Integrated Decision Support System for Bridge Type Selection at Conceptual Design Stage

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ABSTRACT

Integrated Decision Support System for Bridge Type Selection at Conceptual Design Stage

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Selecting a new bridge type at the conceptual design phase is subject to many weaknesses in the processes conducted. Given that the engineers' decisions are based on their subjectivity, it is worthwhile to establish a Decision Support System (DSS) to effectively address different problems of consistency in decisions. In designing a new bridge, many factors, such as the cost and aesthetic appearance of the bridge, have to be considered due to their ability to affect the final decision. Generally, decision-makers will base their final design decisions on those factors as well as on human subjectivity.

The objective of this research is to propose a methodology to develop systematic procedures that can help decision-makers select the most appropriate bridge type with its diverse components and to forecast its Life-Cycle Cost (LCC) and other characteristics such as the level of public satisfaction and the environmental sustainability of the selected bridge type. The proposed methodology integrates a decision support system with a relevant data structure within an artificial intelligence (AI) environment and bridge information management tools in order to reduce the impact of human subjectivity on the decisions taken during the conceptual design stage of a bridge's life. The Artificial Neural Network (ANN) with its back-propagation algorithm is adopted in order to identify the appropriate solution by setting up its engine guidelines. Elements of the ANN layers (Engine model) which include: input, hidden and output layers, have to be described based on a systematic and standardized process. The proposed methodology has the potential to be used at lower levels to determine other bridge components

such as vertical structures, foundations, and connection types. The objectives of the proposed methodology are as follows: (a) Highlighting the influence of human subjectivity on the decision-making process; (b) Listing and ranking the potential alternatives in term of their performance criteria; (c) Ensuring equivalent and fair consideration for selected factors affecting the decision, and especially reducing the possibility of missing or overlooking the impact of some factors that could be ignored while proceeding with making the right decision by using conventional decision-making approaches; and (d) Developing a systematic methodology that can be considered as a guideline for further use within any decision-making environment, based on a relevant historical database and experts' input.

For public benefit, governmental and private agencies may use this DSS in order to provide a suitable solution abiding by different opinions in a systematic way taking into consideration the factors that have most influence.

A case study has been conducted with appropriate questionnaires to collect the needed data from experts, the public and previous project sites. This case study has shown the influence of decision maker subjectivity and how it could be controlled by inducing expert opinions through questionnaires to collect valuable data that have influence on the final decision. Also, data related to existing similar projects in the same area have been collected and used in order to show their influence on the results. Data were manipulated in order to analyze them and to show their accuracy and influence on the results. For that, a sensitivity analysis has been conducted in order to determine how the final decision could be affected by a fluctuation in the decision maker opinions contained in the input data for the proposed method.

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On the other side, I would like to dedicate this thesis and to express my deepest appreciation to my wife Abir and my two daughters (Kiyana and Maria) and my son (Jean-Paul-Maroun), thanking them for their continuous encouragement and extreme love, to the soul of my father, mother, uncle, and aunts for their care, to my parents for their love, to my brothers, Jacob, Miled, and Jean for their educational, spiritual and financial support respectively.

Finally, all the previous people didn't haphazardly appear on my way and for that, gratefulness and humble thanks are mainly, first and last, addressed to GOD.

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List of Abbreviations &Acronyms

AD	:	Anno Domini (Christ era) (see CE also)
AFI	:	Aesthetic Factor Impact
AI	:	Artificial Intelligence
AIR	:	Aesthetic Impact Rate
AIR-PS	:	Aesthetic Impact Rate – Public Satisfaction
ANN	:	Artificial Neural Network
BC	:	Before Christ
BCA	:	Benefit-Cost Analysis
BIM	:	Building Information Modeling
BMS	:	Bridge Management System
BrIM	:	Bridge Information Modeling
BT	:	Bridge Type
CBR	:	Case-based Reasoning
CE	:	Current Era (see AD also)
CoRe	:	Commonly Recognized
CT	:	Column Type
CTM	:	Actual Construction Time / Estimated
DL	:	Dead Load
DT	:	Deck Type
ECC	:	Engineered Cementitious Composite
EIR	:	Environmental Impact Rate
EIR-LA	:	Environmental Impact Rate – Local Authorities
ES, ESs	:	Expert Systems
FHWA	:	Federal Highway Administration
FS, FSs	:	Fuzzy Systems
FT	:	Foundation Type

GA, GAs	:	Genetic Algorithms
HC	:	Hard Constraints
HOV	:	Height Occupancy Vehicles
HP	:	Highest Point under Bridge
I	:	Importance Factor
IMS	:	Infrastructure Management System
INT ( )	:	The Integer Function
IR	:	Importance Rating
KBS	:	Knowledge-Based Systems
L	:	Length
LCA	:	Life-Cycle Analysis
LCC	:	Life-Cycle Cost
LCCA	:	Life-Cycle Cost Analysis
LCCB	:	Life-Cycle Cost-Benefit
LL	:	Live Load
LR	:	Level of Realistic
LS	:	Longest Span
m	:	Meters
MI	:	Material Impact
ML	:	Machine Learning
MR&R	:	Maintenance, Repair and Rehabilitation
NBI	:	National Bridge Inventory
NBIS	:	National Bridge Inspection Standard
NL	:	Number of Lines
NN, NNs	:	Neural Networks
NPV	:	Net Present Value
PE	:	Processing Elements

PL	:	Project Location
POI	:	Public Opinion Impact
PS&E	:	Plans, Specifications & Estimate
PV	:	Present Value
QFD	:	Quality Function Deployment
QFD-M	:	Quality Function Deployment Modified
R&D	:	Research & Development
RC	:	Reinforced Concrete
RBES	:	Rule-Based Expert System
RMS	:	Root Mean Square
SA	:	Sensitivity Analysis
SC	:	Soft Constraints
SI	:	Surround Impact
SN	:	Number of Spans
t	:	Tons
TC	:	Traffic Capacity
V	:	Values in the QFD / value of a Variable
YC	:	Year of Construction

β	:	Reliability Index
μ	:	Mean Value
σ	:	Standard Deviation

Chapter 1
Introduction

1.1 Synopsis

Infrastructure Management Systems (IMS), especially Bridge Management Systems (BMS), have been a major concern for decision makers for many years. PONTIS and BRIDGIT are widely used in North America to optimize and select the necessary action needed to maintain certain levels of serviceability and performance of the existing bridge network. Numerous other management systems and commercial software such as SQL, Oracle, Access, Delphi and Power Builder are used around Europe and in countries of the Far East *(Woodward, 2001)*.

Life-Cycle Cost Analysis (LCCA) is a crucial concept that has resulted in a widespread number of research papers. Some have been investigating the accuracy of existing methods; while others are proposing new concepts, inspection routines, and methods of collecting necessary data that can be analyzed and used to find results to be implemented in future tasks in order to maintain the structural behavior and performance of existing infrastructure assets. Maintaining existing infrastructure systems within an acceptable level of serviceability and performance resulted in a $57 billion spend in 2003, with $110 billion expected to be spent in the next 25 years *(Abu Dabbus, 2008)*. A huge amount will be allocated for the bridge network. However, the scarcity and lack of information and accuracy of historical data are the factors that affect the efficiency of any decision. It is noteworthy that, with every proposal for a new methodology, criticism by other researchers has been made, highlighting the weak points of the new suggestions. For instance, *Abu Dabbus, (2008)* listed the weakness of the previous decision support systems by modeling a new methodology based on how it must disseminate the available limited budget for many bridges that need some kind of MR&R (Maintenance, Rehabilitation, and Repair) to maintain their operational condition. Throughout his study, he has omitted the preventive actions that could be taken into consideration and those which may have major implications and results, once made, on the actual decision-making.

Many researchers and organizations are relentlessly working on enhancing the decision support process by creating new methodologies, aiming to cover, as much as possible, the needs of the bridge network system. This thesis will focus on what engineers must consider while making their decision to select the appropriate bridge type; what parameters, factors and concerns they have to take into consideration to avoid or minimize current and future bridge network system deficiencies, based on the fact that the design phase has a major influence on the total project cost as mentioned by *Hendrickson (2008)* and shown in Figure 1-1. Thus, it is important to focus and put more efforts on the design phase to optimize the project life-cycle cost.

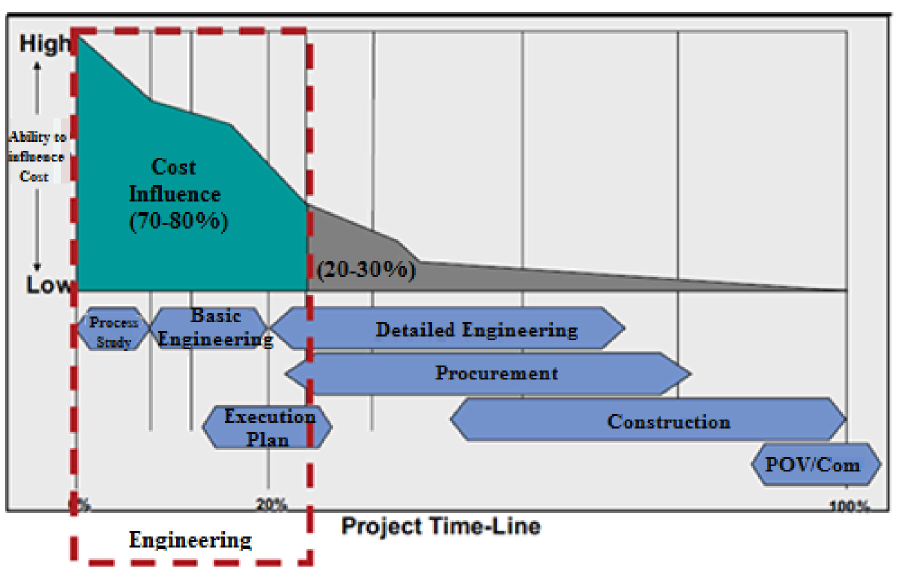


Figure 1-1 - Project Cost Influence *(Hendrickson Chris, 2008)*

1.2 Background &Problem statement

As mentioned in the previous section, time, money, and effort have been allocated in order to create and establish methodologies and procedures to maintain the existing bridge network, enhance its performance, extend its life-cycle and minimize its risk to users in order to minimize the necessary major rehabilitation or replacement actions. The MR&R (Maintenance, Rehabilitation & Repair) procedures; the development of computerized system, such as BMS (Bridge Management System) technology; the use of commercial software such as Pontis, Bridgit, and bridge LCC are the tools to maintain the performance of the existing system. For that, we should start by identifying all the problems and missing functionalities of these structures in order to avoid their negative and costly effects on users, as well as the negative aspects that should be considered at the conceptual design phase of the required structural elements of the bridge.

Many researchers have partially dealt with several topics related to this matter; some have proposed models to define a suitable deck structural system to be selected and applied for rehabilitation and replacement needs; while others have concentrated on available methods to be integrated to support their decision processes. Another group of researchers has proposed algorithms to be applied while selecting a suitable structural system in order to match societal needs and environmental sustainability (e,g., reducing pollution). There is no specific literature that constitutes a satisfactory study or proposal to select a suitable bridge type, based on a theoretical and analytical analysis. Based on the literature review presented in Chapter 2, the main problems are stated as follows:

(1) We lack a clear and systematic method to define the factors to be considered at the conceptual design phase. This issue leads to different decisions for the same project without

being able to highlight the conditions and reasons for this difference in opinion.

(2) Engineering judgments and subjectivity have been widely adopted. This matter leads to not having clear arguments for why such a decision has been selected, and it will be hard for the decision maker to convince the others of his decision. The introduction and consideration of influence factors as important features for the decision is also lacking.

(3) Flexibility is lacking in the existing research; this lack of flexibility is observable in existing methods that are restricted to specific cases and limited to restricted conditions.

(4) Implementation of BrIM into decision-making is not widely done at the conceptual design phase and therefore we cannot realize its full benefits. Its benefit at the conceptual design phase is missing and it is currently restricted to a limited benefit involving some items related to estimation processes.

(5) The disparity between experts' opinions is noted. This issue may lead to conflict between the different proposed decisions and may also lead to a wrong decision if decision makers try to provide a balanced decision from among the different opinions;

as well as other problems mentioned in the literature review.

1.3 Research Objectives

In selecting a bridge type, the decision maker's opinion has a big influence based on his or her wide experience. Different decision makers may provide different final decisions. In order to reduce this decision maker subjectivity, it is important to highlight the factors that have influence on the decision. Different factor types related to experts combined with others related to the location are highlighted through statistical processes. Those factors are manipulated within an Artificial Intelligent (AI) environment in order to figure out their influence on the decision. According to the decision maker's opinion, some performance criteria are assigned a higher importance rate which lead to different decisions. Finally, the different potential alternatives are ranked based on the selected factors and according to the performance criteria ranking. The reliability of the selected factors is verified and supported by a sensitivity analysis conducted over the selected factors. The objective of this thesis is to develop a DSS model to provide engineers additional useful tools to select a bridge type along with suitable components for it; for this reason, the focus is on the conceptual design phase where comprehensive research and analysis will be completed and the results of that will be used to identify what is needed to achieve this objective. The decision made at the conceptual phase of bridge design is considered one of the tasks that have a significant influence on the sustainability of infrastructure projects through the bridge division. *Miles & Moore (1991)* found that selecting a bridge type depends on engineering judgment in addition to some instantaneous factors such as location, topographical constraints, and the engineer's capability to go forward with an appropriate design.

Therefore, the main research objective of this thesis is to analyze these instantaneous factors and compare and relate them to future constraints in order to select the best choices that optimize the LCC of the bridge performance during its entire anticipated life.

Malekly et al. (2010) listed two approaches to defining the stages of bridge design: Artificial Intelligence (AI)-based techniques and Mathematical programming (optimization techniques). The focus of their study was on the deck type that should be selected for a bridge according to certain factors. Their study combines some novel criteria added to the knowledge of an expert team by applying methodologies such as TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) and QFD (Quality Function Deployment) to select the adequate bridge superstructure, and more specifically, the deck type.

Another objective of this thesis is to propose a methodology that can be used to select the appropriate bridge type by defining its different components that lead to optimizing the bridge LCC and other restrictions such as aesthetic satisfaction level and environmental protection. The procedure will be inspired by previous research work that defined the factors affecting the decision making process by applying deterministic and/or probabilistic methods at the conceptual design phase based on available and collected data. The chapters that follow will discuss the factors (those that have influence on the decision) and their established functions in order to retrieve the appropriate values to be included in the Decision Support System (DSS) engine to find the required values related to the acceptable and efficient levels of LCC, user satisfaction (including the acceptable level of aesthetics and environmental sustainability). Therefore, selecting the suitable bridge type under certain conditions and ranking all the potential alternatives will be one of the proposed methodology's goals. On the other hand, the beneficiaries of the research are government agencies (by reducing bridge sustainability cost during its life-cycle) and society (by raising the bridge performance level and the length of its life-cycle).

In order to clarify the objectives of this thesis, a list of potential features is summarized as follow:

1. Highlighting the human factor (engineer subjectivity) and its influence on the decision-making.
2. Ranking the potential alternatives automatically in term of the performance criteria.
3. Taking equitably and fairly the factors that affect the decision and trying to avoid as much as possible the potential of missing any factor that may affect the traditional decision-making process (based on human subjectivity and perception).

4. Generating a systematic methodology to make decisions based on the appropriate historical data and experts' opinions.

Based on the above-listed research objectives, and based on the literature review analysis in the coming chapter, the research contributions of this study and its limitations will be highlighted.

1.4 Research Methodology

The methodology that will be considered to achieve the objectives listed will be divided into the following steps:

1.4.1 Literature Review

A comprehensive literature review will be conducted in two directions:

The first direction is to investigate the existing bridge types, their components, and all related parameters like construction date and period, the initial and total life-cycle cost, their performance and public satisfaction with them. The construction materials used (such as concrete, steel, and wood) and a mixture of structural components such as joints, bearings, and other relevant elements will also be investigated and highlighted. The design processes and methods that are used to address the difficulties and challenges that are identified during the design and construction phases will be considered. The purpose of doing this is to define the possible bridge types with their pros and cons based on previous experience and expert opinions by building a pertinent data system. Many reports and investigations tagging this purpose were conducted and reported *(*such as *Al Ghorbanpoor, 2007)*. An in-depth investigation will be conducted to identify and understand the factors that affect the decision. These factors are grouped into two different groups, which are classified as input and output factors; where the input factors are those that define the project constraints, such as topographical constraints, traffic capacity requirements, and many other relevant parameters to be considered as input data. The output factors include data such as life-cycle cost, environmental sustainability level (e.g., minimizing the environmental impact of the used materials), aesthetics, public satisfaction, and other factors that guide such decisions. Other limiting factors such as constructability and design difficulties will surely affect the decision and they could be considered in the proposed system.

The second direction of the literature review will be directed at evaluating the existing software to select methods that will be used for the mentioned methodology and to identify how they can be included in the proposed methodology, which will be an integrated system incorporating many inter-related methods and modules, where every module is used and modified in order to fit into the system's engine so it achieves its mission. Machine Learning, which is based on ANN, will be the main development environment that will perform all the procedures of the DSS. Methods and decision support systems also have to be explored and used with the structured data. Furthermore, Bridge Information Modeling (BrIM) tools will also be incorporated into the proposed methodology in order to visualize and accordingly minimize any ambiguity that may exist in each decision and to clarify its weakness, if it exists, in order to avoid it, and moreover to predict any problem that may arise during the construction phase. For the two aforementioned directions, the coming chapter will highlight the missing factors to be considered, limitations and weaknesses of previous research and will try to fill in a portion of the gaps in existing research, regarding what should be considered at the conceptual design phase.

1.4.2 Data Collection

The data to be collected and used in the development of the mentioned thesis are mainly based on existing similar bridge projects. Bridge types and their structural components, project parameters, characteristics, location (i.e., topography), and many other factors, including cost and performance, will be collected in order to design and develop an appropriate frame for the mentioned data. Note that, for every specific project, all of the related data has to be collected from the same region for purposes of consistency.

1.4.3 Development of the mentioned DSS

Since the mentioned system integrates many applications, the development will be carried out through the following three steps:

1. Structuring the data frame to store all the parameters related to the bridge types and their components and the factors that have influence on the decision and by providing an environment to convert all parameter information to numerical functions.
2. Establishing and running the system's engine under appropriate values and their functions, which are retrieved from the stored data in order to acquire the desired decision.
3. Integrating the results with BrIM tools by using different applications in order to visualize and realize the decision and to avoid or minimize any ambiguity.

1.4.4 Expert Consultation

Once the DSS is developed, it will be presented to experts and practitioners for consultation, feedback, and criticism. Key persons and managers from government and private sectors will be addressed in order to validate the mentioned DSS.

1.5 Thesis Organization

Chapter 2 introduces an intense literature review. It will focus on screening the available strategies to maintain the performance of the bridge network system and it briefly describes the models and software used by the involved agencies to find an efficient way to make the optimum decisions. Chapter 2 will also investigate, study, and evaluate different strategies used by other researchers during the conceptual design process. The mentioned task is needed in order to learn about the used procedures throughout the selection process of an appropriate structure system to fill all kinds of social needs. The following three main themes will be considered: 1) History and fundamental functions of bridge types; 2) Factors and constraints; and 3) Models and methodologies as well as the applied bridge information modeling tools.

Chapter 3 explains the methodology development that will highlight the parameters and characteristics of the mentioned system; strategies will be defined and we will present the conceptual design methods that will be conducted through the four phases previously mentioned. Data collection will be discussed and structured, while a summary of the steps that will be undertaken during the development will be explained. At the end of Chapter 3 the research development process will be proposed and detailed.

Chapter 4 describes a methodology to establish the required data frame to be used during a new project analysis.

Chapter 5 defines the BrIM tools that seem most suitable to support the proposed project.

Chapter 6 describes the DSS engine, and its elements and the kind of data needed and the kind of results that it will provide.

Chapter 7 validates the system by using a case study of a real project that will use most of the DSS steps. Toward the end, results and analysis will be provided in order to identify the benefits of the stated DSS.

Chapter 8 consists of the final conclusion and opinions and it lists the research contributions and limitations, as well as future expansions and enhancements.

1.6 Summary

This chapter listed the objectives of the proposed research, the kind of fields that it covers and the factors, items and tools to be implemented. The structure of the mentioned research has been highlighted. The orientation of the methodology development is divided into three phases: **(1)** data collection for the bridge types and components after defining the factors that have influence on the decision, **(2)** the engine of the DSS and the process of its running, and **(3)** BrIM tools and applications to be implemented in order to realize the decisions made. The methodology organization is presented and will be described in Chapter 3, which will be followed by five chapters (4, 5, 6, 7 and 8) presenting the development of the stated system, including a case study project; and then the conclusion that also covers the contribution, limitations and the future work sections.

Chapter 2
Literature Review

2.1 Introduction

Many references have stated that bridge design is divided into two stages: conceptual and analytical design *(Miles & Moore, 1991; Chen Wai-Fah & DuanLian, 2000)*; the analytical design is very well defined by applying codes and formulas, while the conceptual design is not well defined. Also, various studies conducted by many engineering agencies and consultants, have drawn, more or less, a diversity of opinions, which lead to a diversity in the final decision results *(Smith et al, 1994 and Mahmoud, 2015)*. Based on several factors, the design decision-maker (engineer) will choose the final perception by proposing the bridge type to be adopted; the decision is based on their previous experience and scoring factors that have remarkable influence on the selected choice. Neither mathematical formulas nor deterministic or stochastic models are used while making that decision; only engineering judgment and subjectivity are pursued to lead to the preferred types.

In this chapter a comprehensive review of the literature will be conducted. The areas mentioned are related to: 1) bridge design and decisions that determine the potential bridge types; 2) factors that will be taken into consideration during the decisions; 3) existing methods and models in the same field as the proposed methodology.

2.2 History and Fundamental Functions of Bridge Types

In order to clearly understand bridge concepts, it is crucial to bring in the history and evolution of bridge structures and their related philosophies. Many references, reports, and dissertations about bridge architecture philosophies are available from which to extract the required information and to understand bridge philosophy, which is an essential component of this research.

2.2.1 Bridge Development

Assumptions have been made by *Tang (2007),* which led Tang to divide bridge evolution into two major periods within the last four thousand years: the Arch Era and the Contemporary Era.

2.2.1.1 Arch Era (2000 BC – 18th Century)

To pass over physical obstacles, which could be a body of water, valley or road, a bridge must be used. The nature of terrain, the material used, and availability of finances are the aspects of bridges that will guide the bridges' designs. Bridge, as a word, was derived from an old English word "*brycg,*" which is derived from a hypothetical Proto-Germanic root "*brugjo.*" Bridges first appeared in nature itself through logs and/or stones across a stream or a river.

The "Culvert of Arkadiko bridge," from 1300-1190 BC, is among the first bridges constructed thousands of years ago (Figure 2-1); it is one of the oldest arch bridges that still exist and is still used. In Appendix A, parameter details are listed and laid down in an appropriate form to identify the bridge configurations.

The greatest bridge builders of antiquity were the ancient Romans. Arch bridges and aqueducts were built to resist attacks and stand in aggressive conditions. "Alcantara Bridge" 104-106 AD (known as Puente Trajan at Alcantara) is a Roman arch Bridge (Figure 2-2). Cement types (e.g., Pozzolana) were used by the Romans, however, they were replaced by brick and mortar as the technology of cement was lost after the Roman era, to be rediscovered later.

Figure 2-1 - Culvert of Arkadiko Bridge *(Wikipedia)*

Figure 2-2 - Alcantara Bridge *(Wikipedia)*

"Anji Bridge" (Figure 2-3) in China is characterized by a rise-to-span ratio of 0.197. This feature allows it to be classified among the best constructions for "saving of material" reaching about 40% of material saving.

Figure 2-3 - Anji Bridge *(Wikipedia)*

Iron was widely used as a material up to the 19th century before the discovery of steel. Iron arch bridges were largely used during that period due to iron's compression capacity compared to that of the stone and lime mortar construction used in the same period and earlier. The "Iron Bridge" (Figure 2-4) was constructed in the 18th century and, since then, it was subject to a number of maintenance and rehabilitation plans to maintain its abutment and supports.

Figure 2-4 - Iron Bridge near Coalbrookdate *(Wikipedia)*

2.2.1.2 Contemporary Era (19th Century to Date)

The introduction of steel into the bridge industry has enhanced aspects of the contemporary bridge as well as the aesthetics and span length. Before the completion of the Quebec Bridge in 1917, the "Forth Rail Bridge" was the most significant, being the longest-spanning steel bridge in the world (Figure 2-5). It was among the first bridges to use steel in the construction of its structure. Many other arch bridges existing from the 19^{th} and 20^{th} centuries were constructed with steel structural systems. The "Quebec Bridge" was completed in 1917 with a longest span of 549 meters; the "St. Louis Bridge," completed in 1874, had three main arch spans of 153 meters each; the "Sydney Harbour Bridge" in Australia was completed in 1932 with a 503-meter span; in 1978 in the USA the "New River Gorge Bridge" was completed with a 518.3-meter span; "Lupu Bridge" in China was completed in 2004 with a 520-meter main span and 552 meters of total length.

Suspension bridges have been used since the 19^{th} century. The "Grand Suspension Bridge" was one of the first suspension bridges in the world, completed in 1834 over the Sarine Valley in Fribourg with a main span of 273 meters. In the past, the main problem that the suspension bridge faced was the effect of wind, before relevant aerodynamics research became available.

Figure 2-5 - Forth Rail Bridge *(Wikipedia)*

However, even before aerodynamics and wind resistance of bridge structures were known, John Roebling was the first to stabilize a bridge against wind effects by introducing inclined cables. His intuition to implement such a kind of bracing was widely successful and demonstrated that longer-lasting and longer bridge spans can be achieved with suspension bridges. A 1,000-meter span length was achieved in 1931 with the "George Washington Bridge" (Figure 2-6). The "Golden Gate Bridge" (Figure 2-7), was completed in 1937 with a 1,280-meter span length. Another suspension bridge, the "AkasiKaikyo Bridge," was completed in 2000 in Japan with a 1,991-meter span length. Much longer spans are possible depending on steel wire specifications and engineering innovation and knowledge. This can be seen in the following two bridges currently under construction: the "Messina Bridge" in Italy with a span length of 3,300 meters and the "Gibraltar Strait Bridge" with a span of 5,000 meters; these two bridges are under construction and they will be among the longest suspension bridges in the world.

Reinforced Concrete (RC) bridges were first engineered and developed approximately 150 years ago. Post- and pre-tension as well as RC bridge sections using high strength tendons are another significant innovation that has pushed concrete into being the most popular construction material for bridges.

Figure 2-6 - George Washington Bridge *(Wikipedia)*

Figure 2-7 - Golden Gate Bridge *(Wikipedia)*

A quick review of the most important bridges with this type of material will be carried out to generate an idea of the values of its related factors. Two main well-known bridges will be screened: the "Bendorf Bridge" with a 208-meter span with a RC section and the "Second Shibanpo Bridge" (Figure 2-8) formed with a box girder RC section with a main span of 330 meters; these two bridges are constructed using the cantilever construction method *(Tang, 2007)*. Another long span concrete bridge of 301 meters (Stolmasundet Bridge) is ranked as the longest full concrete bridge, using light concrete to reduce its weight. A steel section in the middle of the main span has been used for the "Shibanpo Bridge". After recognizing the high strength of steel and the high compressive strength of concrete, cables (post- and/or pre-tensioned) were used in the bridge's girders.

Cable-stayed bridges were first developed in 1955 the first one being "Stromsund Bridge" in Sweden (Figure 2-9). It is considered very efficient for its medium-sized spans. This type of bridge has proven to be usable and efficient with the availability of high-strength wires. Many notable bridges have been built through its development, increasing in span length.

Figure 2-8 - Second Shibanpo Bridge *(Wikipedia)*

Figure 2-9 - Stromsund Bridge *(Wikipedia)*

The 602-meter span “Yangpu Bridge” in China in 1994, 856-meter span “Normandy Bridge” in France in 1995, the 890-meter span “Tatara Bridge” in Japan in 2000 and the two newest super long cable-stayed bridges of 1088 meters (“Stonecutters Bridge”) and 1088 meters (“Sutong Bridge”) in Hong Kong (Figure 2-10) and China respectively would be considered the latest in cable-stayed bridges’ technological evolution (Appendix A). A combined bridge type or hybrid type could be one suitable solution for some esthetic and economic constraints. Some suspension bridge types are combined with cable-stayed to achieve design and efficiency requirements (Roebling’s Bridge, Figure 2-11). In the past, all bridges were designed without any knowledge of structural dynamics especially aerodynamics; intuitively, the stay cables were used against wind vibrations. Evolution and bridge development are affected by many factors, such as equipment availability, materials, and cost vs. value. An interpretation of all those factors will be discussed in the following sections.

2.2.2 Bridge Types

It’s not easy to classify bridges into a limited number of types. *Tang (2007)*, in his study of bridges’ evolution, limited the bridge types to four (Figure 2-12): Girder Bridges, Cable-stayed Bridges, Arch Bridges and Suspension Bridges. This segmentation is based on the A-B-C Basic elements in structures: Axial forces, Bending and Curvature. Other references have classified the bridges within seven types: Beam Bridges, Cantilever Bridges, Arch Bridges, Suspension Bridges, Cable-stayed Bridges, Movable Bridges and Double-Decked Bridges.

Figure 2-10 - Sutong Bridge *(Wikipedia)*

Figure 2-11 - Roebling's Bridge *(Wikipedia)*

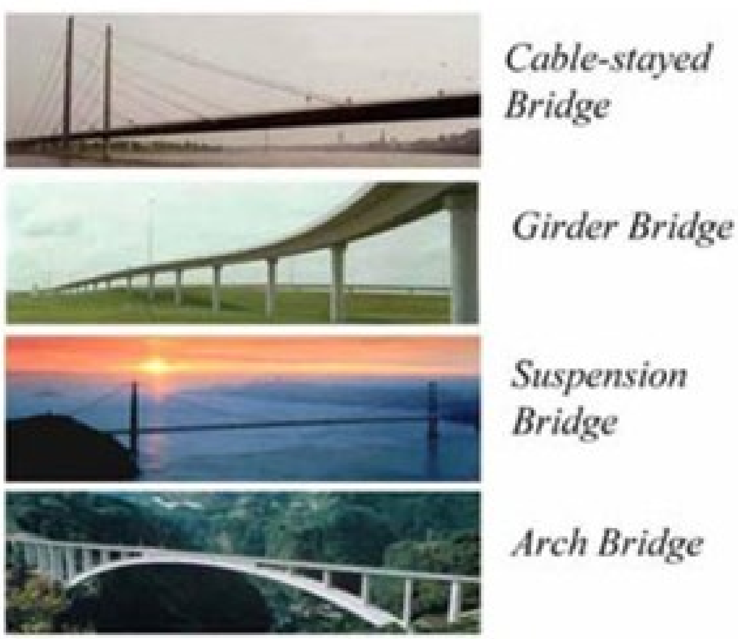


Figure 2-12 - Four Types of Bridges *Tang, (2007)*

2.2.3 Bridge Elements and Components

Tang (2007) has summarized the bridge types, behaviors and forms as follows:

- The anatomy of all structures in the world is a combination of three types of structural elements: Axial, Bending and Curvature; these can be defined as the "ABC" of structure. These elements take one of four basic forms: truss, box, stiffened plate or solid member; and
- Conceptually, he clusters all bridges in the world into four basic bridge types: girder bridges, cable-stayed bridges, arch bridges and suspension bridges.

However, in order to define such bridge types well, it is necessary to recognize the elements and components of the bridges. It is important to establish an inventory that will act as a "geometric" database to help decision makers in their selection. Similarly, work has been conducted by *Thompson and Shepard (2000)* who proposed an inventory that will be the base for the inspection and maintenance tasks. In their report they divided the bridge components into four main groups: Superstructure, Substructure, Decks, and Culverts. Those components are important to rating the bridge based on its performance and sustainability.

The types of materials used also have their own special influence. *Smith et al. (1994)* published some material characteristics and how they have influenced bridge components.

2.3 Influence Factors and constraints

In order to cover all the aspects of selecting a bridge type, many factors (defined sometimes as criteria) and information must be known. A literature review has been conducted to collect most of these factors from previous studies, research, and completed projects in order to use them in this research. The Minnesota Department Of Transportation (*NMDOT, 2005)* (Appendix C) has described a development process from the perspective of the bridge designer where seven points have to be tracked as follows:

1. Preliminary Field Review,
2. Preliminary Design Inspection,
3. Pre-Final Design Inspection,
4. Final Design Inspection,
5. Plans, Specifications & Estimate (PS&E) Reviews,
6. Finalizing Plans for Letting, and
7. Bridge Design Process, starts off by selecting the bridge type based on the six previous points.

The following five points have been considered for the bridge type selection: 1) Functional requirements; 2) Economics; 3) Future maintenance; 4) Construction feasibility; and 5) Aesthetics. The information needed was: Project scoping report, Project surveying information, Project roadway typical section sheet, Project roadway P&P sheets, Preliminary drainage report (for stream crossing structures), and Clearance requirements & Preliminary interchange layout sheets (for grade separation structures).

Smith et al. (1994) listed many factors to be considered that affect the decision on selecting the bridge's materials as summarized in Table 2.1. The analytical Hierarchy Process (AHP) has been used to rank the most important factors that have significant impact on the selection of bridge type, based on an official data collection from over thirteen hundred (1,300) highways. The collected data focused on non-structural factors that influence decisions about bridge materials.

Table 2-1 – Factors used to evaluate bridge materials (Smith et al., 1994)

Government research efforts Life-cycle cost of materials	Standards specified by AASHTO Past performance of materials in bridges	Material preference of local officials Availability of design information
Resistance to natural deterioration	Contractor's familiarity with material	Resistance to de-icing chemicals
Expected life of material	Bridge ownership (state, country, town)	Regular inspection requirements
Length of traffic Maintenance requirements Initial cost of material Bridge loading variations	Designer familiarity with material Industrial promotional efforts Aesthetics Daily traffic count	Impact on local economy Environmental considerations Ease of repair

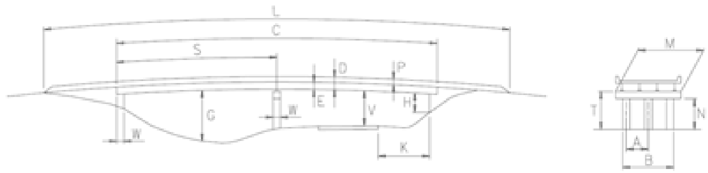
The data collection process profile was based on the location and the level of the interviewer. Between twenty-three (23) factors, the following have been ranked as the most important: 1) Past performance; 2) Lifespan; 3) Maintenance requirement; 4) Resistance to natural deterioration; 5) initial cost and 6) Life cycle cost. *Choi (1993)* grouped the factors that affect the conceptual design into two design constraint categories: "Hard Constraints - HC" and "Soft Constraints - SC." Basic parameters of the bridge have been stated by *Chen and Duan (2000)* by considering different factors: a) technical; b) functional; c) economic; d) construction; and e) material with its geometric dimensions: these parameters define the quality of the structure. In a study *(Ogilvie and Shibley, 2005)* comparing the advantages and disadvantages of several different types of bridges, eight factors were considered and taken into account: aesthetics, public input, operational flexibility, security, historic issues, constructability, environmental impacts, and cost and life cycle cost. *Bridgeman (2012)* considers substantial amount of data to be needed before starting a bridge design, such as: the site plan that shows all obstacles to be bridged (e.g., rivers, streets, roads, railroads, valleys, alignments); a longitudinal section to clarify the required clearances; factors affecting the bridge width (e.g., capacity, sidewalk, safety rails); soil conditions and ground difficulties; local conditions and constructability factors (e.g., availability of services, site accesses, equipment); weather and environmental conditions; topography of the environment and aesthetic requirements. It is clear that *Bridgeman (2012)* omitted the economic and LCC factors from the data needed during the proposed design process.

2.3.1 Soft Constraints - SC

An investigation must be conducted in order to identify these soft constraints which are factors that must meet a specified level of satisfaction. These factors have to meet public satisfaction, economic and cost-accepted values as well as design performance standards. The level of satisfaction can be identified by the decision maker in order to strike a balance among many requirements and constraints. This balanced solution has been mentioned by many researchers; for instance, *Chen and Duan (2000)* proclaimed that it is not possible to satisfy all requirements and constraints; but a comparative study may to lead to a technical ranking of all alternative solutions. One of the famous SCs is the aesthetic one (refer to section 2.3.1.1), which needs special consideration because of conflicting views. This conflict is due to the difference between the different views related to aesthetic practices in engineering. Supporters of the rational analytical trend think that aesthetic demands are not important and not necessary for bridges, while the designers of the creative trend consider these aesthetic values to be more important than the economic ones and equivalent to the requirements of strength and longevity. Another factor attracting wide interest by society is environmental protection, which comes under sustainable bridge investigation (refer to 2.3.1.2).

2.3.1.1 The aesthetic factor

Bridge design is an art that uses sciences and mathematics to support many decisions (Maryland Department of Transportation SHA, 2005). The aesthetic aspect of bridges plays an important role in selecting an appropriate bridge type. Many references mention guidelines to be followed in order to quantify the qualities that make a bridge visually appealing since the selection of a visually pleasing bridge form is largely an intuitive process performed by skilled engineers whose opinions are primarily based on personal experience. Deriving rules for bridge aesthetics requires the acquisition, elicitation, and translation of a large body of subjective opinion (Moore et al., 1996). A bridge designer with experience in bridge aesthetics can recommend measures to ensure an attractive bridge, without forgetting that the public will judge the results. For this reason, Moore et al. (1996) referred to public opinions in their research. Also, through their research, they establish an innovative computational decision support tool, the development of which was based on rules that can be placed into a number of different categories: proportion and geometry, environmental and structural constraints, structural harmony, focus of attention, weathering and surface texture. The rules that constitute geometry and proportion entail several factors that are commonly used to define the overall shape of a bridge (e.g., number of spans, ratio of deck to depth, ratio of deck span to pier height). Furuta et al. (2001) has proposed a decision support system that bridge engineers without the experience and necessary knowledge of aesthetics can easily use to obtain several candidates for designing bridges by using the Immune System. The key to that system is the immune tissues, which has potential to distinguish performance automatically. Furuta et al. (2001) used the Immune System to evaluate bridge aesthetics by taking the following items into consideration: 1) overall configuration of bridge, 2) configuration of pier, 3) configuration of main girder, 4) configuration of handrail, and 5) colors of main girder and handrail. Similar to many other researchers, Maryland Department of Transportation SHA (2005) has mentioned that one of the factors affecting the aesthetic is the relation between the dimensions of the key structural elements. Figure 2-13 defines the abbreviations used to identify the dimensions of those key elements.



Abbreviations used in these guidelines

L = Total Bridge Length (end of end post to end of end post)
C = Bridge Length (center line bearing abutment to center line bearing abutment)
S = Span Length (center line of bearing to center line of bearing)
D = Total Depth of Superstructure (without rail and/or fencing)
P = Parapet Height (top of parapet to bottom of slab)
E = Exposed Girder Depth
G = Vertical Clearance to Ground
V = Vertical Clearance to Roadway
K = Clear Distance from Edge of Roadway (does not include shoulder) to Face of Abutment
H = Height of Exposed Abutment Face (from groundline/slope protection at face of abutment to bottom of superstructure)
T = Height of Pier (from groundline or normal water surface elevation to top of cap)
M = Length of Pier Cap
N = Height of Pier Stem (from groundline or normal water surface elevation to bottom of cap)
W = Width of Pier at Cap or Width of Abutment at Beam Seat
B = Length of Pier (at groundline or normal water surface elevation)
A = Spacing of Columns for Multi-Column Piers

Figure 2-13 - Abbreviation used in Maryland Department of Transportation SHA, (2005)

2.3.1.2 The environmental factor

In the past 15 years, the issue of global warming has drawn worldwide attention to finding out effective ways to reduce greenhouse gas (CO_2) emissions and energy consumption. Bridge construction around the world has a high impact on these environmental factors. Different materials, construction methods, and other considerations, like the protection of the green areas, were addressed in order to reduce environmental impact. Many studies have been conducted to find the factors relevant to evaluating the sustainability of bridges and how the CO_2 emissions and energy consumption are calculated. In their research, *Marzook et al. (2013)* introduced a key-list of important factors that affect the sustainability of bridge projects, determined through interviews and surveys. The degree of importance and weights of these factors are determined using Simos' procedure, in which the main concept consists of correlating a "playing card" with each factor. The results of their study were put into tables presenting the weight for each factor after normalization (Table 2-2) and the proposed credits for a green bridge rating system (Table 2-3). *Keoleian et al. (2005)* demonstrated in their study that the use of Engineered Cementitious Composites (ECC) as nonconventional systems in the construction of a bridge deck may lead to a reduction of 40% in energy consumption and 39% in carbon dioxide production, compared to using a mechanical steel expansion joint, in a cost saving of up to 37%.

