerness to raise the efficiency of the network with the required quality and lowest cost due to the reduced funding sources, it was necessary to find a scientific framework seeks to achieve these goals through the application of Value Engineering (VE) in highway projects and integrating safety performance of highway design alternatives during the value engineering analysis. This research focus on the importance of VE process in highway projects during the design phase, studying its effectiveness to evaluate the different highway design alternatives and ensuring that they provide the needed functions efficiently, reliably, and at the lowest overall cost. The research also focuses on how to examine these alternatives and judge their compatibility with the design specifications, especially the suitability of these alternatives to the highway safety level required on the highway project. One of the important research findings was providing a methodology to quantify highway safety impacts during the development of any highway design alternatives. This quantifying assists VE specialists to identify and recommend required safety enhancements for these alternatives. And therefore, any unexpected increasing in crash frequency can be eliminated before implementing any proposed design alternative.

Keywords: Value Engineering, Highway Projects, Highway Design Alternatives, Safety Performance

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1. INTRODUCTION

For many years in different countries in Europe and North America, VE has been used to improve highway projects. It was initially applied during construction, in the form of Value Engineering Change Proposals (VECP) to reduce overall construction costs. Transportation agencies in these countries realized that huge benefits can be achieved in case of applying VE earlier in the development of highway projects. Therefore, it was necessary to raise awareness of the importance of applying VE in construction projects in Egypt, especially in highway projects.

Due to the failure of many public works sector projects to achieve the expected project goals, the project delivery within a reasonable amount of time and costs within their budgeted amounts, it is necessary to have a powerful methodology for solving these problems and reducing costs while improving performance and quality. VE can be used to reduce or avoid excess capital construction expenditures coincide with the Egyptian government trend in the last period for the development and improvement of the highway network in Egypt. VE can play a broader role to support effective decision making for highway projects to increase project performance and quality, balance project objectives, and manage community expectations.

On the other hand, there have been several examples where value engineering process has resulted in value engineering proposals that may increase the crash risk for road users. Then, it was important to understand the safety implications of relevant value engineering proposals, and this can be achieved by integrating safety performance of highway design alternatives in value engineering analysis. The integration of safety performance in value engineering analysis will help VE teams if they suggest changes to a specific project element, they can understand the safety implications of those changes and justify their suggestions and recommendations. In this way, safety can be considered in conjunction with the anticipated operational and environmental impacts. Then any unexpected increasing in crash frequency can be eliminated before implementing any proposed design alternative.

The main objectives of this study are to measure the effectiveness of VE application in highway projects and to develop a framework that streamline a systematic approach which can be used for any VE study related to highway projects considering highway safety impacts early in the development process of highway projects.

2. LITERATURE REVIEW

National Cooperative Highway Research Program (NCHRP, 2005) defines VE as the systematic review of a project, product, or process to improve performance, quality, and/or life-cycle cost by an independent multidisciplinary team of specialists. Its focusing on the functions that the project, product, or process must perform sets it apart from other quality improvement or cost-reduction approaches.

Value Engineering is one of the most effective techniques known to identify and eliminate unnecessary costs in product design. It is a function oriented technique that has proven to be an effective management tool for achieving improved design, construction, and cost-effectiveness in transportation program elements. The successful implementation of a VE program will result in additional benefits beyond design and cost savings; for example, constant updating of standards and policies, accelerated incorporation of new materials and construction techniques; employee enthusiasm from participation in agency decisions; increased skills obtained from team participation (WVDOH, 2004).

2.1 Value Management versus Cost Management

Peter (2010) stated that being function orientated rather than item orientated leads to a more creative solution for the user needs. The acknowledged foundation of the value engineering methodology and the key activity that distinguishes the methodology from other problem-solving or improvement practices is function analysis (SAVE, 2007). To distinguish between both value management and cost management, a brief comparison prepared to summary the major differences between them according to the literature of this issue as shown in Table 1.

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Table 1. Literature Comparison between Value Management and Cost Management

Reference	Value Management	Cost Management
Kelly and Male (1993)	• A service which utilities structured functional analysis and other problem solving tools and techniques in order to determine explicitly a client's needs and wants related to both cost and worth	• A service that synthesis traditional quantity surveying skills with structured cost reduction or substitution techniques using a multidisciplinary team
Ellis (2005)	• Looks holistically at the project as a whole. • Project scope changes are often considered. • Focuses on the value rather than the cost. • Seeks to achieve a balance between quality, life cycle costs and time. • Seeks to maximize the creative potential of all project participants.	• No major changes to the project scope and concept. • Focuses on the cost rather than the value.
WVDOH (2004)	• Doesn't nibble at costs to make the item "cheaper". • Sets a target cost, and finds the design alternative(s) meeting all needs at a lower overall cost • Yields more cost reduction without adversely affecting performance. • Improve design simplification, reliability, maintainability and quality.	• Nibbles at costs to make the item "cheaper". • Analyzes an item from the standpoint of how to reduce the cost of the elements that make up the item. • May scarify quality and performance to reduce cost.

Kee and Robbins (2004)	• Incorporates the customer's perspective. • Establishes the value they place on each function to determine precisely where cost reduction can be achieved.	• Have an inward focus, concentrating on a firm's operations without a specific consideration of the owner needs.
Dell'Isola (1982)	• Focuses on function analysis which is regarded as the cornerstone of VM study and the key factor of VM.	• Concentrates on making the same item, only cheaper.

2.2 Terminology and Mathematical Expression of Value

Definitely, value is one of the most fundamental concepts in value techniques. However, value is a term with different interpretations within different situations. In order to obtain a clear understanding of the term, the following paragraphs will examine what value is in the context of VM and explore its root in economics (Guiwen Liu, 2003).

Anil (2009) stated the constituents of economic values in today's economic environment as following:

1. Exchange value
2. Esteem value
3. Use value
4. Cost value

Dell'Isola (1997) described value as the relationship between function, quality and cost. He also defined it with the most cost-effective way to reliably accomplish a function that will meet the user's needs, desires, and expectation.

$$\textbf{Value} = \frac{\textbf{Function} + \textbf{Quality}}{\textbf{\textit{Cost}}}$$

Based on the above equation, value of a product or service could be theoretically increased either by:

- Increasing the function with the same cost;
- Decreasing the cost with the same function;
- Increasing the function with reduction of cost;
- Increasing the function significantly with slight addition of cost;
- Decreasing the cost significantly with slight reduction of function.

2.3 Job Plan of VE

A value study must follow a systematic process - The Job Plan - which consists of six sequential phases as indicated in Table 2 below. There are 3 stages to a value study, the preparatory pre-workshop stage, the workshop (using the 6 phase job plan) and the post workshop stage for implementation and follow up (SAVE, 2007). The precise number of stages and the specific names of these stages in the job plan often vary but the same general process is always identifiable. The principles of the value engineering job plan, reflecting classical research techniques, are generally regarded to be sound (Kelly and Male, 1993).

Table 2. The six sequential phases of VE Job Plan developed from SAVE (2007)

The Job Plan sequential phases	Outline
Information phase	Project definition and goals
Function analysis phase	Function definition and analysis
Creative phase	Identification of alternatives
Evaluation phase	Structured evaluation of alternatives
Development phase	Development of alternative into proposals
Presentation phase	Report / Presentation of the opportunities

2.4 Experience Accumulated by VE in Transportation Projects

Value engineering has been used for a period of over 35 years by the U.S. Department of Defense, the U.S. Department of Transportation, the General Services Ad- ministration, the California Department of Transportation, the U.S. Federal Highway Administration (FHWA) and several other American organizations as well as corresponding agencies in Europe and the Far East Japan. In the Middle East, value engineering lectures have been initiated at the King Saud University in Riyadh, Saudi Arabia, while there are also plans to introduce graduate engineering classes at the King Fahd University of Petroleum and Minerals in Dhahran; seminars on value engineering have been carried out also in Kuwait, Bahrain and other areas in the Emirates (Leonidas, 1989).

Federal Highway Administration (FHWA) annually collects information on VE accomplishments achieved within the Federal-aid Highway Program, including the projects administered by Federal Lands Highway. For VE studies conducted during the preconstruction phase of projects, the FHWA tracks the number of studies conducted; proposed and implemented recommendations; and the value of the implemented recommendations. Additionally, similar information is compiled for the VE change proposals (VECP) that are submitted by contractors during the construction of the projects (FHWA, 2017). Table 3 illustrates summary of past VE savings federal-aid and federal lands highway programs.

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Table 3. Summary of past VE savings federal-aid and federal lands highway programs (FHWA, 2017)

	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015
Number of VE Studies	378	352	281	135	135
Cost to Conduct VE Studies and Program Administration	$12.5 M	$12.0 M	$9.8 M	$8.7 M	$6.4M
Estimated Construction Cost of Projects Studied	$32.3 B	$30.3 B	$23.0 B	$20.9 B	$14.1B
Total Number of Proposed Recommendations	2,950	2,905	2,381	1,664	1,233
Total Value of Proposed Recommendations	$2.94 B	$3.78 B	$2.91 B	$3.0 B	$2.5B
Number of Approved Recommendations	1,224	1,191	1,011	697	504
Value of Approved Recommendations	$1.01 B	$1.15 B	$1.15 B	$1.73 B	$831M
Percent of Project Cost Saved	3.12%	3.78%	5.01%	8.32%	5.9%
Return on Investment	80:1	96:1	118:1	200:1	129:1

3. QUANTIFYING HIGHWAY SAFETY IMPACTS IN VE PROCESS

(NCHRP, 2005) stated that the relationship between VE and road safety has long been questioned, and possibly been misunderstood, by transportation agency decision makers. This is likely because of previous suggestions that VE can diminish road safety or that VE and road safety initiatives cannot coexist. Although these suggestions might hold true in specific situations, there is enough recent experience to counter these arguments.

Historically, quantify safety has been a challenging issue explicitly along with other factors such as operational and environmental impacts during the project development process. Substitute for that, safety has been assumed to be inherent in design policies and practices. During the VE process safety is a traditional consideration, but much of the consideration has been qualitative in nature. Recently developed methods may allow VE teams to quantify the safety impacts of various design alternatives and operational features. If a VE team suggests changes to a specific project element, these methods may help them understand the safety implications of those changes and justify their suggestions and recommendations. In this way, safety can be considered in conjunction with the anticipated operational and environmental impacts (FHWA, 2017).