On the other hand, *Itoh et al. (2000)* addressed the need for proper planning of the infrastructures to ensure the optimum use of resources. In their research, the environment factor was considered in developing a bridge type selection system, the environmental impact of each candidate bridge type and details for every bridge's components, being evaluated on the basis of the energy consumption and the CO_2 emissions of their construction materials.

Table 2-2 – Simos' estimated weights of criteria *(Marzouk et al., 2013)*

ID	Criteria	Weight
PR-1	Lifecycle Cost Analysis	0.0348
PR-3	Noise Mitigation Plan	0.0294
PR-4	Waste Management Plan	0.0306
PR-5	Pavement Management plan	0.0343
PR-6	Site Maintenance Plan	0.0294
PR-7	Potential for Innovations	0.0301
PR-8	On-site Renewable Energy	0.0348
EW-2	Habitat Restoration	0.0592
EW-3	Sustainable sites Selection	0.0669
EW-4	Respect for historic sites	0.0783
AE-1	Intelligent Transportation Systems	0.0403
AE-2	Providing a Bridge User Guide	0.0358
AE-4	Pedestrian/Bicycle Access	0.0403
AE-5	Transit Access	0.0403
AE-6	Visual Enhancements	0.0346
CA-1	Equipment Emission Reduction	0.0964
CA-3	Storage/Separation areas	0.1120
MR-1	Pavement Reuse	0.0386
MR-2	Earthwork Balance	0.0403
MR-3	Recycled Materials Reuse	0.0392
MR-4	Regional Materials	0.0444
MR-5	Long-Life Pavement	0.0432

Table 2-3 – Proposed credits for green bridge rating system *(Marzouk et al., 2013)*

Criteria	Proposed credit
Project Requirements (26 Credits)	
Lifecycle Cost Analysis	4
Noise Mitigation Plan	3
Waste Management Plan	4
Pavement Management plan	4
Site Maintenance Plan	3
Potential for Innovations	4
On-site Renewable Energy	4
Environment and Water (21 Credits)	
Habitat Restoration	6
Sustainable sites Selection	7
Respect for historic sites	8
Access and Equity (23 Credits)	
Intelligent Transportation Systems	5
Providing a Bridge User Guide	4
Pedestrian/Bicycle Access	5
Transit Access	5
Visual Enhancements	4
Construction Activities (6 Credits)	
Equipment Emission Reduction	3
Storage/Separation areas	4
Materials and Resources (20 Credits)	
Pavement Reuse	4
Earthwork Balance	5
Recycled Materials Reuse	4
Regional Materials	5
Long-Life Pavement	5
Total	100

Based on the *Kyoto Protocol (1997)* and its associated data, *Itoh et al. (2000)* established a number of charts for the energy consumption and CO_2 emissions for every bridge component (Figure 2-14).

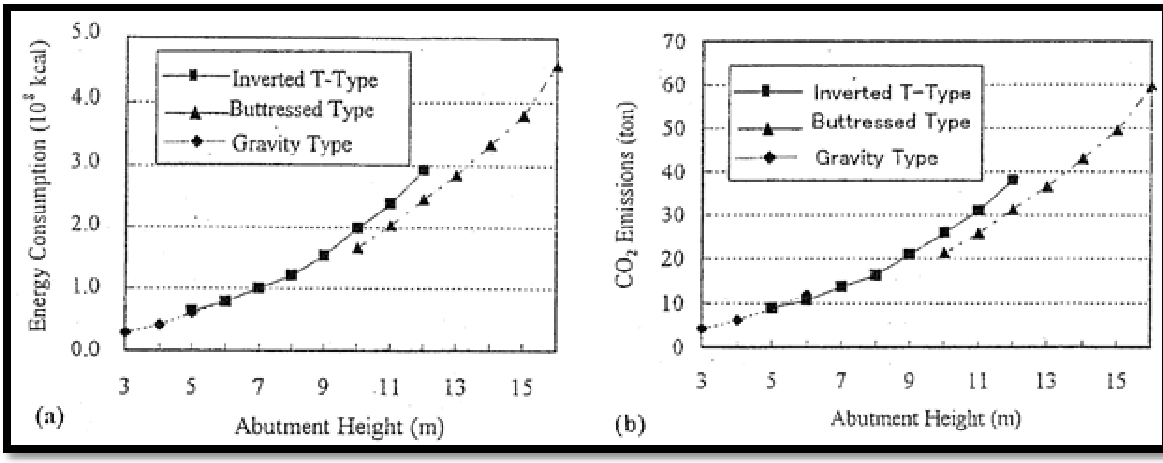


Figure 2-14 - Environmental Impact from Abutments - *Itoh et al., (2000)*
(a) Energy Consumption ; (b) CO2 Emissions

Hunt (2005) stated in his thesis that the largest environmental impact for bridges is based on location, materials, and traffic usage on the bridge. The principles used to determine the factors for this rating system were:

Minimize location impacts by:

- Choosing sites that tie directly into existing routes,
- Not using virgin sites,
- Not affecting historic sites,

Minimize material impacts by:

- Quantity reduction of needed material,
- Using materials with lower embodied energy,
- Using recycled materials and recycling wastes,
- Allowing for future expansion.

Minimize traffic impacts by:

- Providing High Occupancy Vehicle (HOV) lanes,
- Providing bike and pedestrian lanes,
- Reducing the idle time for cars.

2.3.2 Hard Constraints - HC

Similarly to SC, the hard constraints (HC), which are also considered to be factors related to making the decision are imposed by the project's characteristics themselves. The values for these factors or descriptions are mainly imposed and generated by the project's location. These factors are automatically identified once a decision has been made to build a bridge at a specific location to join two areas together. Similar to the SC, the HC are identified either by their values or by their definition in the literature. *Chen and Duan (2000)* mentioned two basic types of criteria have to be met for a proper design method:

a. Design methods that are based on scientific engineering research, comprehensive research and logical conclusions; and

b. Design methods that must be based on previous design and construction experience, in addition to the creativity and the innovation of the decision maker(s).

2.4 Bridge Management Systems (BMS)

BMS is a field where the bridge Life-Cycle is being managed. We cannot separate the bridge LCC influences from the purposes of the proposed research, because they are both directly related to every design decision at the conceptual or detailed phase. *Al-Hajj and Aouad (1999)* mentioned that design, construction and maintenance have to be addressed for any holistic productivity study, and life-cycle costing elements should be considered during the design phase. This will allow users to investigate further information about the components that require replacement or repair. Their research covered building components but it can be applied to bridge components as well. The following two major categories are considered to be obstacles to introducing LCC during the design phase;

- Managerial: covering the failure of designers to be able to visualize and include life-cycle cost goals; failure of owners and/or managers to effectively consider the longer-term impact while their responsibility stays within the short term; and general desires to minimize the initial expenditures.

- Technical: covering the lack of data, application and feedback; inexistence of a database; assumptions and predictions for future expenditures.

Al-Hajj and Aouad, (1999) showed the type of information within the framework of an LCC model as indicated in Figure 2-15, where the design factor is listed at the level of the element that affects the LCC. The following section will address and summarize the available software used to run a study about bridge performance, such as Pontis and Bridgit. Furthermore, the succeeding sections will expose some studies that suggested prediction and preventive actions in order to avoid or reduce the impact of any forecast mis-functionality in the future of a bridge during the design phase.

2.4.1 Bridge Management System (BMS) Software

For many years, researchers and practitioners working for associations that are interested in bridge management have tried to standardize their studies by introducing models and methodologies to manage bridge network performance. *Abu Dabous (2008)* referred to Pontis and Bridgit software; these two applications are widely known and used in the USA. Pontis is an advanced bridge management program that includes functions, data collection, and predictions of needs and performance for bridges. Optimum policies among these components are developed and based on the minimum expected life-cycle cost. Bridgit is used by smaller departments of transportation, and can be used in parallel with Pontis. It aids in the development of bridge maintenance, rehabilitation and replacement programs in order to enhance the benefit cost analysis. These two programs need additional enhancements so they can offer users a complete satisfactory solution either through the collected data and its available database, during process implementation or within non-standard situations.

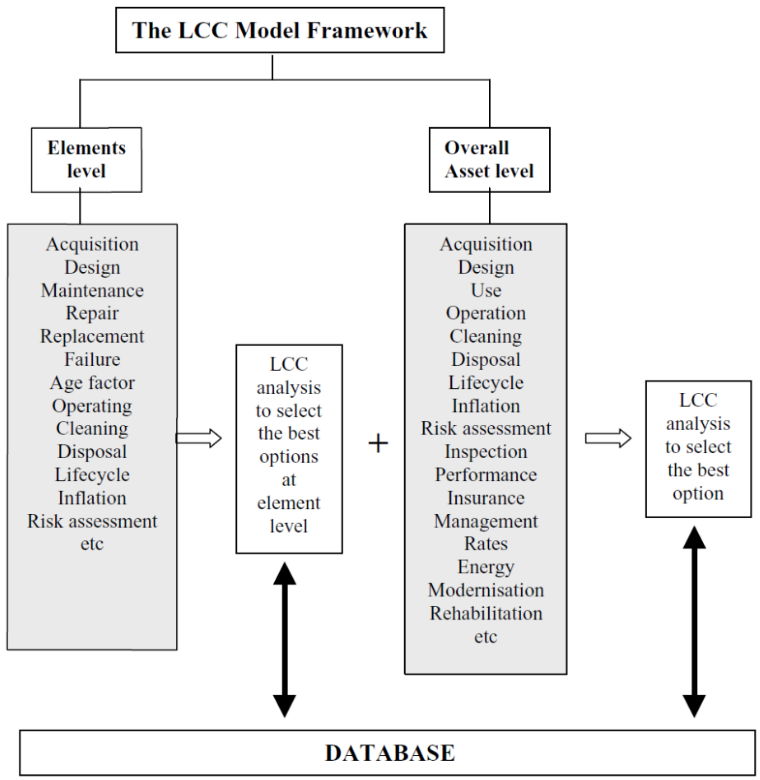


Figure 2-15 - LCC Framework - *Al-Hajj and Aouad (1999)*

2.4.2 Bridge Management System (BMS) Functions

Performance level and sustaining assets within budget limitations and restraints are the main objectives for the BMS. Inspection routines, data collection and storage, maintenance and repair planning, and other actions are the core of the BMS. The engine of the BMS is based on the methods and models to analyze available information in order to facilitate the decision making process and to implement the most convenient maintenance plan. The National Bridge Inventory (NBI) standard in the United States is based on a bridge inspection program where periodic inspections are conducted in order to collect performance data of bridge components and to build a database. *Frangopol et al. (2001)* proposed well planned maintenance and an efficient budget allocation to maintain some level of asset performance based on the reliability index β either by applying an "essential maintenance" or a "preventive maintenance" parameter, where the reliability index β, which is used as a measure of bridge safety, is time dependent and is affected by essential and preventive bridge maintenance. A probability density function of several random variables might be associated with the whole life-cycle process. These variables are: (a) initial performance level; (b) time of damage initiation; (c) performance deterioration rate without maintenance; (d) first rehabilitation time; (e) improvement in reliability level; (f) time of damage initiation after essential maintenance has been done; (g) reliability deterioration rate after essential maintenance has been done; (h) second rehabilitation rate. Monte Carlo simulation is used to generate the random variables' numbers from the probability-density functions. Life-cycle Cost Analysis (LCCA), which is a subset of the Benefit-Cost Analysis (BCA), is considered the essential analytical tool for decision makers to maintain performance while keeping the total cost controlled and optimized for the available alternatives *(DOT, 2002)*. *Thompson and Shepard (2000)* addressed the CoRe (Commonly Recognized) elements for bridge inspection as the basis for data collection, performance measurement, resource allocation, and management decision support. Prior to the CoRe elements, bridge managers used data based on the National Bridge Inspection Standards (NBIS) that helped them decide on how to address some problems due to the limitations of the bridge groups (Superstructure, Substructure, Deck, and Culverts). For instance, the bridge was divided into four main parts for condition assessment (Superstructure, Substructure, Deck, and Culverts) where each part was rated on a 0-9 scale. For these reasons, CoRe has been established with as many as 160 elements to be investigated and inspected. As per the *MnDOT Bridge Inspection Manual (2011)* the CoRe elements are arranged in groups based on the element type and/or material while each structural element is assigned a number as follows: *(refer to Appendix C)*:

1. AASHTO CoRe deck elements are assigned numbers between 1 and 99;
2. AASHTO CoRe elements superstructure elements between 100 and 199;
3. AASHTO CoRe substructure elements between 200 and 299;
4. Smart Flag elements and elements added by MnDOT between 300 and 999; (all the elements with numbers higher than 370 were added by MnDOT). In order to facilitate the inspection process, the *FHWA (1991)* has divided the three major bridge components (Deck, Super-, and Substructure), into 13, 16, and 20 elements, respectively, as shown in Table 2-4. In 2010, the *Ohio Department of Transportation* introduced into its manual some bridge elements to be highlighted while inspections are performed. In 2008, the *Illinois Department of Transportation* proposed a procedure involving checklists with the appropriate components to define the bridge.

2.5 Bridge Information Modeling (BrIM)

This section will focus on "Bridge Information Modeling" (BrIM) and "Bridge Analysis & Design," which is part of BrIM. BrIM is 3D geometric modeling that includes all the BrIM components as bridge element definitions such as Deck, Beam and Columns with their relevant data. The second part covers the analysis and structural design aspects by using a relevant analysis programs such as "Autodesk Robot Structural Analysis Professional," "Sap 2000" from

CSI, or other similar programs. The structure analysis and design part is already one of the BrIM components. Few research articles have widely implemented Bridge Information Modeling because this topic has been introduced into the research field with its full benefits only recently.

Table 2-4 – Bridge Elements *(FHWA, 1991)*

Deck	Superstructure	Substructure
1. Wearing surface 2. Deck condition 3. Curbs 4. Median 5. Sidewalks 6. Parapets 7. Railings 8. Paint 9. Drains 10. Lighting 11. Utilities 12. Joint leakage 13. Expansion joints	1. Bearing devices 2. Stringers 3. Girders 4. Floor beams 5. Trusses 6. Paint 7. Machinery 8. Rivets-Bolts 9. Vibrations 10. Welds 11. Rust 12. Timber decay- 13. Concrete cracks 14. Collision damage 15. Deflection 16. Alignment of members	1. Bridge seats 2. Wings 3. Back wall 4. Footings 5. Piles 6. Erosion 7. Settlement 8. Pier-cap 9. Pier-column 10. Pier-footing 11. Pier-piles 12. Pier-scour 13. Pier-settlement 14. Pier-bents 15. Concrete cracks 16. Steel corrosion 17. Timber decay 18. Debris seats 19. Paint 20. Collision damage

2.5.1 Bridge Analysis & Design

Bridge conceptual design has been known for decades, but there is still limited knowledge of how it should be carried out. *Nedev and Khan (2011)* mentioned that most often engineers base their decisions on past experience and standard solutions, which is probably the ideal method. Even for small bridge projects, the elements of bridges and their associated materials are not followed in a structured format. Despite their research and proposed methodology, Nedev and Khan revealed some limitations such as the number of alternatives that can be compared, span length, type of bridge, and others. Their research started by showing how the conceptual design time period is important and is directly affected by the cost. According *Dekker (2000),* engineers in Sweden have stated that the biggest problem-causing obstacle is the shortage of time. They gave different reasons for that but the conclusion was that engineers need more time/money in order to create and produce better and more optimal structures (by reducing the errors and omissions that could occur during the detailed design). This can be observed in Figure 2.16; obviously if more time is spent at the conceptual design stage, better and more appropriate solutions can be found. On the other hand, *Niemeyer (2003)* explained his methodology in a graphical format as illustrated in Figure 2.17. Five main keys are described: 1) need definition, 2) design requirements, 3) key parameter identification, 4) configuration and 5) evaluation. *Engstrom (2002)* stated that every structure has to meet a wide range of demands; six main areas were outlined for buildings in general and might also be adapted for bridges. Figure 2.18 demonstrates the demand tree given by *Engstrom, (2002)*. *Chen and Duan (2000)* proposed and discussed an empirical design method based on a developed practice, using mathematical models. They built an equation (Eq. 2.1) in which many parameters (x, y, z…) affect the alternative selection (U). For each parameter, the minimum or maximum value has to be identified by using the differential equations (Eq. 2.2), while maintaining the other parameters fixed.

$$U = u(x, y, z, \dots) \qquad \textbf{[2.1]}$$

$$\frac{\partial u}{\partial x} = 0; \frac{\partial u}{\partial y} = 0; \frac{\partial u}{\partial z} = 0; \dots \qquad \textbf{[2.2]}$$

In their method, *Chen and Duan (2000)* took into consideration that each parameter has diverse values among the alternatives, which led to difficulties during the calculation process, and furthermore, the function "u" by itself, will be difficult to define.

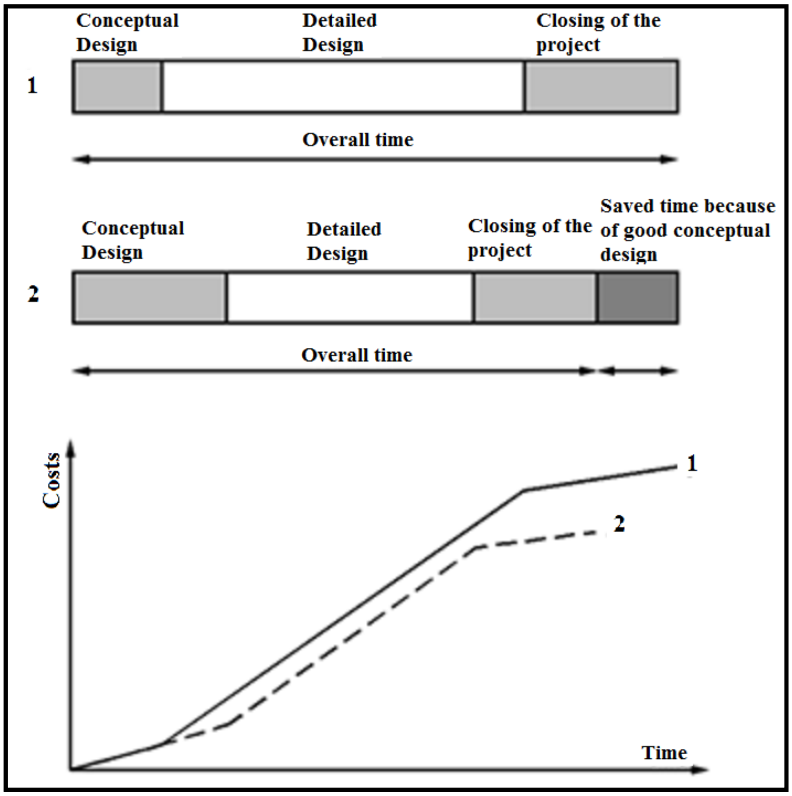


Figure 2-16 - Effect of time spent on conceptual design *(Dekker 2000)*

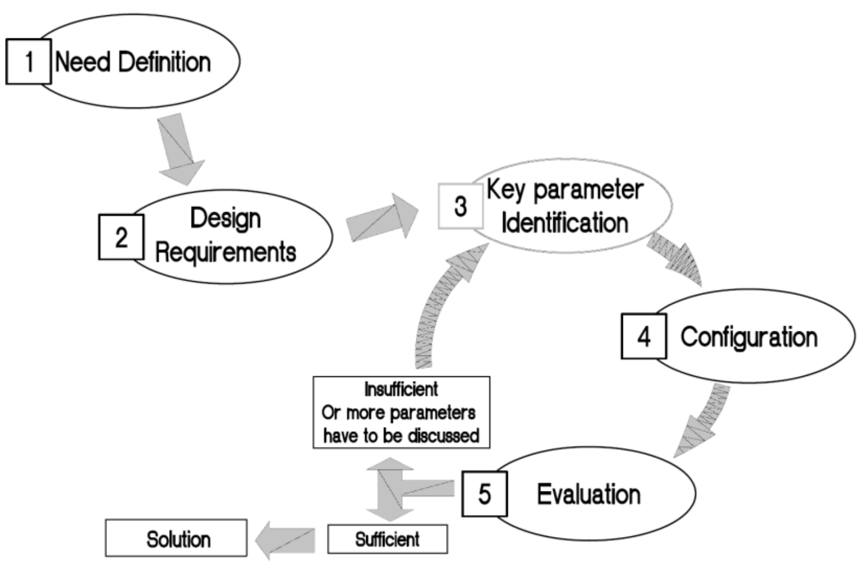


Figure 2-17 - Five-step methodology *(Niemeyer, 2003)*

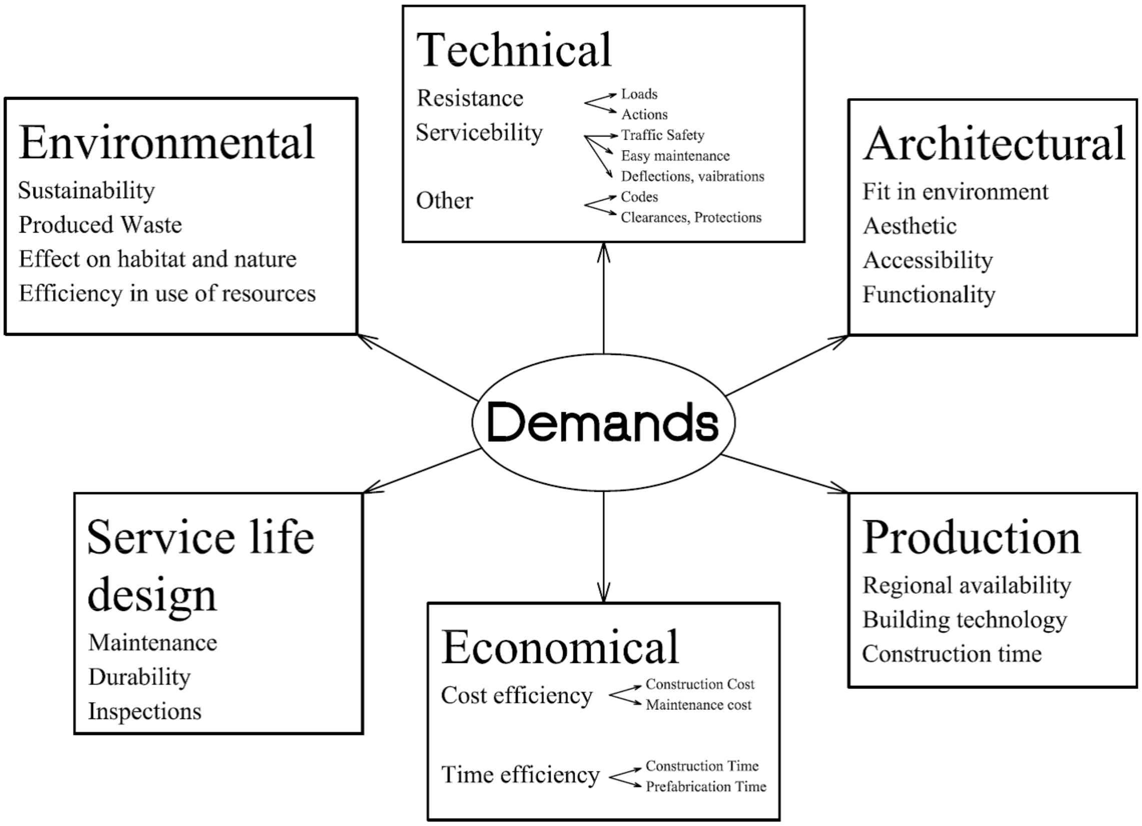


Figure 2-18 - Demand Tree *(Engstrom, 2002)*

2.5.2 Bridge Information Modeling (BrIM), Geometrical Section

Technology plays an important role in Bridge Information Modeling. Many sources, systems, methods and computer-storage media are available allowing bridge design and construction data to be included in a common bridge information modeling system *(Herman et al., 2008)*. Since the bridge information includes geometric, structural, physical, and survey information, BrIM became an important decision-making tool, prediction of performance, and means of meeting required satisfaction levels. The importance of BrIM is that it is considered to be a container of spatially-referenced data from different sources. The type of information may vary from basic metadata (geographic location, origin, classification, design specifications) down to the reference attributes of specific bridge components (material types, manufacturer, specifications) *(Herman* *et al., 2008)*. Based on its 3D-dimensional geometric representation ability, the structural elements and all other components with details down to the smallest element of a bridge structure could be realized and checked in order to make a suitable decision and to avoid heterogeneity between the components of the project. Much research and experimental work has been conducted to clarify the usability of BrIM and to show its efficiency in bridge design, construction, and operation.

2.5.2.1 3D Modeling and BrIM

For many years, 2D drawings were the main tool for doing bridge design work, whereas now 3D modeling is being applied more in the bridge design, too. For that reason, many researchers are influenced by this environment in order to enhance and ameliorate their 3D modeling. The 5D-bridge consortium from Finland has board meetings every three months to discuss and share their experiences and R&D (Research & Development) advancements in the bridge construction cluster. Their work is based on software such as Tekla and CAD tools *(Kivimaki & Heikkila, 2010)*. Furthermore, machine control has been used experimentally with some limitations and research is restricted to the theory level. The contractors' concern was about the practicability of facilitating the flow of information between different parties involved in a bridge construction process and to reduce the waste of resources. The main objective of the consortium was to produce a library of frequently used components. In order to meet and achieve their aims, connectivity between the 3D software and site work surveying has been done through a GPS tool and has become known as machine control. The results of the consortium were summarized by a draft listing guidelines that cover the following:

- Description of modeling and model detail levels.
- Information model contents, technical guideline discussion.

- Design blueprints and 3D modeling process influences.
- Quality control.
- Model utilization at work site.
- Model handovers.

Performing 3D modeling can be done using many software applications and tools, and their use and benefits have been increased by new software applications and by introduction of` additional tools and levels of details. For 3D CAD software, Autodesk with its Revit software has been the best-known tool; Tekla structures offers a reasonable way for modeling the rebarring for concrete bridges, while SolidWork CAD has been used for terrain modeling around the bridge. Referring to Figure 2-19, a simple 3D bridge model is presented using Tekla structures software, showing the geometric shapes of the bridge with some of its components. More detailed information such as rebar and RC sections can also be realized with this software, but many of the software's components were working poorly and were not reaching the quality level needed by users for effective. In addition to the previous software components and benefits, an integrated system of surveying processes could be connected to a 3D office work model to transfer the actual bridge situation during construction from the site work in order to be implemented in a 3D modeling environment so that data can be used and visualized later for future projects and for further review by the designer or to be stored as an as-built.

2.5.2.2 BrIM Benefits and its Processes

An efficient study of BrIM benefit and verification have been conducted by *Don (2009)* through using the "Sutong Bridge in China" to highlight the competence of BrIM in Bridge LCA. Many requirements have been set for this bridge, starting with designing it to resist environmental and natural factors (e.g., wind, earthquakes, ship impacts), through the complexity of fabrication and construction, ending with the required performance and safety level for 120 years. A set of processes have been described to cover the model used during the bridge's conceptual phase (Figure 2-20). These processes cover the whole life-cycle of the bridge from planning and bridge selection to operation, maintenance and rehabilitation and covering all intermediate phases. All these phases are highlighted by different Bentley software that has been used for this purpose:

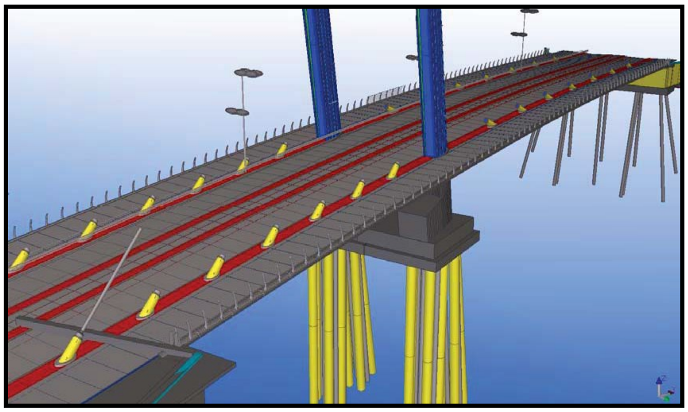


Figure 2-19 - Cruselli Bridge Tekla structure application *(Kivimaki & Heikkila, 2010)*

a. **Bentley RM Bridge**; for design purposes and supported by specialized engineering for bridges of all types.
b. **Bentley LEAP Bridge**; additional parameters for design covering the precast, cast-in-place, reinforced and post-tensioned concrete.
c. **Bentley Bridge Modeler and Bentley LARS**; companion products for bridge load-rating, analysis, and analytical modeling for existing and planned bridges with conformity to ASHTO specifications and database.
d. **Bentley SUPERLOAD**; for permitting oversize and overweight vehicles and routing that takes full account of bridge load-rating and analysis data.

Figure 2-20 - Processes Covered by the Model *(Don, 2009)*

From another point of view, *Kivimaki and Heikkila (2009)* mentioned in their study, while proposing to integrate 5D product modeling, that Tekla Structures and CAD software are underutilized in this area, probably because the design of previous bridges has been done in two dimensions; however tests indicated that they have a viable tool for surveying, but still need further development in their usability and measuring features. Meanwhile, the cost effectiveness is increased by using this approach to surveying, to gather and then to store the data in a server or central memory so it would be considered as built-in data and to detect any error during the construction and the need for any adjustment in the future, to avoid additional errors. *Chen and Tangirala (2006),* in their turn, stated that the main missing link is an industry standard bridge data modeling language that is sufficiently robust to support interoperability of bridge information for the entire bridge life-cycle, and they proposed enhancement procedures in order to leverage maximum benefit from the 3D parametric Bridge Information Modeling, and certainly, as they stated, it was not desirable to reduce the role of data entry done by engineers, since a practical result of robust 3D BrIM software and workflows ought to free up engineers for more creative work that only humans can do in exploring a wider set of options for a given bridge crossing.

2.5.2.3 "Linking" between BMS & BrIM

For many researchers, the design and construction phases are the main and most important ones that directly impact the bridges' LCC. BMS became the area to attract bridge engineers in the last few decades. Before that time the attention was on new bridge design, mainly due to an increased rate of structural deterioration. *Brito and Branco (1998)* mentioned that the most important associated costs were not the direct cost of repair and maintenance, but the functional costs due to traffic detours or disruption. Therefore, these costs have to be considered during the original design even if this will lead to increasing the initial cost. When designing a new bridge, two points have to be considered: (a) upgrading the bridge a few years after it has been constructed, which can lead to costs higher than the initial cost; and (b) this upgrading also will cause very high functional costs (e.g., traffic problems, congestions, public complaints). In this way it is important to merge two things and coordinate between them: the Bridge Management System, focusing on managing the performance of the existing bridge, and the Bridge Information Modeling that focuses on modeling and realizing the new bridge to be constructed and predicting its possible defects. Therefore, many factors have to be considered during the design phase in order to ease the BMS processes. The life span of the bridge could be defined and considered during the design stage to maintain this period, which will be depend on many factors such as the materials used in the construction. The obsolescence of the structure may also be considered at the design stage by allowing a relatively inexpensive upgrade of the functionality of the bridge during its life-cycle. Reducing or spreading the repair cost through the bridge life-cycle period in order to achieve a minor repair cost is a goal that could be planned for during the design phase. Analysis of performance and durability of the constructed elements should be considered at early stages. A detailed cost analysis was described by *Brito and Branco (1998)*, where they showed the multiple aspects of cost that need to be considered.

2.5.2.4 Available BrIM Components

The economy and benefits of 3-D design methods in bridge engineering was mentioned by *Kivimaki and Heikkila (2010)*. The introduction of 5-D product modeling (which differs from the 5D parameters) extends to the geometric aspects of bridges by adding to the research and development performed by many parties in order to increase the BrIM benefits and reduce the risks; while the main objective was to produce a library of frequently used components to be used with and introduced into commercial 3-D design software. Many types of software have been used to test the 5-D product modeling, like Tekla Structures and Solidworks, while Autocad Revit and Microstation have been evaluated. The results were: a) a variable success by utilizing new tools to model concrete bridges and rebars in Tekla Structures; b) a relative success through iteration regarding bridge blueprint production in actual bridge modeling and construction projects; and c) relative failures in creating and maintaining a national custom bridge components library for different CAD software. Nevertheless, it is important to mention that those tools are not only very helpful for the design phase, but their advantages can also be extended to the construction and operation phases by using additional tools to transfer information from the site into 3-D software solutions.

Bentley systems' software has been evaluated and tested with many projects. *Don (2009)* used these tools and tested their efficiency through the Sutong Bridge in China's Jiangsu province. Bentley tools have been introduced during the planning, and stayed in use through the design and construction phases. That way, the benefit from the BrIM is spread over the life-cycle of the bridge and in the selection of the rehabilitation plan by developing new practices based on closing the gaps identified in the traditional process by facilitating the flow of digital information between the various stages. In addition to the common software used for 3-D design, other interfaces were implemented to exchange the data between these software applications and the onsite survey tools in order to save and register the data; XML, APIs, C++ and C# are examples of the file formats and programming languages that make it possible to build a reliable electronic exchange of bridge data in support life-cycle applications *(Shirole et al., 2009)*. *Shirole et al. (2009)* also mentioned that the lack of industry-wide standards for interoperability and compatibility continues to contribute to the bridge industry's lagging behind the building industry in BIM/BrIM related areas. *Marzouk and Hisham (2011*) proposed the use of a bridge Information Modeling framework that adopts BMS features that include a database, an inspection module, and a condition assessment module. The importance of their study lies in the fact that the structural condition assessment with the inspection sheets and results are added to the 3D bridge module (Figure 2-21) to establish bridge component information that will be useful and helpful to estimate the lifecycle of the proposed bridge.

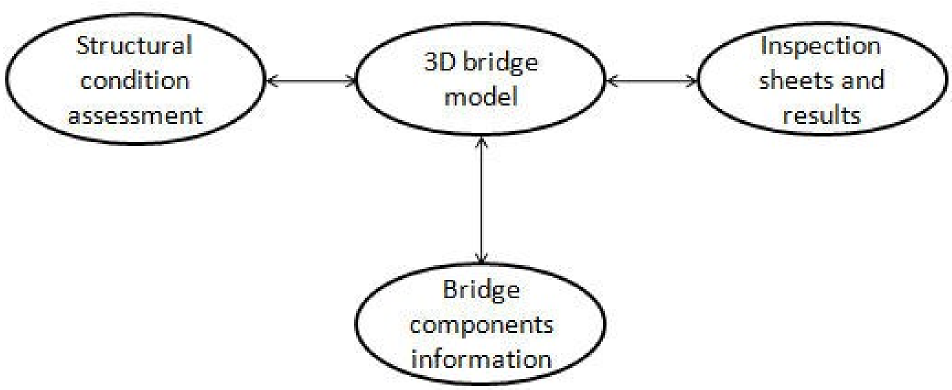


Figure 2-21 - Using BrIM in Bridge Management *(Marzouk & Hisham, 2011)*

In conclusion, any methodology for using BrIM has to be based on three main divisions: (1) the geometric aspect of the bridges that could be implemented by some kind of software like AutoCAD, Civil 3D design, and others. (2) The structural 3-D aspects introduced and highlighted by software like Tekla structures and Solidworks, and (3) a database and library for commonly used components that have been established by a relevant department of transportation.

2.6 Applied Models and Methods

Over time, the construction industry has used different methods based on artificial intelligence and human reasoning processes. In recent years, there has been increased interest among most transportation researchers in exploring the feasibility of applying artificial intelligence (AI) paradigms in order to improve the efficiency, safety, and environmental compatibility of transportation systems *(Sadek et al., 2003)*. AI has been used to solve problems that are difficult to solve by classical mathematical methods. Many researchers have found labeling methodologies to solve some aspect of the transportation problems and to facilitate the decision-making process while bridge replacement or maintenance plans are executed. Quality Function Deployment (QFD), Knowledge-based Systems (KBS), Case-based reasoning (CBR), Expert Systems (ES), Fuzzy Systems (FS), Artificial Neural Networks (ANN), Genetic Algorithms (GA), and other Machine Learning (ML) systems are among the models that have been established in the transportation field and they are especially useful during design decision making. The Gradient Descent methods as well as regression methods are widely used to define some functions to be employed through the models. By screening much research work, the following sections will cover a number of models and methodologies related to bridge management and information modeling established and applied to estimate bridge performance and to provide and suggest some preventive action and to help the engineers make a decision based on previous projects and similar situations and circumstances. The main subject of the following section is to investigate to find out more bout these methods as well as their requirements and the benefits that they provide and to investigate what type of problems they could be applied to.

2.6.1 Artificial Intelligence Systems

AI application areas are quite diverse as mentioned by *Sadek et al. (2003)*; recently, AI has been widely used in the transportation area. *Sadek et al.* revealed that AI methods can be divided into two broad categories: (a) symbolic AI focusing on the development of knowledge-based systems (KBS), and (b) computational intelligence including methods such as: Neural Networks (NN), Fuzzy Systems (FS), and evolutionary computing. In this study, I will focus on Artificial Neural Networks (ANN), in addition to other hybrid systems.

2.6.1.1 Artificial Neural Networks (ANN)

Neural Networks are innovative computing paradigms that try to imitate the biological brain; millions of neurons work together in parallel, each trying to solve a small part of a big problem. This type of problem solving seems very effective, judging by the ability of humans to recognize speech and image data, to make decisions based on past experiences, and to associate and apply acquired knowledge to new situations. Training data can be obtained from historical cases or given through the help of experts. The neural network of the brain is considered to be the fundamental functional source of intelligence, which includes perception, cognition, and learning for humans as well as other living creatures *(Toshinori, 2008)*. Similar to the brain, a neural network is composed of artificial neurons (or units) and interconnections. When we see such a network as a graph, neurons can be represented as nodes (or vertices), and interconnections as edges.

*Srinivas and Ramanjaneyulu, (2007) c*arried out a study by using trained ANN for the feasibility of a T-girder bridge deck in order to reduce computational effort and design space. A study for T-Girder deck section capacity and design responses (Figure 2-22) was done using ANN under live and dead loads. Input parameters were: span length, carriage-way width, total depth, number of longitudinal girders, number of cross-girders, spacing of longitudinal girders, spacing of cross-girders, thickness of deck slab at center, thickness of cantilever end slab, thickness of web, width of bottom flange of main girder and thickness of bottom flange of main girder; while the output parameters were: maximum bending moment due to Dead Load, maximum bending moment due to Live Load, shear stresses due to DL and shear stresses due to LL. The architecture of ANN paid great attention to defining the number of the hidden layer and the number of processing elements (or neurons) (PE) for each layer. Referring to Figure 2-23, the root mean square (RMS) error has been presented through a chart showing its values according to the numbers of the selected hidden layers and the number of the processing elements. *Mukherjce & Deshpande (1993)* explicitly explained the development of a net and how they were processed in selecting the input, hidden and output layers' components. Accordingly, the input layer has to be configured taking into account the possible parameters that may influence the output; the threshold function depends on the intended use of the network and method of learning. Usually the Sigmoidal non-linear nodal function is used. The selection of the number of hidden layers and the number of nodes spends a long time training the network to achieve the required convergence. The output parameter selection is the simplest task which is related to the number of desired output parameters. Normalization is required for the values of both the input and output parameters. Further to the hidden layer and neuron numbers, *El-Sawah and Moselhi (2014)* have conducted a study on the use of artificial neural networks, by considering the Back Propagation Neural Network (BPNN), Probabilistic Neural Network (PNN) and Generalized Regression Network (GRNN) as well as regression analysis in order to highlight how the results obtained from the model will be affected among the different models for the accuracy of the estimated cost.