3.1 Methods for Quantifying Safety Impacts in the VE Process

In 2014, Federal Highway Administration issued a report which identifies several methods and related tools that can be used to compare the safety impacts of various opportunities or project elements. The report title was **"Using Crash Modification Factors to Quantify Safety in the Value Engineering Process"** and it stated that safety impacts can be estimated using a number of methods which incorporate one or more of the following inputs:

- Crash Modification Factors (CMFs);
- Safety Performance Function (SPF);
- Observed Crash Frequency;
- Predicted Crash Frequency; and
- Expected Crash Frequency.

Engineering judgment is an essential component of each method, so that it must be defined also.

3.2 Selecting an Appropriate Quantifying Safety Method

It is important to select an appropriate method to assess the safety impacts during the VE process. The selection of an appropriate method is based on the complexity of the decision at hand and the availability of required inputs. It does not depend on the specific phase of the project development process. For example, the preferred method is to estimate crashes based on the Expected Crash Frequency with CMF Adjustment; however, this method requires an applicable crash history and would not apply to new construction projects. As another example, the Relative Comparison of CMFs may not be appropriate when there are substantial differences in the fundamental characteristics of the alternatives (e.g., different area type, number of lanes, and/or traffic volume). In such cases, it is necessary to conduct a more detailed analysis, preferably using expected crashes with or without CMF adjustment.

We can confirm that there are several opportunities to identify and address safety impacts in the VE process. We can identify several methods and related tools that can be used to compare the safety impacts of various opportunities or project elements. Safety impacts are quantified by estimating the extent to which each opportunity or given set of conditions is likely to impact the frequency and severity of crashes. The safety impacts can then be compared among the alternatives and considered in conjunction with other factors such as operational and environmental impacts and overall project cost (FHWA, 2014). Table 4 provides a summary of the quantifying safety impacts methods along with the required inputs. Note that engineering judgment is an essential component of all methods.

Table 4. Summary of Quantifying Safety Impacts Methods along with the Required Inputs (FHWA, 2014)

Methods for Quantifying Safety Impacts	Required Inputs			
	Applicable CMF	Applicable Crash History (Observed Crashes)	Applicable SPF (Predicted Crashes)	Engineering Judgment
Relative Comparison of CMFs	•			•
Observed Crash Frequency with CMF Adjustment	•	•		•
Predicted Crash Frequency			•	•
Predicted Crash Frequency with CMF Adjustment	•		•	•
Expected Crash Frequency		•	•	•
Expected Crash Frequency with CMF Adjustment	•	•	•	•

4. CASE STUDY: THE 30 JUNE CORRIDOR PROJECT

To achieve the objectives of this research, the VE methodology was applied on a highway project through its design stage. The selected subject of the study is "THE 30 JUNE CORRIDOR" which follows Sinai Development and Improvement Authority, Ministry of Housing, Utilities and Urban Communities, Egypt. "THE 30 JUNE CORRIDOR" will be the main transport hub to serve the Suez Canal development projects, accelerate the development rates on both sides of the Suez Canal axis, and develop and connect the ports of Egypt (East and West Port Said, Damietta, Alexandria, Arish, Suez Gulf) to each other. Also it will increase the link between Sinai and Delta. This project will provide employment opportunities and put important archaeological places on the map of tourism areas (Tal Defna and the island of Tenees), in addition to connecting between Egypt and Africa by the future link on the axis of Africa.

4.1 Case Study Description

Based on contact with the project engineering consultant and the site investigation, it was obtained that "THE 30 JUNE CORRIDOR" begins from the west of Port Said city. The project starts from (Port Said-Damietta) International Road and extends 95 km to (Cairo-Ismailia) Desert Road. It is a divided expressway. Each direction consists of 5 traffic lanes (2 lanes for heavy traffic and 3 for vehicles) separated by a concrete barrier. The design speed of this project is 120 km/hr. The project includes fourteen bridges; eight of them are major bridges and six minor bridges. Figure 1 illustrates the project layout. The project also includes:

- 16 tunnels of service roads for cars and Pedestrians;
- Two Pedestrian tunnels; and
- Service Stations and Toll Stations.

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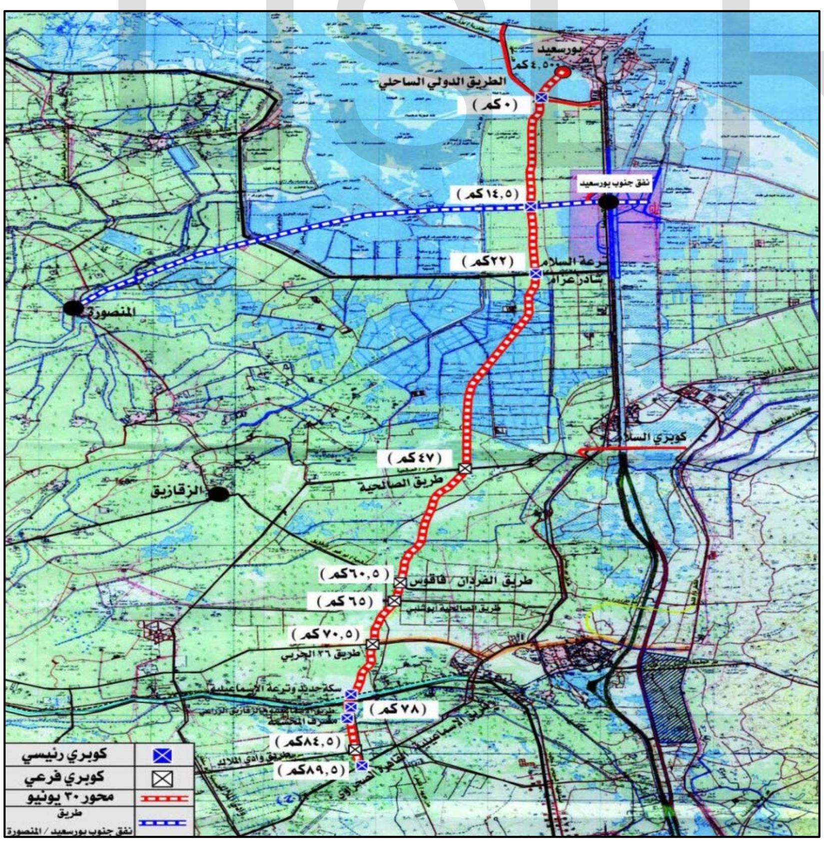

Figure 1. "THE 30 JUNE CORRIDOR" Layout and Main Junctions

4.2 Scope and Constraints of the Study

The selected case study includes many opportunities to improve and add value in terms of capital cost, constructability, maintenance of traffic and the basic functional requirements of the project. However, the scope of this research focused on the work area of the highway cross section which gives a great chance to consider important safety related issues as an essential objective of the research goals. The area under study is a part of "THE 30 JUNE Corridor" project that extends from Station (26+480) to Station (42+000).

As part of the case study briefing, the following project constraints and controlling decisions were needed to be taken into consideration during developing possible alternatives:

1. No highway alignment change.
2. No additional Right of Way.
3. Maintain 5 traffic lanes; 2 lanes for heavy traffic and 3 for vehicles; for each direction.

4.3 Cost Model for the Major items of the Case Study

For a complete analysis of any project, the total cost of the item, the cost of each component, and the cost of each design element are needed. According to Pareto's Law, it is often that 20 percent of a project's elements constitute 80 percent of its cost. Accurate and detailed cost estimates should be obtained for each proposed design to identify the alternative that provides the largest added value. Therefore, a cost model is organized to identify major construction elements of the highway cross section. The unit bid prices provided within the cost estimate were used to prepare the cost model. Figure 2 demonstrates the cost model for the major design elements. This model illustrate that binder course layer is the higher cost element with cost of EGP 59,720,960 and the embankment work is the lowest cost element with cost of EGP 2,545,668 .

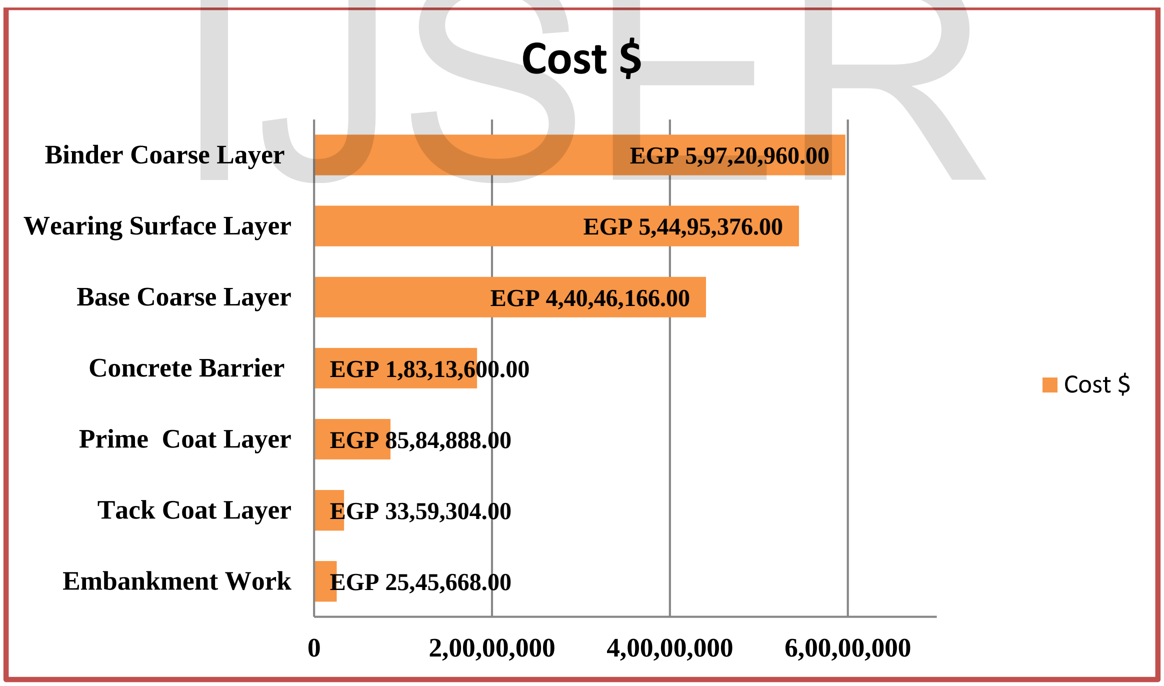

Figure 2. Cost Model for the Major Construction Elements

4.4 Performance Criteria

The performance criteria represent those aspects of a project's scope that has a set of potential values. When ideas weighted; a set of standards or criteria are needed, so to choose a suitable set of criteria, the question is asked, "What will be affected by this idea if implemented?" The performance attributes that was used throughout the study to identify, evaluate, and document ideas and recommendations are as following:

- Cost
- Safety Impacts
- Environmental Impacts
- Operational Performance
- Constructability
- Schedule Impacts
- Maintainability

A performance criteria matrix was used to determine the relative importance of the individual performance attributes for the case study. The relative importance was evaluated for the performance attributes that would be used to evaluate the creative ideas. For more confidence and accuracy, a questionnaire was designed to be filled by the experts of highway construction and design. Figure 3 demonstrate an example for performance criteria matrix that filled by a highway expert. The questionnaire was performed to a sample of 30 highway expert and the mean percentage of each criteria was calculated. Table 5 shows the calculated relative importance for each performance criteria.

Key of Importance Degree

- **3 Major Importance**
- **2 Minor Importance**
- **1 Slight Importance**
- **(Letter/Letter) Same importance, each scrod one point**

Performance criteria							
(A) Cost	A						
(B)Safety Impacts	A/B	B					
(C) Environmental Impacts	A/2	B/3	C				
(D) Operational Performance	A/D	B/D	D/3	D			
(E) Constructability	A/3	B/3	C/E	D/2	E		
(F) Schedule Impacts	A/3	B/3	C/1	D/3	E/2	F	
(G) Maintainability	A/1	B/3	C/G	D/2	E/2	G/1	G
Weight	11	14	3	12	5	0.0	2
% of The Total	23.4	29.8	6.4	25.5	10.6	0.0	4.3

Figure 3. An Example for Performance Criteria Matrix Using Paired Comparison Method

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Table 5. Relative Importance for Each Performance Criteria

Performance Criteria	Cost	Safety Impacts	Environmental Impacts	Operational Performance	Constructability	Schedule Impacts	Maintainability
Relative Importance	20.3 %	29.9 %	12.5 %	23.7 %	5.5 %	1.6 %	6.7 %

5. FUNCTION ANALYSIS

Functional analysis makes a unique vision of the project. It converts the project elements to functions, which moves the mind away from the original design of each element and towards a functional concept of the project. The function of each design element defined using two words; an action verb and a measurable noun; to reduce the needs of the project to their most important level. Functions identification allows a broader view of alternative ways to accomplish these functions. The following functions considered as the major functions of the Study work area:

- Accommodate traffic volume
- Improve economic vitality

Table 6 shows the functions related to the major design items as defined by the cost model.

Table 6. Function Analysis

Overall Function: Accommodate Traffic Volume					
Item No.	**Description**	**Function**			**Cost ($)**
		Verb	**Noun**	**Classification B=Basic S=Secondary**	
1	**Binder Course Layer**	Distribute	Load	B	59,720,960
2	**Wearing Surface Layer**	Carry Resist Provide Shed Improve Define	Vehicles Load Distortion Skid-Resistance Water Ride Quality Traveled Way	B B S S S S	54,495,376
3	**Base Course Layer**	Transfer Facilitate Stop	Load Drainage Ground Water	B S S	44,046,166
4	**Concrete Barrier**	Reduce Separate	Crash Severity Traffic	B B	18,313,600
5	**Prime Coat Layer**	Provide Plug Prevent	Bonding Voids Water	B S S	8,584,888
6	**Tack Coat Layer**	provide	bonding	B	3,359,304
7	**Embankment Work**	Support Enhance	Loads Stability	B B	2,545,668

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6. FAST DIAGRAM

To represent the functional logic applied to the original design graphically, the Functional Analysis System Technique or FAST diagram was prepared. FAST diagram developing required asking the questions, HOW is the basic function (verb) (noun) actually accomplished, or HOW is it proposed to be accomplished? The answer, expressed as a verb and a noun, is written in the next block to the right of the scope line. Asking HOW is continued to the right for each new function on the diagram until the answer exceeds the scope of the study.

To check the answers to the HOW questions, the functions answer the question HOW when read from left to right. If the diagram is read from right to left, the functions answer the question WHY. Functions connected with a vertical line are those that happen at the same time as, or are caused by, the function at the top of the column. Figure 4 shows the developed FAST Diagram for the 30 June Corridor case study.

The FAST Diagram for this research shows the following:

- **Design Objective:** The FAST Diagram of the research scope focus on Improve Corridor Value as the objective of the design.
- **Higher Order Functions:** The FAST Diagram illustrate Accommodate Traffic Volume and Improve Economic Vitality as the higher order functions of this case study.
- **Basic Functions:** Maintain Traffic and Improve Project Value considered as the basic functions of the entire project.
- **Key Secondary Functions:** The key secondary functions include Construct Travel-way and Review Original Design.
- **"All the time" Functions:** For accomplishing the basic function, Satisfy Highway Safety and Enhance Constructability were considered as functions that occur all the time.
- **Lower Order Functions:** The FAST Diagram illustrate Specify Design Needs as the lower order function of this study.

This representation of the functional logic in FAST diagram form provide understanding the project design rationale and shows functions that have best opportunities for cost or performance improvement.

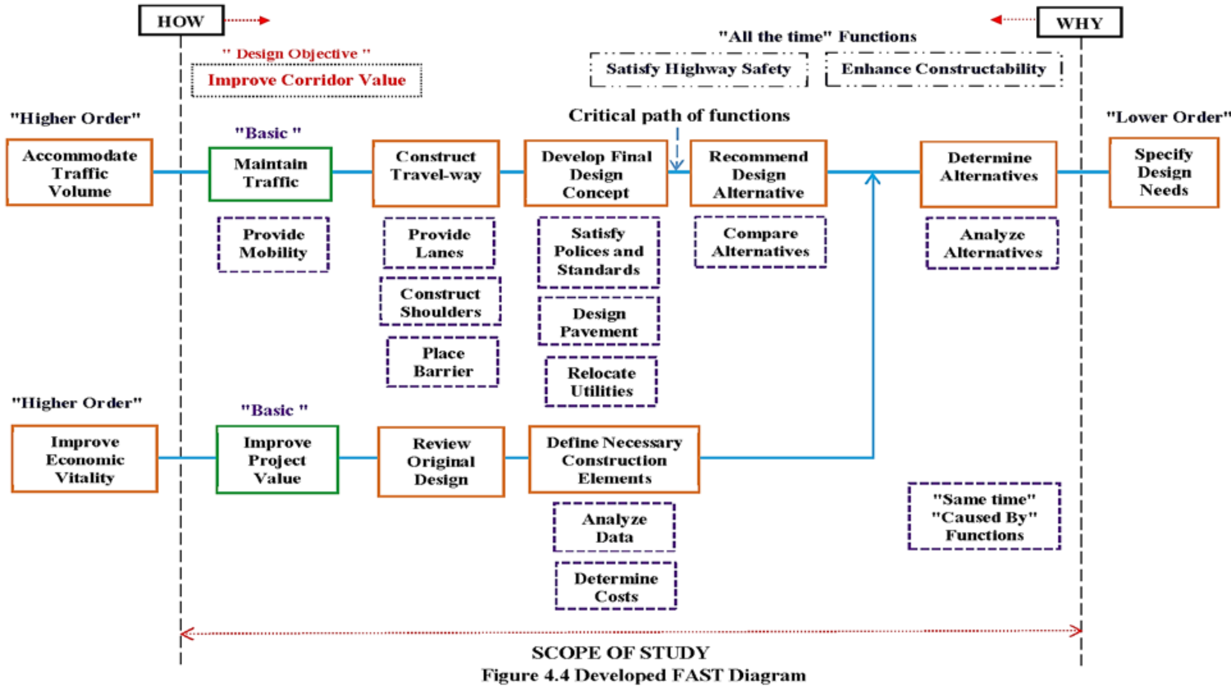

Figure 4. Developed FAST Diagram

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7. CREATIVE PHASE

The main objective of the Speculation Phase is to "brainstorm" the functions of the design elements, and to develop a number of alternatives to each. To perform this phase, the brainstorming technique was used with the participation of highways design and construction experts. This participation was essentially because the greater the number of ideas conceived, the more likely that better quality, less costly alternatives will be among the ideas. Creative effort was directed toward the development of alternative means to accomplish the needed functions in more creative manners. The ideas were based on the available information at the time of the study, taking into consideration the constraints and controlling decisions of the study that were obtained. Table 7 shows a list of all generated ideas that satisfy the functions of the various project components which have more opportunity for adding value and greatest potential savings.

Table 7. List of Generated Ideas for Speculation Phase

Item	Basic Function	Generated ideas
A- Binder Course Layer	▪ Distribute Load	• Rigid pavement • Polymer Modified Asphalt • Recycled Asphalt • Nano Asphalt • Recycled Tires Asphalt • Reduce typical lane width coincide with checking capacity and safety • Reduce shoulder width coincide with checking capacity and safety • Change shoulder type coincide with checking capacity and safety • Combine Reduce typical lane width, shoulder width and shoulder type coincide with checking capacity and safety

B- Wearing Surface Layer	▪ **Carry vehicle loads** ▪ **Resist Distortion**	• Rigid pavement • Nano Asphalt • Recycled Titers Asphalt • Asphalt Stabilizers • Thin Asphalt • Densiphalt Pavement System • Reduce typical lane width coincide with checking capacity and safety • Reduce shoulder width coincide with checking capacity and safety • Change shoulder type coincide with checking capacity and safety • Combine Reduce typical lane width, shoulder width and shoulder type coincide with checking capacity and safety
C- Base Course Layer	▪ **Transfer Load**	• Foamix Base course • Remix Stabilization (REST) • Slag Bound Materials (SBM) • Composite Stabilization • Reduce typical lane width coincide with checking capacity and safety • Reduce shoulder width coincide with checking capacity and safety • Combine Reduce typical lane width and shoulder width coincide with checking capacity and safety
D- Concrete Barrier	▪ **Reduce Crash Severity** ▪ **Separate Traffic**	• Steel Median Barrier • Cable Median Barrier • W-Beam Barrier • Precast Concrete Barrier

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8. EVALUATION PHASE

The main objective of the Evaluation Phase as a phase of VE Job Plane is to analyze Speculation Phase results through review of the generated ideas and select the best ideas for further development. The following two basic steps were used to perform this phase:

- Preliminary Screening
- Alternatives Evaluation

8.1 Preliminary Screening

The creative ideas that have been developed in brainstorming sessions were reviewed. The alternatives that thought to be unacceptable or unrealistic have been crossed out. The remaining alternatives have been recorded and their advantages and disadvantages have been listed using a consecutively numbering system such as (A-1, A-2, A-3, A-4; etc.)

Taking into consideration the project constraints and controlling decisions, each idea or alternative was discussed based on its advantages and disadvantages. Then each alternative was given an overall rank (zero through five).

High-rated ideas (four or higher) were developed further and low-rated ones (two or lower) were dropped from further consideration. Table 8 show the screened alternatives for further consideration and evaluation.

The details of the ranking were as following:

- 5 = Great Opportunity
- 4 = Good Opportunity
- 3 = Fair Opportunity
- 2 = Minor Value Degradation
- 1 = Major Value Degradation
- 0 = Fatal Flaw (unacceptable impact or doesn't meet the project purpose)

Table 8. The Screened Alternatives for Further Evaluation

Idea Code	Idea Description
A-3, B-2	Recycled Tires Asphalt
A-4, B-3, C-2	Reduce typical lane width coincide with checking capacity and safety
A-5, B-4, C-3	Reduce shoulder width coincide with checking capacity and safety
A-6, B-5	Change shoulder type coincide with checking capacity and safety
A-7, B-6	Combine Reduce typical lane width, shoulder width and shoulder type coincide with checking capacity and safety
C-1	Foamix Base course

8.2 Alternatives Evaluation

The final selection for the screened alternatives was performed during this step. Each alternative was weighted against the chosen performance criteria. The performance of each idea is rated against the original design using a rate number (one through five). The details of this rating were as following:

- 5 = Superior
- 4 = Good
- 3 = Average
- 2 = Fair
- 1 = Poor

The cumulated experience in problem-solving shows that anybody tend to rate the preferred alternative high if the alternative is rated against each criteria. To avoid this arbitrariness, each performance criteria was rated against each alternative. And so, the evaluation matrix was designed as shown in Table 9 and each idea was given an evaluation objectively as possible with the help of highway design and construction experts.

For each rating between the original design and the design alternatives according to a specific performance criteria, the total performance was computed by multiplying the weight of the criteria times the rate and the results inserted in the last column of Table 9. The overall performance of each alternative was then calculated and the percentage of the related change in performance was also computed as shown in Table 10.

Table 9. Evaluation Matrix for Screened Design Alternatives against Performance Criteria

Performance Criteria	**Relative Importance**	**Design Alternatives**	**Performance Rating**					**Total Performance**
			Poor (1)	**Fair (2)**	**Average (3)**	**Good (4)**	**Superior (5)**	
Cost	**20.3%**	**Original Design**		**2**				**20.3*2= 40.6**
		A-3, B-2	**1**					**20.3**
		A-4, B-3, C-2				**4**		**81.2**
		A-5, B-4, C-3				**4**		**81.2**
		A-6, B-5				**4**		**81.2**
		A-7, B-6					**5**	**101.5**
		C-1			**3**			**60.9**

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Safety Impacts	**29.9%**	**Original Design**				**4**		**29.9*4=119.6**
		A-3, B-2				**4**		**119.6**
		A-4, B-3, C-2				**4**		**119.6**
		A-5, B-4, C-3			**3**			**89.7**
		A-6, B-5			**3**			**89.7**
		A-7, B-6				**4**		**119.6**
		C-1				**4**		**119.6**
Environmental Impacts	**12.5 %**	**Original Design**		**2**				**12.5*2= 25**
		A-3, B-2				**4**		**50**
		A-4, B-3, C-2				**4**		**50**
		A-5, B-4, C-3				**4**		**50**
		A-6, B-5		**2**				**25**
		A-7, B-6					**5**	**62.5**
		C-1			**3**			**37.5**
Operational Performance	**23.7 %**	**Original Design**				**4**		**23.7*4= 94.8**
		A-3, B-2				**4**		**94.8**
		A-4, B-3, C-2			**3**			**71.1**
		A-5, B-4, C-3				**4**		**94.8**
		A-6, B-5				**4**		**94.8**
		A-7, B-6			**3**			**71.1**
		C-1				**4**		**94.8**
Constructability	**5.5 %**	**Original Design**			**3**			**5.5*3= 16.5**
		A-3, B-2		**2**				**11**
		A-4, B-3, C-2			**3**			**16.5**
		A-5, B-4, C-3			**3**			**16.5**
		A-6, B-5			**3**			**16.5**
		A-7, B-6			**3**			**16.5**
		C-1	**1**					**5.5**
Schedule Impacts	**1.6 %**	**Original Design**			**3**			**1.6*3= 4.8**
		A-3, B-2		**2**				**3.2**
		A-4, B-3, C-2				**4**		**6.4**
		A-5, B-4, C-3				**4**		**6.4**
		A-6, B-5				**4**		**6.4**
		A-7, B-6				**4**		**6.4**
		C-1		**2**				**3.2**
Maintainability	**6.7 %**	**Original Design**			**3**			**6.7*3 = 20.1**
		A-3, B-2		**2**				**13.4**
		A-4, B-3, C-2			**3**			**20.1**
		A-5, B-4, C-3			**3**			**20.1**
		A-6, B-5				**4**		**26.8**
		A-7, B-6				**4**		**26.8**
		C-1		**2**				**13.4**

Table 10. Overall Results of the Evaluation Matrix

Design Alternatives	Overall Performance	
	Performance (P)	% Performance Change
Original Design	40.6 + 119.6 + 25 + 94.8 + 16.5 + 4.8 + 20.1 = 321	
A-3, B-2	312	-2.8%
A-4, B-3, C-2	365	13.7%
A-5, B-4, C-3	359	11.8%
A-6, B-5	340	6%
A-7, B-6	404	25.9%
C-1	335	4.4%

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9. DEVELOPMENT OF HIGHWAY DESIGN ALTERNATIVES

The core objective of the Development Phase of the Value Engineering Job Plan is to discuss and analyze the best alternatives that chosen and elected during the Evaluation Phase. Also, the purpose of the Development Phase is to perform the required initial designs and the cost estimates that will show and confirm the validation and degree of acceptance for these selected design alternatives.

According to Evaluation Phase, the most alternatives that have a good opportunity to add value and have a higher percentage of performance change to better were (See Table 10):

- **(A-4, B-3, C-2)-** Reduce typical lane width coincide with checking capacity and safety.
- **(A-5, B-4, C-3)-** Reduce shoulder width coincide with checking capacity and safety.
- **(A-6, B-5)-** Change shoulder type coincide with checking capacity and safety.
- **(A-7, B-6)-** Combine Reduce typical lane width, shoulder width and shoulder type coincide with checking capacity and safety.

Based on these major design alternatives, about 51 case were developed for the Multi-Purpose Road and the Truck Road. Table 11 show the possible cases for individual modification in lane width, shoulder width and shoulder type. Table 12 show the possible cases for the combination of modifying lane width and shoulder width. Table 13 show the cases for the combination of modifying lane width and shoulder type. Table 14 shows the cases for the combination of modifying shoulder width and shoulder type. Table 15 shows the cases for the combination of modifying lane width, shoulder width and shoulder type.

Table 11. Cases for Individual Modification in Lane Width, Shoulder Width and Shoulder Type

Case No.	Modification Type	Case Description	
		Multi-Purpose Road	Truck Road
1	Lane Width	Reduce lane width from 12 ft to 9 ft	Reduce lane width from 13.1 ft to 9 ft
2		Reduce lane width from 12 ft to 10 ft	Reduce lane width from 13.1 ft to 10 ft
3		Reduce lane width from 12 ft to 11 ft	Reduce lane width from 13.1 ft to 11 ft
4	Shoulder width	Reduce Paved Right Shoulder width from 8 ft to 6 ft	Reduce Paved Right Shoulder width from 8 ft to 6 ft
5		Reduce Paved Right Shoulder width from 8 ft to 4 ft	Reduce Paved Right Shoulder width from 8 ft to 4 ft
6		Reduce Paved Right Shoulder width from 8 ft to 2 ft	Reduce Paved Right Shoulder width from 8 ft to 2 ft
7		Reduce Paved Right Shoulder width from 8 ft to 0 ft	Reduce Paved Right Shoulder width from 8 ft to 0 ft
8	Shoulder Type	Convert 8 ft Paved Right Shoulder type to 8 ft composite shoulder	Convert 8 ft Paved Right Shoulder type to 8 ft composite shoulder
9		Convert 8 ft Paved Right Shoulder type to 8 ft turf shoulder	Convert 8 ft Paved Right Shoulder type to 8 ft turf shoulder