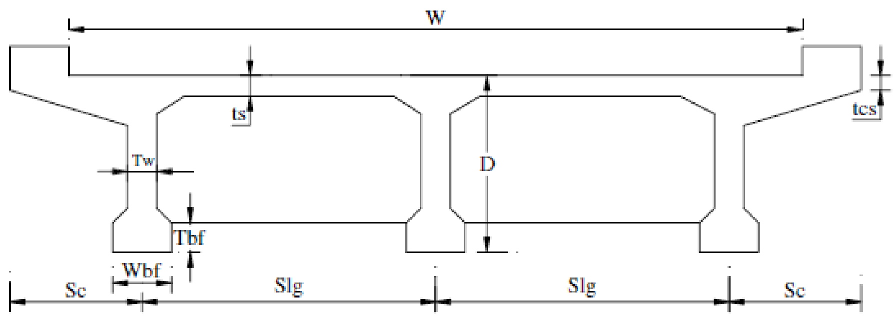


Figure 2-22 - Typical cross-section of T-girder bridge deck *(Sriniva and Ramanjaneyulu, 2007)*

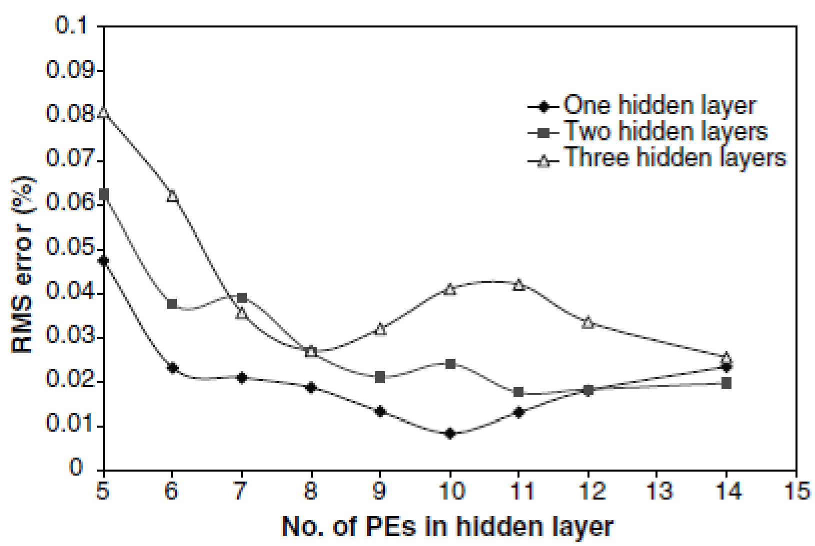


Figure 2-23 - Variation of RMS error with number of nodes in hidden layer *(Sriniva and Ramanjaneyulu , 2007)*

Modeling with machine learning (ML) is a valuable skill for anyone working with data. How to choose the right classification model, having the available data, and how to avoid and correct overfitting, are the challenges of this technique. In order to select the right model, the following questions have to be answered: (1) How much data do you have? Is it continuous? (2) What type of data is it? (3) What are you trying to accomplish? (4) How important is it to visualize the process? (5) How much detail do you need? Therefore, understanding the type of data to use will highlight the strengths of various models. For instance, working with a large amount of data (where a small variation in its accuracy can have a large effect), and choosing the exact approach, often requires trial and error analysis to achieve the right balance of complexity, performance, and accuracy (refer to MATLAB Guide for more details, Matlab, 2015). Machine-learning proficiency requires a combination of diverse skills, but the applications, functions, and training should be available in whatever software is used in order to master this technique to achieve the goal of using it. One of the many features of the artificial neural network (ANN) is learning, and therefore it can be trained to find solutions, recognize patterns, classify data, and forecast future events. It is used to solve the most complex problems. One ANN feature is the weights that are automatically adjusted by training the network according to a specified learning rule until it correctly performs the desired task. ANNs are suitable for modeling nonlinear data with a high number of input features, meaning that ANNs can solve the most complicated problems, even those that are too difficult to address with a straightforward algorithm. It is important to understand that it is difficult to recognize how an ANN reaches a solution. To overcome the difficulties that might affect the system, it is noteworthy that changing the inputs of the training set and retraining powers the system to run efficiently. Moreover, assessing the performance of the system is mandatory while working with such model. The cross-validation method is used to assess the performance of the machine learning algorithm. This method partitions a dataset into sets for training, for validation, and for testing. Because the cross-validation method does not use all the data to build a model, it is used to prevent overfitting during training by randomly selecting the training and testing sets during any round. The dataset is divided into training and testing sets used, respectively, to train a supervised learning algorithm and to evaluate its performance. This process is repeated several times and the average cross-validation error is used as a performance indicator. The simplest NN algorithm is the Back Propagation (BP) Algorithm. The output of NN is evaluated against the desired output by changing connections (weights) between layers, which are modified, after which the process is repeated until the error is negligible. Then the ANN will be used as a main component for the DSS Engine with its Feed-forward, BP algorithm with the following elements and characteristics: neuron (input, output), architecture, nodes and layers, setting weights, training, and activated function. Such an algorithm has advantages and disadvantages.

2.6.1.2 Fuzzy Systems

Toshinori (2008) stated that the term "fuzzy systems" includes fuzzy sets, logic, algorithms, and control. The common fundamental idea of these "fuzzy domains" is the exploitation of the concept of fuzziness, which is a concept that allows a gradual and continuous transition. Fuzzy systems are suitable for uncertain and approximate reasoning when mathematical models are hard to derive. The primary types of applications for which fuzzy systems are particularly useful are difficult cases where traditional techniques do not work well. Also, fuzzy systems can be obtained by applying the principles of fuzzy sets and logic to other areas. For example: fuzzy knowledge-based systems, such as fuzzy expert systems, which may use fuzzy if-then rules; "fuzzy software engineering," which may incorporate fuzziness into its programs and data; fuzzy databases, which store and retrieve fuzzy information; fuzzy pattern recognition, which deals with fuzzy visual or audio signals; and applications for medicine, economics, and management problems, which involve fuzzy information processing. *Takagi (1997)* introduced the basic knowledge of Fuzzy Systems (FSs) through his presentation of soft computing technology used in the industry. A multi-dimensional input-output space or searching space is the basic of the FSs functions as well as for the NNs and GAs (Figure 2-24). Fuzzy systems are used and applied in many construction and design fields. They have been used in a risk management analysis and have also been used to predict some aspect of construction management such as delay estimation, cost estimation, and so on. *Moselhi and Alshibani (2013)* implement the Fuzzy set theory in their research to perform risk analysis for different schedule compression plans and to perform different scenarios expressing vagueness and imprecision of data.

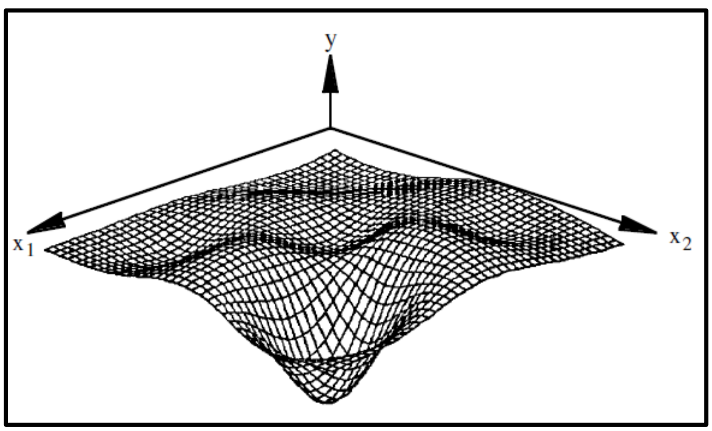


Figure 2-24 - Example of a multi-dimensional space *(Takagi, 1997)*

In the same context, *Moselhi and Lorterapong*, (1995) have conducted a comparative study between the probabilistic and the fuzzy-set-based methods by considering three aspects: 1) theoretical assumptions, 2) data acquisition and computational effort, and 3) scheduling information. The conclusion was that the fuzzy set overcomes some of the limitations associated with PERT and Monte Carlo Simulation.

2.6.2 The Gradient Descent Method

Gradient-descent methods, which are also called the steepest descent method, are among the most widely used of all function approximations. This method is used in the ANN model with its back-propagation algorithm to identify an appropriate solution by calculating the weights' values. The methodology of this method is to attend the target either by ascendant or descendant steps, where the target can be a minimum, maximum or optimum value. Also, the gradient descent is used in a Case-Based Reasoning CBR system to optimize its weights as explained and presented by *Dogan et al. (2006)*. Since the gradient descent is considered a long-established search technique and is commonly used to train multilayer feed-forward neural networks, *Zhang and Smart (2005)* introduced this approach into their research to state the optimal weight values and to determine the degree of contribution of the sub-program (sub-modules run apart for weight value verifications) tree under the link with the weight.

2.6.3 Regression Method

Regression analysis is a statistical tool for the investigation of relationships between variables. Usually, the investigator seeks to ascertain the causal effect of one variable upon another. Many types of regression are available to be applied such as simple regression, multiple regressions, and others. Regression process methods derive functions to be used and applied among models and decision systems and to extract appropriate values. The process for using this method is based on data collection, and then the data are drawn into two dimension domains (axes) to subsequently extract usable functions. After that, we can predict the appropriate assessment for any parameter values which are needed for a functional engine.

2.6.4 Hybrid and other Systems

Many other methods can be used for decision making and machine learning processes. Genetic algorithms are among these methods, computer models based on genetics and evolution in biology. The basic elements of a genetic algorithm are: selection of solutions based on their goodness, reproduction for crossover of genes, and mutation for random change of genes. Through these processes, genetic algorithms find better and better solutions to a problem just as species (natures and types) evolve to better adapt to their environments *(Toshinori, 2008)*. Case-based reasoning, Knowledge-based systems, Quality Function Deployment, and many other expert systems are used to predict the performance and the behavior of a project with its relevant components and serve to make the right decision based on the available database and on the previous performance history and they are considered as essential input for problem solving. *Arain and Pheng (2006)* proposed the Knowledge-based System (KBS) as a decision tool to provide an effective management of variations and design improvements for an educational building project. They started their work by collecting the necessary data, through a questionnaire survey and literature review. Based on previous cases, the KBS provides an excellent opportunity to designers and project managers to learn from past experiences. The components of the proposed decision-making tools are shown in Figure 2-25, where the data have been stored in a database after collecting them from many sources. Afterwards, the data was sieved through an inference mechanism to develop the Knowledge-base. The inference mechanism assisted in coding, filtering and categorizing the information based on certain given rules. Without going in detail, *Arain et al. (2006)* presented an explicit framework for their knowledge-based system (KBS) (Figure 2-26), showing how the database has been developed, and how the data has been documented in the system, and then, based on certain rules, the information has been developed through initial filtering. The importance of their research lies in the knowledge-base that was divided into three main segments, namely: macro layer, micro layer, and effects and controls layer. The system contains one macro layer that consists of the major information gathered from source documents, and 80 micro layers that consist of detailed information pertinent to variations and variation orders for each project. For information management through the cited layers, the suggested controls were also rated in order to find a kind of comparative task between alternatives, and then to select the best control based on the given criteria. In other research, *Malekly (2011)* has proposed a comparative study that was conducted to evaluate the performance between three optimization techniques, namely feature counting, gradient descent, and genetic algorithms in generating attribute weights that were used in a spreadsheet-based case reasoning prediction model. In their research, *Dogan et al. (2006)* described these three techniques that are used in the CBR model.

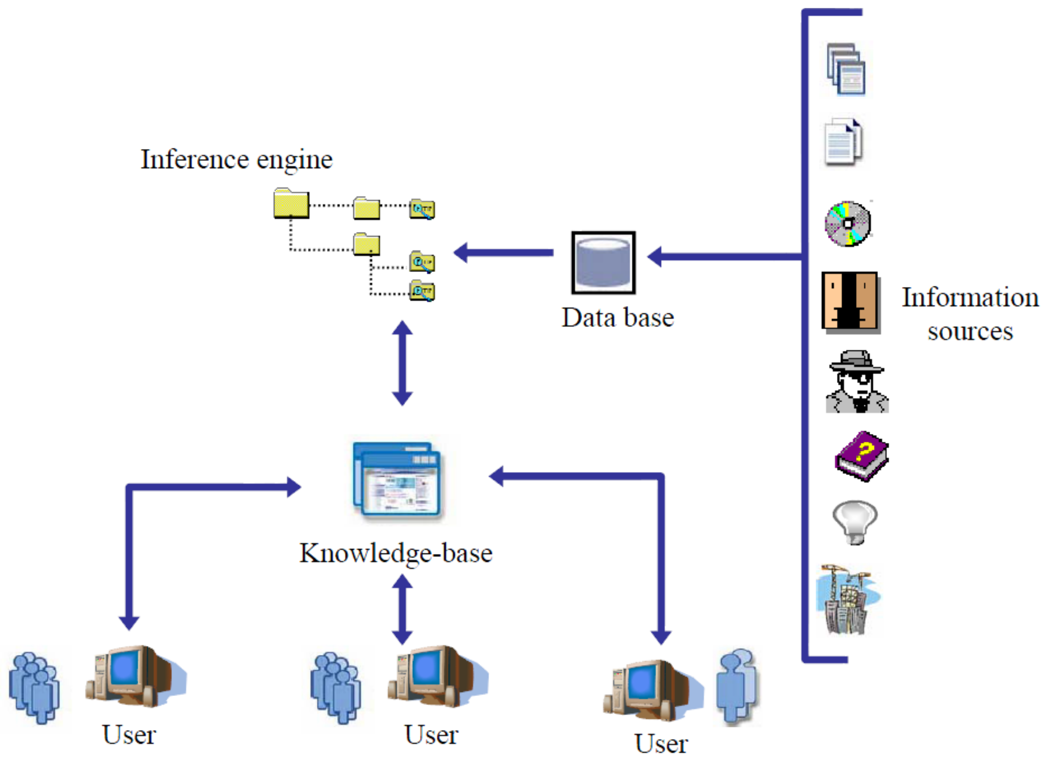


Figure 2-25 - The Main Components of the KBS (*Arain & Pheng, 2006)*

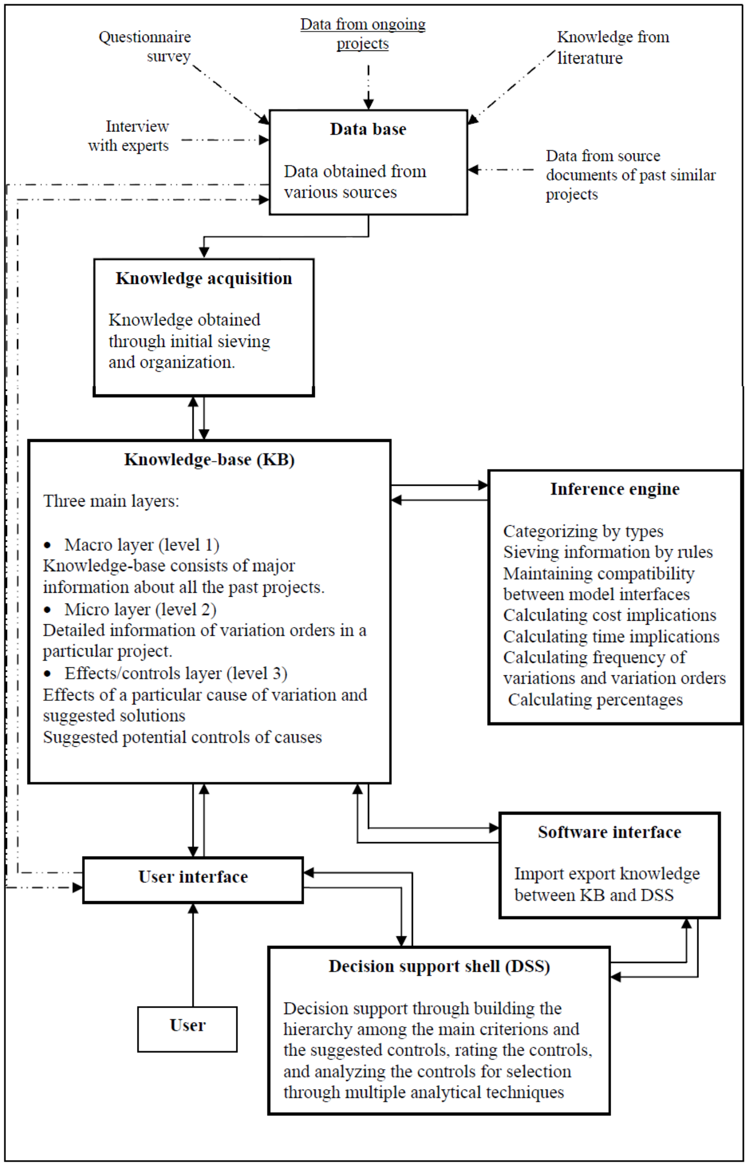


Figure 2-26 - Framework for knowledge-based system (KBS) *(Arain & Pheng, 2006)*

The CBR utilizes existing data as cases; it can retrieve previously stored solutions from a case base to predict the outcome of a test case (Figure 2-27). Figures 2-27, 2-28, and 2-29 summarize the basic process of CBR with its spreadsheet simulation to register, store, and retrieve data collected from previous cases. The knowledge acquisition effort can be minimized by determining the most representative case attributes, optimizing the case base organization and case retrieval, and refining the process of similarity assessment (*Dogan et al., 2006)*. As shown in Figure 2-28, the data is organized in the form of two matrices, one for the test cases and another one for the input cases. Figure 2-29 presents the calculated attribute similarities where its functions are used to define how similar attribute values are to each other. Attribute similarities are computed with respect to each test case versus every case retrieved from the input case base. Furthermore, *Yau and Yang (1998)* utilized the CBR in order to overcome some drawbacks of other AI technologies applied in construction management, where the CBR is considered as an alternative to solve experience-oriented problems. My concern with *Yau and Yang's (1998)* paper falls in the application of the CBR to estimate the duration and cost at the preliminary design stage. In their study they mentioned that the CBR's drawbacks lie in blindness of using retrieved cases which can be compensated for by incorporating similar technologies such as ESs or NNs.

2.7 Summary

This chapter was a review of the literature about the selection of a suitable bridge type. A history of bridge types has been presented and how bridges have evolved since 2000 BC. This survey did not find any unified form or list of the bridge types that could be used in any decision support system since many references have mentioned different groups of bridge types. Many researchers have attempted to define the factors that have great influence on the selection of the type of bridge that is suitable according to some related parameters such as area to overpass, type of soil, and traffic capacity. The disparity between those studies showed that there is no systematic procedure to be followed to determine the level of influence for each factor or to identify if they have any influence on the decision and how to evaluate their influence, if it exists.

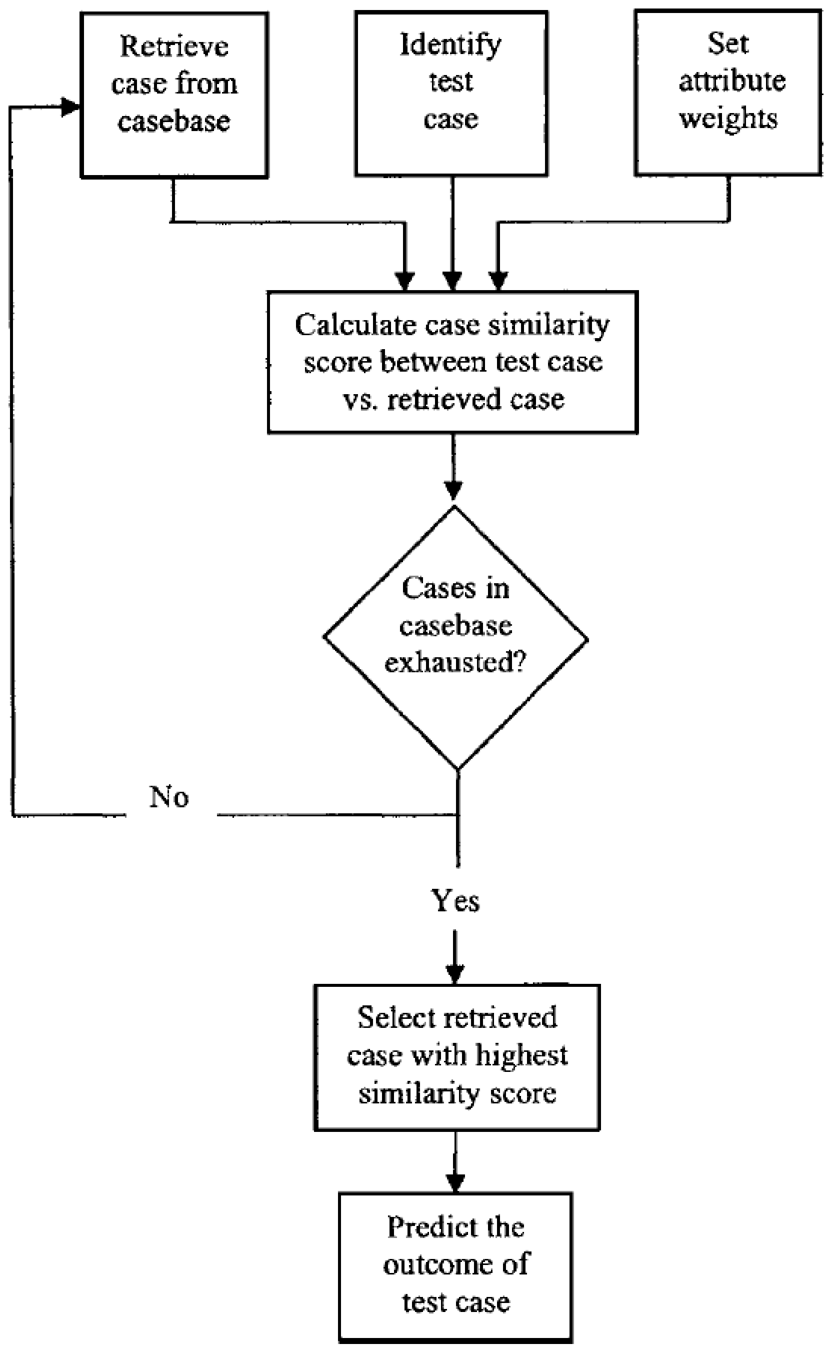


Figure 2-27 - Basic Process of CBR *(Dogan et al., 2006)*

1	A	B	C	D	E	F	G	H
2	Weights	w_1	w_2	w_3	…		w_p	0
3	**Case No.**	TEST CASEBASE **Attributes**						**Output Attribute**
4		1	2	3	…		p	
5	Case 1	I_{11}	I_{12}	I_{13}	…		I_{1p}	O_1
6	Case 2	I_{21}	I_{22}	I_{23}	…		⋮	O_2
7	⋮	⋮						⋮
8	Case m	I_{m1}	I_{m2}	I_{m3}	…		I_{mp}	O_m
9								
10	**Case No.**	INPUT CASEBASE **Attributes**						**Output Attribute**
11		1	2	3	…		p	
12	Case 1	I'_{11}	I'_{12}	I'_{13}	…		I'_{1p}	O'_1
13	Case 2	I'_{21}	I'_{22}	I'_{23}	…		⋮	O'_2
14	⋮	⋮						⋮
15								
16	Case n	I'_{n1}	I'_{n2}	I'_{n3}	…		I'_{np}	O'_n
17								

Figure 2-28 - Formatting data to a case spreadsheet *(Dogan et al., 2006)*

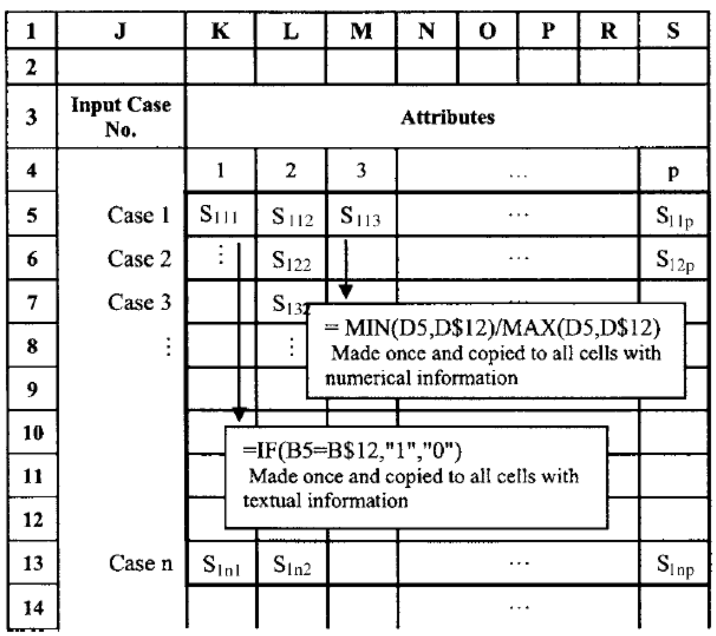


Figure 2-29 - Attribute Similarity matrix for Test Case 1 (i=1) *(Dogan et al., 2006)*

A systematic and unified procedure to determine the influence of the factors still needs to be constructed. Many AI methods and models used in the construction management fields were presented especially those used for bridge feature analysis such as Life-Cycle Cost Analyses (LCCA) of bridges and their performance, and the efficiency of these methods was evaluated. These methods and models have drawbacks that were listed and discussed. Most of these methods and models are used to resolve limited aspects of problems. Other researchers have conducted comparative studies for limited subjects, while overlooking the absence of these types of approaches at the conceptual design phase. This research will gather some of these methods into a DSS that aims to present a complete and comprehensive solution. This DSS will be well defined and explained in the next chapter. The literature review showed the effectiveness and the benefit of using BrIM tools, while identifying their limitations. BrIM was used to realize an existing or newly designed situation without introducing BrIM tools directly into a DSS as a main model. Meanwhile, BrIM contribution in the process was necessary to make the final decision by interacting with the factors and their influences.

Based on the literature review, the following references provide the motivation behind the research conducted:

(a) a diversity of opinions has been noticed and mentioned by *Smith (1994)* in his research. This leads to diversity in the resulting final decision, and this happens because engineers most often base their decisions on past experience, as mentioned by Nedev and Khan (2011);

(b) subjectivity, in any decision made, has been criticized by many authors. *Moore et al. (1996)* has mentioned that the aesthetic performance for a bridge was based on personal experience and on skilled engineers' opinions. *Smith et al. (1994)* also noticed the lack of a mathematical and systematic methodology to make a decision related to bridge type selection. While the subjective factors have been criticized by many researchers, *Yao et al. (2011)* proposed a Fuzzy NN method to partially fill in the gap caused by this subjectivity and to deal with some uncertainty;

(c) There is a noticeable interesting in using BrIM, as mentioned by *Herman et al. (2008)*, but only during the detailed design phase. *Dekker (2000)* stated that the benefit of BrIM at the conceptual design phase is restricted due to a shortage of time;

To cover these problems, authors have proposed many models that had some limitations and were restricted to special cases. For this reason, these problems have been highlighted in this research in order to provide a generalized methodology.

Chapter 3

System Methodology and Research Development

3.1 Introduction

Any decision made by any expert could be criticized by any other opinion, and may be challenged by any other alternative. It is not enough to base a decision on expert subjectivity as many authors have emphasized, so it is useful to follow some systematic methodology to support the expert's decision by tangible argument, especially if the decision based on the mentioned methodology will highlight some evidence related to relevant performance criteria. Conceptual design is the most creative part of bridge engineering, but at the same time probably the most demanding. It requires experience and broad knowledge of all areas connected with bridges – from legal aspects, to technical details and the ability to extract and understand the needs of the client. Most often the problem is open and it is the designer's responsibility to find the most appropriate solution. Even though conceptual design has been known for centuries, there is still a lack of helpful guidelines and methodologies to support the designer. That is why it is very common that the engineer chooses very well-known solutions without considering other options. The reason for this is mainly time limitations.

Conceptual Design is the first step in any kind of structure design; bridges are one type of structure that needs to be well assessed before proceeding with any theoretical analysis and detailed design. In selecting bridge systems, material, proportions, dimensions, foundations, aesthetics, and other considerations such as surrounding landscape and environmental aspects are taken into consideration in the conceptual design process. The proposed methodology will be implemented in the "conceptual" stage, which is the first one among the six stages in the life of a bridge, as presented in Figure 3-1.

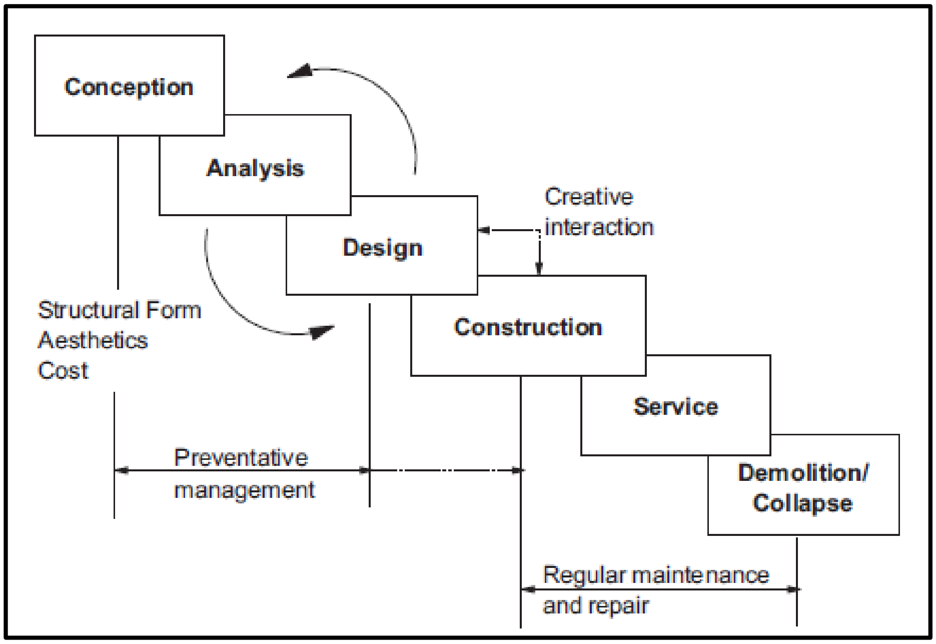
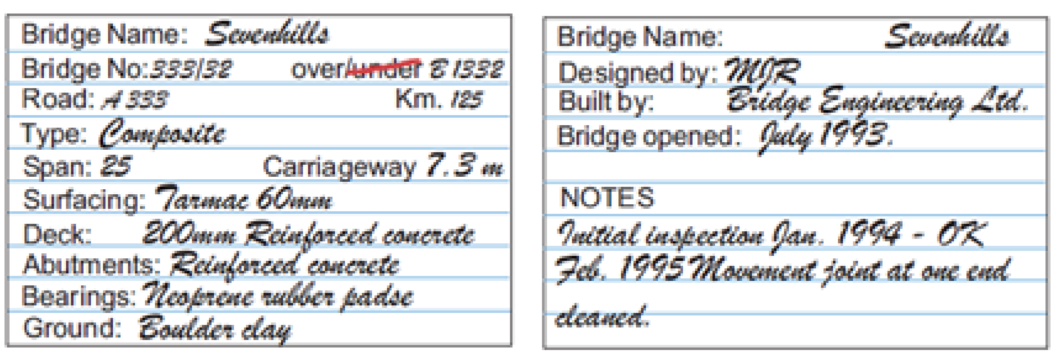


Figure 3-1 - The Six Stages in the Life of a Bridge *(Ryall 2001)*

This research considers the quality of the structure to be evaluated by considering different criteria: technical, functional, and economic, in addition to the material of the system and the geometric dimensions of the bridge. To rate the affecting factors, they are grouped into two main categories, hard factors and soft factors. For instance, the first includes site type, capacity, and complexity of the construction, while the soft factors may contain those that define the performance level (e.g., benefit/cost rating, aesthetics ranking, and environment impact level). The main objective of this research is trying to highlight and/or minimize global subjectivity and to reduce and limit its impact; the purpose is to move from the ambiguity of the subjectivity towards an accurate one and to control this subjectivity in order to reduce the erroneousness and/or the inaccuracy if it still exists. It is important to mention that the proposed model will not replace the engineer’s role that would be mandatory to establish the conceptual design of the bridge and to make necessary modifications based on many factors that have been omitted from the proposed model. This research aims to predict and define a methodology to be followed through a built-in, structured approach that takes many factors and constraints into account. These factors will be defined and evaluated by the user according to the available data from the existing projects that will be considered to establish a relevant data module. It is also worthy to mention that some decisions should be made before launching the process of the actual model, such as project location, which will be restricted by the existing transportation network and its connectivity to the new bridge.

3.2 Common Rules and Answers

To ascertain a suitable base for the proposed model, questions, such as “What is the total length of the bridge?” must be answered in order to set the minimum necessary factors and restrictions that should be considered for the proposed model. Bridge parameters and characteristics should be listed in a standard form in order to establish the bridge’s identity by way of the values and characteristics of these parameters. Figure 3.2 presents an index card system that contains the bridge parameters and can identify the bridge behavior and performance



Bridge Name: Sevenhills
Bridge No: 333/32 over/~~under~~ B1332
Road: A 333 Km. 125
Type: Composite
Span: 25 Carriageway 7.3 m
Surfacing: Tarmac 60mm
Deck: 200mm Reinforced concrete
Abutments: Reinforced concrete
Bearings: Neoprene rubber padse
Ground: Boulder clay

Bridge Name: Sevenhills
Designed by: MJR
Built by: Bridge Engineering Ltd.
Bridge opened: July 1993.
NOTES
Initial inspection Jan. 1994 - OK
Feb. 1995 Movement joint at one end cleaned.

Figure 3-2 - Card Index System (ID)

A general form, including relevant parameters, will be established through this thesis without any limitation to a specific number of factors. Some parameters and factors will be presented in this research/study just to find the idea of the Decision Support System (DSS). Other parameters might be added or ignored accordingly. Part of the research will be to establish general rules to be followed, which will cover the commonly related parameters to be defined before taking any action. The same design pre-process is used for any kind of project. For instance, the location of the project has to be defined before data collection and verification. This part of the DSS will be structured to be uniform and compatible with any type of case that will be handled by the stated DSS.

3.3 Models and Methods

Structural design problems are often complicated and the synthesis of a good solution requires human qualities such as engineering judgment, intuition, experience, and creative abilities. Many approaches have the capability to incorporate some of these requirements with their corresponding drawbacks. The development of the proposed DSS follows three steps: **(a)** establishing an accurate library of bridge types and their components, by structuring necessary data forms that store appropriate information retrieved from previous projects, **(b)** defining the model's engine that will process the information and that will provide a convenient solution as output, and **(c)** using BrIM concepts and tools to provide a visualization of the generated outputs. The most important and difficult part of the proposed model is to be able to define and convert into numbers some aspects and situations, such as soil behavior, that an engineer has to evaluate and consider for his final decision, and also the data structure itself and how it will be established in an appropriate manner for the DSS engine mentioned earlier.

The performance of a bridge is predicted and evaluated according to how much the following factors are rated: Aesthetic, LCC, Environment, and Public satisfaction/capacity and services, based on existing bridges and the fact that the same conditions lead to the same consequences.

The DSS will be established to make the model's parameters as flexible as possible in order to provide users with the capability of including other parameters and conditions and to show how these parameters affect the DSS outputs.

3.3.1 DSS framework

The main components of the DSS are: the data module that contains the bridge types with their components (related to their geometric parameters) and the bridges' parameters that influence their performance (such as the area to overpass, soil behavior, bridge capacity, number of lanes, number of spans, total length), the DSS engine that includes input and output parameters, and the BrIM process to visualize and then verify the accuracy and suitability of the decision maker's selections based on the output values provided by the DSS Engine. Thus, the DSS is summarized by the framework shown in Figure 3-3. The DSS starts by collecting the necessary information from appropriate resources to be included in the data module. After establishing the data frame, necessary analysis will ensue in order to convert the data to suitable numerical values to be implemented in the DSS engine. The DSS engine, which works under the AI environment and which will be detailed in the coming sections, is running under these input data in order to deliver the appropriate output values. These values will be verified and analyzed simultaneously through two processes: **(1)** through engineering judgment, and **(2)** by implementation of the output values in BrIM tools. Afterwards, a final decision will be made, to either accept them or to require some modification.

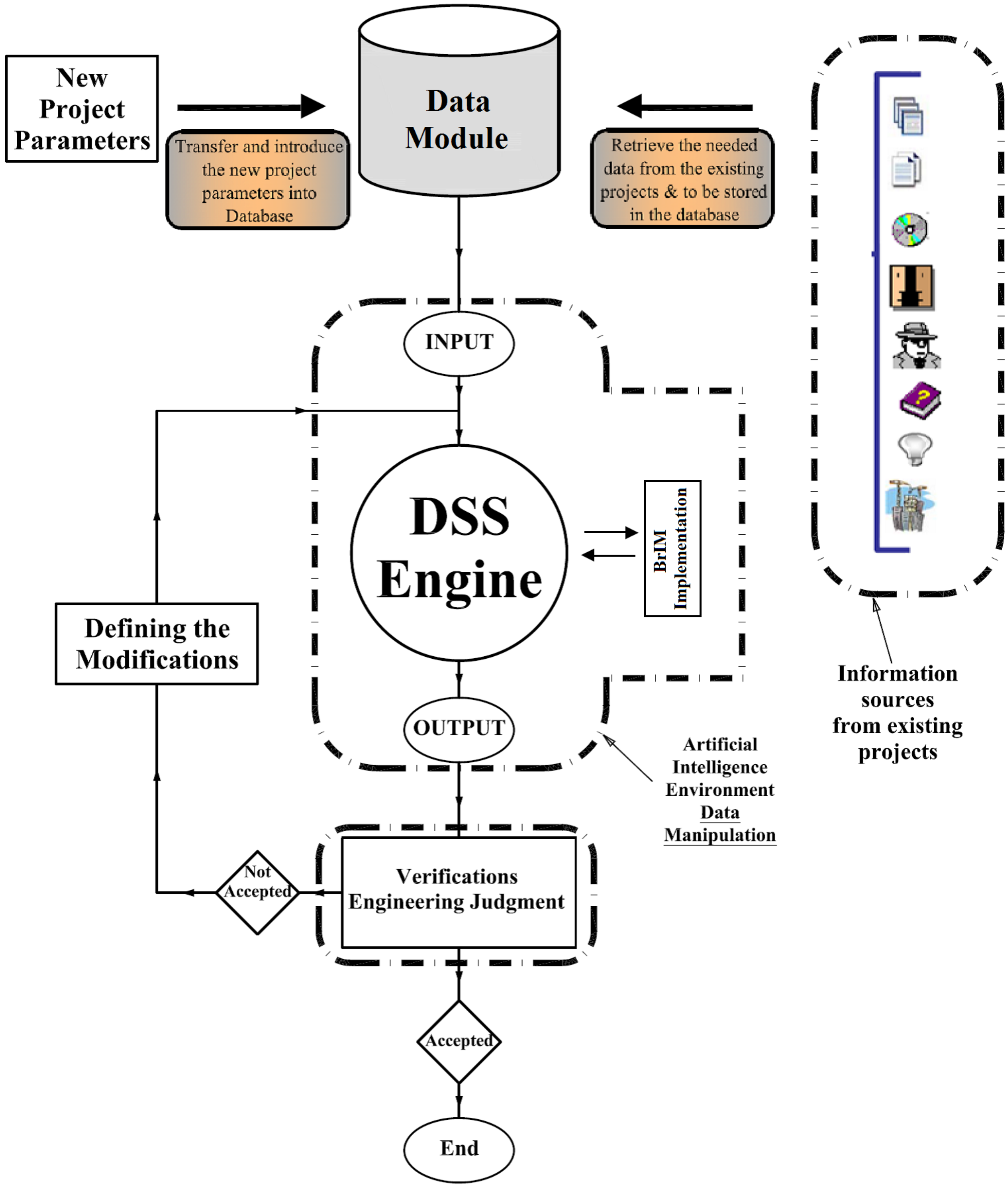


Figure 3-3– DSS Framework

3.3.2 Data Module: Components and Included Information

A data structure is a collection of information that is organized so it can be easily accessed, managed, and updated. In computing, data are classified according to their organizational approach. The most prevalent approach is the relational database, a tabular database in which data is defined so that it can be reorganized and accessed in a number of different ways. Meanwhile, the data and data manipulation used could be classified as a "traditional database application" as mentioned by *Elmasri R. and Navathe S. B. (2016),* without the need to use an advanced technology for it. For that, the types of information that will be included with their characteristics should be well defined. Therefore, Figure 3-4 describes the appropriate information to be included in a well-structured data frame that will provide, after a suitable analysis, the proper values for the DSS engine.

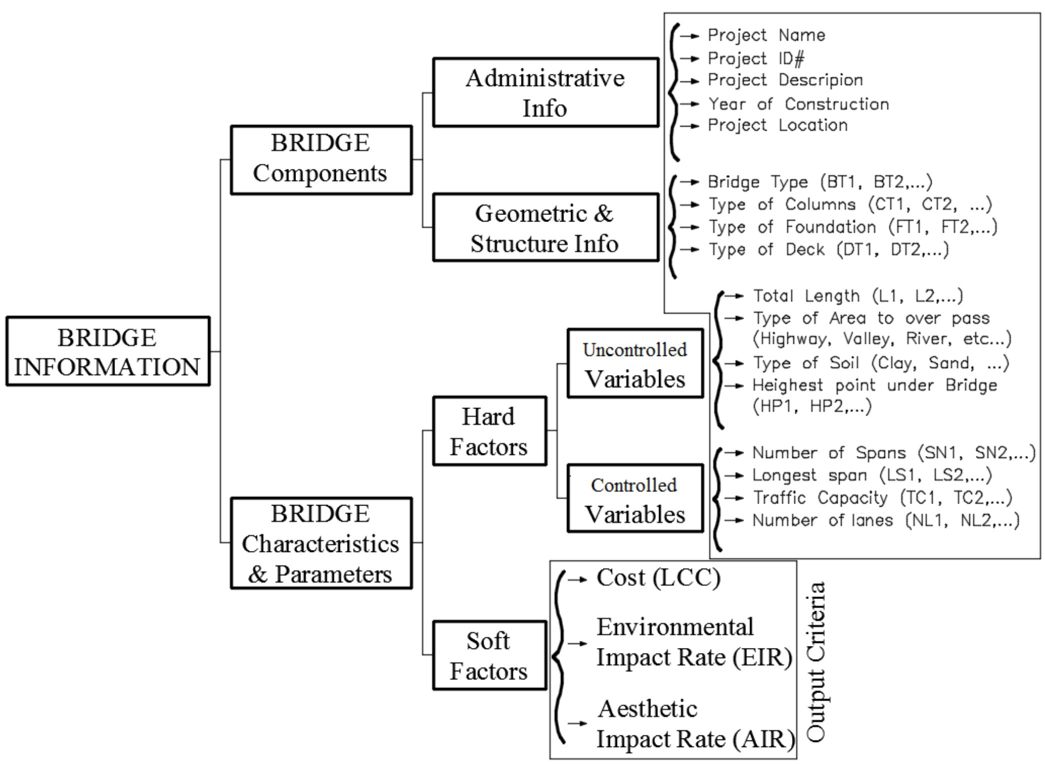


Figure 3-4 – Bridge Information Algorithm

As seen in the diagram (Figure 3-4), the criteria are presented under Bridge Information. For that, all needed criteria and their appropriate descriptions are gathered under the Bridge Information set, which is divided into two main categories: **(a)** Bridge Components, and **(b)** Bridge Characteristics and Parameters. The criteria grouped under the bridge components are divided into two sets: **(i)** Administrative Info, which holds, for instance, the project Name and its identification number, a brief project description, and **(ii)** Geometric and Structure Info related to the elements' description such as Bridge Type (BT), Type of Columns (CT), Type of Foundation (FT), Type of Deck (DT). In the second category, the criteria under the Bridge Characteristics and Parameters are clustered into two types, controlled and uncontrolled variables, and these two types of criteria are presented as hard factors. Other criteria, considered as output criteria, according to the values of which a decision will be made, are presented as soft factors. Examples of these output criteria are as follows:

(1) the Cost (LCC) related to the bridge which will be defined partially in the coming sections and totally in the development process;

(2) the Environment Impact Rate (EIR); and

(3) the Aesthetic Impact Rate (AIR) that could be provided within the information package coming from resources or could be evaluated based on many factors implemented into a Quality Function Deployment (QFD) system (see Section 3.3.3).

3.3.3 Data module: Criteria Description and Information Analysis

In order to present the data structure that will cover all information mentioned in the previous section, a Data Modeling (DM) and a Physical Implementation (PI) will be presented and detailed. For that, in order to detail the criteria's definitions from the bridge information algorithm (Figure 3-4), it is noted that all criteria are grouped under **5 categories**: **(1)**

Administrative Information, **(2)** Geometric and Structure Information, **(3)** Uncontrolled Variables, **(4)** Controlled Variables, and **(5)** Soft Factors. We note also that the criteria listed in this research section can later be subject to some additional or retention of items in the final development process of the proposed DSS. The value for each criterion will be presented by the symbol shown in Figure 3-5, where the “Cr” symbol presents the type of the criterion and the subscript “a” denotes the project ID.

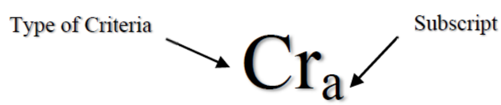


Figure 3-5 – Criteria Symbol

➔Administrative Info

The information contained in this category aims to identify the project; such information includes the following criteria:

- Project Name (e.g., Champlain Bridge)
- Project ID#, to identify the received data in the Data module (e.g., 001)
- Project Description, to provide some special information related to the mentioned project that could be useful for any engineering judgment.
- Year of Construction (YC), that will define the starting year of the construction and it will be useful to identify the adjustment cost factor related to the construction year.
- Project Location (PL) which defines the city and/or country of the project. This will be used to identify the adjustment cost factor related to the location.
- Other items could be added, if necessary, to establish the final structure in the development process of the DSS.

➔ Geometric and Structure Info

This category of criteria is defined as one of the input sets to be considered for the DSS engine. These criteria define the geometric and structural elements constituting a specific bridge. The linguistic information for these criteria have to be converted into numerical values through point scales that will be defined separately for each type of criteria. For instance, all existing bridges could be grouped under four types of bridges: (BT1) Girder Bridge, (BT2) Arch Bridge, (BT3), Cable-stayed Bridge and (BT4) Suspension Bridge. We note that the movable bridge is excluded from this sample. For these four linguistic types, we assign the 4-point scale mentioned in Figure 3-6.

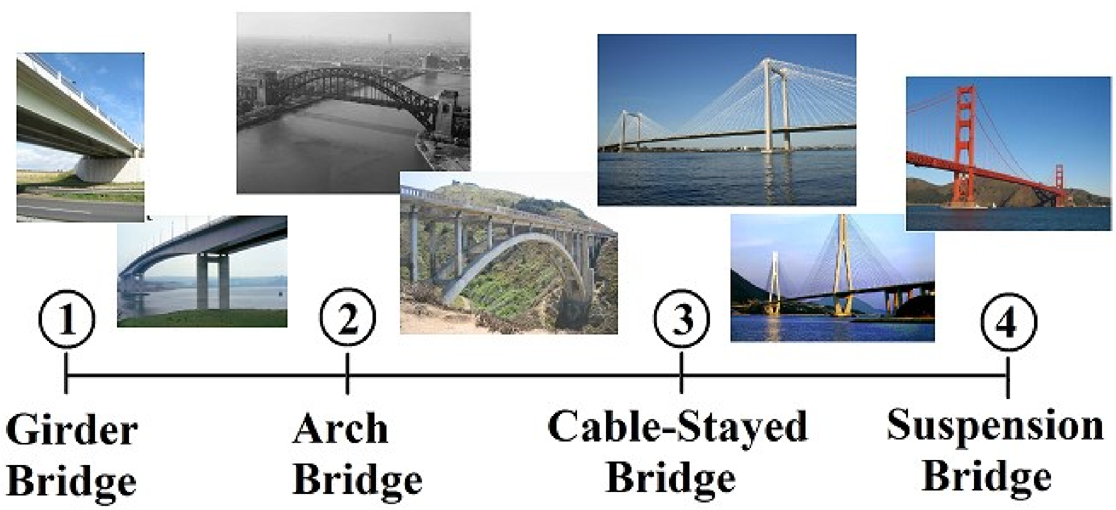


Figure 3-6 – A 4-point scale for bridge types

According to this scale, the value "1" is assigned to the Girder bridges, "2" to the Arch bridges, "3" to the Cable-Stayed bridges, and "4" to Suspension bridges. The point-scale method is widely used to convert linguistic information to numerical data to simplify its use; the selected scale from one to four or any other scale segment no longer has any noticeable effect as long as we follow the same method of assigning the values to linguistic information, and this issue has been verified in the case study presented in Chapter 7, where many point-scales have been used and the results were not noticeably affected. A library of photos could also be established in order to clarify the point scale assigned to a specific bridge. This library will be established by the designer in order to cover most of the bridge cases; and also another point scale might be used to present, in an illustrative manner, the element types of the projects that will be stored in the data module. So the value of "BT_i" (where i=1, …, n; n is the number of cases to be stored in the data module) will present the value assigned to the bridge type criteria. Similarly, we proceed by the same manner to assign the appropriate values for all the other criteria. "CT_i" are the values to be assigned for the column types, and "FT_i" will be those values for the foundation types and so on.

➔ **Hard Factors (Controlled and Uncontrolled Variables)**

This is another category of input criteria. The values of these criteria are obtained from the bridge characteristics defined by their position on the site and their connections to the existing networks. Most of these criteria are defined by their values such as total length of the bridge (L_i), highest point under the bridge deck (HP_i) and the number of the spans (SN_i); on the other hand, some criteria are defined by their geologic behaviors (type of Soil [TS]) or by area description (Type of Area to over pass [TA]) and these linguistic types have to be converted to values by using a point scale process. For instance, the geologic behavior will be presented on a point scale ranging between the loose soil to the hard soil behaviors, and this point scale will be well established based on the existing cases that will be considered in the data module. For the existing projects, all of the criteria values listed under the controlled and uncontrolled variables are well defined according to the real and existing situation of the bridges, while for a new case being analyzed, the criteria values found under the controlled variables, could be altered according to the designer's insight, whereas the uncontrolled variables are considered to be unchangeable values that are related to the bridge location constraints. Among the different factors of categories III and IV, (a) Environmental Impact Rate (EIR) and (b) Aesthetic Impact Rate (AIR) are two factors have to be evaluated for every bridge depending on many parameters.

- **Environmental Impact Rate (EIR)**: As defined by many specialists, the conceptual design is approached differently by each engineer. Usually, the conceptual design starts with a brainstorming session by a group comprising different specialists. We cannot consider a bridge as an isolated structure; it has to be integrated with the road, landscape and environment. Hence, the bridge engineer starts the work in coordination with a road designer, a geotechnical engineer, and a landscape architect, especially for larger projects. Moreover, society demands safe, economical, and quick solutions with good aesthetic features. That is why the designer always evaluates and assesses different options, while keeping in mind the requirements and demands of the client (government representing society). For that, it is mandatory to evaluate the environment impact of any existing bridge that will be designated by the EIR factor, and its value is relative in a set of bridges being considered in such analysis. EIR is also considered to be a criteria value to be collected and stored in the data frame related to the appropriate bridge. If such information is not available from existing bridges, a brief methodology will be defined and a rudimentary model will be presented to calculate the required values of EIR based on the "WHATs" factors implemented in a QFD system.

  In order to define the "WHATs" factors that affect the EIR, we refer to many researches to listed many factors to be considered in the study of environmental aspects that could be impacted by a bridge. In addition to CO_2 emissions, pollution, and raw materials to be used with their wastage, there are many other factors to be considered. The main environmental and social impacts resulting from the bridge and border crossing facility construction activities will include creation and expansion of borrow pits, dust, soil erosion, noise, loss of vegetation, water pollution, potential loss of archaeological and cultural sites, limited loss of property and land and subsequent displacement of persons, and other cumulative impacts such as increased population due to influx of construction workers, increased cross border traffic, tourists and business people in general due to more efficient border crossing arrangements, and therefore improved access to the area, increased pressure on social services, and land and natural resources such as trees and wildlife. Among the negative social impacts, will be those resulting from land and property loss. These factors could be grouped into two main categories: (1) A Material Impact (MI_i) indicator related to the CO_2 emission, and (2) A Surround Impact (SI_i) indicator that includes factors related to the bridge surround site and society. The final value of (EIR) will be:

$$\mathbf{EIR_i = A.(MI_i) + B.(SI_i)} \qquad \textbf{[3.1]}$$

where,

i, reference number, existing project ID

A, importance percentage assigned by the designer to the MI

B, importance percentage assigned by the designer to the SI

Noting that A+B = 100%

We note that the values of (MI_i) should be obtained from the collected data and assigned to the existing bridges; otherwise, charts and values should be implemented in the model item that will be stated in the development process, whereas the methodology to evaluate

(MI_i) is excerpted from existing and/or future researches who delivered a methodology to count the environmental impact of a bridge based on the materials used and the energy consumed, and the final values of (MI_i) should be presented within a 1-99 scale.

On the other hand, the values of (SI_i) are calculated based on the defined factors mentioned by "WHATs" implemented in a QFD system as shown in Figure 3-7.

	Importance Rating	Bridge1	Bridge2	Bridge3	Bridge4
Loss of Vegetal	5	5	1	3	1
Potential loss of cultural Site	5	7	1	5	9
Water pollution	5	3	1	7	3
Raw Score		75	15	75	65
Surround Impact - SI		**99**	**1**	**99**	**83**

Figure 3-7 – QFD Sample

These factors will be assigned an importance rating (IR_j) according to their significance from the decision-maker's point of view. The customers of the QFD are the existing bridges and for each bridge case, the mentioned factors (WHATs) will be assigned a value ($V_{j,i}$) based on a point scale (e.g., from 1 to 10) and according to the level of correlation between Customers (existing bridges) and WHATs. The Roof part represents the correlation that exists between the customers, and this QFD part will be omitted in our study. In order to better understand the calculation process of (SI_i), we list the following three factors, which are considered as "WHATs" in the QFD: (1) Loss of vegetation, (2) potential loss of cultural site, and (3) water pollution. The importance rating for each factor is given in an appropriate column in Figure 3-8, therefore we considered them to have the same importance rate. Four Bridges will be ranked according to the three factors mentioned. For each bridge, three values ($V_{j,i}$) are presented:

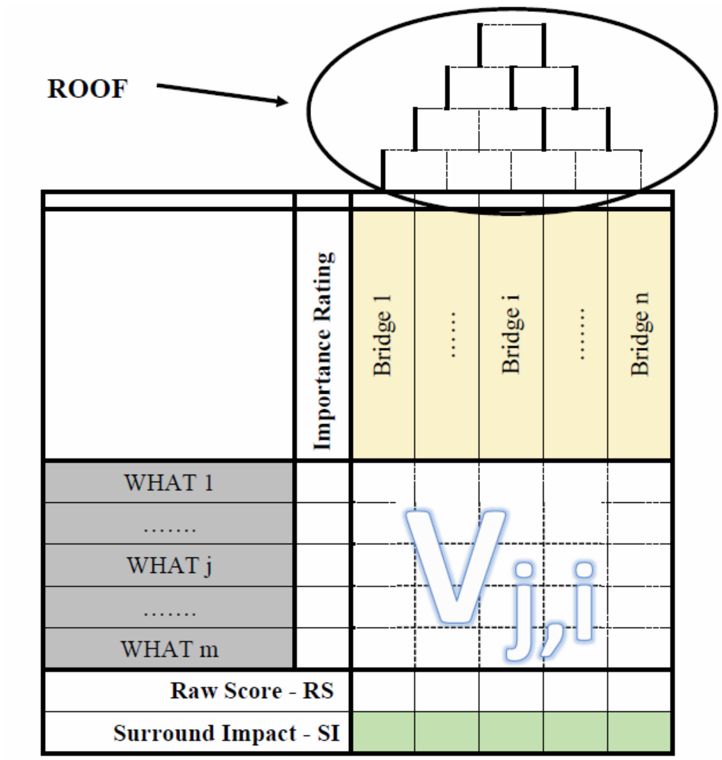


Figure 3-8 – QFD Schema

Bridge1 has respectively 5, 7, and 3 values for the mentioned factors. These values mean that Bridge1 has a medium damage impact on the existing vegetation and high damage impact on the existing water and low damage impact on the cultural site.

Bridge2 has 1, 1, and 1 respectively

Bridge3 has 3, 5, and 7 respectively

Bridge4 has 1, 9, and 3 respectively

After filling out the required data, the two lower rows are calculate as follows:

Raw Score: $$RS_i = \sum_{j=1}^{m} V_{j,i} \times IR_j \qquad \textbf{[3.2]}$$

Surround Impact: $$SI_i = INT\{\frac{RS_i - MIN[RS_i]}{\frac{MAX[RS_i] - MIN[RS_i]}{98}} + 1\}$$ **[3.3]**

The aim of Equation 3.3 is to fit the (SIi) values onto a 99-point scale which is based on the normalization procedure. After evaluating the RSi values, this set of numbers is presented within a scale going from 1 to 99. So the lower value among the SIi will be substituted by 1 and the upper value by 99, and the intermediate values will be calculated according Equation 3.3. The "INT" function obtains the integer part of the equation results, because the fraction does not affect the intended goal of its use later on in the DSS engine. By simple linear interpolation, this equation is defined as follow:

$$\left.\begin{array}{ccccc} \mathbf{Min[RSi]} & < & \mathbf{RS_i} & < & \mathbf{Max[RSi]} \\ \mathbf{1} & < & \mathbf{SI_i} & < & \mathbf{99} \end{array}\right\} \longrightarrow \textbf{SI}_\mathbf{i} \textbf{ according to Equation 3.3}$$

As conclusion, the above-listed methodology is one among many others that could be implemented in order to evaluate the environmental impact due to the bridge type selection; in the methodology's development, a suitable approach will be proposed according to the availability of the data type.

- **Aesthetic Impact Rate (AIR)**: Another important criterion considered as an area of great interest to designers is the Bridge Aesthetics, which is considered to be a difficult area to research because of its subjective nature and being an ill-defined concept (lack of consistency). Like the (EIR) value, the Aesthetic Impact Rate (AIR) has to be provided for the use of the proposed DSS. A methodology will be proposed to evaluate the (AIR) based on an innovative computational decision support tool since, to date, most of the published work on bridge aesthetics are based on the judgment of the bridge designers and on some rudimentary calculation related to bridge elements dimensions and to the bridge location and surroundings description. The opinion of the public also has an influence on the aesthetic evaluation. For that, the evaluation of the (AIR) will be based on the two main factors: (1) Public Opinion Impact (POI), and (2) Aesthetic Factor Impact (AFI).

The (POI) values are calculated upon public opinion statistics related to their level of satisfaction on a specific bridge, and this variable will be considered as performance criteria and will be presented as soft factor. The (AFI) values are defined based on many factors grouped within the following categories:

(1) Proportion and geometry: Ensuring that the deck looks reasonably slender and relating to the shape of supporting piers (i.e., round or rectangular).

(2) Environmental: Ensuring that the bridge is in harmony with its surroundings and that bridges on a road have some relationship to each other.

(3) Structural harmony: Relating to the ability of the bridge to carry the imposed loads and the way in which the loads are carried (should be obvious and should “look right,” e.g., forces should be seen “to flow” through the bridge).

(4) Focus of attention: Relating to the recognized problem with two-span bridges that the eye has nothing to focus on (bridges with an odd number of spans do not seem to suffer from this problem).

(5) Weathering and surface finish.

Many other categories might be added during the development process or/and even later on by the designers.

After screening the appropriate factors, a QFD system could be used in the same manner described previously in order to evaluate the AFI values corresponding to each bridge case, and then, the AIR value is calculated by way of the following relation:

$$\mathbf{AIR_j} = \sum_{i=1}^{14} I_i * V_i \qquad \mathbf{[3.4]}$$

where,

j, reference number, existing project ID

i, parameter indices

V, harmonic stated measure that exists between the bridge and its surroundings

A model will be established for this purpose (evaluation of AIR) to be incorporated into the model set in the data file and to be used when necessary, and this model will refer to many research projects and delivered methods.

➔ **Soft Factors (Output Criteria)**

At this point in the research, suppose that the following three criteria will be considered to make a decision. These three criteria will be considered as unknown for any new case to be analyzed, and the target of the DSS engine is to define these values based on the previous cases already stored in a data frame. Cost (C_i), Environmental Impact Rate - Local Authorities Evaluation (EIR-LA), and the Aesthetic Impact Rate – Public Satisfaction (AIR-PS) are the criteria that will be considered to evaluate and to determine an acceptable level of performance for the proposed project.

- **Cost**: One of the factors that has notable influence on a decision is the cost. Bridge cost is a vague and wide area covering many cost definitions, analyses, and factors that are considered to evaluate the "cost." Previous studies handled the bridge cost by analyzing many descriptions related to this subject such as Life-cycle cost (LCC) which covers initial cost and commissioning and operating cost, Benefit-Cost Analysis (BCA) to quantify the benefit of the asset, and so on. Every cost description will be designated by a cost Indicator (Cj_i) where "j" designates the cost indicator number in case we have more than one cost indicator to be introduced and considered in the analysis (e.g., Initial cost, LCC, BCA; each one could be considered as one indicator) and the subscript "i" denotes the project ID. Many factors with their influence on the total cost of a bridge should be considered in the stored data as criteria that affect the final decision. These factors may include, but are not limited to: (1) Location — rural or urban, or remote regions; (2) Type of crossing; (3) Type of superstructure; (4) Skew of bridge; (5) Bridge on horizontal curve; (6) Type of foundation; (7) Type and height of piers; (8) Depth and velocity of water, if it exists; (9) Type of abutment; (10) Need for special equipment; (11) Span arrangements, beam spacing. We note that the unit of any kind of cost (i.e.: LCC, BCA) that will be considered in the DSS is the "us$/sq.m" and it has to be assigned by the adjustment factors (year, location, size) in order to calculate its present net value so it can be a comparable value. The final factors (as hard and soft factors) to be considered in the methodology will be defined according to the investigation that will be conducted to find out the experts' opinions. For this reason, for every special case we may select different factors.

- **Environmental Impact Rate - Local Authorities Evaluation (EIR-LA):** This is a value defining the level of satisfaction related to the environment impact. This value could be defined based on some data and investigation, if exists and if the DSS will be applied in an area where the necessary data are available, otherwise, the government agencies and the specialists will provide their perceptions of how much, in fact, the environment has been harmed by a such bridge.

- **Aesthetic Impact Rate - Public Satisfaction (AIR-PS):** An investigation and questionnaire will be established in order to receive public opinions related to the bridge aesthetic based on many criteria which will be defined and detailed in Chapter 4, section 4.4.3.

After defining most of the criteria categories, a structure for the data module will be defined based on Figure 3-9:

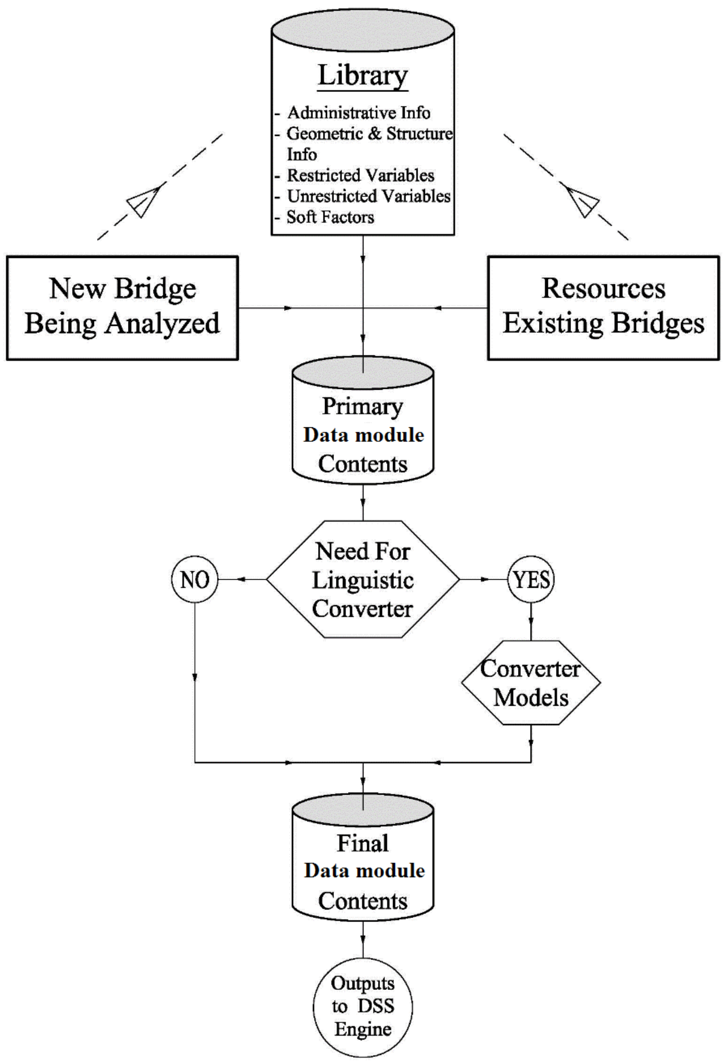


Figure 3-9 – Global Data Framework

The main component of the Data framework is the Library block. The library contains five defined categories, and the information (factors and variable definitions) incorporated into these categories will be established according to the available information gathered from the resources. After establishing the library (covering all the possible factors for the 5 categories), values (numerical and/or linguistic) will be assigned to the library items in order to define all of the criteria incorporated in the primary data module. To avoid any confusion between factors, variables, and criteria definitions, here is a brief listing of the meaning of each one used in this proposal:

"Factor" means the definition of an item related to the bridges; this item could be geometric, structure, or any kind of information that describe and define information associated with bridges. For instance, the following terms are considered factors: Number of spans, type of bridge, LCC, highest point under bridge.

"Variable" is used when it is required to discuss the values assigned to a factor.

"Criteria" is labeled as the factor with its assigned value with which it influences the decision.

Microsoft Excel and/or Access software are the tools that will be used in order to computerize the process of the data contents. It gives us true command of the data, enabling us to retrieve it, sort it, analyze it, summarize it, and report results. It combines data from various files, so that information will never have to be entered twice. It makes data entry more efficient and accurate. It will be much more than just a list or table, because it will also contain the defined models (e.g., linguistic convertor, point scale, QFD system) that aim to analyze the information and to deliver it in a suitable manner and usable form. To clarify and visualize the data flow of the Data frame, we started with: **(a)** a Data Modeling (DM), where Figure 3-10 shows the connectivity between each Bridge ID (including the related administrative info) to information on the remaining four categories (Geometric & Structural parameters, Uncontrolled, Controlled, and Soft Criteria), and **(b)** a Physical Implementation (PI), where Figure 3-11 represents the tables that enclose the criteria related to the collected bridge data. This section will be further developed in Chapter 4.

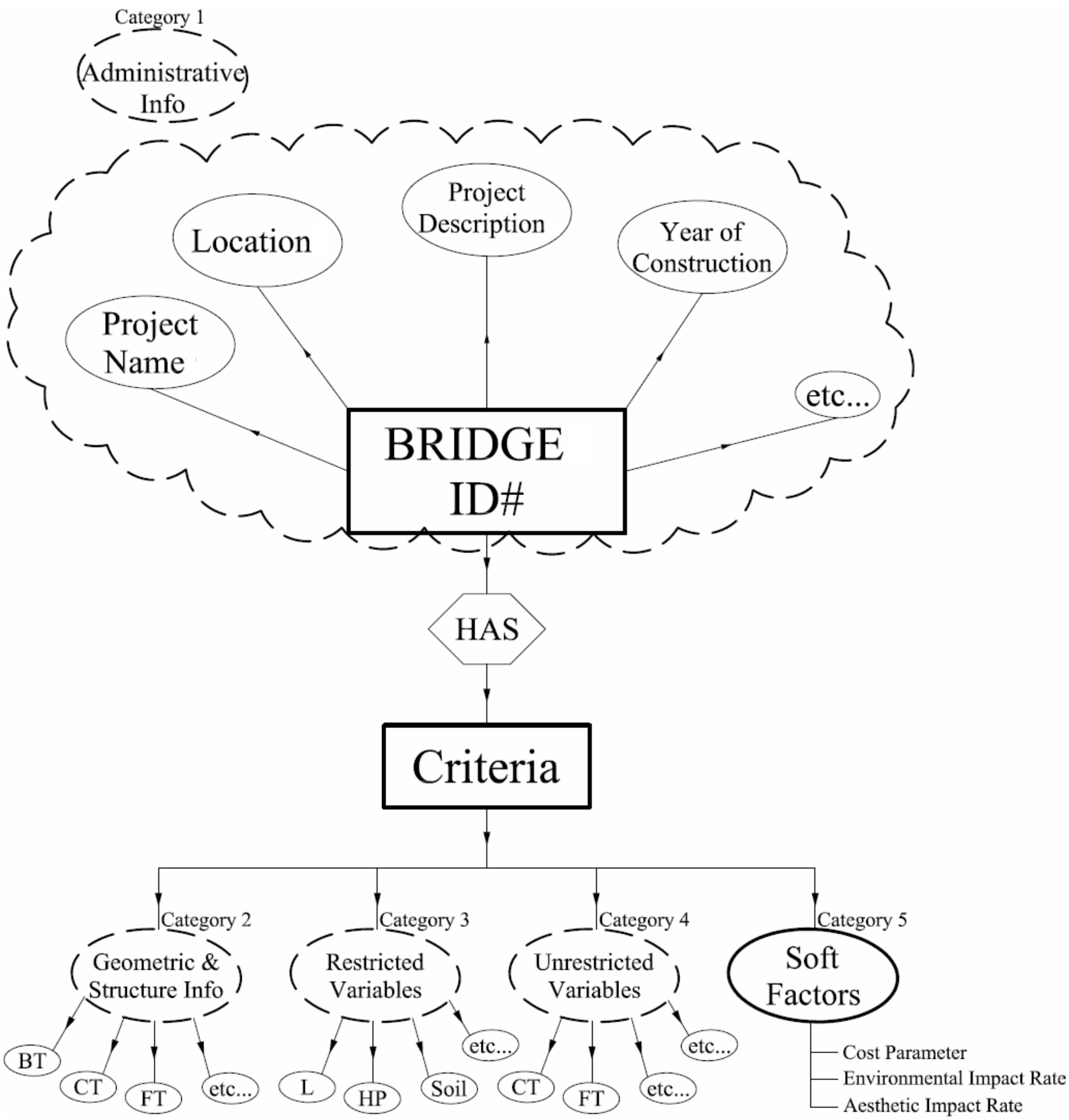


Figure 3-10 – Data Modeling (DM)

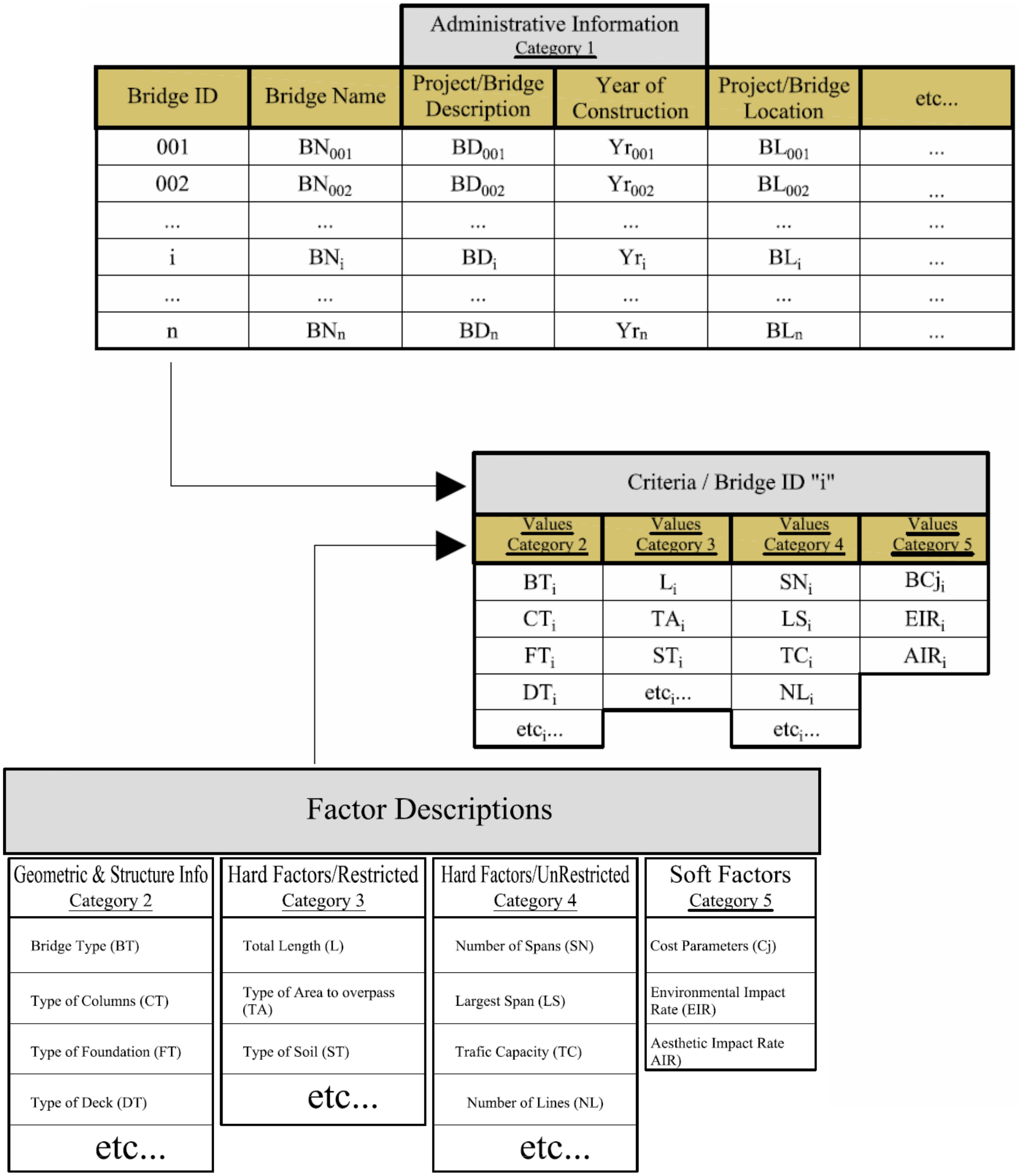


Figure 3-11 – Data Physical Implementation (PI)

3.3.4 DSS Engines

The engine of the Decision Support System will be developed in Chapter 6, which will provide a detailed explanation concerning the work within an artificial intelligence environment by analyzing its input and output data.

3.3.4.1 Introduction to the Artificial Intelligence AI

Since Artificial intelligence (AI) aims to replace human intelligence with machines, and since the main goal of the proposed methodology is to highlight and control human subjectivity, the Artificial Neural Network (ANN), which is considered one of the AI fields, will be adopted to serve and achieve the DSS objective. Many definitions delineate what Artificial intelligence (AI) is. AI could be considered an intelligent computation based on a computerizing process and characterized by considering the types of computations that do not seem to require intelligence (human intelligence). Many techniques fall in the (AI) environment, such as Fuzzy systems (FS), Genetic Algorithms (GA), and many other knowledge engineering systems and logic programming. ANN is most suitable to serve our goal in this proposal since it was tested and used on several similar cases and approaches.

3.3.4.2 Artificial Neural Network Frame

An artificial network consists of a pool of simple processing units, which communicate by sending signals to each other over a large number of weighted connections. A set of major aspects of a parallel distributed models can be distinguished by a set of processing units (Neurons), state of each neuron (as output), connection between the units (input, hidden, and output neurons), propagation rules, an activate function which determines the new level of activation based on the effective input and the current activation, an external input, a method for information gathering (stored in a data structure and then implemented into the ANN – Learning rules) and an environment within which the system must operate. Within ANN systems, three types of units have to be distinguished: input units, which receive data from outside the neural network; output units, which send data out of the neural network; and hidden units whose input and output signals remain within the neural network. The main characteristics of the ANN that have to be specified in order to describe the process that will be adapted by using an ANN are as follow:

(1) Back propagation learning rule, where the main idea behind this solution is that the errors for the units of the hidden layer are determined by back-propagating the errors of the units of the output layer.

(2) Number of the hidden layers and their neurons that will be defined according to the number of cases to be adapted in the training process. As mentioned by "Neuroshell" software manual, the number of the neurons in the hidden layers could be defined by equation (eq. 3.5) mentioning that the default number of the hidden neurons for a 3-layer network is related to the number of input and output neurons and the number of patterns (cases):

# of hidden neurons = 1/2(Inputs + Outputs) + Sqrt(# of Patterns) [3.5]

(NB: For more than one hidden slab divide the number above by the number of hidden slabs.) Also, it is mentioned in the software's manual that the training numbers should be more than 10 times the input neurons number.

(3) The activation function will be a standard sigmoid function (Eq. 3.6) since it is considered to be very similar to the input-output relationships of biological neurons and it is the one of the more popular activation functions for back-propagation networks.

$$S_c(x) = \frac{1}{1+e^{-cx}} \quad [3.6]$$

Where,

Sc: presents the activation function.

c: Constant provided for the activation function

It is obvious how ANN works in detail and how the weights will be adjusted by the back-propagation paradigm since many studies provide plenty of information related to this subject. Additional guide lines related to the ANN frame and their functions will be detailed in Chapter 6 where a full development process will be provided.

3.3.4.3 Input and Output Data

After introducing a brief description of ANN, the proposed ANN frame will cover the following characteristics (Figure 3.12):

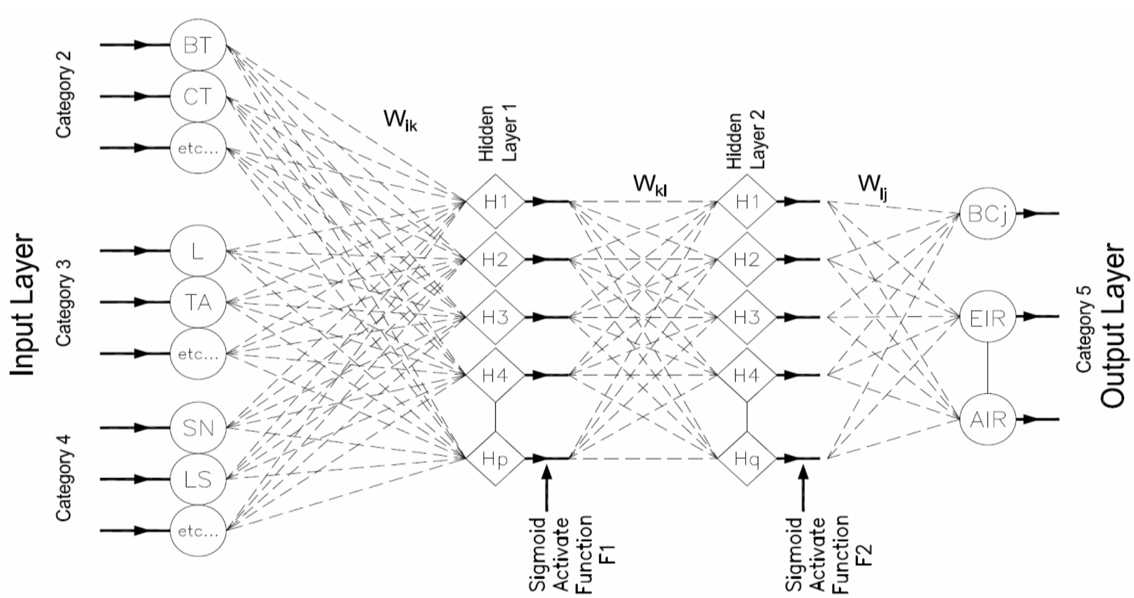


Figure 3-12 – ANN Framework

Input Layer, covers three categories: (1) Geometric and structural information, (2) Uncontrolled variables, and (3) Controlled variables. The selected factors to be included in these categories are selected based on the expert opinions obtained through interviews and questionnaires where the factors are proposed, ranked, and selected accordingly, taking into consideration the particulars of the location as well as the available data to be used. The values assigned to the input neurons are retrieved from the appropriate tables in the data module according to the existing cases used for the learning process of the network.