Table 12. Cases for the Combination of Modifying Lane Width and Shoulder Width

Case No.	Modification Type	Case Description	
		Multi-Purpose Road	Truck Road
10	Lane Width and shoulder width	(Reduce lane width from 12 ft to 9 ft) + Reduce Paved Right Shoulder width from 8 ft to 6 ft	(Reduce lane width from 13.1 ft to 9 ft) + Reduce Paved Right Shoulder width from 8 ft to 6 ft
11		(Reduce lane width from 12 ft to 9 ft) + Reduce Paved Right Shoulder width from 8 ft to 4 ft	(Reduce lane width from 13.1 ft to 9 ft) + Reduce Paved Right Shoulder width from 8 ft to 4 ft
12		(Reduce lane width from 12 ft to 9 ft) + Reduce Paved Right Shoulder width from 8 ft to 2 ft	(Reduce lane width from 13.1 ft to 9 ft) + Reduce Paved Right Shoulder width from 8 ft to 2 ft
13		(Reduce lane width from 12 ft to 9 ft) + Reduce Paved Right Shoulder width from 8 ft to 0 ft	(Reduce lane width from 13.1 ft to 9 ft) + Reduce Paved Right Shoulder width from 8 ft to 0 ft
14		(Reduce lane width from 12 ft to 10 ft) + Reduce Paved Right Shoulder width from 8 ft to 6 ft	(Reduce lane width from 13.1 ft to 10 ft) + Reduce Paved Right Shoulder width from 8 ft to 6 ft
15		(Reduce lane width from 12 ft to 10 ft) + Reduce Paved Right Shoulder width from 8 ft to 4 ft	(Reduce lane width from 13.1 ft to 10 ft) + Reduce Paved Right Shoulder width from 8 ft to 4 ft
16		(Reduce lane width from 12 ft to 10 ft) + Reduce Paved Right Shoulder width from 8 ft to 2 ft	(Reduce lane width from 13.1 ft to 10 ft) + Reduce Paved Right Shoulder width from 8 ft to 2 ft
17		(Reduce lane width from 12 ft to 10 ft) + Reduce Paved Right Shoulder width from 8 ft to 0 ft	(Reduce lane width from 13.1 ft to 10 ft) + Reduce Paved Right Shoulder width from 8 ft to 0 ft
18		(Reduce lane width from 12 ft to 11 ft) + Reduce Paved Right Shoulder width from 8 ft to 6 ft	(Reduce lane width from 13.1 ft to 11 ft) + Reduce Paved Right Shoulder width from 8 ft to 6 ft
19		(Reduce lane width from 12 ft to 11 ft) + Reduce Paved Right Shoulder width from 8 ft to 4 ft	(Reduce lane width from 13.1 ft to 11 ft) + Reduce Paved Right Shoulder width from 8 ft to 4 ft
20		(Reduce lane width from 12 ft to 11 ft) + Reduce Paved Right Shoulder width from 8 ft to 2 ft	(Reduce lane width from 13.1 ft to 11 ft) + Reduce Paved Right Shoulder width from 8 ft to 2 ft
21		(Reduce lane width from 12 ft to 11 ft) + Reduce Paved Right Shoulder width from 8 ft to 0 ft	(Reduce lane width from 13.1 ft to 11 ft) + Reduce Paved Right Shoulder width from 8 ft to 0 ft

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Table 13. Cases for the Combination of Modifying Lane Width and Shoulder Type

Case No.	Modification Type	Case Description	
		Multi-Purpose Road	Truck Road
22	Lane Width and shoulder Type	Reduce lane width from 12 ft to 9 ft + Convert 8 ft Paved Right Shoulder type to 8 ft composite shoulder	Reduce lane width from 13.1 ft to 9 ft + Convert 8 ft Paved Right Shoulder type to 8 ft composite shoulder
23		Reduce lane width from 12 ft to 10 ft + Convert 8 ft Paved Right Shoulder type to 8 ft composite shoulder	Reduce lane width from 13.1 ft to 10 ft + Convert 8 ft Paved Right Shoulder type to 8 ft composite shoulder
24		Reduce lane width from 12 ft to 11 ft + Convert 8 ft Paved Right Shoulder type to 8 ft composite shoulder	Reduce lane width from 13.1 ft to 11 ft + Convert 8 ft Paved Right Shoulder type to 8 ft composite shoulder
25		Reduce lane width from 12 ft to 9 ft + Convert 8 ft Paved Right Shoulder type to 8 ft turf shoulder	Reduce lane width from 13.1 ft to 9 ft + Convert 8 ft Paved Right Shoulder type to 8 ft turf shoulder
26		Reduce lane width from 12 ft to 10 ft + Convert 8 ft Paved Right Shoulder type to 8 ft turf shoulder	Reduce lane width from 13.1 ft to 10 ft + Convert 8 ft Paved Right Shoulder type to 8 ft turf shoulder
27		Reduce lane width from 12 ft to 11 ft + Convert 8 ft Paved Right Shoulder type to 8 ft turf shoulder	Reduce lane width from 13.1 ft to 11 ft + Convert 8 ft Paved Right Shoulder type to 8 ft turf shoulder

Table 14. Cases for the Combination of Modifying Shoulder Width and Shoulder Type

Case No.	Modification Type	Case Description	
		Multi-Purpose Road	Truck Road
28	Shoulder Width and Shoulder Type	Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft composite shoulder	Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft composite shoulder
29		Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft composite shoulder	Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft composite shoulder
30		Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft composite shoulder	Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft composite shoulder
31		Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft turf shoulder	Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft turf shoulder
32		Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft turf shoulder	Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft turf shoulder
33		Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft turf shoulder	Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft turf shoulder

Table 15. Cases for the Combination of Modifying Lane width, Shoulder Width and Shoulder Type

Case No.	Modification Type	Case Description	
		Multi-Purpose Road	Truck Road
34	lane width, Shoulder Width and Shoulder Type	Reduce lane width from 12 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft composite shoulder	Reduce lane width from 13.1 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft composite shoulder
35		Reduce lane width from 12 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft composite shoulder	Reduce lane width from 13.1 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft composite shoulder
36		Reduce lane width from 12 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft composite shoulder	Reduce lane width from 13.1 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft composite shoulder
37		Reduce lane width from 12 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft turf shoulder	Reduce lane width from 13.1 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft turf shoulder
38		Reduce lane width from 12 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft turf shoulder	Reduce lane width from 13.1 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft turf shoulder
39		Reduce lane width from 12 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft turf shoulder	Reduce lane width from 13.1 ft to 9 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft turf shoulder
40		Reduce lane width from 12 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft composite shoulder	Reduce lane width from 13.1 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft composite shoulder
41		Reduce lane width from 12 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft composite shoulder	Reduce lane width from 13.1 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft composite shoulder
42		Reduce lane width from 12 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft composite shoulder	Reduce lane width from 13.1 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft composite shoulder
43		Reduce lane width from 12 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft turf shoulder	Reduce lane width from 13.1 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft turf shoulder
44		Reduce lane width from 12 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft turf shoulder	Reduce lane width from 13.1 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft turf shoulder
45		Reduce lane width from 12 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft turf shoulder	Reduce lane width from 13.1 ft to 10 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft turf shoulder
46		Reduce lane width from 12 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft composite shoulder	Reduce lane width from 13.1 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft composite shoulder
47		Reduce lane width from 12 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft composite shoulder	Reduce lane width from 13.1 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft composite shoulder

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48		**Reduce lane width from 12 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft composite shoulder**	**Reduce lane width from 13.1 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft composite shoulder**
49		**Reduce lane width from 12 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft turf shoulder**	**Reduce lane width from 13.1 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 6 ft + Convert to 6 ft turf shoulder**
50		**Reduce lane width from 12 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft turf shoulder**	**Reduce lane width from 13.1 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 4 ft + Convert to 4 ft turf shoulder**
51		**Reduce lane width from 12 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft turf shoulder**	**Reduce lane width from 13.1 ft to 11 ft + Reduce Paved Right Shoulder width from 8 ft to 2 ft + Convert to 2 ft turf shoulder**

10. QUANTIFYING HIGHWAY SAFETY IMPACTS FOR THE DESIGN ALTERNATIVES

It can't be judged that the alternative which lead to the highest cost reduction is the best one. On the other hand, we can't say that the alternative which lead to the lowest cost reduction is the worst one. The logical reason for not rushing to judge the preference of alternatives is that the highway safety impacts of these design alternatives are unknown. The highway safety impacts is one of the important criteria that have been taken into consideration during the initial evaluation of the main alternatives, so it can't be abandoned in order to achieve economic savings. In most previous Value Engineering studies that related to highway projects, there was no clear approach to quantify safety impacts. Instead of that, safety has been assumed to be inherent in design policies and practices.

Based on the above, it was necessary and essential to find a way for quantifying the highway safety impacts for each case of the design alternatives. The quantifying process includes determining the number of accidents that can occur because of the design alternative and also determining the related economic impacts of these accidents.

10.1. Selecting Appropriate Method to Quantify Safety Impacts

According to the research case study as a new highway project under construction with no crash history available to estimate the observed crashes, **"Predicted Crash Frequency with Crash modification factors (CMFs) Adjustment"** was selected as an appropriate method to quantify highway safety impacts (See Table 4). In this method the predicted crashes for baseline conditions were calculated and then the predicted crashes are multiplied by the applicable CMFs to estimate the predicted crashes for the conditions of interest for each design alternative.

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10.2. Predicted Crash Frequency for Original Design and Design Alternatives

The predicted number of accidents for the baseline conditions or the original design was calculated using three accident prediction models that have been developed for analysis and evaluation of highway safety in Egypt. These prediction models are for three types of accidents which include:

- Total Accident Model
- Injury Accident Model
- Fatal Accident Model

Table 16 shows the accident prediction of the original design for whole corridor

Table 16. Accident Prediction for Original Design (Whole Corridor)

Whole Corridor	
Accident Type	No. of Accidents for Two Directions
Total Accident	63.9
Injury Accident	34.88
Fatal Accident	3.56
Damage Only Accidents	25.46

Crash modification factors (CMFs) were identified to reflect the conditions of modifications for each design element. The Highway Safety Manual Part C provides specific CMFs in case of freeways for use with the Accident Prediction Models. The combined CMFs were then calculated for each design alternative case to estimate the overall safety impact of the modification conditions for each case. The combined CMFs are the result of multiplying CMF for all types of modifications as stated in Equation 1.

$$\mathbf{CMF_{combined} = CMF_{lane\ width} \times CMF_{shoulder\ width} \times CMF_{shoulder\ type}} \qquad \textbf{(Equation 1)}$$

Where:
$CMF_{combined}$ = Crash modification factor for combined set of roadway modifications.
$CMF_{lane\ width}$ = Crash modification factor for the modification in lane width only.
$CMF_{shoulder\ width}$ = Crash modification factor for the modification in shoulder width only.
$CMF_{shoulder\ type}$ = Crash modification factor for the modification in shoulder type only.