Output Layer, presenting the soft factors, is defined as "performance criteria" and is also selected based on the expert opinions obtained through interviews and questionnaires. For instance, for this moment, these soft factors could be the Cost, Environmental Impact Rate, and Aesthetic Impact Rate. Their values are retrieved from the tables in the data module for the learning process.

Hidden Layers, that are interconnected by the weights (Wik, Wkl, Wlj) and using an appropriate activate function (Sigmoid functions F1 and F2). One or two hidden layers will be included with defined numbers of neurons according to the number of input and output neurons and patterns. The mentioned weights and the hidden neuron values are defined after network training based on the existing cases that should be considered and used in the stated methodology.

Based on the previous and existing cases, a training process will be launched to generate the appropriate weights. Sets of patterns will be selected to test the results. Once all parameters of the ANN are well-defined, the data related to a new case will be prepared in order to be implemented in the ANN and to acquire the required results. The data related to Categories 3 and 4 are well recognized for the new case based on the constraints related to the project site, while the data of Category 5 will be generated by the networks and a decision will be made based on an analysis of their values. What remains is the data related to Category 2. The procedure to determine their values (for the new case being analyzed) will be detailed in the following section, based on a statistical study, where different alternatives will be defined based on different values that could be assigned for the factors. Another procedure is also detailed in Chapter 6, where the values for the appropriate alternatives are defined based on the running for a "first arrangement" of the ANN by considering the Category 3 and 4 factors as input and Category 2 factors as output data retrieved from the ANN.

3.3.4.4 Charts for the Geometric and Structure Criteria

In general, the ANN, presented in the previous section, is able to accept any values concerning the criteria of Category 2 as input values for the neurons, but, in order to be more realistic and accurate, it will be better to select a set of values based on an analysis of the existing cases, taking into consideration the experts' opinions whereas the different proposed alternatives to be evaluated are approved by them. For that, charts have to be established for each criterion (from Category 2) showing its relation to another criterion from Categories 3 and 4 in order to provide a guideline while choosing the appropriate variable values. For instance, let us develop the charts for the BT (Bridge Type) criteria with the SN (Span Number) from Category 4. Suppose that we have "M" previous cases to be considered in our study, and we have four values for the BT criteria, which are noted (BTi = girder bridge (1), arch bridge (2), cable stayed bridge (3), and suspension bridge (4)), while the noted values for the SN are: 1, 2, 3, 4, 5 spans. Based on the existing cases, percentage schedules will be established by calculating the number of the cases that have BT=1 with SN=1, then BT=1 with SN=2 and so on to finally get the results that are represented in Tables & appropriate charts. For instance, for a set of one hundred existing bridges, we noticed that sixteen bridges (7+5+3+1=16) have a single span. Among these bridges, we have 7 bridges falling under bridge type BT1, 5 bridges in bridge type BT2, 3 bridges in bridge type BT3, and 1 bridge in bridge type BT4. This information is presented in the corresponding raw allocated for single Span (SN=1) (Table 3-1-(a)). The mentioned information is also presented as percentages in Table 3-1 (b). These percentages are defined as follow: for bridges with single span, 7 out of 16 bridges (7/16=44%) fell under bridge type BT1, 5 out of 16 (5/16=31%) under bridge type BT2, 3 out of 16 (3/16=19%) under bridge type BT3, and 1 out of 16 (1/16=6%) under bridge type BT4. The percentages are presented in the corresponding raw allocated for single span (SN=1) (Table 3-1-(b)). The same procedures are applied to assign the appropriate values, as well as percentages, related to the different span numbers. After that, a chart (Figure 3.13) will be presented based on the information shown in the table mentioned (Table 3-1). We proceed in the same manner to present all of the relationships between each criterion from Category 2 to each criterion from Categories 3 and 4. After that, we continue with the new case being analyzed to extract the criteria values (the inputs). As explained previously, the criteria values of Categories 3 and 4 will be envisioned based on the real situation on site, and based on these values we may extract the percentage from the charts already established in a manner of defining the percentage spread over the different types of each criterion (of Category 2). After extracting the relevant values, a QFD will be constructed for each criterion from Category 2 (the different types of the selected criteria will be considered as HOWs) in relation with the criteria from Categories 3 and 4, in order to evaluate a percentage of influence for these criteria on the different types of a criteria from Category 2 (Figure 3-14).

Table 3-1 – BT / SN Relationship – Tabular presentation form : (a) Numbers; (b) Percentages;

# of Cases	BT = 1	BT = 2	BT = 3	BT = 4
SN=1	7	5	3	1
SN=2	8	10	5	2
SN=3	3	4	8	5
SN=4	2	3	4	10
SN=5	1	4	5	10
Total number of cases:				100

(a) Numbers

%	BT = 1	BT = 2	BT = 3	BT = 4
SN=1	44%	31%	19%	6%
SN=2	32%	40%	20%	8%
SN=3	15%	20%	40%	25%
SN=4	11%	16%	21%	53%
SN=5	5%	20%	25%	50%

(b) Percentages

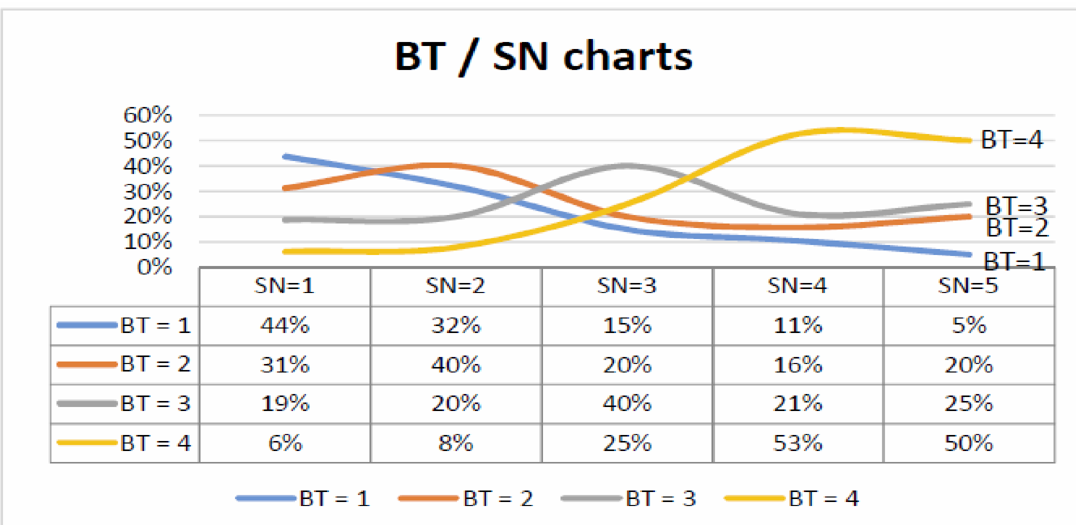


Figure 3-13 – BT / SN Relationship – Graphical Representation by Charts

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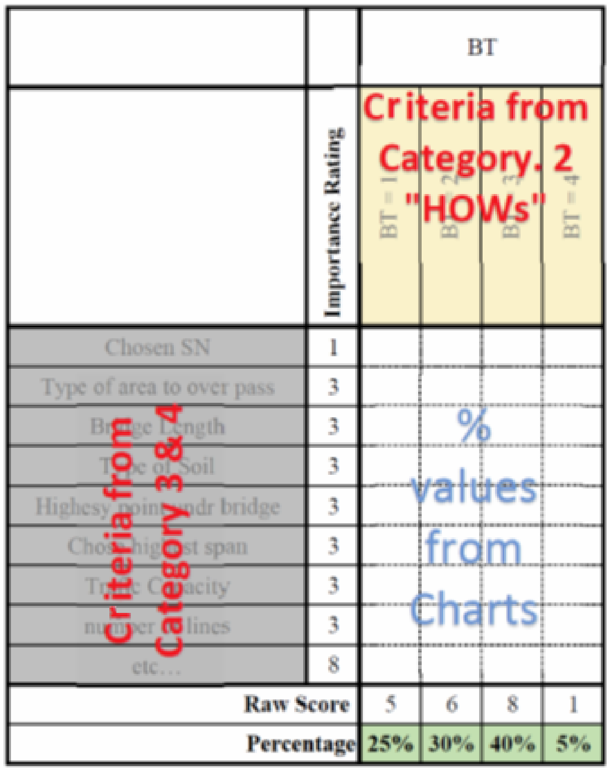


Figure 3-14 – QFD of the percentage Criteria's type

The Importance Rating (from 1 to 9) presented in the mentioned QFD is established by the decision maker based on his own insight concerning the appropriate importance for each criterion (These Importance Rating values are subjected to "decision-maker subjectivity," but they will be flexible to be modified and the location's subjectivity is defined so that it can be easily controlled which is the purpose of introducing these IR values). Finally, the criteria type (HOWs) that will get the highest percentage will be selected to be introduced into the DSS engine as a criteria value of the new case. In this manner, the selection of the criteria values belonging to Category 2 will be based on a systematic process. Another method to define the possible alternatives is to launch the engine in a first arrangement as will be detailed in Chapter6. At the end, after extracting the relevant input values to be used, a final engineering judgment, analysis, and criticism of these values will have to be carried out in order to avoid any discrepancies and inconsistencies.

3.3.5 BrIM Tools

Many tools and software programs are used to apply the BrIM concept. Geometric (covering the architecture elements) and structural (concerning the structure elements' capacity to resist) are implemented through commercial software/tools used by the construction industry in order to control and ease the engineer's tasks. As will be detailed in Chapter 5, these tools will receive the results from the DSS engine and will transfer them into the real world environment. The decision makers (engineers) will verify all the bridge aspects already extracted from the input and output data of the DSS engine and will conduct verification over the project visualization through a 3D model, then a decision will be considered by the decision maker. Either the extracted results are acceptable, or they should be rejected or modified and in this case, launching other iteration will be required. For this purpose, different types of software are proposed to be used (e.g., Tekla structure, Bridge CSI) for the structure analysis, and (e.g., Autodesk 3D Civil CAD and Design and Revit) aspect verifications in a 3D environment.

3.3.6 Sensitivity Analysis (SA) and Level of Realistic (LR)

As described in the previous sections, the DSS is based on many criteria (Categories 2, 3 and 4) that affect the results (criteria from Category 5). In order to verify the influence of each input criterion on the results, a Sensitivity Analysis (SA) will be carried out in order to understand the relationships between input and output criteria. Also, the importance of the SA is that it will study how the uncertainty in the output of the DSS can be apportioned to different sources of uncertainty in its inputs, and the SA will identify the DSS inputs that cause significant uncertainty in the output in order to reduce its uncertainty.

On the other hand, a level of realistic (LR) will be analyzed over each output value provided by the DSS engine based on charts produced from the Sensitivity Analysis. This verification aims to quantify how much the results are realistic. This procedure will be based on a comparative process between the ratio of the estimated over the actual values of a specified criteria (from Category 5) from an existing case with the ratio of the estimated value over the value given by the DSS engine for this specific criterion. Through this comparison, we may have a tool to judge how much the output values make sense.

3.4 Summary

It is commonly known that the experts' decisions are based on their wide experience. At the conceptual stage of a bridge design, the experts propose a bridge type with their components based on their own experience in a reasonable way; but what will happen, for instance, if the following problems are noticed:

(a) The expert has some doubt about his decision, especially with missing arguments for any needs of convenience.

(b) Another expert has an opposing opinion. How would that expert be convinced?

(c) How to clarify that the distinctiveness of the bridge area has been well considered.

In this way, it will be necessary to provide some tools, based on a scientific and systematic methodology, to help the experts to convince themselves first and to convince others if there is any doubt or any opposition to their opinions. The aforementioned tools could be considered as an argument to defend the expert's decision and to convince others. The results of the described DSS are intended to be considered as a guideline for a novel tool to be adapted and to be improved later on through additional investigations and testing. A systematic methodology is stated based on the AI environment to help decision makers in their decision through the selection of the bridge type at the conceptual design phase based on and taking into consideration the performance (e.g., cost, environment, aesthetic) of existing bridges; this aims to flip the high percentage of the subjectivity to objectivity for any conceptual design process in order to highlight/increase objectivity more than subjectivity. The collected data from existing cases are treated through steps (linguistic-numerical converting, point scale) to convert them to suitable values to be used in the DSS engine. Sensitivity Analysis (SA) and the level of realistic (LR) will serve to understand well the relationship between the input and output criteria. BrIM implementation tools are used to realize the decision parameters and to provide additional tools for the decision maker to verify any missing or conflicting data and also to benefit from the outcomes and information given by the BrIM tools such as quantities of construction materials. Working under the BrIM environment will lead to considerable profit, especially once it is used at the conceptual design phase. Its use will significantly reduce the design problems that could happen during the production of the detailed design. Also, when the decision-maker proposes different alternatives, the BrIM will help to show different relevant aspects. For instance, the appropriate material quantities will be automatically counted and, for any modification or adjustment, these quantities will be updated. 3D visualization for the different alternatives is well presented with their surroundings, helping to evaluate the extent of satisfaction of aesthetic goals. For the DSS engine, it will be designed under an ANN environment. Many considerations have been taken into account during the ANN training when they are automatically covered by the selected software that will be used. The number of hidden layers with the hidden neurons is related to the number of cases with the input and output neurons to be considered for the training process with the appropriate activation function as mentioned in Section 3.3.4.2. The training process will be presented, and generalization for errors is controlled by the validation and test curves. If the test curve had increased significantly before the validation curve increased, then it is possible that some overfitting might have occurred. The next step in validating the network is to create a regression plot, which shows the relationship between the outputs of the network and the targets. If the training were perfect, the network outputs and the targets would be exactly equal, but the relationship is rarely perfect in practice. All these verifications are achieved automatically and by simple control through the chosen software (refer to Section 6.3). Most of the equations and related tables and framing are based on two main techniques: (a) Quality function deployment (QFD) and (b) Normalization.

Quality Function Deployment (QFD) is a technique presented as a structured method to identify and prioritize customer expectations quickly and effectively. The QFD method identifies and classifies customer desires, identifies the importance of those desires, identifies engineering characteristics which may be relevant to those desires, correlates the two, allows for verification of those correlations, and then assigns objectives and priorities for the system requirements. This process can be applied at any system composition level in the design of a product (decision), and can allow for assessment of abstraction systems at different levels, based on the output of QFDs matrices assessed for those system levels.

The **Normalization** technique is used to compare scores or sets of scores obtained on different scales. In order to do so, we need to "eliminate" the unit of measurement; this operation is called normalizing the data. We may fit any range of data within a defined scale (e.g., 1-10) by a linear interpolation procedure. It is not recommended to eliminate engineer participation and insight, because his engineering judgment is mandatory for any decision to be made and this may have occurred through the investigations and his analysis of the DSS outcomes either through BrIM tools or by inspecting the results of the SA and LR. Based on many pieces of research, any decision related to bridge type selection, with its related components, is affected by many factors. These factors have been grouped into 4 categories:

Category II (entitled "Geometric and Structural Information"): These are the factors that describe the bridge and bridge component (element) types, as well as the estimated quantities of the bridge materials.

Category III (entitled "Uncontrolled Variables"): This category covers unchangeable variables that are evaluated according to location constraints (i.e., total bridge length, highest point, type of the overpass, and any other variables proposed by experts being investigated according to a specific project)

Category IV (entitled "Controlled Variables"): This category covers changeable variables that are assigned by the designer (decision-maker) (i.e., number of spans, traffic capacity, number of lanes, and any other variables proposed by experts being investigated according to a specific project).

Category V (entitled "Soft Factors"): This category covers criteria concerning the performance of the proposed bridge.

The factors in Category I are just used to identify the bridges by their names, years of construction, locations, and general appropriate information. The formulas used are based on two main approaches: (a) Quality Function Deployment (QFD) based on the different criteria correlated with the appropriate parameters where the "what's" and "customers" of the QFD are defined by the factors and parameters respectively, and adjusted in order to fit the needs of the QFD; and (b) the interpolation formula to identify the relevant values.

Chapter 4
Data Structure and Analysis

4.1 Introduction

There are many theories and approaches which have been proposed for decision-makers to come to a decision for a bridge type with its components. For instance, *Mahmoud (2015)* considered an approach of reducing the subjectivity at the beginning of the conceptual design phase. Figure 4.1 shows the major considerations for bridge type and span length. However, the mentioned approach is unconvincing for not observing the performance indicator properly. Therefore, the aim of this research is to propose an approach to determine appropriate bridge type based on various performance indicators. In point of fact, there are many factors to be considered in this chapter, both the influence factors and the performance factors designated by performance criteria. Moreover, in this thesis an analysis will be carried out by selecting the appropriate factors in order to determine the alternatives and evaluate their performance.

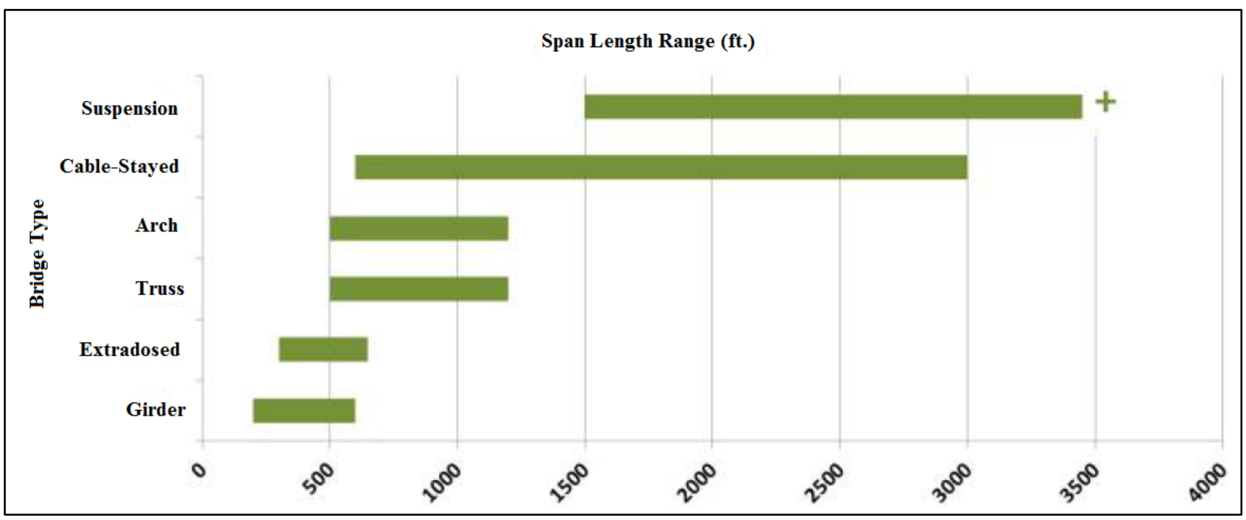


Figure 4-1 - Recommended span ranges for various bridge types, *(Mahmoud, 2015)*

After selecting the appropriate factors, alternatives will be defined. Each alternative will be analyzed in order to rank the proposed alternatives and to identify their performance. Since the presented DSS aims to reduce subjectivity and go further toward objectivity, it is vital to provide a detailed methodology, known as a flexible methodology, in order to help the decision-maker to perform any changes during any part of the DSS, and observe the effects that might occur with any modification. Yet, the flexible methodology has to be implemented by using two important measurement terms such as the subjectivity and flexibility. In fact, "Subjectivity" and "Flexibility" are two major issues that will be addressed extensively during the structuring of the data module components. Term "Flexibility" means that all forms, tables and data presented in the methodology are not restricted by their presented way, and it is easy to be subjected to any kind of adaptation. The following paragraphs will provide a methodology to establish/design and construct/develop an editable data frame in which users will be able to be update, manipulate and compile the collected and stored data.

4.2 Research Structure

To define the different parts of the delivered DSS, Figure 4-2 provides the three components to be customized and analyzed. The data module, BrIM, and DSS engine will interact and exchange information in order to attain the desired decision and appropriate results.

The first component of the DSS is the Data module. Once the user decides to use the DSS, there are two possibilities for monitoring the usage process, either by selecting an existing data module that has been previously established, or by proceeding with establishing appropriate new data module that suits the case project.

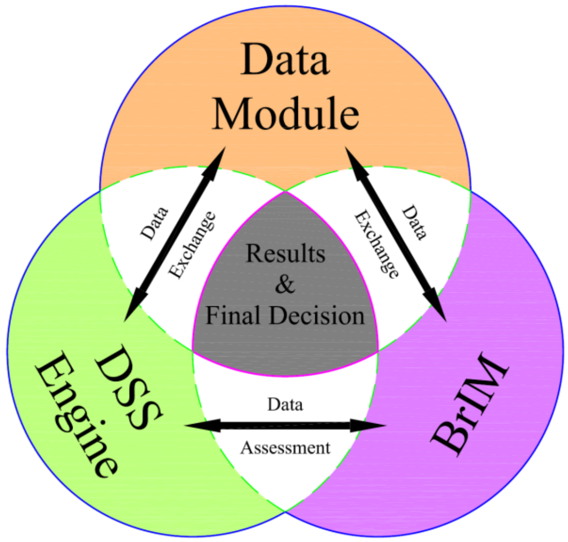


Figure 4-2 – Interconnection of DSS Components

4.3 Data Module

To establish a data frame it is important to define and consider the factors that might influence the decision related to the bridge components. This chapter provides a methodology to define the influence factors with their relevant components where each region has its own particularity. The data module frame with its different sections and the relevant collected information is structured as follows:

(1) a list of influence factors to be established and grouped within five categories. Bridge ID and the different categories are detailed in Section 4.3.1;

(2) a questionnaire (Q01) addressed to experts and professionals in order to define the mentioned factors, as detailed in Section 4.3.1;

(3) the appropriate values for the mentioned factors are defined as follows:

a- numerical information directly collected from the existing bridge by simple investigation and a search for data. Samples of these types of factors are the geometric aspect, capacity, material quantities, and many other factors;

b- linguistic information (e.g., bridge type, soil type) that needs a linguistic converter as presented in Appendix F;

c- some formulas are established in order to define some other variables (e.g., EIR, AIR, AIR-PS) (refer to Sect. 4.4);

(4) a complete data schedule is established (refer to Appendix D-7);

(5) statistical analysis is conducted for two purposes: (refer to Sect. 4.7)

(i) to highlight the homogeneity/heterogeneity of the data; and

(ii) to provide hints for the decision maker on what kind of alternatives could be proposed based on the existing cases;

(6) based on the existing cases, the ANN is trained in order to extract the performance of each alternative;

(7) factors considered as input neurons as well as the factors considered as output (performance criteria) are as defined in Section 4.3.1

4.3.1 Influence Factors and Bridge Components

As discussed in previous sections, particularity has to be considered for each region; therefore, based on the influence factors, a questionnaire is addressed to the government and private agencies involved in bridge construction, bridge management, and bridge design, to get their opinions of the common factors that have the most influence on their decision. In order to organize the factors, different categories are defined to distinguish between different factor types. It is known that these factors are related to bridge projects (existing or to be constructed), so the first category will cover administrative information: Bridge "ID," Bridge Name "BN," Bridge Location "BL," and any other factor could be useful (Refer to table 4-1). This information, if needed, is made available by storing it in a data frame to be suitable for many projects with different locations and years of construction. Two other categories (Categories II & V) define the alternatives and their performance indicators and present a set of results for the final decision. Category II, entitled "Geometric and Structure Info," covers the factors that define the bridge components.

Table 4-1 – Category I

Groups			Abr.	Parameters
Administrative Info	Category I	I.1	ID	Bridge ID
		I.2	BN	Bridge Name
		I.3	GD	General Description
		I.4	BL	Bridge Location
		I.5	YD	Year of Decision made
		I.6	YS	Starting Year of Construction
		I.7	YC	Ending Year of Construction
		I.8	YO	Year Put in Operation

For a specified bridge (ID), the following bridge elements are presented: Bridge Type "BT," Column Type "CT," Foundation Type "FT". All these factors with their associated values are provided for different existing projects as well as for proposed alternatives concerning new projects (refer to Table 4-2). For existing bridges, the values assigned to the factors of Category II are collected from the real situation. For a new bridge under study, the relevant values are assigned based on the proposed alternatives and from the BrIM analysis after the implementation in the appropriate tools. Category V variables are collected from the existing cases based on the level of their performance; for a new bridge under study, the variables will be extracted from the DSS engine working under an ANN environment. The factors presented in Category V are known as performance indicators. For instance, the appropriate factors defined as performance indicators are: Actual Initial Cost – PV "IC," Operation & Maintenance Cost over 100 Years "OC" (refer to Table 4-3).

Table 4-2 – Category II

Groups			Abr.	Parameters
Geometric & Structure Info	Category II	II.1	BT	Bridge Type (Girder, Arch, etc…)
		II.2	DT	Structure Type for Deck
		II.3	CT	Column Type
		II.4	FT	Foundation Type
		II.5	MT	Material Type
		II.6	CV	Volume of Concrete
		II.7	ISW	Industrial Steel Weight
		II.8	CS	Exposed Concrete Surfaces
		II.9	SS	Exposed steel surfaces
		II.10	EIC	Estimated Initial Cost - PV
		II.11	EIR	Environment Impact Rate
		II.12	AIR	Aesthetic Satisfaction Rate

Table 4-3 – Category V

Groups			Abr.	Parameters
Performance Factors	Category V	V.1	IC	Actual Initial Cost - PV
		V.2	OC	Operation & Maintenance Cost over 100 Years
		V.3	DC	Dismantling Cost
		V.4	EIR-LA	Environment Impact Rate - Local Authorities Evaluation
		V.5	AIR-PS	Aesthetic Satisfaction Rate - Public Satisfaction
		V.6	FS	Functional Satisfaction at first use
		V.7	CTM	Actual Construction Time / Estimated

The factors considered as performance indicators are defined according to the questionnaire addressed to professionals working in bridge management and relevant governmental and private agencies, to be specific to the project's region. In addition to the performance indicator factors, two categories of factors remain, which are defined according to the questionnaire previously mentioned, these categories are: (a) Category III, known as "Uncontrolled Variables" (Table 4-4), covering the "unchangeable variables" that are automatically recorded once the location of the bridge is determined; (b) Category IV, known as "Controlled Variables" (Table 4-5), collecting the "changeable variables" that could be modified (as appropriate values) toward an optimal solution. For instance, to cross over an obstacle, the main span is likely to be controlled by the local topography.

Table 4-4 – Category III

Groups			Abr.	Parameters
Uncontrolled Variables	Category III	III.1	L	Total Length
		III.2	TA	Type of Area to overpass
		III.3	RBT	Road-Bridge Type
		III.4	Com	Complexity
		III.5	TS	Soil Type
		III.6	HP	Highest point
		III.7	AP	Availability of Professional Companies in Bridge Construction

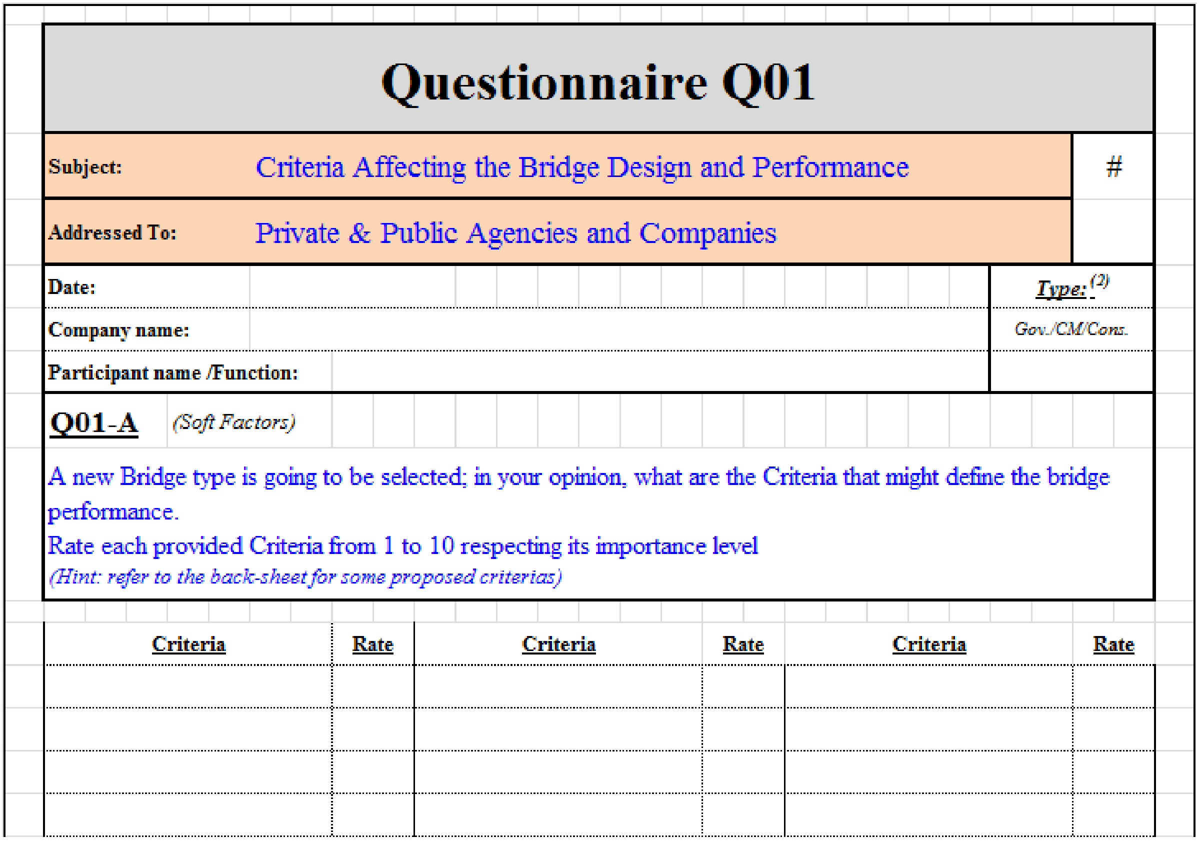
Even for minor crossings, the physical size of the obstacle to be crossed will be the largest determinant of span. However, an expert bridge design engineer should hunt for the most economical choice. Categories III, IV and V are grouped under two main types of factors: (i)

Hard Constraints, covering categories III & IV, and (ii) Soft Constraints, for category V.

Table 4-5 – Category IV

Groups			Abr.	Parameters
Controlled Variables	Category IV	IV.1	SN	Number of Span
		IV.2	LS	Longest Span
		IV.3	NL	Number of Lanes
		IV.4	TW	Total Width
		IV.5	MS	Max Speed
		IV.6	ML	Max Load
		IV.7	TRC	Traffic Capacity
		IV.8	BG	Bridge Geometric (Straight, Skewed, Curved)

As mentioned earlier, the questionnaire is used to define the appropriate factors needed to consider the particularity of the area under consideration. Referring to Figures 4-3 and 4-4, and Appendices D-1 and D-2, the questionnaire “Q01” is used to collect the necessary opinions of professionals. The questionnaire is addressed to experts and professionals working in the bridge management field. Their opinions about the performance criteria that define specific alternatives are valuable. As the professionals they are asked to provide the criteria with an importance rating (Figure 4-3). Aside from that, the experts are also asked for their opinion about the factors that influence the performance of the selected alternative. Figure 4-4, asks for the factors with their importance rates. To help the professionals with filling in the questionnaire, a pool of factors and criteria are mentioned in Appendix D-2. In Appendix D-2, professionals can either select a factor from the provided pool or introduce other factors according to their experience. After collecting the expert opinions, a simple evaluation is conducted in order to rank the different factors using the following equation (Eq. 4-1):



Questionnaire Q01

Subject:	Criteria Affecting the Bridge Design and Performance	#
Addressed To:	Private & Public Agencies and Companies	
Date:		***Type:*** (2)
Company name:		*Gov./CM/Cons.*
Participant name /Function:		

Q01-A *(Soft Factors)*

A new Bridge type is going to be selected; in your opinion, what are the Criteria that might define the bridge performance.

Rate each provided Criteria from 1 to 10 respecting its importance level

(Hint: refer to the back-sheet for some proposed criterias)

Criteria	**Rate**	**Criteria**	**Rate**	**Criteria**	**Rate**

Figure 4-3 – Questionnaire Q01-A – Performance Criteria

$$RFC_j = \frac{\sum_{i=1}^{n} R_{ij}}{\sum_{j=1}^{m}\sum_{i=1}^{n} R_{ij}} \qquad \text{(Refer to Table 4-6)} \qquad [\,\mathbf{4\text{-}1}]$$

Where n is the number of participants to the questionnaire Q01

i indicates a specific participant

m is the number of factors considered

j indicates a specific factor

R_{ij} is factor j of participant I

RFC_j is the rate value for the j factor

The decision maker will consider the appropriate factors based on their higher ranking RFC_j.

Q01-B *(Hard Factors)*

A new Bridge type is going to be selected; in your opinion, what are the factors that have influence on the bridge performance Criteria.
Rate each provided factor from 1 to 10 respecting its influence level.
(Hint: refer to the back-sheet for some proposed factors)

Factors	**Rate**	**Factors**	**Rate**	**Factors**	**Rate**

NB:
1. It is preferable to participate more than one participant (decision-maker, Senior Engineer) from one Company/Agency
2. Gov.: Government Agency; CM: Construction Management or Main Contractor; Cons.: Consultant Agency
3. Use another sheet if more space is needed.

Figure 4-4 – Questionnaire Q01-B – Influence Factors

Table 4-6 – Summary Form for the Questionnaire Q01

Q01 - Summary Results							
Factors for each Category alone	**Participant #01**	……	**Participant #i**	……	**participant #n**	ΣR_{ij}	RFC_j
Factor 1	R_{11}		R_{i1}		R_{n1}	ΣR_{i1} (i=1to n)	$\Sigma R_{i1}/\Sigma\Sigma R_{ij}$
…….							
Factor j	R_{1j}		R_{ij}		R_{nj}	ΣR_{ij} (i=1to n)	$\Sigma R_{ij}/\Sigma\Sigma R_{ij}$
….							
Factor m	R_{1m}		R_{im}		R_{nm}	ΣR_{im} (i=1to n)	$\Sigma R_{i1}/\Sigma\Sigma R_{ij}$
						$\Sigma\Sigma R_{ij}$ (i,j=1 to n,m)	

The previous procedure highlights the factors to be considered among Categories III, IV, and V. The factors embedded in the first category are easy to define since they present administrative information and do not need any engineering insight. For the second category, bridge components will be defined according to the needed and proposed details of the selected alternatives. In general, the following factors will be considered among Category II, with the flexibility to add or reduce any related factors: Bridge Type (BT), Column Type (CT), Deck Type (DT), Foundation Type (FT), and Material Type (MT). Further to these factors, others may also be considered, such as Concrete Volume (CV), Industrial Steel Weight (ISW), Exposed Concrete Surface (CS) and Exposed Steel Surface (SS), which will be retrieved after implementing the alternatives in BrIM tools. In addition, Estimated Initial Cost (EIC), which is calculated by the traditional method, could be included also. Two other factors, Environment Impact Rate (EIR) and Aesthetic Impact Rate (AIR) can also be calculated and included.

4.3.2 Factor Values

After defining the factors included in each category, variables (factor values) have to be evaluated. Three types of variables are considered: the first type covers the variables that can be automatically defined without the need of any interpretation, since they are numerical values: (i.e., Bridge Total Length (TL), Number of Spans (NL), Maximum Load (ML) ,Maximum Speed (MS)). The second type comprises factors like the Environment Impact Rate (EIR), Aesthetic Impact Rate (AIR); these factors need some formulation in order to be evaluated. The third type is a linguistic converter model that converts alphabetic variables to numeric variables.

4.4 Formulation for Variables

Based on the factors mentioned in Tables 4-1 to 4-5, some formulation is needed to produce the following:

(1) Environment Impact Rate (EIR) from Category II

(2) Aesthetic Impact Rate (AIR) from Category II

(3) Aesthetic Impact Rate – Public Satisfaction (AIR-PS) from Category V based on Questionnaire Q02.

4.4.1 Environmental Impact Rate (EIR)

At the conceptual design phase, parameters that affect the environment must be verified. This is due to the lack of detailed execution drawings, construction processes, and the needed equipment. Thus, at this stage, the analysis is based on the estimation of CO_2 emissions with the inclusion of energy consumption and its impact on the environment, by indirectly taking into consideration the quantities of the materials used, using the following equation:

$$\boldsymbol{EIR}i = ANA_{Ni} + CV_{Ni} + ISW_{Ni} \qquad [\,\mathbf{4\text{-}2}]$$

Where,	ANA_N	Normalized Factor [1-10] related to Affected Natural Area
	CV_N	Normalized Factor [1-10] related to the Concrete Volume
	ISW_N	Normalized Factor [1-10] related to Industrial Steel Weight
	i	Bridge ID

The ANA_N, CV_N and ISW_N have to be evaluated for each bridge based on the following normalization procedure:

$$\left.\begin{array}{ccccc} \mathrm{Min}[ANA/TBA]_i & < & [ANA/TBA]_i & < & \mathrm{Max}[ANA/TBA]_i \\ 1 & < & ANA_{Ni} & < & 10 \end{array}\right\}$$

$$\longrightarrow \quad ANA_{Ni} = \frac{[ANA/TBA]_i - MIN[ANA/TBA]_i}{\dfrac{MAX[ANA/TBA]_i - MIN[ANA/TBA]_i}{9}} + 1\} \qquad [\mathbf{4\text{-}2a}]$$

→ $$CV_{Ni} = \frac{[CV / TBA]_i - MIN[CV / TBA]_i}{\frac{MAX[CV / TBA]_i - MIN[CV / TBA]_i}{9}} + 1\} \qquad [4\text{-}2b]$$

→ $$ISW_{Ni} = \frac{[ISW / TBA]_i - MIN[ISW / TBA]_i}{\frac{MAX[ISW / TBA]_i - MIN[ISW / TBA]_i}{9}} + 1\} \qquad [4\text{-}2c]$$

Where	ANA	Affected Natural Area (m^2)
	TBA	Total Bridge Area (m^2)
	CV	Total Concrete Volume (m^3)
	ISW	Total Industrial Steel Weight (T)
	EIR	Environment Impact Rate

The values of these factors are specified in Table 4-7.

Another method could be used by implementing of the Quality Function Deployment (QFD) which uses the "what" and "how" approach for different environment characteristics (Fig. 3-7).

Table 4-7 – Environment Impact Rate – EIR (Category II)

Environment Impact Rate **EIR** **(Cat. 2)**			
			EIR
Totat Bridge Area - **TBA**	**TBA (m^2)**		EIR
Affected Natural Areas - **ANA**	**ANA (m^2)**		
Total Concrete Volume - **CV**	**CV (m^3)**		
Total Industrial Steel Weight - **ISW**	**ISW (T)**		
Natural Damage Factor:	**ANA_N**		
Pollution due Concrete Volume:	**CV_N**		
Pollution due Industrial Steel Weight:	**ISW_N**		

4.4.2 Aesthetic Impact Rate (AIR)

For the aesthetic rating, it is easier to estimate its value since there are many theoretical studies that provide methodology and formulas to evaluate the aesthetic appraisal considerably based on many characteristics. Further to the method described in Section 3.3.3, a method is applied using the given parameters described by Maryland Department of Transportation (2005). Among those parameters, the following will be considered: (1) Ratio of deck span to depth; (2) Ratio of deck span to pier height; (3) Ratio of deck depth to pier width; (4) Deck curvature in elevation; (5) Deck super-elevation; (6) Bridge skew angle; (7) Integrity to surrounding topography; (8) Structure impression (strength through form); (9) Clear display; (10) Lighting, shade, shadow; (11) Relationship with the substructure; (12) Pier dimension ratios; (13) Color and textures; (14) Architectural element consistency. After highlighting the characteristics, two values have to be identified for each one: "I" Importance factor, rated between 1 and 10, which defines the characteristic importance level for the decision maker, and the second factor "V" that helps measure the harmonic state that exists between the bridge and its surroundings (refer to Table 4-8). Based on these evaluations, a bridge may have a minimum evaluation equal to 14 (14 x 1 x 1) and a maximum of 1400 (14 x 10 x 10) referred as a good evaluation. For the "AIR" expression, the following formula is used in order to verify if the bridge will be considered or not:

$$\left.\begin{array}{ccccc} 14 & < & \Sigma(I_i * V_i) & < & 1400 \\ 1 & < & AIR & < & 10 \end{array}\right\}$$

$$\longrightarrow \quad AIR = INT\left[\left(\frac{(\sum_{i=1}^{14} I_i * V_i) - 14}{1386}\right) * 9 + 1\right] \qquad [4\text{-}3]$$

Where,	INT ( )	is the Integer Function
	AIR	Aesthetic Impact Rate – Category II

The above formula is employed to categorize the results between 1 and 10, where 10 refers to the most important factor in the Bridge Aesthetic (refer to Appendix D-3 to see some of the characteristic aspects and how they are considered).