The predicted crash frequency for the original design is adjusted with the combined CMFs, using Equation (2) to estimate the predicted crash frequency for the design alternatives.

$$N_{Predicted} = N_{Original\ Design} \times CMF_{Combined} \qquad \textbf{(Equation 2)}$$

Where:
$N_{Predicted}$ = Predicted crash frequency for the design alternative.
$N_{Original\ Design}$ = Predicted crash frequency for original design conditions.

Table 17 illustrate the whole corridor crash frequency for each case of the design alternatives.

Table 17. Whole Corridor Crash Frequency for Cases of Design Alternatives

Case No.	Annual Crash Frequency According to Crash Type				Case No.	Annual Crash Frequency According to Crash Type			
	Total Accidents	Injury Accidents	Fatal Accidents	Damage Only Accidents		Total Accidents	Injury Accidents	Fatal Accidents	Damage Only Accidents
1	79.88	43.59	4.46	31.83	27	73.06	39.87	4.08	29.11
2	73.49	40.11	4.10	29.29	28	69.12	37.72	3.86	27.54
3	65.82	35.92	3.67	26.23	29	71.75	39.15	4.00	28.59
4	66.46	36.27	3.71	26.48	30	73.66	40.20	4.11	29.35
5	69.66	38.01	3.89	27.76	31	71.78	39.17	4.00	28.60
6	72.21	39.41	4.03	28.78	32	73.14	39.91	4.08	29.15
7	75.41	41.15	4.21	30.05	33	74.38	40.59	4.15	29.64
8	67.74	36.97	3.78	26.99	34	86.40	47.15	4.82	34.43
9	70.94	38.71	3.96	28.27	35	89.68	48.94	5.00	35.74
10	83.08	45.34	4.64	33.11	36	92.07	50.25	5.14	36.69
11	87.07	47.52	4.86	34.70	37	89.72	48.96	5.01	35.75
12	90.27	49.26	5.04	35.97	38	91.43	49.89	5.10	36.43
13	94.26	51.44	5.26	37.56	39	92.98	50.74	5.19	37.05
14	76.43	41.71	4.26	30.46	40	79.49	43.38	4.43	31.67
15	80.11	43.72	4.47	31.92	41	82.51	45.03	4.60	32.88
16	83.05	45.32	4.63	33.09	42	84.71	46.23	4.73	33.75
17	86.72	47.33	4.84	34.56	43	82.55	45.05	4.61	32.89
18	68.46	37.36	3.82	27.28	44	84.11	45.90	4.69	33.52
19	71.75	39.15	4.00	28.59	45	85.54	46.68	4.77	34.09
20	74.38	40.59	4.15	29.64	46	71.19	38.85	3.97	28.37
21	77.67	42.39	4.33	30.95	47	73.90	40.33	4.12	29.45
22	84.68	46.21	4.72	33.74	48	75.87	41.40	4.23	30.23
23	77.90	42.51	4.35	31.04	49	73.93	40.35	4.12	29.46
24	69.77	38.08	3.89	27.80	50	75.33	41.11	4.20	30.02
25	88.67	48.39	4.95	35.33	51	76.61	41.81	4.27	30.53
26	81.58	44.52	4.55	32.51					

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Comparing to the crash frequency of the original design it is obviously that all the design alternatives resulted in more accidents due to the performed modifications. Figure 5 illustrates the total number of accidents for each case compared to the original design. The developed 51 design alternatives may have a good opportunity to add value to the corridor from the perspective of many decision makers. That belief based on the high overall rating of these alternatives in different performance criteria such as cost, environmental impacts, constructability and maintainability. Otherwise, there is another justification that reinforces this belief. This justification is “already there will be accidents on the road in any case even in the original design case”.

Therefore, it was possible to give recommendations from these alternatives which caused a slight increasing in the crash frequency. This can be possible if the crash increasing can be contained economically during the life cycle cost analysis compared to the high construction costs which these alternatives can save. However, the evaluation process has not been viewed from a strictly economic point of view as long as preventive measures can be taken to reduce the number of potential accidents and increase road safety of these alternatives.

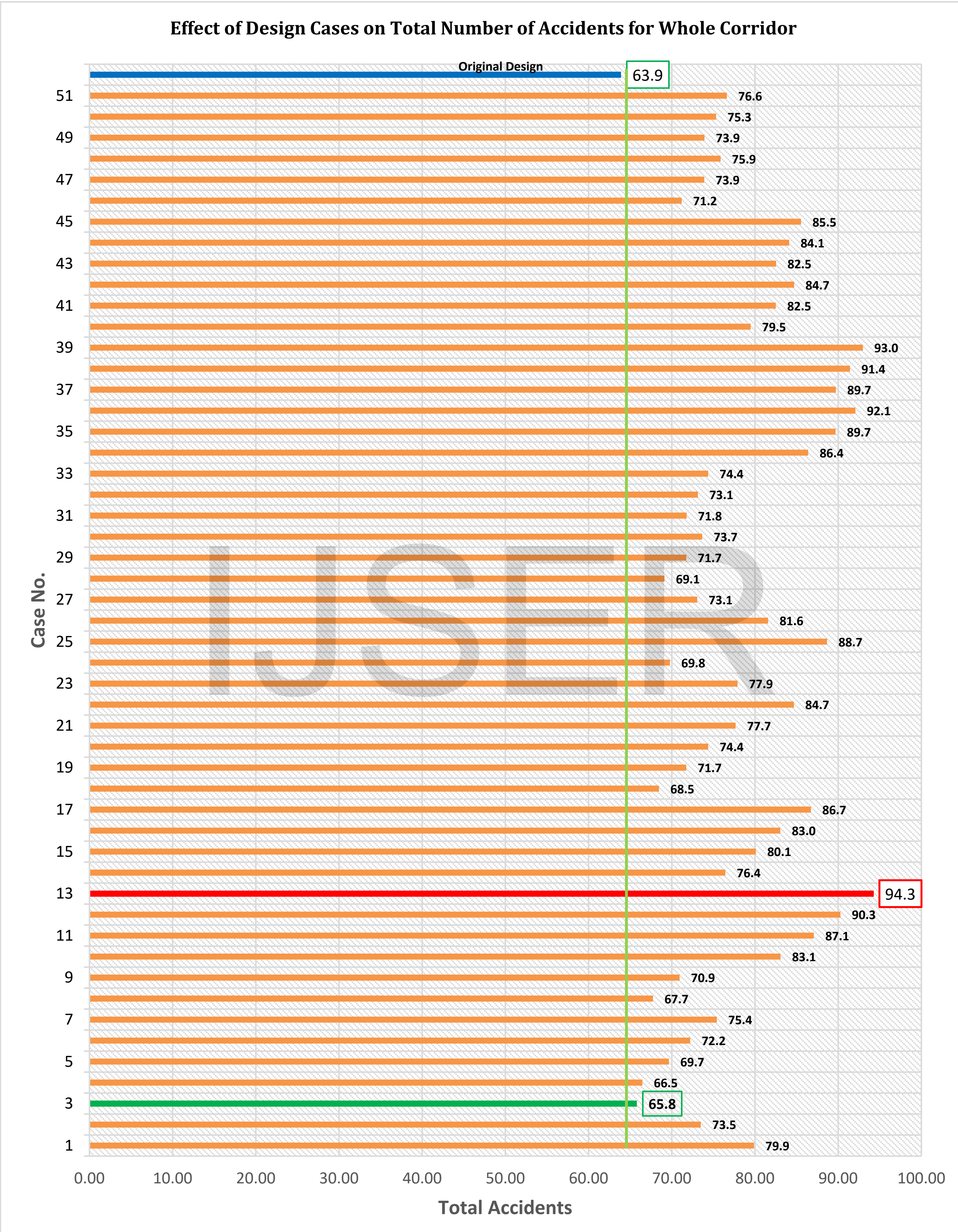

Figure 5. Effect of the Different Design Cases on the Total Number of Accidents

11. IMPLEMENTING COUNTERMEASURES TO ENHANCE HIGHWAY SAFETY

To enhance highway safety of the design alternatives there are many countermeasures that can be taken to reduce the crash frequency on the corridor. The most cost-effective solutions can be achieved through implementation of lower cost countermeasures. Selecting an appropriate countermeasure was the biggest challenge due to the lack of the previous research related to the type of the case study as a rural freeway. In case of selection any countermeasure, a valid CMF must be available to quantify the impact of using it on the crash frequency.

Install continuous milled-in shoulder rumble strips was selected as an appropriate countermeasure to enhance highway safety of the corridor for each design alternative. Figure 6 show continuous milled-in shoulder rumble strips. Research has shown that rumble strips are an effective countermeasure for reducing the number and severity of roadway departure (RwD) crashes, such as single-vehicle run-off-road (SVROR), head-on, and opposing-sideswipe. An FHWA-sponsored research project with Texas Transportation Institute has shown that rumble strips are an effective means to alert drivers and promote proper positioning within the lane. In addition, the National Cooperative Highway Research Program (NCHRP) has published data on the effect of rumble strip installation on crash reduction (RSG, 2015). The 51 case have been filtered to 19 case which have possible opportunity to install rumble strips.

Figure 6. Continuous Milled-in Shoulder Rumble Strips (FHWA, 2017)

11.1. Predicted Crash Frequency after Install Rumble Strips

According to Carrasco et al., (2004), install continuous milled-in shoulder rumble strips lead to a decrease in crash frequency for all crash types and severity by 16%. Based on this research results, the combined crash modification factor after install rumble strips was computed using Equation (3).

$$(CMF_{combined})_{R.S.} = (CMF_{combined})_{before\ R.S} \times CMF_{R.S.} \qquad \text{(Equation 3)}$$

Where:

$(CMF_{combined})_{R.S.}$ = Crash modification factor for combined set of roadway modifications after install rumble strips
$(CMF_{combined})_{before\ R.S}$ = Crash modification factor for combined set of roadway modifications before install rumble strips.
$CMF_{R.S.}$ = Crash modification factor for installing rumble strips.