4.4.3 Aesthetic Impact Rate – Public Satisfaction (AIR-PS)

One of the problems associated with the performance criteria of the aesthetic behavior is public satisfaction. Such a problem needs considerable treatment during the conceptual design phase; hence, public opinions concerning aesthetic satisfaction have to be investigated. For this purpose, a questionnaire is established in order to rate the public satisfaction to the aesthetic appearance of existing bridges. Based on lots of studies, many characteristics related to the aesthetic have to be verified, In this thesis, the following characteristics are investigated and evaluated through the proposed questionnaire: (1) Proportion and geometry; (2) Environmental; (3) Structural harmony; (4) Focus of attention; (5) Weathering and surface finish. Through a statistical study, the public has to rate the importance of the listed characteristics, and then, based on public opinion, the level of each characteristic is calculated. For the mentioned task, Questionnaire Q02 is proposed, and public opinions are registered for every existing bridge. Consequently, all of the public questionnaires are compiled and evaluated using a linear interpolation assumption determined by Equation 4-4 in order to estimate the "AIR-PSj" for every existing bridge, which include values between 1 and 10 (10 is assigned to the design with full satisfaction). Moreover, the importance rating "I" and value "V" are highlighted. Refer to Table 4-9 for more details.

Table 4-8 – Aesthetic Impact Rate – AIR (Category II)

Aesthetic Impact Rate AIR (Cat. 2)		
Aesthetic Factors:	**Calculated**	
	Importance Factor (1-10) "I"	Rate (1-10) "V"
Ratio of deck span to depth		
Ratio of deck span to pier height		
Ratio of deck depth to pier width		
Deck curvature in elevation		
Deck superelevation		
Bridge skew angle		
Integrity to surrounding topography		
Structure Impression (strength through form,)		
Clear Display		
Lighting, Shade, shadow.		
Relationship with the substructure		
Pier Dimension Ratios		
Color & Textures		
Architectural Elements Consistancy		

$$AIR - PS_j = INT\left(\frac{\sum_{i=1}^{n} I_i * V_i}{495} * 9 + 1\right) \quad [4\text{-}4]$$

Where INT ( ) is the Integer Function

$AIR\text{-}PS_j$ Aesthetic Impact Rate – Public Satisfaction - Category V

j Related to one of "m" persons investigated for a specified bridge

Then, for a specified Bridge, the "AIR-PS" is given by the Eq. 4-5:

$$AIR-PS = INT\left(\frac{\sum_{j=1}^{m} AIR-PS_j}{m}\right) \qquad \textbf{[4-5]}$$

Where m is the number of investigated persons

The hard numbers (i.e., 495 and 9) in Equation 4-4 are defined according to the maximum and minimum values that could be assigned to the "I" and "V" parameters. The minimum rating value for a bridge (according to one person from the public) is defined by assigning "1" to "I" and "V" for five aesthetic factors (Table 4-9), so a minimum rating for a such bridge is: 5 x 1x1 = 5; while a maximum rating value is defined by assigning "10" to "I" and "V", so a maximum rating for a such bridge is: 5 x 10x10 = 500. To normalize the evaluations between 1 and 10, the following linear interpolation is to be applied:

$$\left.\begin{array}{ccccc} 5 & < & \Sigma(I_i * V_i) & < & 500 \\ 1 & < & \text{AIR-PS} & < & 10 \end{array}\right\} \longrightarrow \quad \text{Equation [4-4]}$$

Table 4-9 – Aesthetic Impact Rate-Public Satisfaction – AIR-PS (Category V)

Aesthetic Impact Rate - Public Satisfaction - AIR-PS (Cat. 5)		
Aesthetic Factors:	**Public Opinion - Statistic**	
	Importance Factor (1-10) "I"	Rate (1-10) "V"
Proportion and geometry		
Environmental		
Structural harmony		
Focus of attention		
Weathering and surface finish		

4.5 Linguistic Converter Models

A third type of data is the linguistic data, which is non-numerical information. Because of that, the data needs to be converted into a numerical value and used in the appropriate DSS Engine. Suitable modules must be used to convert the information related to these factors to numerical values. Therefore, the simplest method is Point-scale Linguistic Converter modules. Tables 4-1 to 4-5 cover the following factors that need such interpretation: (1) Bridge Type (e.g., Girder, Arch); (2) Structure Type for Deck; (3) Column Type; (4) Foundation Type; (5) Material Type; (6) Type of Area to overpass; (7) Road-Bridge Type; (8) Complexity; (9) Soil Type; (10) Bridge Geometric (Straight, Skewed, Curved); (11) Environmental Impact Rate - Local Authorities Evaluation; (12) Functional Satisfaction at first use. Appendix F provides a list of the Point-Scale Linguistic Converters that are provided and used for the case study presented in Chapter 7.

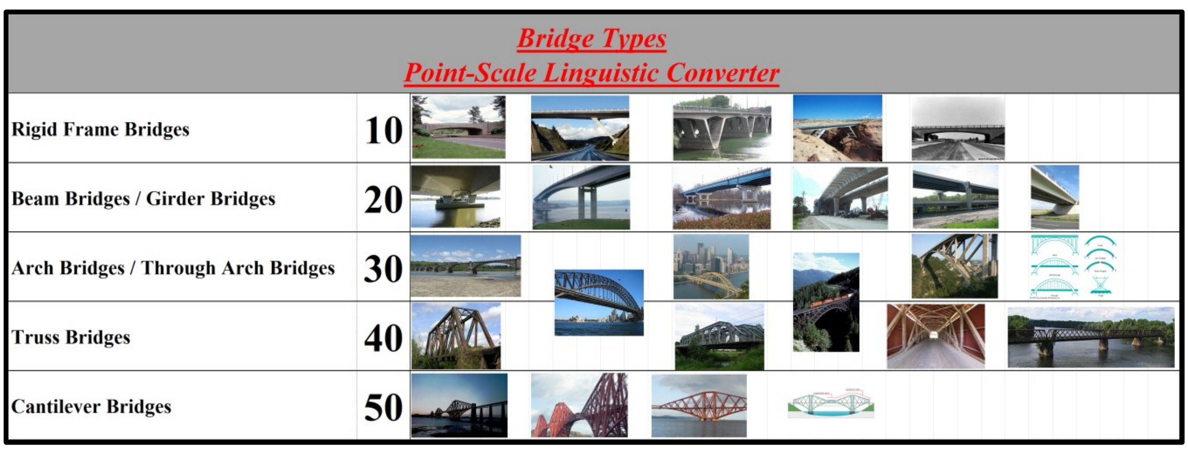


Figure 4-5 – Linguistic Converter for Bridge Type

A sample of the Point-Scale Linguistic Converter is provided in Figure 4-5. Figure 4-5 shows that each bridge type is assigned a numerical value, in order to use it in the DSS engine input data. The selection of the mentioned values depends on the subjectivity of the decision maker; for instance the selection of these values, in general, is based on the sorting of bridges from the simplest toward the more complex.

4.6 Cost Indices for Location and Time Adjustment

Since the collected data covers many bridges with different time of construction requirements and from different periods of construction it is important to do a cost adjustment. Therefore, an appropriate data structure needs to be elaborated to minimize all the shortcomings. Category I comprises the needed data for cost adjustment related to location and to the present value PV. The present value PV is taken from the economic analysis parameters. So, two cost indices have to be defined: location factors and inflation/interest factors.

For **Location Adjustment**, cost indices can be found in different sources, including: the Engineering News Record (ENR) Index, Means City Cost Index, Marshall and Swift, Chemical Engineering Plant Cost Index, and Nelson Refinery Construction Index, but these resources could be applied in some countries and not in others. To adjust the previous project cost data for location, Equation 4-6 is used:

$$C_A = C_N\left(\frac{I_A}{I_N}\right) \quad \textbf{[4-6]}$$

Where, C_A Cost in dollars for City A

C_N National average cost in dollars

I_A Index for City A

I_N Index based on the 30 major city average of 100

Time Adjustment is defined as time value adjustment, and in order to compare between different projects constructed within different timelines, it is necessary to do cost adjustment and present all costs within a specific date (i.e., Present Value, PV) using inflation and interest rates if needed. This adjustment is conducted by employing the appropriate equations for this purpose.

4.7 Data Statistically Analysis & New Bridge Characteristics

A Bridge ID format is established to present all the characteristics related to a defined project. Figure 4-6 presents a Bridge file grouping five categories as defined earlier. After collecting all the necessary data, a unique table is created covering all candidates (Figure 4-7). At this level, a statistical analysis is performed to observe the scattered data points. The statistical analysis is based on three categories (II, III, and IV). The first step of the process is based on the data related to the existing projects to find the relation between every factor from Category II with other factors from Categories III and IV. For instance, among the previous bridges stored in the data module, the bridge types are defined and related to the bridge length. Considering that one hundred bridges are stored in the data module, each bridge has been classified by a type BT, also, a total length (TL) between 0 and 100 meters, 100 and 200 meters and so on for each bridge; therefore, a distribution of the number of bridges based on their relations between BT and TL is made. Referring to Figure 4-8(a), the total number of bridges is distributed based on the row/column as defined; the same table is converted to percentage values (Figure 4-8(b)) and then a graphical presentation is provided (Figure 4-8(c)). This task will be repeated to relate the different factors from Category II to those from Categories III and IV. After plotting the appropriate charts, the bridge type might be statistically defined. This method can be applied to any related project based on the variables compiled from Categories III and IV. Figure 4-9 shows the relation between TL, TA, RBT, ST, and HP versus the BT according to their values based on a new case under study. It should be noted that the values shown in Table 4-9 are retrieved from the charts already explained and previously established. The detailed process will be provided and explained in Chapter 7. Furthermore, the represented values are to be considered as a guideline without any tangible meanings.

Bridge File

Category I *Administrative Info*		
Criteria		
	Factor *(Definition)*	**Variable** *(Values)*
I.1	Bridge ID	NA
I.2	Bridge Name	NA
I.3	General Description	NA
I.4	Bridge Location	NA
I.5	Year of Decision made	year
I.6	Starting Year of Construction	year
I.7	Ending Year of Construction	year
I.8	Year Put in Operation	year
0	0	

Category cover general information concerning the bridge, administrative information might help the decision maker to figure out some special aspect.

Category II *Geometric & Structure Info*		
Criteria		
	Factor *(Definition)*	**Variable** *(Values)*
II.1	Bridge Type (Girder, Arch, etc…)	converted to #
II.2	Structure Type for Deck	converted to #
II.3	Column Type	converted to #
II.4	Foundation Type	converted to #
II.5	Material Type	converted to #
II.6	Volume of Concrete	m3
II.7	Industrial Steel Weight	T
II.8	Exposed Concrete Surfaces	m2
II.9	Exposed steel surfaces	m2
II.10	Estimated Initial Cost - PV	$/m2
II.11	Environment Impact Rate	Calculated Rate
II.12	Aesthetic Impact Rate	Calculated Rate
0	0	

Category III *Uncontrolled Variables*		
Criteria		
	Factor *(Definition)*	**Variable** *(Values)*
III.1	Total Length	m
III.2	Type of Area to overpass	converted to #
III.3	Road-Bridge Type	converted to #
III.4	Complexity	converted to #
III.5	Soil Type	converted to #
III.6	Highest point	m
III.7	Availability of Professional Companies in Bridge Construction	#
0	0	

Category IV *Controlled Variables*		
Criteria		
	Factor *(Definition)*	**Variable** *(Values)*
IV.1	Number of Span	#
IV.2	Longest Span	m
IV.3	Number of Lanes	#
IV.4	Total Width	m
IV.5	Max Speed	km/hr
IV.6	Max Load	T
IV.7	Traffic Capacity	Vehicule/day
IV.8	Bridge Geometric (Straight, Skewed, Curved)	converted to #
0	0	

Category V *Performance Criteria*		
Criteria		
	Factor *(Definition)*	**Variable** *(Values)*
V.1	Actual Initial Cost - PV	$/m2
V.2	Operation & Maintenance Cost over 100 Years	$/m2
V.3	Dismantling Cost	$/m2
V.4	Environment Impact Rate - Local Authorities Evaluation	converted to #
V.5	Aesthetic Impact Rate -Public Satisfaction	Based on Q02
V.6	Functional Satisfaction at first use	converted to #
V.7	Actual Construction Time / Estimated	#
0	0	

Operation cost could be divided into many cost types to figure out all cost aspects (maintenance, rehabilitation, retrofitting, preventive action cost, etc…)

Figure 4-6 – Bridge ID File

Types	Groups	Categorys		Abreviations	Parameters	Units	Existing Bridge #01	Existing Bridge #02	Existing Bridge #03
Bridge Components	Administrative Info	Category I	I.1		Fact. I.1		001	002	003
			I.2		Fact. I.2				
			I.3		Fact. I.3				
			I.4		Fact. I.4				
	Geometric & Structure Info	Category II	II.1		Fact. II.1				
			II.2		Fact. II.2				
			II.3		Fact. II.3				
			II.4		Fact. II.4				
			II.5		Fact. II.5				
			II.6		Fact. II.6				
Hard Factors	Uncontrolled Variables	Category III	III.1		Fact. III.1				
			III.2		Ffact. III.2				
			III.3		Ffact. III.3				
			III.4		Ffact. III.4				
			III.5		Ffact. III.5				
	Controlled Variables	Category IV	IV.1		Fact. IV.1				
			IV.2		Fact. IV.2				
			IV.3		Fact. IV.3				
			IV.4		Fact. IV.4				
			IV.5		Fact. IV.5				
			IV.6		Fact. IV.6				
			IV.7		Fact. IV.7				
			IV.8		Fact. IV.8				
			IV.9		Fact. IV.9				
Soft Factors	Performance Criteria	Category V	V.1		Fact. V.1				
			V.2		Fact. V.2				
			V.3		Fact. V.3				
			V.4		Fact. V.4				

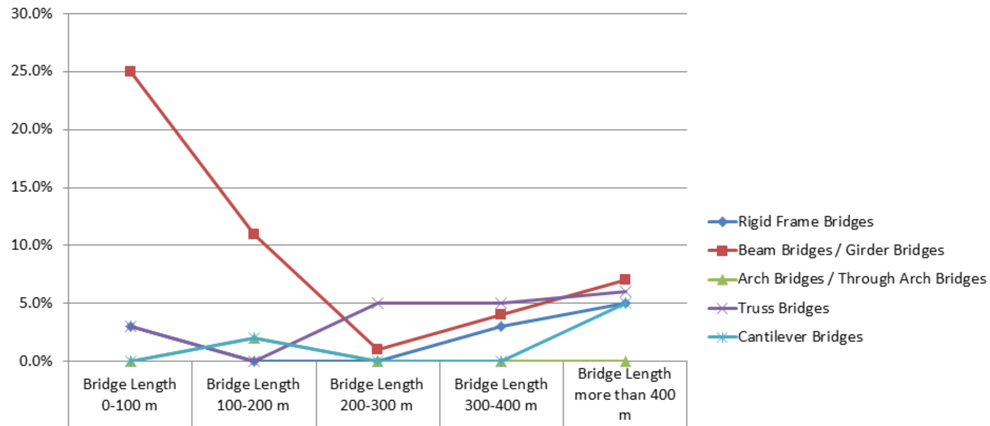
Figure 4-7 – Complete Data Schedule

			III.1 - TL - Total Length					
		Number of Bridges	Bridge Length 0-100 m	Bridge Length 100-200 m	Bridge Length 200-300 m	Bridge Length 300-400 m	Bridge Length more than 400 m	
II.1 - BT	10	Rigid Frame Bridges	3	0	0	3	5	6
	20	Beam Bridges / Girder Bridges	25	11	1	4	7	4
	30	Arch Bridges / Through Arch Bridges	0	2	0	0	0	3
	40	Truss Bridges	3	0	5	5	6	0
	50	Cantilever Bridges	0	2	0	0	5	0
								100

Figure 4-8(a) - Distributed Bridge Numbers

			III.1 - TL - Total Length					
		Number of Bridges	Bridge Length 0-100 m	Bridge Length 100-200 m	Bridge Length 200-300 m	Bridge Length 300-400 m	Bridge Length more than 400 m	0
II.1 - BT	10	Rigid Frame Bridges	3.0%	0.0%	0.0%	3.0%	5.0%	6.0%
	20	Beam Bridges / Girder Bridges	25.0%	11.0%	1.0%	4.0%	7.0%	4.0%
	30	Arch Bridges / Through Arch Bridges	0.0%	2.0%	0.0%	0.0%	0.0%	3.0%
	40	Truss Bridges	3.0%	0.0%	5.0%	5.0%	6.0%	0.0%
	50	Cantilever Bridges	0.0%	2.0%	0.0%	0.0%	5.0%	0.0%
								100.0%

Figure 4-8(b) - Distributed Bridge percentage



	Bridge Length 0-100 m	Bridge Length 100-200 m	Bridge Length 200-300 m	Bridge Length 300-400 m	Bridge Length more than 400 m
Rigid Frame Bridges	3.0%	0.0%	0.0%	3.0%	5.0%
Beam Bridges / Girder Bridges	25.0%	11.0%	1.0%	4.0%	7.0%
Arch Bridges / Through Arch Bridges	0.0%	2.0%	0.0%	0.0%	0.0%
Truss Bridges	3.0%	0.0%	5.0%	5.0%	6.0%
Cantilever Bridges	0.0%	2.0%	0.0%	0.0%	5.0%

Figure 4-8(c) - Distributed Bridge - Graphic presentation

Figure 4-8 – Statistical Analysis of Bridge Types – (a) Numbers; (b) Percentages; (c) Graphic

		II.1 - BT				
For the actual case study	***Importance Factor***	Rigid Frame Bridges	Beam Bridges / Girder Bridges	Arch Bridges / Through Arch Bridges	Truss Bridges	Cantilever Bridges
Chosen as per actual case study		**10**	**20**	**30**	**40**	**50**
III.1 - TL - Total Length - 310 m	5	0	7.5	0	0	0
III.2 - TA - Type of Area to overpass - 5	5	0	7.5	3.8	0	0
III.3 - RBT - Road Bridge Type - 1	5	3.8	30.2	3.8	0	0
III.5 - ST - Soil Types - 1	5	3.8	24.5	0	0	0
III.6 - HP - Highest point - 90 m	5	0	1.9	0	0	0
Raw Score		38	358	38	0	0
Percentage		**8.8**	**82.5**	**8.76**	0	0

Figure 4-9 – Statistical Definition for a Bridge Type

4.8 Summary

The Data module is the most important part for any decision making process; the better the data is structured to fit the DSS the more the results are accurate, reliable, and well defined. Based on the project being studied, a data module is to be investigated; for an existing data module, a verification of its liability (suitable for the actual case) has to be conducted, then a decision should be made, either by using it as it is, where slight modifications have to conducted, or a new data module contents has to be provided based on the project surroundings constraints of the new project. Referring to expert opinions, a pool of factors are defined based on their influence rates on the final decision; these factors are grouped into five different categories: Category I contains the administrative information, Category II holds the characteristics and project components for any potential alternative, Category III covers the uncontrolled influence factors, Category IV covers the controlled influence factors and Category V shows the factors that highlight the alternative performance. The factors covered by Category V are known by “performance criteria”; ranking the alternatives is related to the level of importance assigned to these criteria. For instance, assume that we have three factors belonging to Category V: (a) initial cost, (b) maintenance cost, and (c) aesthetic satisfaction. The decision maker may propose that the most important factor is the initial cost, but other factors have lower importance and accordingly the alternatives will be ranked as presented in Chapter 7 Table 7-17. After investigating all possible factors, a Bridge ID is established (refer to Figure 4-6 for more details). All variables for those factors are defined either by assigning direct numerical values, or by formulation or by linguistic converter models. Linguistic Converter techniques are defined by many research papers and many models and suggestions are available; the point-scale technique is the simplest and most commonly used to convert the linguistic data to numerical data. Further to the bridge types that need such a converter (Figure 4-5), many other factors are subjected to this kind of conversion, like the column type, foundation type, and geometric type, as mentioned and presented in Appendix F. Using fuzzy rules is also an available technique that could be used to serve the same goal but it needs a complicated structure while the benefits of its accuracy is not needed at the conceptual design phase. A global data schedule (refer to tables embedded in Appendix D-7) is provided to show all the appropriate data related to the existing bridges as considered in the assigned data file. Statistical Analysis is conducted in order to highlight the homogeneity/heterogeneity, and the asymmetry and irregularity of the data considered and it could serve to aid with the alternatives selection. The variables used in the DSS are selected and proposed by the expert independently of each other without any correlation, but it is important to mention that some variables are automatically related; for instance, the volume of concrete and the exposed surfaces of the concrete elements are somewhere reliant on each other. The simplified method as proposed is due to the fact that the methodology is going to be applied in a location where we are faced with a scarcity of data. For this reason a simplified model is provided to be appropriate to the available data. Meanwhile, once the DSS is used for an area with sufficient data, with the flexible methodology as presented, we may replace the simplified models by another one in order to maximally benefit from the existing useful data. Finally, a full analysis has been presented in order to control subjectivity, and to provide a clear data module in order to understand the final results by providing a tool for potential verification among the final results, which are based on relevant data. As mentioned in the chapter 3, the formulas are based on the use of the adjusted QFD and the interpolation formulas. In order to avoid data anomalies and to reduce and even eliminate data redundancy, data normalization is conducted for most of the values in order to categorize them into different intervals (i.e., [1-10], [5-500]).

Chapter 5

Information Modeling Tools with Conceptual Design Procedures

5.1 Introduction

3D information modeling for bridge structures has been used to improve design quality in terms of accurate drawings, constructability and collaboration. It is used to enable interoperability between different design and construction processes. Moreover, 3D information modeling is used in the design phases. Its primary job is to connect the design and construction phases together in order to enhance the current practice within cost and time constraints. For instance, it is a well-organized data architecture for infrastructure and it is also important for the effective collaboration between different disciplines. The integrated information model aims to realize a virtual construction system for bridges and to increase the productivity of the whole management process. However, for the sake of brevity, only 3D information modeling is going to be discussed in this thesis. 3D information modeling is implemented for the bridge through a schema as shown in figure 5-1. As it is noted in the literature, BIM is an efficient tool that may enhance the design revision process and communication with workers on the construction site, and its use at the conceptual design phase may reduce any conflict that might occur during the detailing processes. In this thesis, the main purpose of BrIM is to implement the different alternatives suggested by the decision maker in a 3D environment. The implementation aims to extract the necessary data related to some factors selected to be input neurons for the DSS engine (e.g., volume of concrete, exposed concrete areas). Another advantage is to visualize the conformity of the different alternatives with their surround. This procedure will lead to an acceptable level of accuracy (at the conceptual design phase) with a minimum of time spent and minimum potential error during the detailed design. The BrIM implementation occurs during the running of the DSS engine as presented in Chapter 6 (Sect. 6.2.3) between the first and final arrangements.

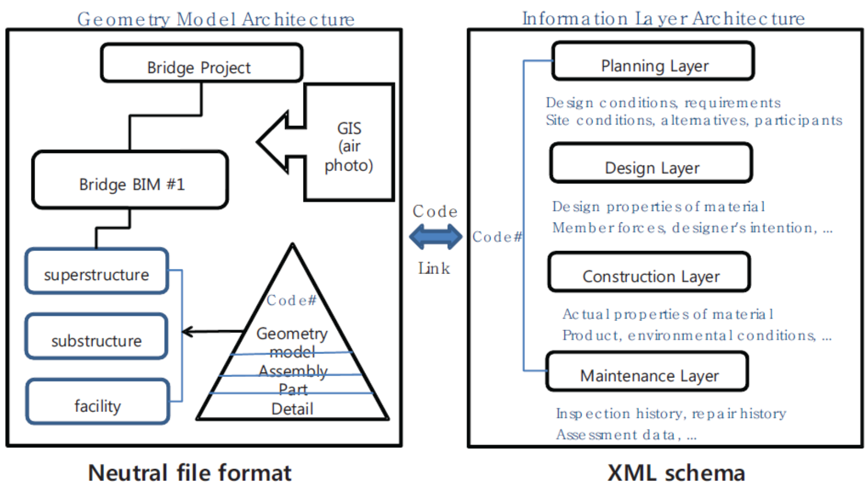


Figure 5-1 - Architecture of 3D Bridge Information Model *(Smith 2011)*

5.2 Bridge Information Modeling (BrIM)

5.2.1 BrIM Tools

Many software packages exist to enhance the application of information modeling; Architectural and Structural modules are available to guide decision makers toward the best solution. As stated previously the first goal for the decision maker is to determine the bridge type. After that, the design process starts, based on the comprehensive bridge design manuals, without specifying the design tools that the engineer must use. Different software products are capable of performing a 3D structural analysis to AASHTO - LRFD for a variety of different bridge types. In general, those programs have CAD formats, and “Smart” data inputs. However, those programs are limited and have restrictions for bridge plan production. As structural tools, many programs are recognized for information modeling processes, such as CSI Bridge Design, Structural Bridge Design from Autodesk, Tekla, Sap2000, and Robot Structural analysis that also have finite element analysis. For architectural modeling, the best-known software packages are Civil 3D and

Revit from Autodesk. Even though these software packages have many advantages, they also have many limitations. The disadvantages of these software programs are discussed in the next Section.

5.2.2 BrIM Tools – Goals and Benefits

As is well-known, many of the issues that owners face are related to the construction, operations, and maintenance phases. These issues are highlighted and predicted through the BrIM implementations that benefit from many advantages during the design phase, such as: (1) efficiency of deliverability; (2) a defined criteria path; (3) reduction of uncertainty, (4) minimization of construction impact, (5) reduction of risk, and (6) seeding of the database of bridge management. The type of data used during each phase in the life-cycle of a bridge and their file formats can also be used for data translation, as identified and presented by the *FHWA*. Figure 5-2 illustrates some software products for the different disciplines and functions during bridge design. Autodesk products have not been developed for bridge design, so they will not fulfill all the needs of a total BIM solution for a bridge; therefore, the usage of this software application is inconvenient to the current investigation. Nevertheless, using BrIM is of utmost importance to achieve the objectives of this thesis, thus, in order to overcome all the shortcomings from the above mentioned software, data exchange between different disciplines will be covered and discussed extensively in the following sections using various relevant software products.

5.3 Bridge Information Modeling Implementation

5.3.1 Benefit from BrIM Implementation

The benefit from BrIM implementation covers many project phases, starting at the conceptual design phase and it could be extended to include the total life-cycle of a project.

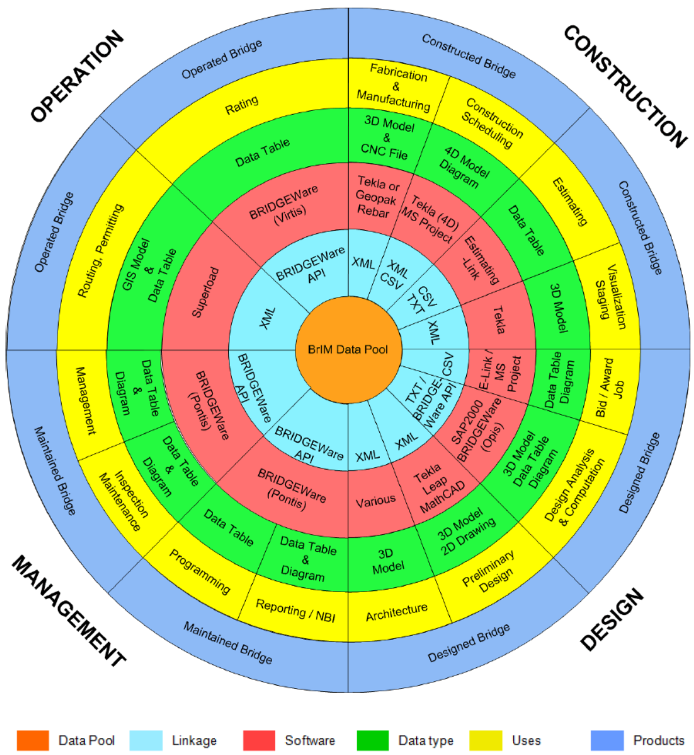


Figure 5-2 - Bridge Life-cycle Processes and Products (*FHWA Contract DTFH61-06-D-00037*)

Using these modules has a positive impact on achieving the aims of this thesis by: (1) visualizing the proposed alternatives inserted in its surround situations, (2) retrieving the appropriate data needed for the DSS Engine, (3) conducting a preliminary structural analysis, since most of the detailed analysis problems could be resolved and mitigated by an accurate analysis at the conceptual phase. The interoperability between different BrIM software enhances accuracy and provides consistency to the results. It is complex to design a bridge and follow up the detailed process; however, using the BrIM software may clear up this complexity by using a flowchart showing the whole process in detail.

5.3.2 Selection of BrIM Tools

As discussed earlier, many software packages are available for the process of bridge design. For clarity, only the appropriate software used in this thesis will be discussed, such as: (1) Autodesk Revit for geometric modeling; and (2) Autodesk Robot Structural Analysis for preliminary design analysis. There are many other pieces of software for design analysis, such as CSI Bridge Design and Bridge Modular (replaced by Structural Bridge Design - Autodesk), but those software packages have limitations in their geometric shape and bridge type libraries. Therefore, in order to overcome all the problems associated in the above mentioned software, Autodesk Revit is used for CAD modeling along with Autodesk Robot. Autodesk Revit includes Revit Architecture and Revit Structure in a single module, which gives additional controls by including the architectural and structural libraries under the same interface. This feature provides consistency and avoids many mis-coordination problems between the architectural and structural elements. Figure 5-3 shows all of the steps for 3D modeling as well as the Bridge Design workflow. The mentioned flow will be adopted at the conceptual design phase

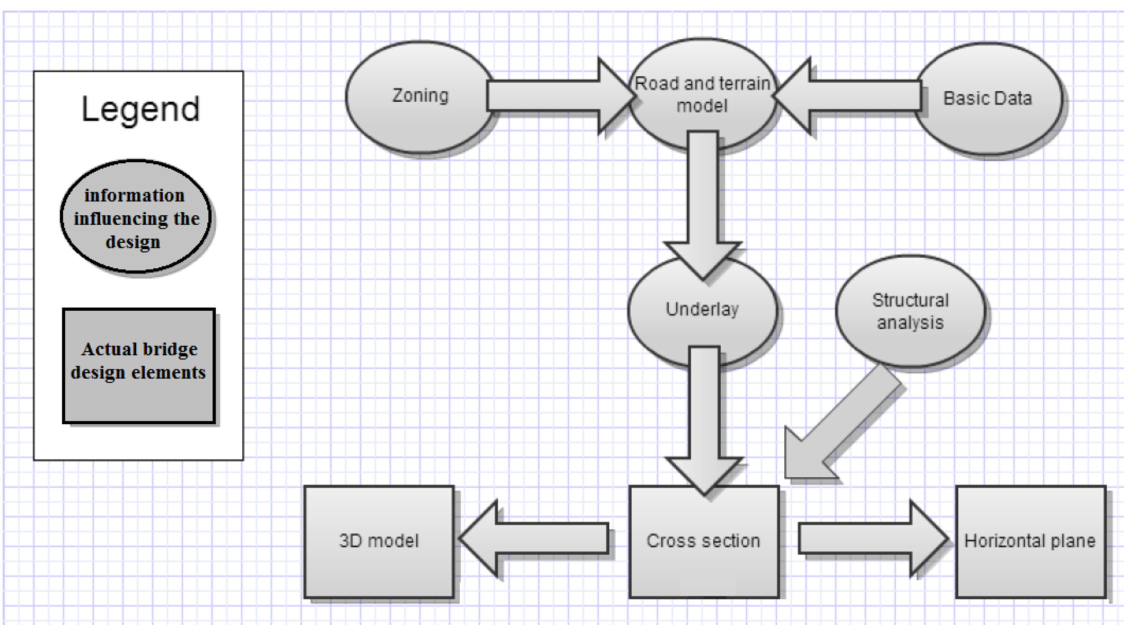


Figure 5-3 - Bridge design work

Figure 5-4 shows the potential of the Revit software that presents the bridge element, which afterwards can be imported for 3D surveying land analysis software. The defined module in Revit, could be transferred to Autodesk Robot to conduct a quick and preliminary design analysis to verify if the provided dimensions are acceptable from a structural point of view. Figure 5-5 shows a model for the stress analysis of different structural elements using Robot, whereas all previous analyses were conducted using standards such as AASHTTO, LFRD and the CSA-S6 Canadian Highway Bridge Design Code.

5.4 Development of the BrIM Tools in the DSS

After establishing the data module in its appropriate format to be used by the DSS engine, the required data is retrieved and classified and considered as input and output neurons for the ANN algorithm. As will be defined in chapter 6, the ANN will be launched in two phases named First Arrangement and Final Arrangement respectively.

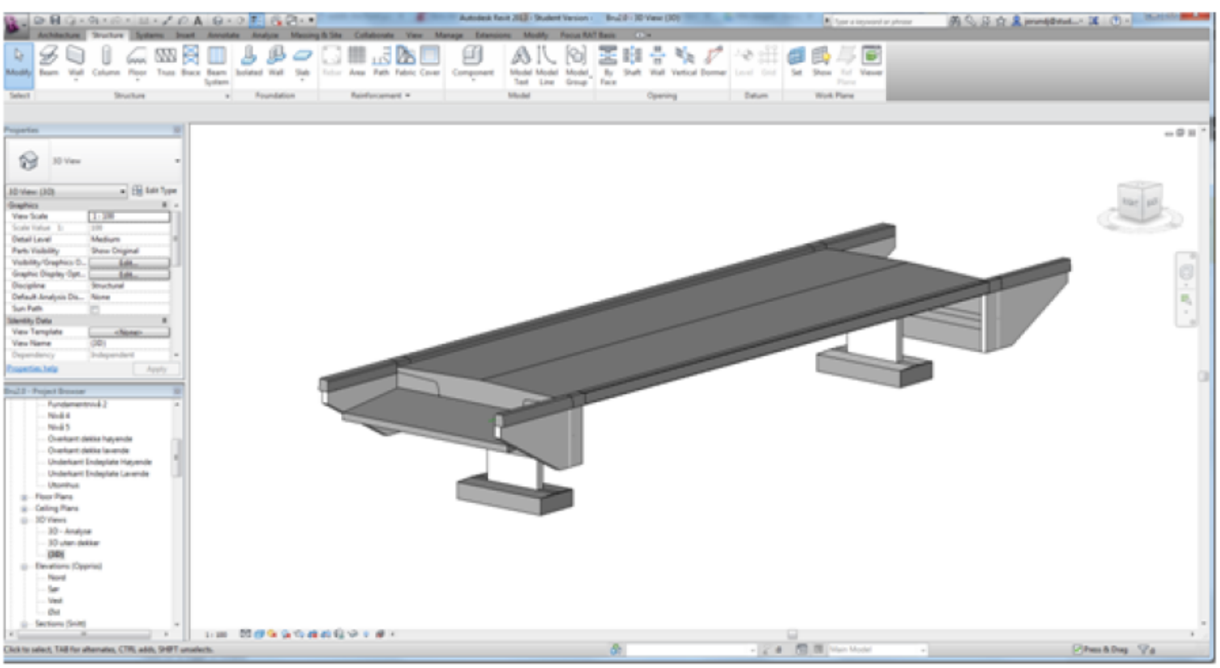


Figure 5-4 - Bridge design work *(Autodesk Revit)*

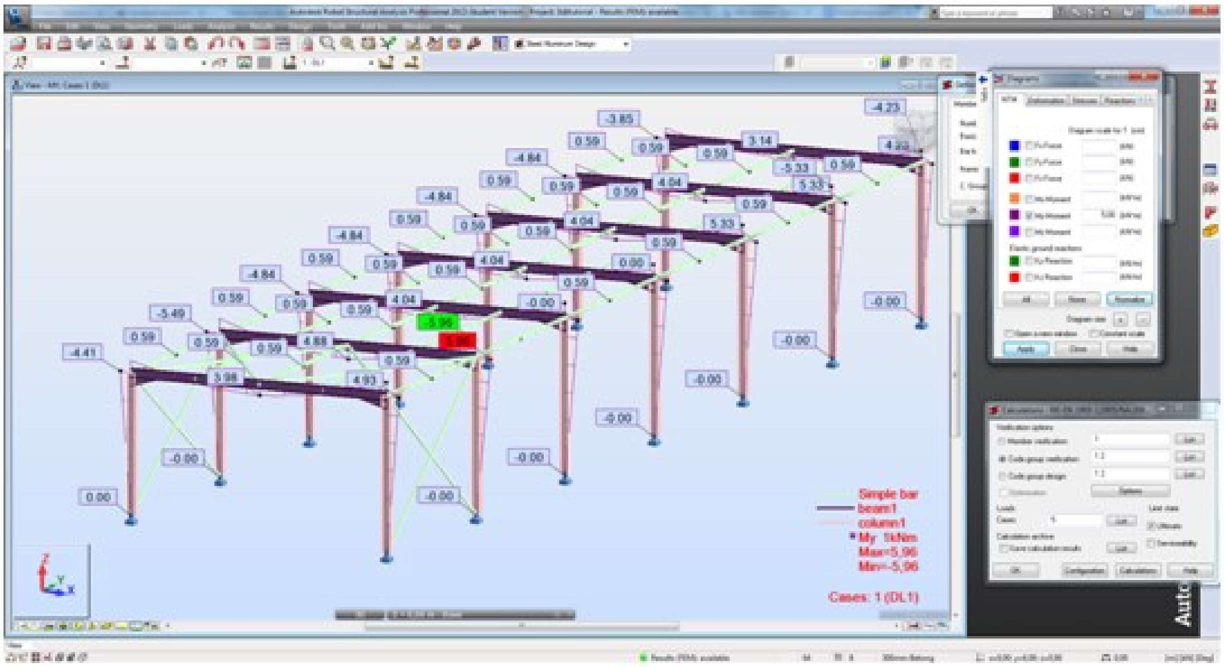


Figure 5-5 - A structure analyzed in Robot *(Autodesk Robot)*

For the first one, some data will be used in order to define the potential alternatives for the bridge type with its components (BT, CT, DT, FT, MT). After this phase, the BrIM implementation will be started. Before implementing the alternatives in a 3D model, it is required to model the land and other characteristics. Autodesk Civil 3D was considered for the 3D surveying presentation. However, the newest features in Revit may provide the 3D surveying model without the need of Autodesk Civil 3D (refer to Figure 5-6). Based on the first arrangement of the DSS engine, many bridge types with their components may be suggested and considered as alternatives, each one presented in a 3D geometric format using Revit Software. Figure 5-7 shows one of the proposed alternatives. Dimensions are selected based on architects' experience and using some aesthetic constraints. Before implementing the bridge in the 3D surveying model in order to visualize the overall situation of the project to see how it will fit into its surrounding, Autodesk Robot will import the aforementioned bridges (alternatives) in order to do some verification under a preliminary load design related to the selected standards.

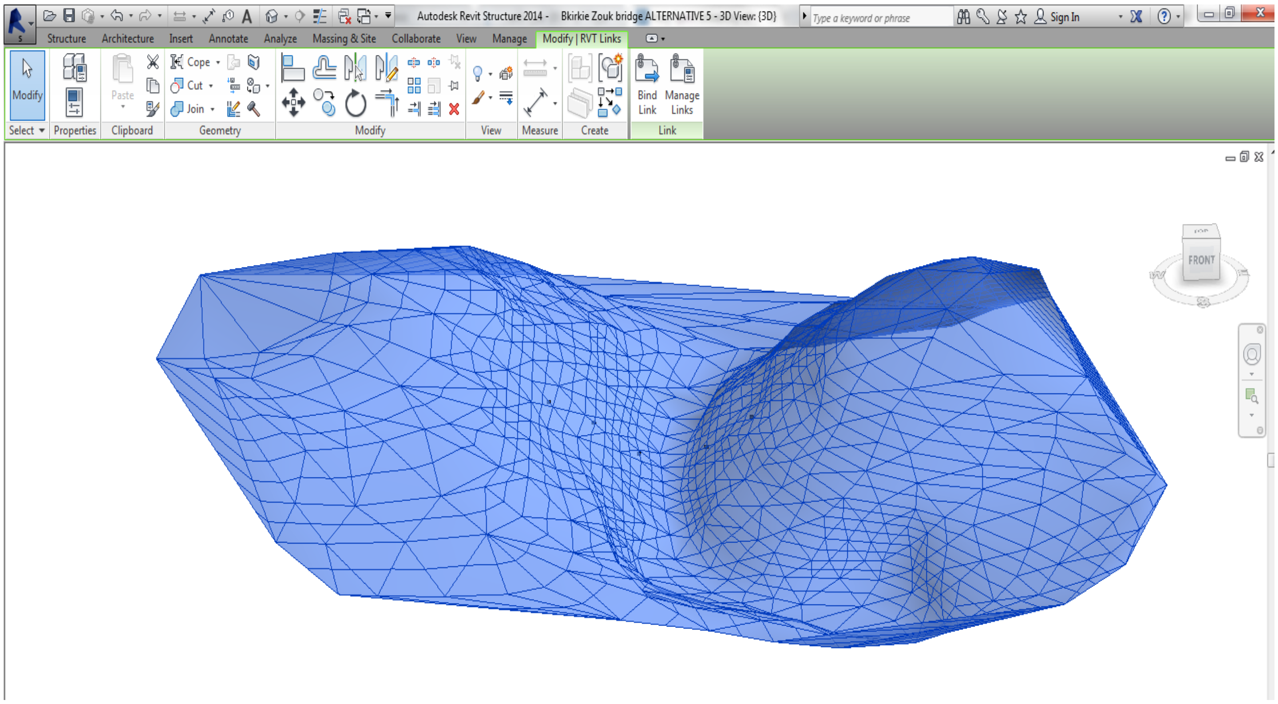


Figure 5-6 – 3D Surveying Model *(Autodesk Revit)*

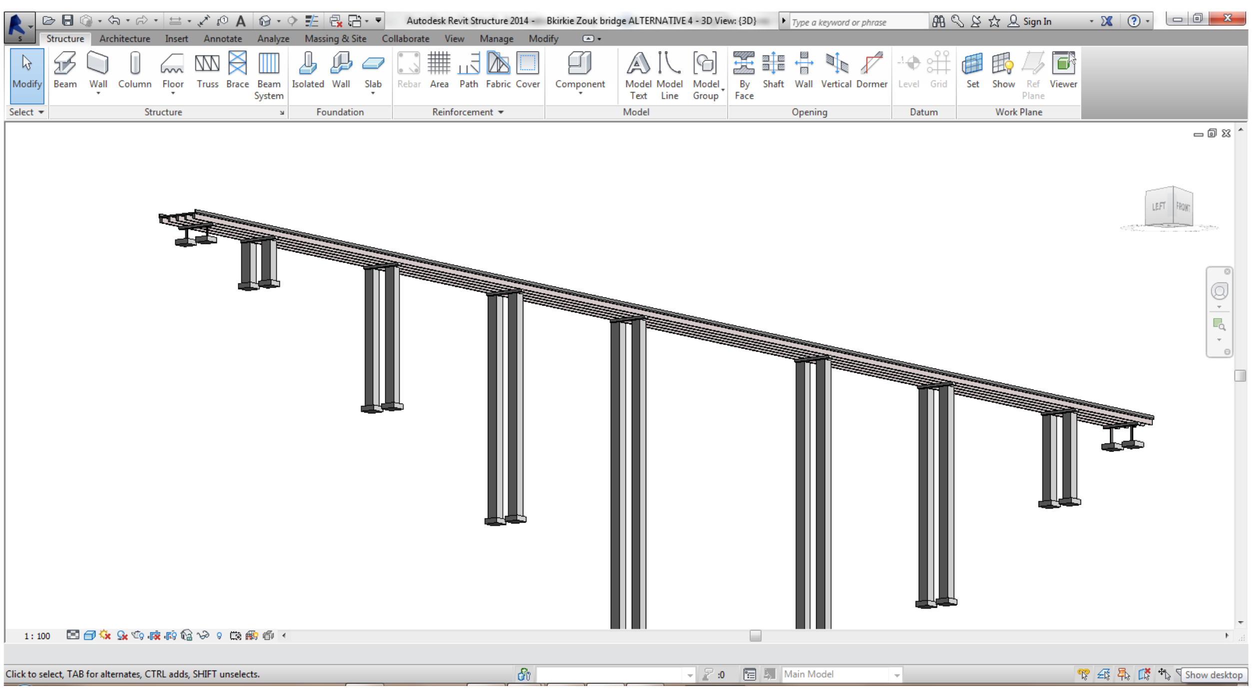


Figure 5-7 – 3D model for an alternative *(Autodesk Revit)*

The purpose of using Robot analysis includes: (1) minimize structural problems and major modifications as much as possible during the detailed analysis and design, and (2) realize rational dimensions in order to retrieve the appropriate quantities. According to the results of the structural analysis in Robot, final dimensions will be provided and these will be transferred to the Revit model to set the final decision for each alternative at this stage. Figure 5-8 shows the 3D model using Robot structural analysis; where advanced calculation could be conducted. The next step that follows is having the Revit module update the final dimensions, according to the site restrictions presented by the surveying 3D model. Necessary information will be retrieved and provided in order to fulfill the variables falling in Category II. Figure 5-9 illustrates a sample of the quantity schedule provided by Revit; much of the other information could also could be retrieved and used for other purposes.

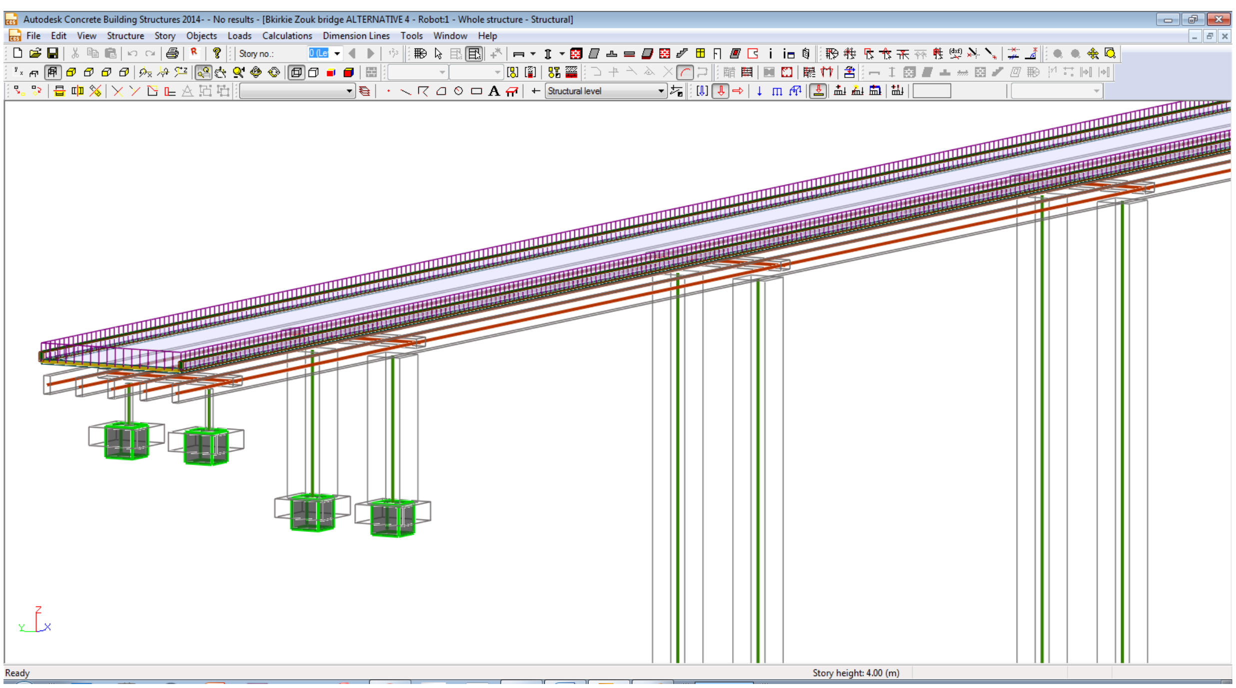


Figure 5-8 – 3D structural analysis model *(Autodesk Robot)*

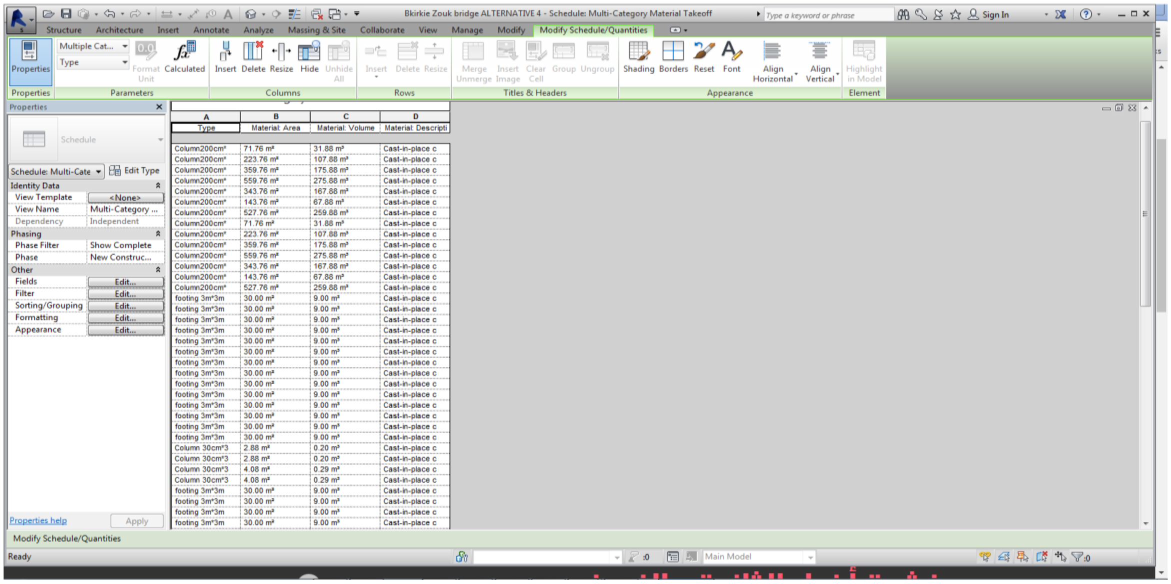


Figure 5-9 – Sample of Quantities from Revit 3D Model *(Autodesk Robot)*

5.5 Summary

The benefit of using BrIM tools is extended to include the bridge life-cycle. Autodesk Revit and Robot are the two pieces of software that are used for the geometric and structural 3D modeling respectively. The purpose of using such software at the conceptual design phase is to reduce the possible conflicts during the detailed analysis, and to retrieve the required quantities for the DSS engine which can be used for further 3D visualization options. Interoperability between these modules is semi-automated since they are from the same product family. Because Autodesk products are developed specifically for building design, they may not fulfill all the needs for a total BIM solution for a bridge design. Customizing this product leads to the maximum benefit applicable from its current release. However, these inconvenient deficiencies are not major problems that can affect the usage of the BrIM, since their main role is data exchange. Appendix H provides a table that lists some software products for the various functions during bridge design.

Chapter 6
DSS Engine – Procedures & Analysis

6.1 Introduction to Artificial Intelligence (AI)

Artificial Intelligence (AI) attempts to diagnose intelligent entities of seeing, learning, remembering and reasoning, and see how the sequence of execution could be done. The major challenge of this thesis is to acquire such processes, away from human subjectivity, but within the human-level of intelligence (or better), therefore the application of an AI approach would have a major influence on the objectives of the thesis, first by reducing subjectivity, and second by providing a systematic methodology to offer the optimal solution for any associated problem within a project. Moreover, since this research investigates a system acting rationally like human, it is important to choose subsets of AI. ANN will be used for this thesis based on its benefit and characteristics defined in the section 2.6.1.

Many software packages exist to serve as ANN applications. Two of them will be highlighted in this section, and one will be adopted for the rest of this thesis. The selection of these pieces of software is due to their popular use and especially due to their availability to be implemented in this thesis. The selected ANN software could be replaced by different software and could even be replaced by another model in the AI environment. The two software packages are NeuroShell 2 and MATLAB with its “nntool” module.

Figure 6-1 shows the interface of **Neuroshell 2** with its Beginner and Advanced Neural Networks. As shown, many parameters must be defined and established. Input and data entry, followed by the ANN Architecture, defining the test set, and then the learning process toward the required output are presented. Additional characteristics related to the learning process are also accessible in the advanced NN module. Further to the number of hidden neurons defined by Equation 3.5, an activation function, testing set, and the number of hidden layers have to be defined as well.

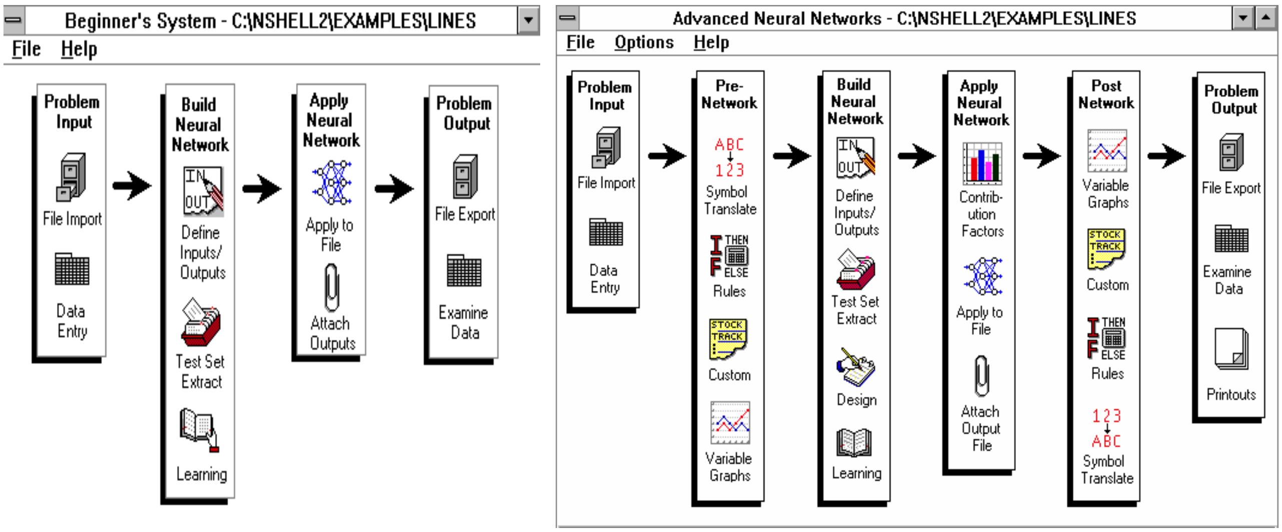


Figure 6-1 – NeuroShell 2 Interface

Figure 6-2 shows the launching of **Matlab** with the **nntool** interfaces. The advantage of this software is the Simulink option, which is a graphical programming environment for modeling, simulating and analyzing multi-domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries that facilitate the work. On the other hand, normalization, training, validation and testing sets are automatically launched in order to provide the best solution, taking into consideration all ANN concerns like avoiding overfitting and the cross-validation process.

Knowing that ANN is often called a black box, it has the potential to solve any kind of problem in an obscure manner. At this point, it is worthwhile to list the advantages and disadvantages of ANN. As for advantages, it can adapt to new scenarios, it is fault tolerant and can deal with noisy data, but the time to train is probably identified as the biggest disadvantage. An ANN also requires very large sample sets of data to train the model efficiently. It is hard to explain results and what is going on inside an ANN.

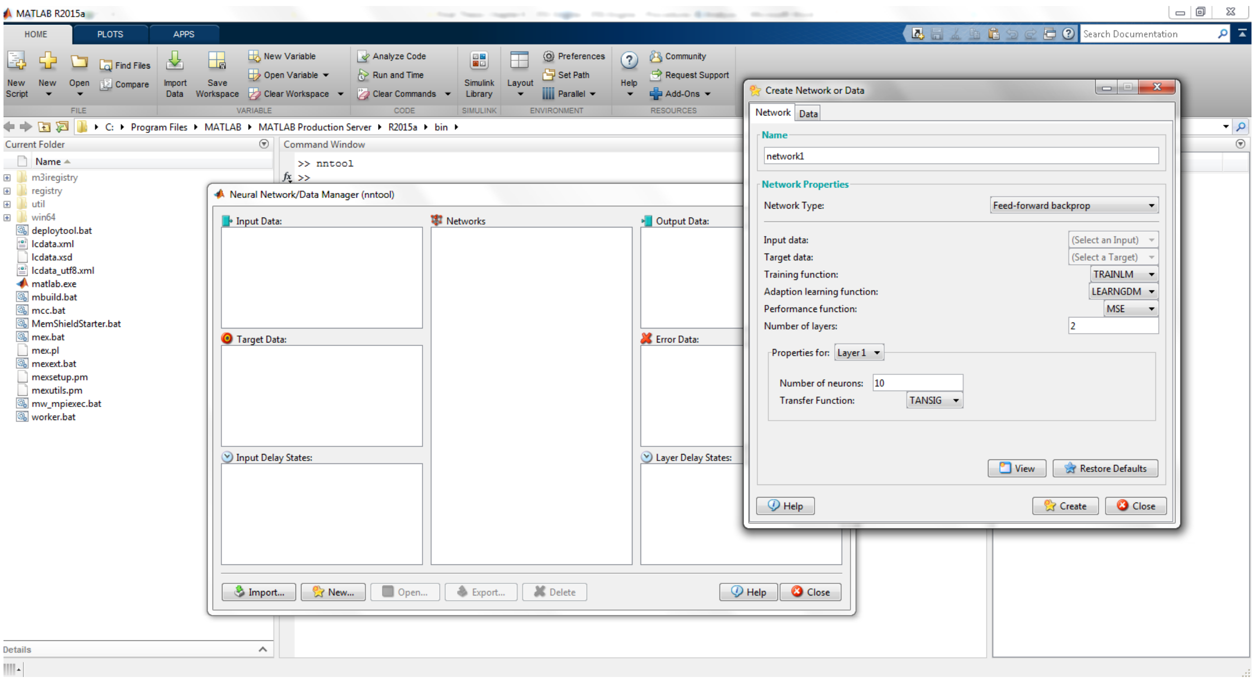


Figure 6-2 – Matlab / nntool Interface – *Matlab, 2015*

6.2 DSS Engine

6.2.1 ANN in DSS

Matlab with the nntool will be the most efficient model for the problem faced in this thesis. Based on the interviews and questionnaires compiled in Chapter 4, the numbers of factors and performance criteria are defined. Moreover, a data module interpretation is created to make them suitable for the DDS engine. It should be noted that the learning process for the ANN is divided into two steps: First Arrangement and Final Arrangement. As defined, the factors included in the first category are not to be used in the direct calculation. The factors from Categories III and IV are used for the first arrangement of the learning process in order to provide potential alternatives that define Category II according to the new project's site characteristics, and after that, based on the factors of Categories II, III, and IV factors, a final arrangement will be launched in order to predict the performance criteria for the new bridge to be constructed. By applying the conditions discussed above, it is expected that the BrIM environment is going to occur between the first and the final arrangement as it will be shown in the next sections.

6.2.2 First Arrangement

The goal from the first arrangement is to deliver the potential alternatives for a new project which is defined by its characteristics (based on the location constraints). These characteristics will evaluate some of the variables related to the factors from Categories III and IV. Figure 6-3 shows the flow chart of this process. Before using the data of a new project (bridge), the training process of the proposed ANN has to be conducted based on the data module that has been already established as mentioned in Chapter 4. The data from Categories III and IV are used as input neurons and the data from Category II are selected as target values (as output for the training process). After training, validation, and testing, the trained ANN is used to define the potential alternatives, and according to the expert judgment and suggestions, the bridge types with their components (BT, CT, DT, FT) are defined, and they are included in Category II. After that, the variables of Categories II, III, and IV for new proposed bridges are defined and ready to be implemented in the BrIM tool environment.

6.2.3 BrIM Implementation

After retrieving the output data from the first arrangement and according to the expert suggestions that defines the alternatives, the new project characteristics for different alternatives will be implemented in the BrIM environment. The flow chart is presented in Figure 6-4, where data are implemented in Revit software that interprets the characteristic geometrically, based on architecture perception. Thus, the model will be transferred to Robot for preliminary design verification; the data are exchanged between these two modules (Revit and Robot), based on the coordination between the architecture and structure disciplines. After matching the architecture and structure constraints, the final data will be provided for each alternative, and then transferred to the final arrangement process.

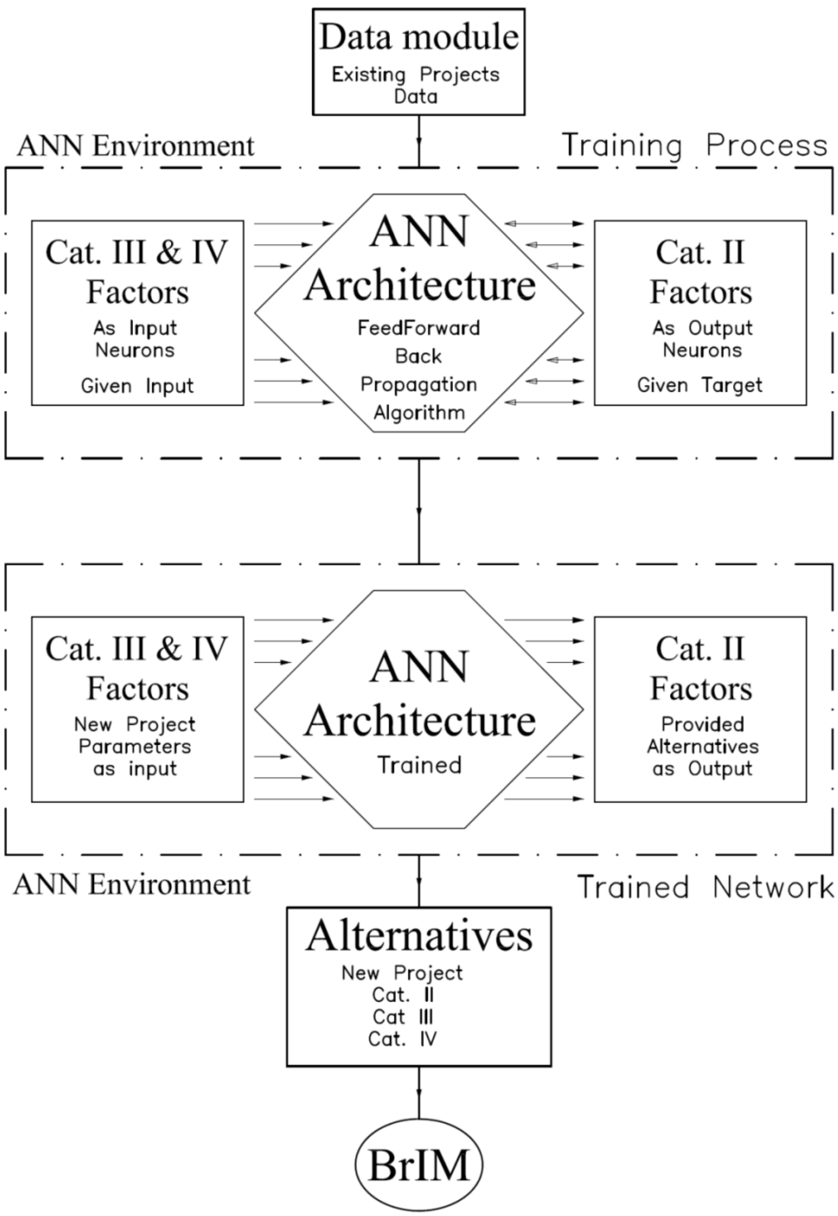


Figure 6-3 – First Arrangement Flow Chart

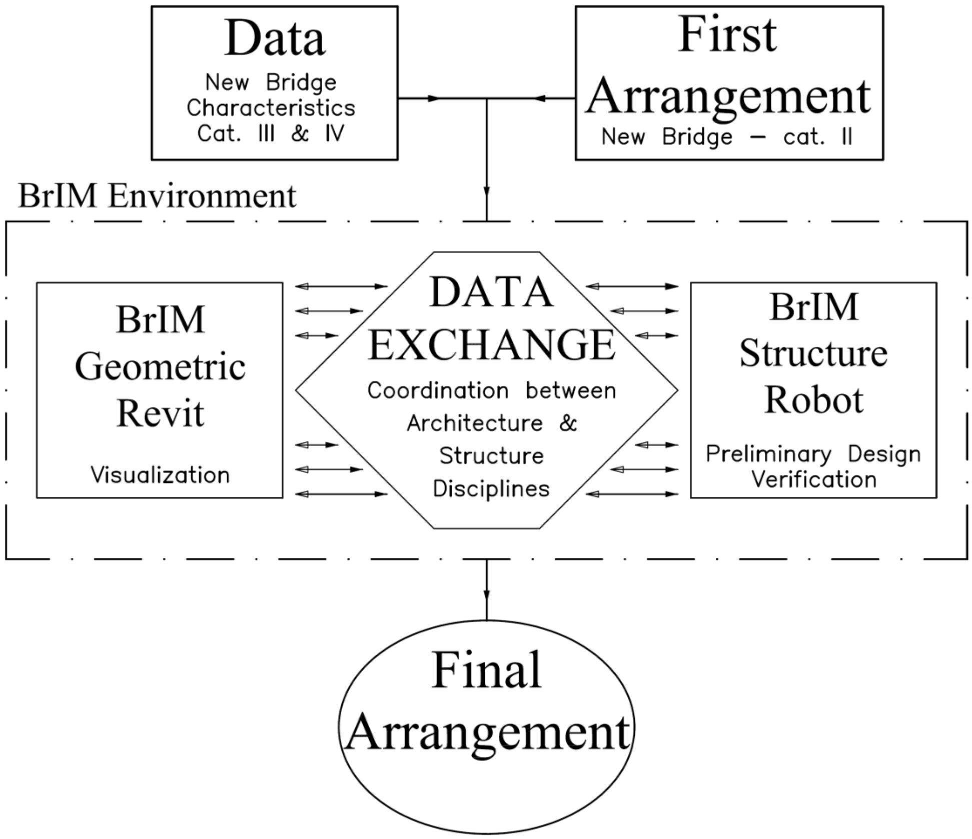


Figure 6-4 – BrIM data interchange Flow Chart

6.2.4 Final Arrangement

At this final step of the DSS engine, and before analyzing the results, the performance criteria, defined in Category V, have to be evaluated for each proposed alternative. By following the same procedure as with the first arrangement, an ANN has to be trained based on the established data module as shown in Figure 6-5. Data from the existing projects are used to train the ANN, where the variables from Categories II, III, and IV are considered input neurons and the variables from Category V are considered output neurons (target values). The trained ANN will be used to define the performance criteria for each alternative, where the input neurons are those of the variables from Categories II, III, and IV of a new project. At this point the performance criteria are provided and the next step is to analyze these results.

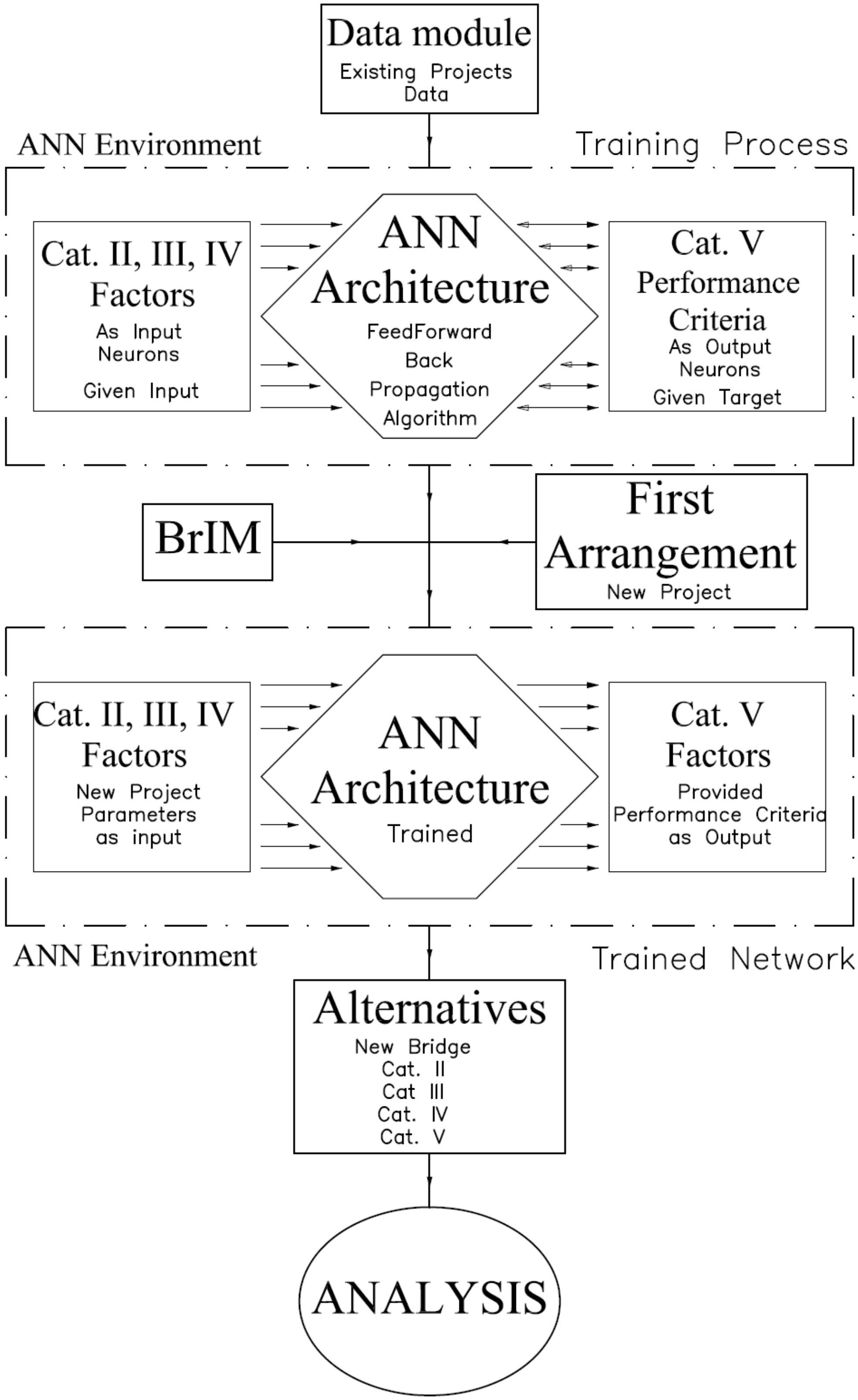


Figure 6-5 – Final Arrangement Flow Chart

6.3 Analysis of Results

Section 6.2 described the three steps of the results obtained, which are related to the proposed alternatives for a new bridge to be constructed. For each alternative, Category I describes general administrative information, Category II defines the project characteristics, Categories III and IV contain the hard factors related to the project with its location constraints, and Category V defines the performance criteria. It is vital to analyze and study these results; for that, the Reliability of the ANN training as well as the results have to be addressed, and a Sensitivity Analysis (SA) related to some factors is to be conducted, in order to find the reasoning of the results. Furthermore, the Level of Realistic outcomes (LR) methods will be discussed, before providing a unique final decision among the proposed alternatives that will be considered as the best solution.

6.3.1 ANN Reliability

Since the ANN is defined as a black box, and the processes leading to the results are not easily followed, it is vital to define some actions to be applied and verified in order to have a confidence interval within the obtained results. As mentioned by many studies and discussed by experts, the validity of an ANN could be verified by taking some action. Many parameters affect the results provided by the ANN after its training, such as: (1) data set and number of existing cases to train the ANN, (2) number of hidden layers and the corresponding hidden neurons, (3) activation function, (4) selection of the different sets for training, validation, and testing, (5) limits of the acceptable error, and (6) training function, adaption learning function, performance function. Also, even if some selected and specified parameters are launched by the training many times, it is expected to have different results. Besides the Multiple neural network technique, and in order to simplify the verification procedure without being out of the general ANN rules, two issues will direct the current methodology of work: the first aims to get the validation and testing curve as close as possible to the best validation performance as shown in Figure 6-6; the second is to Perform Analysis of the network response (refer to Figure 6-7) by conducting a regression form in the training window; thus, a linear regression is performed between the network outputs and the corresponding targets. The R-values should be more than 0.95 for the total response in order to be in the acceptable ranges. Of course, many training sessions, many functions, and many essays are required to attain the end of the best solution. Moreover, many other procedures and suggestions from many researchers and software guides are available to treat this problem, each of which has its own characteristics and takes a long time to do; therefore, the easiest way to achieve such work is by computerizing the processes, in order to realize the performance and to verify the two parameters mentioned (Validation performance and R-Values). The goal of the ANN reliability procedure, which is performed automatically by Matlab-nntool, is to highlight how much the trained network will serve as good tool to be used for a new case. This reliability check is achieved by the validation and test curves presented in Figure 6-6 where they should be closed as much as possible. The Matlab-nntool is well recognized for auto-check of the network performance and determines if changes need to be made to the training process, the network architecture, or the data sets. As per nntool / Matlab manual and guidelines, when training networks, the general practice is to first divide the data into three subsets. The first subset is the training set, which is used for computing the gradient and updating the network weights and biases. The second subset is the validation set. The error on the validation set is monitored during the training process. The validation error normally decreases during the initial phase of training, as does the training set error. However, when the network begins to overfit the data, the error on the validation set typically begins to rise. The network weights and biases are saved at the minimum of the validation set error. There are four functions provided for dividing data into training, validation and test sets. They are "dividerand" (the default)," divideblock", "divideint", and "divideind". The data division is normally performed automatically when we train the network. The default ratios for training, testing and validation are 0.7, 0.15 and 0.15, respectively. Nntool/Matlab is a very powerful tool and provides a wide range of alternatives and options to be used in order to get the best training and learning results, and the best results are checked by the performance of the parameters as shown in figures 6-6 and 6-7.

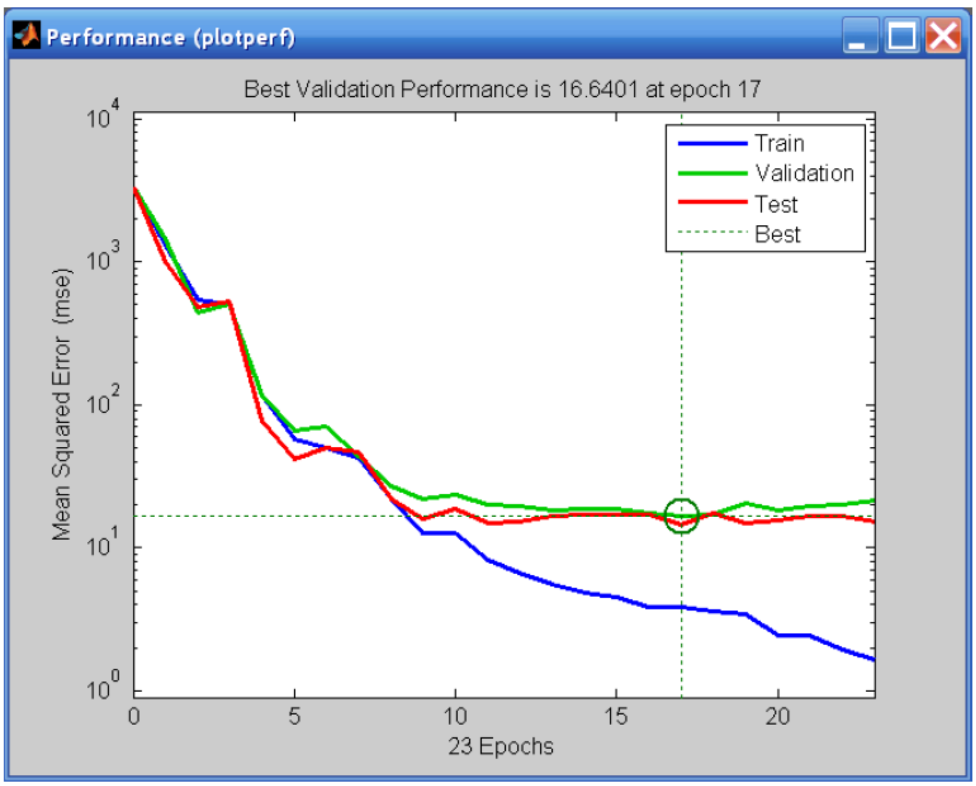


Figure 6-6 – Final Arrangement Flow Chart

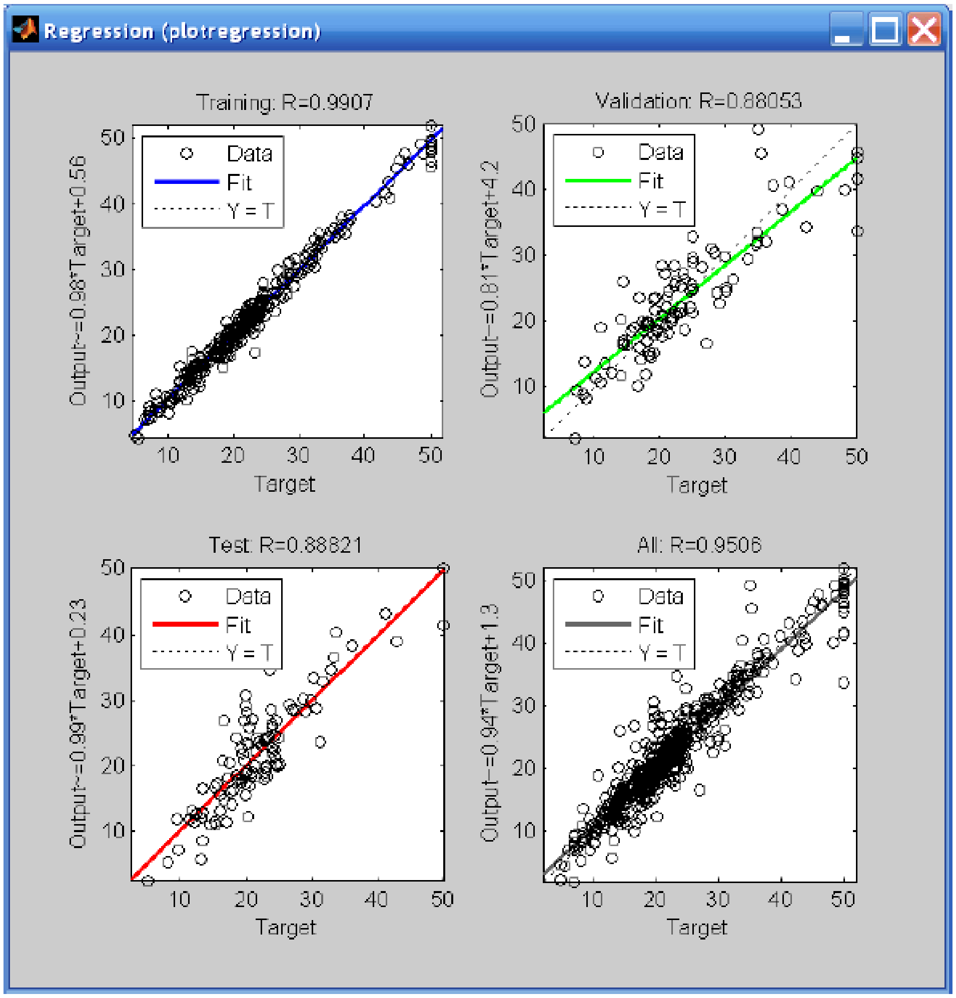


Figure 6-7 – Regression – R-Value

6.3.2 Sensitivity Analysis (SA)

Many factors are considered as input for the DSS engine. In order to study how the uncertainty in the output can be apportioned to different sources of uncertainty of the input and to identify which inputs are the most influential for the prediction, it is essential to apply a sensitivity analysis to highlight the level of influence of the input factors. The sensitivity analysis might be applied on data, parameters, assumptions, scenarios, and alternative model specifications in order to: (1) Prioritize acquisition of information to identify the important factors and to reduce uncertainty of important factors in order to increase the robustness of results, (2) Understand the model and to discover input interactions, (3) Identify inputs with no influence on the prediction process, and (4) Identify the critical regions in the space of inputs, if any. Facing this wide space in the sensitivity analysis technique, a direct application will be carried out in this thesis. The goal of the SA is to identify the effect of each factor over each performance criterion through the final arrangement network. Selecting specified factors from Categories II, III, and IV, individually, and by assigning different reasonable values through the trained ANN in the final arrangement, the variation of each performance criterion can be drawn accordingly. The sensitivity analysis is applied without taking into consideration the correlation between the mentioned input factor variations. According to the SA results, the decision maker may take any appropriate and justified action. Taking into consideration that the ANN is a non-linear process toward the output values, it is logical that the sensitivity analysis curves may take any kind of shapes. Many graphic presentations will be established showing the described analysis, which are presented in Appendix I-3.