The predicted crash frequency for the original design is adjusted with the combined CMFs after using rumble strips, using Equation (4) to estimate the predicted crash frequency for rumble strips cases.

$$(N_{Predicted})_{R.S.} = N_{Original\ Design} \times (CMF_{combined})_{R.S.} \qquad \text{(Equation 4)}$$

Where:

$(N_{Predicted})_{R.S}$ = Predicted crash frequency for design alternatives after install rumble strips.
$N_{Original\ Design}$ = Predicted crash frequency for original design conditions.
$(CMF_{combined})_{R.S.}$ = Crash modification factor for combined set of roadway modifications after install rumble strips.

Table 18 contains the whole corridor crash frequency for each case of the 19 case which have possible opportunity to install rumble strips.

Table 18. Whole Corridor Crash Frequency for Cases of Design Alternatives after Install Rumble Strips

Case No.	Annual Crash Frequency According to Crash Type				Case No.	Annual Crash Frequency According to Crash Type			
	Total Accidents	Injury Accidents	Fatal Accidents	Damage Only Accidents		Total Accidents	Injury Accidents	Fatal Accidents	Damage Only Accidents
1	67.10	36.62	3.74	26.74	18	57.50	31.38	3.21	22.91
2	61.73	33.69	3.44	24.60	19	60.27	32.89	3.36	24.01
3	55.29	30.17	3.09	22.03	22	71.12	38.82	3.97	28.34
4	55.83	30.47	3.12	22.24	23	65.43	35.71	3.65	26.07
5	58.51	31.93	3.26	23.31	24	58.61	31.98	3.27	23.35
8	56.90	31.05	3.18	22.67	28	58.06	31.68	3.24	23.13
10	69.78	38.08	3.89	27.81	34	72.57	39.61	4.05	28.92
11	73.14	39.91	4.08	29.14	40	66.77	36.44	3.73	26.60
14	64.20	35.04	3.58	25.58	46	59.80	32.64	3.34	23.83
15	67.29	36.72	3.75	26.81					

Figure 7 illustrate the reduction in total accidents for each design alternative after install of shoulder milled-in rumble strips. From the figure it is clear that install of rumble strips lead to a significant crash frequency reduction.

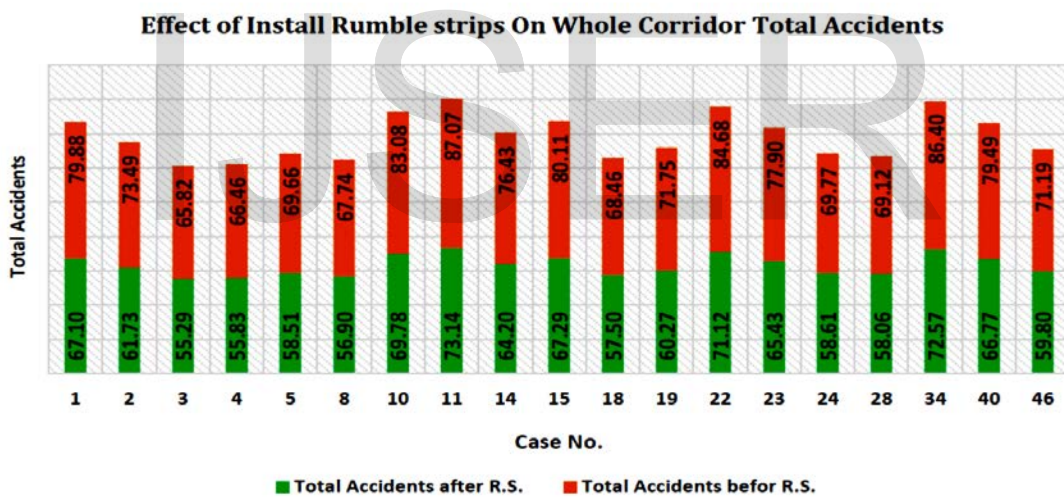

Figure 7. Effect of Install Rumble Strips on Whole Corridor Total Accidents

12. LIFE CYCLE COST ANALYSIS (LCCA) FOR DESIGN ALTERNATIVES

The different alternatives among which the selection is to be made were identified and defined after enhancing the highway safety for the design alternatives through install continuous milled-in shoulder rumble strips. The Value Analysis of any item uses Life Cycle Cost Analysis to evaluate alternatives that have been considered in the selection of the most cost effective one. Costs likely to occur during the life of the project should be considered in LCC analysis. For highway projects the expected costs may include:

- Initial Construction Costs
- Accidents Costs
- Maintenance Costs
- User Costs
- Energy Costs

However, the analysis concentration was on both of initial construction costs and accidents costs. Other costs are almost equal for all alternatives. The LCCA was performed using present worth method. For any design alternative the Net Present Value (N.P.V) was calculated using Equation (5).

$$\textbf{N.P.V = Initial Construction Costs + Annual Accidents Costs} \times \left[\frac{(1+i)^n-1}{i(1+i)^n}\right] \qquad \textbf{Equation (5)}$$

Where:
N.P.V = the Net Present Value for each design alternative
i = Discount Rate = 7 %. (Ireson, 1970)
n = Analysis Period = 25 Year

Table 19 summarize the results of LCCA for original design and design alternatives provided with rumble strips. Figure 8 show saving in N.P.V for each design case. The figure clearly show that case no. 24 **(Reduce lane width 11 ft and Convert 8 ft Paved Right Shoulder type to 8 ft composite shoulder)** caused maximum cost saving of 49.22 Egyptian Million Pounds. On the other hand, case no. 34 **(Reduce lane width to 9 ft, Reduce Paved Right Shoulder width from 8 ft to 6 ft and Convert to 6 ft composite shoulder)** lead to minimum cost saving of 21.80 Egyptian Million Pounds.

Table 19. Life Cycle Cost Analysis for Design Alternatives Provided with Rumble Strips

Case No.	Initial Construction Costs	Annual Accidents Costs	Net Present Value (N.P.V)	Saving in N.P.V
Original Design	**EGP 191,056,962**	**EGP 20,151,900**	**EGP 425,907,805**	**0.0**
1	EGP 148,969,778	EGP 21,160,099	EGP 395,560,749	EGP 30,347,056
2	EGP 161,533,559	EGP 19,467,291	EGP 388,397,252	EGP 37,510,553
3	EGP 174,097,340	EGP 17,435,921	EGP 377,288,300	EGP 48,619,505
4	EGP 185,195,346	EGP 17,605,202	EGP 390,359,035	EGP 35,548,770
5	EGP 176,819,492	EGP 18,451,606	EGP 391,846,819	EGP 34,060,986
8	EGP 180,779,939	EGP 17,943,764	EGP 389,889,083	EGP 36,018,722
10	EGP 140,593,923	EGP 22,006,503	EGP 397,048,534	EGP 28,859,271
11	EGP 132,218,069	EGP 23,064,508	EGP 401,002,228	EGP 24,905,577
14	EGP 153,157,705	EGP 20,245,983	EGP 389,095,946	EGP 36,811,859
15	EGP 144,781,850	EGP 21,219,347	EGP 392,063,277	EGP 33,844,528
18	EGP 165,721,486	EGP 18,133,358	EGP 377,040,085	EGP 48,867,720
19	EGP 157,345,632	EGP 19,005,154	EGP 378,823,779	EGP 47,084,026
22	EGP 136,178,516	EGP 22,429,705	EGP 397,564,946	EGP 28,342,859
23	EGP 148,742,297	EGP 20,635,328	EGP 389,217,813	EGP 36,689,992
24	EGP 161,306,079	EGP 18,482,077	EGP 376,688,497	EGP 49,219,308
28	EGP 181,997,531	EGP 18,309,410	EGP 395,367,767	EGP 30,540,038
34	EGP 137,396,108	EGP 22,886,763	EGP 404,108,903	EGP 21,798,902
40	EGP 149,959,889	EGP 21,055,822	EGP 395,335,661	EGP 30,572,144
46	EGP 162,523,670	EGP 18,858,693	EGP 382,295,013	EGP 43,612,792

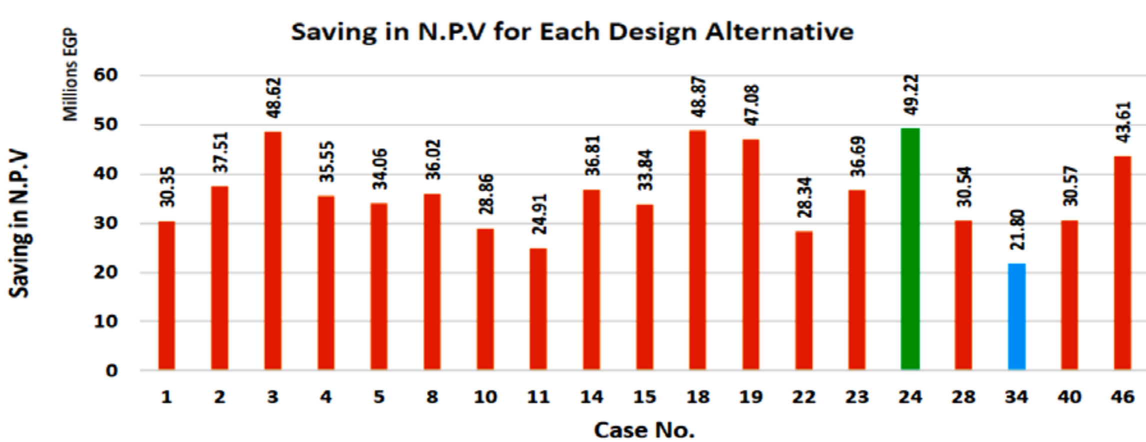

Figure 8. Saving in N.P.V for Design Alternatives provided with Rumble Strips

13. RECOMMENDATIONS

Table 20 show the value index and the percentage of value improvement based on the results of LCCA. These values reflect the improvements that each design alternative can add to whole corridor. To give final recommendations the percentage of value improvements was taken into consideration. The design alternatives with higher percentage of value improvements have the priority of implementation. The selection of the final design alternative always left to be taken by decision makers. Table 21 illustrate design alternatives between them the final selection should be made.

Table 20. Value Index and Value Improvements for Design Alternatives Provided with Rumble Strips

Case No.	Saving in Initial Construction Costs	Performance (P)	% Performance Change	N.P.V	% N.P.V Change	Value Index (P/N.P.V)	% Value Improvement
Original Design		**321**		**EGP 425,907,805**		**0.75**	
1	**EGP 42,096,184**	**365**	**14%**	**EGP 395,560,749**	**7%**	**0.92**	**22%**
2	**EGP 29,532,403**	**365**	**14%**	**EGP 388,397,252**	**9%**	**0.94**	**25%**
3	**EGP 16,968,622**	**365**	**14%**	**EGP 377,288,300**	**11%**	**0.97**	**28%**
4	**EGP 5,870,616**	**359**	**12%**	**EGP 390,359,035**	**8%**	**0.92**	**22%**
5	**EGP 14,246,470**	**359**	**12%**	**EGP 391,846,819**	**8%**	**0.92**	**22%**
8	**EGP 10,286,023**	**340**	**6%**	**EGP 389,889,083**	**8%**	**0.87**	**16%**
10	**EGP 50,472,039**	**404**	**26%**	**EGP 397,048,534**	**7%**	**1.02**	**35%**
11	**EGP 58,847,893**	**404**	**26%**	**EGP 401,002,228**	**6%**	**1.01**	**34%**
14	**EGP 37,908,257**	**404**	**26%**	**EGP 389,095,946**	**9%**	**1.04**	**38%**
15	**EGP 46,284,112**	**404**	**26%**	**EGP 392,063,277**	**8%**	**1.03**	**37%**
18	**EGP 25,344,476**	**404**	**26%**	**EGP 377,040,085**	**11%**	**1.07**	**42%**
19	**EGP 33,720,330**	**404**	**26%**	**EGP 378,823,779**	**11%**	**1.07**	**41%**
22	**EGP 54,887,446**	**404**	**26%**	**EGP 397,564,946**	**7%**	**1.02**	**35%**
23	**EGP 42,323,665**	**404**	**26%**	**EGP 389,217,813**	**9%**	**1.04**	**38%**
24	**EGP 29,759,883**	**404**	**26%**	**EGP 376,688,497**	**12%**	**1.07**	**42%**
28	**EGP 9,068,431**	**404**	**26%**	**EGP 395,367,767**	**7%**	**1.02**	**36%**
34	**EGP 53,669,854**	**404**	**26%**	**EGP 404,108,903**	**5%**	**1.00**	**33%**
40	**EGP 41,106,073**	**404**	**26%**	**EGP 395,335,661**	**7%**	**1.02**	**36%**
46	**EGP 28,542,292**	**404**	**26%**	**EGP 382,295,013**	**10%**	**1.06**	**40%**

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Table 21. Final Design Alternatives Having implementation Possibility

Case No.	Design Alternative	% Value Improvement
24	Reduce lane width 11 ft and Convert 8 ft Paved Right Shoulder type to 8 ft Composite Shoulder with install continuous milled-in shoulder rumble strips.	42%
18	Reduce lane width to 11 ft and Reduce Paved Right Shoulder width to 6 ft with install continuous milled-in shoulder rumble strips.	42%
19	Reduce lane width to 11 ft and Reduce Paved Right Shoulder width to 4 ft with install continuous milled-in shoulder rumble strips.	41%
46	Reduce lane width from 11 ft, Reduce Paved Right Shoulder width from to 6 ft and Convert to 6 ft composite shoulder with install continuous milled-in shoulder rumble strips.	40%
28	Reduce Paved Right Shoulder width to 6 ft and Convert to 6 ft composite shoulder with install continuous milled-in shoulder rumble strips.	36%
3	Reduce lane width to 11 ft with install continuous milled-in shoulder rumble strips.	28%

14. FRAMEWORK FOR EVALUATION HIGHWAY DESIGN ALTERNATIVES USING VALUE ENGINEERING

One of the important research objectives was provide a methodology to consider highway safety impacts during the development of the highway design alternatives. This consideration assists VE specialists to identify and recommend required safety enhancements for these alternatives. And therefore, any unexpected increasing in crash frequency can be eliminated before implementing the design alternative.

Through the methodology that have been followed during application of Value Engineering on the case study, a framework can be developed to streamline a systematic approach that can be used for any VE study related to highway projects. Figure 9 illustrate a framework for evaluation and development of highway design alternatives using Value Engineering.

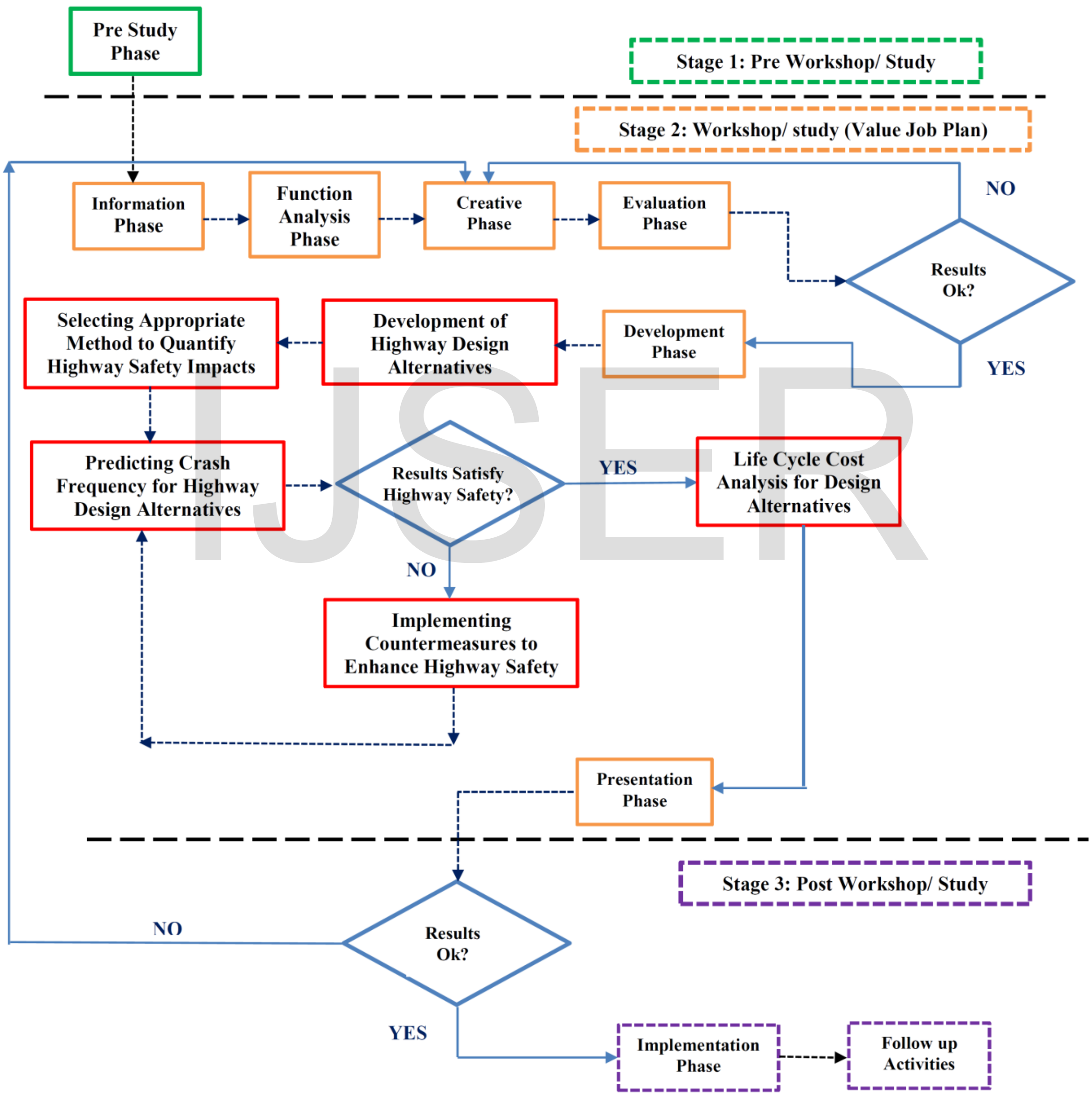

Figure 9. Framework for Evaluation of Highway Design Alternatives Using Value Engineering

15. CONCLUSIONS

While the Egyptian government seeks to strengthen the highway network in order to enhance the national economy and increase investment opportunities, this research assists highway projects to achieve their objectives with the required quality and lowest cost due to reduced funding sources. This research provides a detailed methodology for presenting different alternatives in highway design and how to evaluate them using value engineering. It also focuses on how to examine these alternatives and judge their compatibility with the design specifications, especially the suitability of these alternatives to the highway safety level required on the road under study.

It can be said that the methodology of value engineering has not been generally addressed in the Egyptian construction industry and highway projects in particular, commensurate with the effectiveness of this method. But it can be confirmed that it has not been applied before in road projects in Egypt. Therefore, the research emphasizes the importance of applying value engineering in the field of roads in Egypt because it has a great effectiveness in reducing unnecessary expenses and supporting decision-makers in selecting the best design alternatives that achieves the desired project goals. So, the transport authorities in Egypt must introduce a law that force conducting a Value Engineering study for highway projects.

The research addresses the relationship between Value Engineering and highway safety and corrects the misunderstandings about their incompatibility. The research explained the safety implications of relevant value engineering proposals through integrating safety performance of highway design alternatives in value engineering analysis. It provide a methodology to quantify highway safety impacts during the development of the highway design alternatives. This quantifying assists VE specialists to identify and recommend required safety enhancements for these alternatives. And therefore, any unexpected increasing in crash frequency can be eliminated before implementing the proposed design alternative.

The research resulted in developing framework to streamline a systematic approach that can be used for any VE study related to highway projects.

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