6.3.3 Level of Realistic Outcomes (LR)

The definition of the Level of Realistic outcomes (LR) is a comparison process between results provided by a proposed new methodology and results from an existing method that delivers the same kind of results, in order to evaluate how much the provided results are reliable. Unfortunately, there is no unified process to identify and clarify the LR, since it depends on many aspects, such as the field of study, location and data availability, type of results, and many other factors. For instance, the cost prediction could be compared to the adjusted values provided by the RSMeans, assuming the analysis is conducted in an area where this type of data could be adapted. For other performance criteria, it is expected to obtain many existing statistical data to serve this matter. Also, a traditional method is conducted such as a statistical study, in order to perform the comparison. This issue will be defined and detailed in Chapter 7, and a special case will be treated using a special LR method which will be proposed accordingly.

6.3.4 Final Decision and Commentary

At this point, all the data and results retrieved from the modules and networks are collected and presented, but a final decision has not yet been achieved. Figure 6-8 shows the performance criteria values for each proposed alternative. For each performance criterion, the optimized value can be related to a different alternative. For instance, if the decision maker is more interested in the performance criteria D_1, he/she will propose an alternative that provides an optimized value among D_{1-i} (i=1 to n) and so on. For this reason, a Quality Function Deployment (QFD) house is proposed in order to provide a unique final decision based on the importance factors (IF_j) assigned to the different performance criteria as shown in Figure 6-9, and on the optimized Raw Score value (RS_i). It is important to mention that the values used in the proposed QFD should be normalized (ND_{j-i}) using a linear interpolation between 1 and 10, considering that 10 is assigned to be the best scenario (and not to the highest value), based on Equation 6-1:

$$ND_{j-i} = \left[9 * \frac{D_{j-i} - Min(D_{j-i})}{Max(D_{j-i}) - Min(D_{j-i})} + 1 \right] \qquad [6\text{-}1]$$

Where,	j	Performance criteria indices
	m	Total number of performance criteria
	i	Alternative indices
	n	Total number of alternatives
	D_{j-i}	Performance criteria value

N Normalization symbol

Performance Criteria Definitions				Alt1		Alti		Altn
V.1	**D1**	Definition 1	Units	D1-1		D1-i		D1-n
V.3	**D3**	Definition j	Units	Dj-1		Dj-i		Dj-n
V.m	**Dm**	Definition m	Units	Dm-1		Dm-i		Dm-n

Figure 6-8 – Performance Criteria Values for Alternatives

Performance Criteria Definitions			Imp. Fac.	Alt1		Alti		Altn
V.1	**D1**	Definition 1	IF1	ND1-1		ND1-i		ND1-n
V.3	**D3**	Definition j	IFj	NDj-1		NDj-i		NDj-n
V.m	**Dm**	Definition m	IFm	NDm-1		NDm-i		NDm-n
			Raw Score	RS1		Rsi		RSn

Figure 6-9 – Quality Function Deployment (QFD) – Final Decision

Then, the raw score values are calculated based on Equation 6-2:

$$RS_i = \left[\sum_{j=1}^{m} IF_j * ND_{j-i} \right] \qquad [6\text{-}2]$$

Where, IF Importance Factor

ND Normalized performance criteria value

j Performance criteria indices

m Total number of performance criteria

i Alternative indices

6.4 Summary

After establishing the data module in Chapter 4 to be used by the DSS engine use, the data will train the ANN within two arrangements: the first arrangement is to define the potential alternatives for a new project, then the alternatives, suggested by experts, will be sent to be implemented in a BrIM environment, and after that the final arrangement is conducted to provide the performance criteria for each of the proposed alternatives based on the information retrieved from the data module and the BrIM analysis. General procedures concerning the ANN training, validation, and testing have been discussed. The verification of the ANN reliability is defined as well. In order to provide an understandable environment for the factors and their effects on the decision maker, sensitivity analyses are proposed and carried out for some factors to find their influence direction. For the reliability of these results, a Level of Realistic outcomes method (LR) has been proposed. It is a unique process for each special case. Finally, to provide a unique final decision, a QFD is used based on the selected Importance Factor (IF) for each performance criterion in order to calculate the relevant Raw Scores (RS) for each alternative. Equation [6-1] aims to normalize the values extracted from the DSS to a number between 1 and 10. After normalization, and based on the importance factors assigned by the decision maker, Equation [6-2] aims to rank the different alternatives.

Chapter 7
Case Study and Results Analysis

7.1 Introduction

In order to validate the results based on the methodology previously discussed, this chapter verifies the proposed DSS method using bridge case project designed and planned to be constructed in Lebanon. It should be noted that Lebanon is considered to be an exceptional case in design, bidding, and other concerns that will influence, directly and indirectly, the results and the Artificial intelligence (AI) behavior in the analysis. Therefore, it is expected that a wide diversity and heterogeneity of data will be obtained with different opinions between the experts working in the Middle East. Furthermore, the application of the DSS will be applied in order to identify all kinds of imprecision as much as possible and to validate the proposed DSS.

7.2 Project Description

Congestion and traffic problems are the main reasons that lead to building a new bridge in order to connect two areas, directly, and to ease traffic congestion on the coastal road. A study has been done on the connection between two cities located in Mont Lebanon 30 km away from the capital, Beirut. These two cities are Zouk and Bkirke. According to the Lebanese Ministry of Transportation, there are approximately 4,500 cars per day operating between Zouk and Bkirke that will benefit from the construction of a new bridge connecting those two cities. By a simple check, the public benefit cost from the new bridge is approximately $3,500/day, if we consider the saving for every user to be 45 minutes and 15 km of travel at an average speed of 25 km/h, without taking into consideration the indirect cost that will be saved due to traffic reduction on the coastal road. This traffic reduction means less infrastructure maintenance and less service provided for traffic control. Based on the estimated cost saving, the Lebanese government proposed a strategic plan to build a bridge. Figure 7.1 shows two points defining the start and the end of the bridge which are selected based on the existing road network. Furthermore, according to the government agency requirements appropriate to the site information, the global information concerning the new bridge to be constructed is: (1) Total Length, TL = 310 m; (2) Type of Area to overpass, TA = Valley; (3) Road Bridge Type, RBT = Non-highway; (4) Soil Types, ST = Rock; (5) Highest point, HP = 90m; (6) Maximum Speed, MS = 50km/hr; (7) Maximum Load, ML = 50T; (8) Traffic Capacity, TRC = 6000Veh/day.

Figure 7-1 – Site Plan View

Based on the factors that will be investigated and considered in the coming sections, an advance investigation is fulfilled in order to find the appropriate values related to the new bridge. Figure 7-2 presents a preliminary survey plan view for the bridge location, which will be needed to define some of the variables related to the new bridge for its design. The table 7-1 summarizes all the other variables that could be evaluated in addition to the above-mentioned ones.

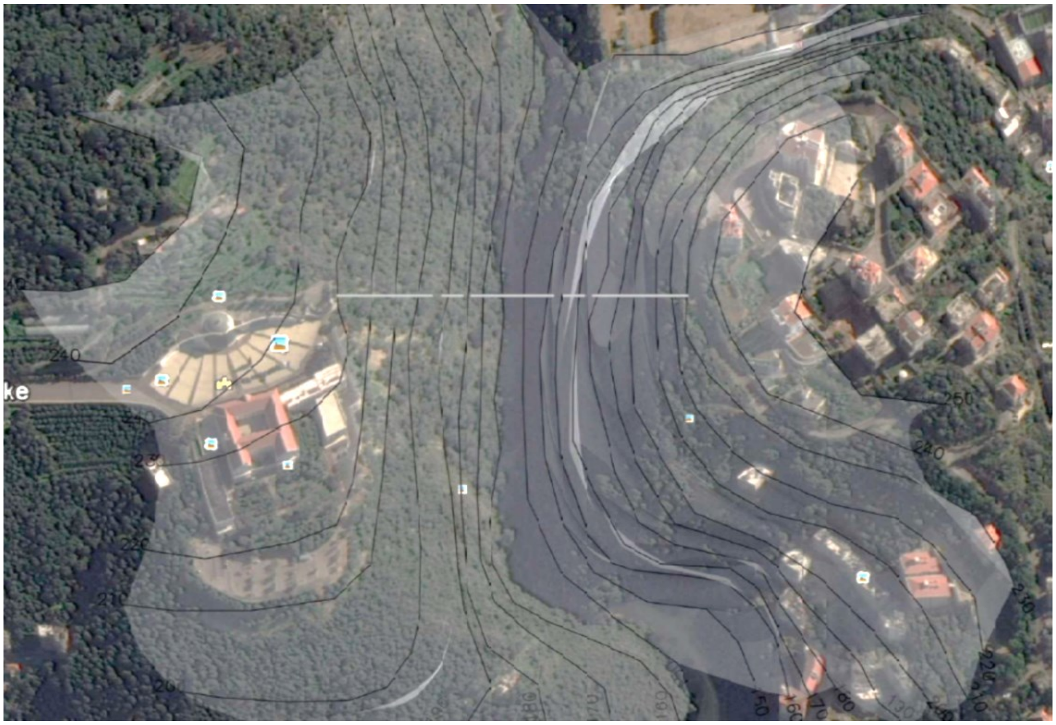


Figure 7-2 – Preliminary Survey Plan

Table 7-1 – New Bridge Information

Factors	Variables	Factors	Variables
Bridge ID	#9999	Total Length	310 m
Bridge Name	Bkirkie-Zouk	Type of Area to overpass	20
General Description	NA	Road-Bridge Type	10
Bridge Location	Bkirkie	Complexity	10
Year of Decision made	2016	Soil Type	10
Starting Year of Construction	2018	Highest point	90 m
Number of Lanes	2	Availability of Professional Companies in Bridge Construction	5
Total Width	9 m		
Max Speed	50 km/hr		
Max Load	50 Tons		
Traffic Capacity	6000 car/day		
Bridge Geometric (Straight, Skewed, Curved)	10		

7.3 Data module Establishment and Analysis

A new data module is established and defined for the DSS. Also, in order to be consistent in the analysis, societal and economic constraints are taken into account, using Questionnaire Q01 (Appendix D-1) and the interviews that have been conducted with 49 experts and participants. The questionnaire was distributed around the bridge location (refer to Figure 7-3) covering an area of approximately 1,500 km^2. The first problem faced in this task is that being in a country where the experts do not have any interest related to research, they are not able to reply to any email or to fill in a questionnaire. Only a very few experts replied to emails asking them to fill in a questionnaire. We were obligated to ask for meetings with many others in order to explain the target of the questionnaire and to explain its content to them in person.

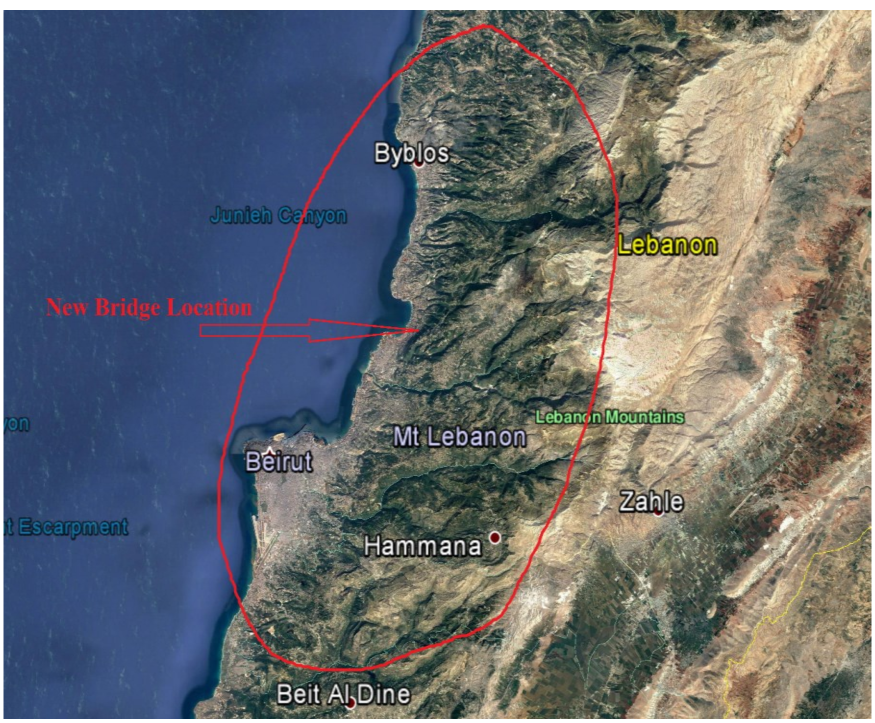


Figure 7-3 – The Area Investigated and Considered for Data Collection

7.3.1 Data module Factors

As discussed in Chapter 4, the factors included in the data module have to be defined based on the expert's opinions. By employing the five categories, the investigation only aims to define the factors of Categories II, III, IV, and V, since the first category defines the administrative parameters, hence, it does not need any further investigation. Moreover, Questionnaire Q01 is of utmost importance in implementing the influence factors based on the opinions of the experts, including the following:

CDR - Council for Development and Reconstruction – represented by the General Director, Elie Helou (as General Manager) - **(4 participants)**

Minister of public works – represented by the General Director, Tanios Boulos. (as Owner) **(6 participants)**

Dar Al-Handasat Chaaer and His Partners – represented by the Head of the civil engineering department, Georges Marj (as general Consultant) - **(12 participants)**

Al-Kharafi – represented by Branch Manager Alfred Fakhry Ibrahim (as General Contractor) **(3 participants)**

Elie Selwan Construction – represented by its owner, Elie Selwan (As General Contractor) **(2 participants)**

RAMCO Group – represented by the member of the board Abdelrahman Labban(As general Contractor) - **(8 participants)**

GENECO – represented by the engineer, Karim Hammoud (as General Contractor) **(6 participants)**

Mouawad & Eddeh – represented by the chairman, Georges Mouawad (as general Contractor) **(8 participants)**

A sample of the expert feedback can be found in Appendix D-4. Moreover, a summary of the schedule is provided in Appendix D-5, presenting all the collected opinions to be analyzed by using Equation 4-1 and Table 4-6. Therefore, the factors having the highest values will be considered in the data module as factors, and a Bridge ID File is established for the purpose of data collection. Figure 7-4 presents the adapted Bridge ID File, holding the factors considered within the appropriate categories showing the factor units. Figure 7-5 shows a summary schedule of the expert opinions. In addition, interviews have been conducted with government and private agencies in order to establish the required data, and collect appropriate variables for the selected factors. This data has been collected either from agencies, or through site visits and investigations, or by conducting a statistical study through Questionnaire Q02. The collected and stored data from sites are numerical and/or linguistic information, and they are defined either directly, by some formulations, or by using linguistic converter modules. Questionnaire Q02 is used for data collection, and which will be formulated later, in order to provide the "Aesthetic Impact Rate – Public Satisfaction (AIR-PS)" as discussed in Chapter 4. During the statistic investigations, the traffic for every existing bridge is calculated and stored in Questionnaire Q2 and transferred later to its appropriate factor in Category IV (Traffic Capacity). Public Opinions are stored in Questionnaire Q02 (refer to Appendix D-6 for a sample) to get opinions concerning the aesthetic satisfaction based on the five characteristics. Using Equations 4-4 and 4-5, the performance criteria for the bridge aesthetic will be rated. Furthermore, two other variables, EIR & AIR, from Category II, are also formulated and rated according to Equations 4-2 and 4-3. For existing Bridge #010, the following information is required in order to rate its EIR and AIR variables, with the information mentioned in Figures 7-6 and 7-7:

Total Bridge Area 11,832 **TBA (m^2)**

Affected Natural Areas	3,550	**ANA (m^2)**
Total Concrete Volume	12,450	**CV (m^3)**
Total Industrial Steel Weight	0	**ISW (T)**

Using Equations 4-2, 4-2a, 4-2b and 4-2c, the EIR variable is obtained (refer to Figure 7-6) with the related quantities collected during the investigations of the existing bridge (#010).

Bridge File

Category I – *Administrative Info*

Criteria

	Factor *(Definition)*	**Variable** *(Values)*
I.1	Bridge ID	NA
I.2	Bridge Name	NA
I.3	General Description	NA
I.4	Bridge Location	NA
I.5	Year of Decision made	year
I.6	Starting Year of Construction	year
I.7	Ending Year of Construction	year
I.8	Year Put in Operation	year
0	0	

Category cover general information concerning the bridge, administrative information might help the decision maker to figure out some special aspect.

Category II – *Geometric & Structure Info*

Criteria

	Factor *(Definition)*	**Variable** *(Values)*
II.1	Bridge Type (Girder, Arch, etc…)	converted to #
II.2	Structure Type for Deck	converted to #
II.3	Column Type	converted to #
II.4	Foundation Type	converted to #
II.5	Material Type	converted to #
II.6	Volume of Concrete	m3
II.7	Industrial Steel Weight	T
II.8	Exposed Concrete Surfaces	m2
II.9	Exposed steel surfaces	m2
II.10	Estimated Initial Cost - PV	$/m2
II.11	Environment Impact Rate	Calculated Rate
II.12	Aesthetic Impact Rate	Calculated Rate
0	0	

Category III – *Uncontrolled Variables*

Criteria

	Factor *(Definition)*	**Variable** *(Values)*
III.1	Total Length	m
III.2	Type of Area to overpass	converted to #
III.3	Road-Bridge Type	converted to #
III.4	Complexity	converted to #
III.5	Soil Type	converted to #
III.6	Highest point	m
III.7	Availability of Professional Companies in Bridge Construction	#
0	0	

Category IV – *Controlled Variables*

Criteria

	Factor *(Definition)*	**Variable** *(Values)*
IV.1	Number of Span	#
IV.2	Longest Span	m
IV.3	Number of Lanes	#
IV.4	Total Width	m
IV.5	Max Speed	km/hr
IV.6	Max Load	T
IV.7	Traffic Capacity	Vehicule/day
IV.8	Bridge Geometric (Straight, Skewed, Curved)	converted to #
0	0	

Category V – *Performance Criteria*

Criteria

	Factor *(Definition)*	**Variable** *(Values)*
V.1	Actual Initial Cost - PV	$/m2
V.2	Operation & Maintenance Cost over 100 Years	$/m2
V.3	Dismantling Cost	$/m2
V.4	Environment Impact Rate - Local Authorities Evaluation	converted to #
V.5	Aesthetic Impact Rate -Public Satisfaction	Based on Q02
V.6	Functional Satisfaction at first use	converted to #
V.7	Actual Construction Time / Estimated	#
0	0	

Operation cost could be divided into many cost types to figure out all cost aspects (maintenance, rehabilitation, retrofitting, preventive action cost, etc…)

Figure 7-4 – Bridge ID File (after collecting Factors)

Q01 - Summary Results																	
Factors (Cat. 3 &4)	**#01**	**#02**	**#03**	**#04**	**#05**	**#06**	**#07**	**#08**	**#09**	**#10**	**#11**	**#12**	**#13**	**#14**	**#15**	**#16**	**#17**
Site Location				5	1	6	8		3	3		3		5			4
Bridge Type (Girder, Arch, etc…)																	
Material Selection	6		4		3		5		7		6			5	4	3	6
Foundation Type																	
Space Usage	5		6		4		6			7		3			5		
Material Type																	
Volume of Concrete																	
Weather conditions	2		3		4		5		3		5		6		3		2
Industrial Steel Weight																	
Scale	4			5			3			6			5		4		2
Exposed Concrete Surfaces																	
Ground condition	1		2		3		3		4	5		5	4	7			7
Exposed steel surfaces																	
Aesthetic Satisfaction Rate																	

Figure 7-5 – Summary Schedule of Expert Opinions (Refer to Appendix D-5 for Complete Schedule)

Environment Impact Rate EIR (Cat. 2)			
Bridge #010			**EIR**
Total Bridge Area - **TBA**	**TBA (m^2)**	11832	13
Affected Natural Areas - **ANA**	**ANA (m^2)**	3550	
Total Concrete Volume - **CV**	**CV (m^3)**	12450	
Total Industrial Steel Weight - **ISW**	**ISW (T)**	0	
Natural Damage Factor:	7		
Pollution due Concrete Volume:	**6**		
Pollution due Industrial Steel Weight:	**0**		

Figure 7-6 – Environment Impact Rate – Cat II – Bridge #010

For the AIR rating, Figure 7-7 presents the corresponding values extracted from the aesthetic characteristics as described in Appendix E, and based on the geometric parameters, the resultant values are presented using Equation 4-3. For consistency, and in order to reduce subjectivity, a bank of photos is established (refer to Appendix G) and linked to the existing bridges considered in the data module to justify the assigned values of their factors (see Figures 7-6 and 7-7).

Aesthetic Satisfaction Rate AIR (Cat. 2)		6
Aesthetic Factors: Bridge #10	Calculated	
	Importance Factor (1-10) "I"	Rate (1-10) "V"
Ratio of deck span to depth	10	8
Ratio of deck span to pier height	10	5
Ratio of deck depth to pier width	10	5
Deck curvature in elevation	10	5
Deck superelevation	5	10
Bridge skew angle	10	10
Integrity to surrounding topography	10	8
Structure Impression (strength through form,)	10	8
Clear Display	10	5
Lighting, Shade, shadow.	10	5
Relationship with the substructure	5	5
Pier Dimension Ratios	10	10
Color & Textures	8	10
Architectural Elements Consistancy	8	10

Figure 7-7 – Aesthetic Impact Rate – Cat II – Bridge #010

On the other hand, the factor units specified by "converted to #" need to use the Linguistic Converter modules already presented in Appendix F. Referring to these modules, for every factor, an appropriate point-scale is employed to provide the assigned numerical variables in the data module (as shown in Figure 7-8). After determining the required variables for all the bridges considered, a summary schedule is provided that holds all the pertinent data to be analyzed and used with the other DSS components. This summary schedule is presented in Appendix D-7. Concerning the point-scale values used as stated in Appendix F, the mentioned values have been established after running many trial options. Instead of 10, 20, 30 … point-scale, we have tried many other point-scales (e.g., 1, 2, 3 … and 1, 5, 10 …) and the alternatives had the same ranking as long as we used the same order in the point-scale.

Bridge #010 ID File

Category I
Administrative Info

Criteria		
	Factor *(Definition)*	**Variable** *(Values)*
I.1	Bridge ID	10
I.2	Bridge Name	Antelias Neccache Bridge
I.3	General Description	NA
I.4	Bridge Location	Naccache
I.5	Year of Decision made	1997
I.6	Starting Year of Construction	2001
I.7	Ending Year of Construction	2003
I.8	Year Put in Operation	2003
0	0	

Category cover general information concerning the bridge, administrative information might help the decision maker to figure out some special aspect.

Category II
Geometric & Structure Info

Criteria		
	Factor *(Definition)*	**Variable** *(Values)*
II.1	Bridge Type (Girder, Arch, etc…)	20
II.2	Structure Type for Deck	60
II.3	Column Type	20
II.4	Foundation Type	10
II.5	Material Type	10
II.6	Volume of Concrete	12450
II.7	Industrial Steel Weight	0
II.8	Exposed Concrete Surfaces	14550
II.9	Exposed steel surfaces	0
II.10	Estimated Initial Cost - PV	1100
II.11	Environment Impact Rate	13
II.12	Aesthetic Impact Rate	6
0	0	

Category III
Uncontrolled Variables

Criteria		
	Factor *(Definition)*	**Variable** *(Values)*
III.1	Total Length	493
III.2	Type of Area to overpass	10
III.3	Road-Bridge Type	10
III.4	Complexity	30
III.5	Soil Type	30
III.6	Highest point	8
III.7	Availability of Professional Companies in Bridge Construction	4
0	0	

Category IV
Controlled Variables

Criteria		
	Factor *(Definition)*	**Variable** *(Values)*
IV.1	Number of Span	18
IV.2	Longest Span	45
IV.3	Number of Lanes	2
IV.4	Total Width	24
IV.5	Max Speed	60
IV.6	Max Load	60
IV.7	Traffic Capacity	12575
IV.8	Bridge Geometric (Straight, Skewed, Curved)	30
0	0	

Category V
Performance Criteria

Criteria		
	Factor *(Definition)*	**Variable** *(Values)*
V.1	Actual Initial Cost - PV	1425
V.2	Operation & Maintenance Cost over 100 Years	2500
V.3	Dismantling Cost	400
V.4	Environment Impact Rate - Local Authorities Evaluation	30
V.5	Aesthetic Impact Rate -Public Satisfaction	7
V.6	Functional Satisfaction at first use	30
V.7	Actual Construction Time / Estimated	2
0	0	

Operation cost could be divided into many cost types to figure out all cost aspects (maintenance, rehabilitation, retrofitting, preventive action cost, etc…)

Figure 7-8 – Bridge #010 ID File

7.3.2 Data Analysis

Adding to the difficulties faced during the collection of expert opinions, data collection for the existing bridges covered by the case study induced challenges for the project. Many problems were encountered during the data collection and they are grouped as follows: (a) Sources and registered data; (b) physical data collection; (c) working in a third world country with political and security factors; and (d) competitive factors and data hiding. It was impossible to collect the needed data from a single source or even from a limited number of sources; even more, some data are not available and there is no possibility to get them. Some data were able to be collected directly from sites such physical data and their performance level, and in this case, many difficulties were faced, for instance issues related to security and political factors especially that we are working in a critical region where doing such a task requires many approvals from official and unofficial references. Further to the previous problems, any government employee considers the information to be his or her own and considers that he has the right to hide it and not to share with others for many reasons especially to conserve his power in his position. Once the data module has been established, it is important to analyze its contents for clarity and consistency, and to find out if it is homogeneous, heterogeneous, asymmetric, and realistic. The aim of the first step is to define the alternatives related to Category II (i.e., BT, DT, and CT). Based on the criteria mentioned in Categories III and IV, a statistical analysis will be done to link Categories III and IV to Category II. On the other hand, by referring to the data schedule, the statistical relation between the bridge types (BT) with their total lengths (TL) shows that the number of a specified bridge type related to its total length is distributed (refer to Table 7-2 for more details). Furthermore, similar relations could be established between any factor from Categories III and IV with different bridge types and linked to any other factor from Category II that defines the bridge components (BT, DT, CT, FT, MT). The relation between the Bridge Types with "Type of Area to overpass", "Road Bridge Type", "Soil Type" and "Highest Point" are presented in Appendix D-8. The information presented in Table 7-2 could be presented as percentages (see Table 7-3) and/or as a graphical relation (see Figure 7-9).

7.3.3 Statistical Alternatives for the New Bridge

After drawing the statistical relations between different factors (refer to Appendix D-8) which presents the probabilities of Bridge Type factors, and based on the parameter values for a new bridge to be constructed, the alternatives for a new bridge type are defined based on the results shown in the Quality function deployment (QFD) house as shown in Table 7-4. The values presented in the middle of the table are retrieved from Figure 7-9 and Appendix D-8.

Table 7-2 – Statistical relationship between BT & TL

			III.1 - TL - Total Length					
		Number of Bridges	Bridge Length 0-100 m	Bridge Length 100-200 m	Bridge Length 200-300 m	Bridge Length 300-400 m	Bridge Length more than 400 m	
II.1 - BT	10	Rigid Frame Bridges	3	0	0	0	0	0
	20	Beam Bridges / Girder Bridges	25	11	1	4	7	0
	30	Arch Bridges / Through Arch Bridges	0	2	0	0	0	0
	40	Truss Bridges	0	0	0	0	0	0
	50	Cantilever Bridges	0	0	0	0	0	0
								53

Table 7-3 – Statistical relationship between BT & TL – Percentage rate

			III.1 - TL - Total Length					
		Number of Bridges	Bridge Length 0-100 m	Bridge Length 100-200 m	Bridge Length 200-300 m	Bridge Length 300-400 m	Bridge Length more than 400 m	0
II.1 - BT	**10**	Rigid Frame Bridges	5.7%	0.0%	0.0%	0.0%	0.0%	0.0%
	20	Beam Bridges / Girder Bridges	47.2%	20.8%	1.9%	7.5%	13.2%	0.0%
	30	Arch Bridges / Through Arch Bridges	0.0%	3.8%	0.0%	0.0%	0.0%	0.0%
	40	Truss Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	50	Cantilever Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
								100.0%

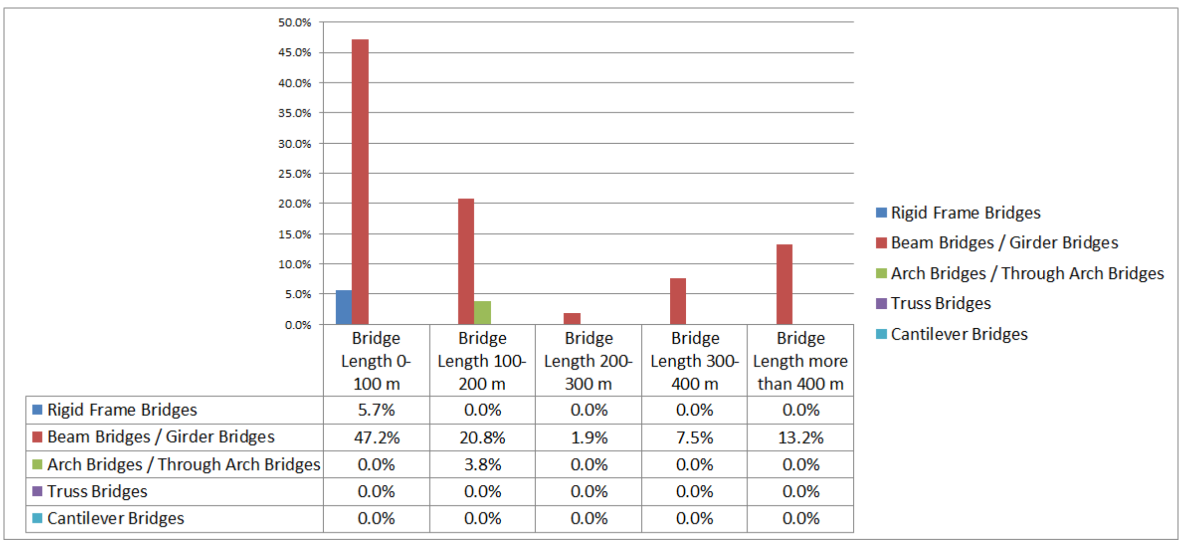


Figure 7-9 – Statistical relationship between BT & TL – Graphic Presentation

Table 7-4 – Quality function deployment QFD – Statistical Alternative for New Bridge

For the actual case study	*Importance Factor*	II.1 - BT				
		Rigid Frame Bridges	Beam Bridges / Girder Bridges	Arch Bridges / Through Arch Bridges	Truss Bridges	Cantilever Bridges
Chosen as per actual case study		10	20	30	40	50
III.1 - TL - Total Length - 310 m	5	0	7.5	0	0	0
III.2 - TA - Type of Area to overpass - 5	5	0	7.5	3.8	0	0
III.3 - RBT - Road Bridge Type - 1	5	3.8	30.2	3.8	0	0
III.5 - ST - Soil Types - 1	5	3.8	24.5	0	0	0
III.6 - HP - Highest point - 90 m	5	0	1.9	0	0	0
Raw Score		38	358	38	0	0
Percentage		8.8	82.5	8.76	0	0

For the TL row, the assigned value of "7.5" is retrieved from Figure 7-9 by considering a range of total length between 300m and 400m that gives a 7.5% for the bridge type, In the same manner (referring to Appendix D-8), we retrieve the values of "7.5" and "3.8" from the TA/BT chart, the values of "3.8," "30.2," and "3.8" from the RBT/BT chart, the values of "3.8" and "24.5" from the ST/BT chart, and finally the value of "1.9" from the HP/BT chart. It should be noted that the raw score for each bridge type candidate has to be calculated based on the importance factor assigned for each influence factor (TL, TA, RBT, ST, HP), using the following equation:

$$\text{Raw Score for } BT_I = \sum \left[\text{Importance factor} * Q_I \right]_J \qquad [5.1]$$

Where, **J** = TL, TA, RBT, ST, HP (Influence factors considered)

I = 10, 20, 30, 40, 50 (Bridge Types)

and then a percentage is calculated and presented in the last row.

7.4 DSS Engine & BrIM

As previously discussed in Chapters 5 and 6, the steps to be followed in this phase are: (1) First Arrangement to define the potential alternatives, (2) BrIM implementation to retrieve the associated quantities and conduct a preliminary engineering judgment after the architectural and structural verifications; and (3) Final Arrangement is to evaluate the performance criteria for each alternative; and (4) the final step is to cover the results by implementing a Sensitivity Analysis (SA), Level of Realistic outcomes, and then the unique final decision will be highlighted.

7.4.1 First Arrangement

The necessary data for this part are based on Categories III, IV and II, which are retrieved from the data module (Appendix D-7) that is established according to existing bridges to train the appropriate ANN. Table 7-5 represents the input data for the ANN and Table 7-6 represents the target (output) values. After training the ANN, and before extracting the results for a new case, Matlab nntool provides an output file based on a testing procedure to evaluate the accuracy of the trained ANN. The obtained values are presented in Appendix I-1, mentioning that the Validation Performance and the R-Values for the ANN are verified to be within the acceptable limits as described in section 6.3.1.

Table 7-5 – Input Data for the First Arrangement – (Refer to Appendix D-7 for complete schedule)

		Input		001	002	003	004	005	006
III.1	L	Total Length	m	140	310	215	35	35	32
III.2	TA	Type of Area to overpass	converted to #	20	20	10	10	10	10
III.3	RBT	Road-Bridge Type	converted to #	10	20	10	10	10	10
III.4	Com	Complexity	converted to #	10	10	30	10	10	10
III.5	TS	Soil Type	converted to #	10	30	10	20	20	20
III.6	HP	Highest point	m	150	30	7	5.5	5.5	6
III.7	AP	Availability of Professional Companies in Bridge Construction	#	5	5	3	3	3	3
IV.1	SN	Number of Span	#	14	7	9	2	2	2
IV.2	LS	Longest Span	m	140	60	25	18	18	18
IV.3	NL	Number of Lanes	#	4	6	2	2	2	2
IV.4	TW	Total Width	m	26	30	12	12	10	10
IV.5	MS	Max Speed	km/hr	80	100	50	40	40	40
IV.6	ML	Max Load	T	60	100	60	30	30	30
IV.7	TRC	Traffic Capacity	Vehicule/day	24352	21572	7588	4792	2014	1556
IV.8	BG	Bridge Geometric (Straight, Skewed, Curved)	converted to #	10	10	10	20	20	10

Table 7-6 – Target Data for the First Arrangement – (Refer to Appendix D-7 for complete schedule)

		Target		001	002	003	004	005	006
II.1	BT	Bridge Type (Girder, Arch, etc…)	converted to #	30	20	20	20	20	20
II.2	DT	Structure Type for Deck	converted to #	10	40	10	10	10	10
II.3	CT	Column Type	converted to #	0	20	10	30	20	20
II.4	FT	Foundation Type	converted to #	10	10	10	10	10	10
II.5	MT	Material Type	converted to #	10	10	10	10	10	10
II.6	CV	Volume of Concrete	m^3	2562	1225	3125	625	560	525
II.7	ISW	Industrial Steel Weight	T	0	0	0	0	0	0
II.8	CS	Exposed Concrete Surfaces	m^2	4320	21550	3325	556	425	380
II.9	SS	Exposed steel surfaces	m^2	0	0	0	0	0	0
II.10	EIC	**Estimated Initial Cost - PV**	$\$/m^2$	**850**	**1150**	**1250**	**950**	**850**	**850**
II.11	EIR	Environment Impact Rate	Calculated Rate	9	6	16	17	17	17
II.12	AIR	Aesthetic Satisfaction Rate	Calculated Rate	8	7	5	4	4	4

Using the trained ANN to predict the results (Category II variables) for a new project defined by the factors presented in Table 7-7, it is obvious that at this stage, the number of spans and longest span cannot be assigned. Thus, the implementation of BrIM is of utmost importance, for the assigned values, by taking those values as average of the existing projects, the analysis proceeds by several iterations, in order to accomplish the first arrangement for the aforementioned values. It should be noted that the trained ANN is used with new inputs presented in Table 7-7, the obtained prediction of the outputs are presented in Table 7-8. Based on these results, the alternatives for the new case study project suggested by expert, are summarized in Table 7-9.

Table 7-7 – Input Data for new case project – First Arrangement

NEW INPUT - Case Study Data				CS 1
III.1	L	Total Length	m	310
III.2	TA	Type of Area to overpass	converted to #	20
III.3	RBT	Road-Bridge Type	converted to #	10
III.4	Com	Complexity	converted to #	10
III.5	TS	Soil Type	converted to #	10
III.6	HP	Highest point	m	90
III.7	AP	Availability of Professional Companies in Bridge Construction	#	5
IV.1	SN	Number of Span	#	10
IV.2	LS	Longest Span	m	30
IV.3	NL	Number of Lanes	#	2
IV.4	TW	Total Width	m	9
IV.5	MS	Max Speed	km/hr	50
IV.6	ML	Max Load	T	50
IV.7	TRC	Traffic Capacity	Vehicule/day	6000
IV.8	BG	Bridge Geometric (Straight, Skewed, Curved)	converted to #	10

Table 7-8 – Predicted outputs for new case project – First Arrangement

Output - From Trained ANN Matlab				CS 1	Equivalents	
II.1	BT	Bridge Type (Girder, Arch, etc…)	converted to #	29.2875	20-30	
II.2	DT	Structure Type for Deck	converted to #	11.25	10	
II.3	CT	Column Type	converted to #	26.6361	20-30	
II.4	FT	Foundation Type	converted to #		10	Selected without analysis - Obviously
II.5	MT	Material Type	converted to #	10.008	10	Obviously
II.6	CV	Volume of Concrete	m^3	Calculated based on the proposed Alternatives & BrIM		
II.7	ISW	Industrial Steel Weight	T			
II.8	CS	Exposed Concrete Surfaces	m^2			
II.9	SS	Exposed steel surfaces	m^2			
II.10	EIC	Estimated Initial Cost - PV	$\$/m^2$	883	885	Value to be verified for each proposed alternative
II.11	EIR	Environment Impact Rate	Calculated Rate	Values to be calculated based on EIR-Cat II &		
II.12	AIR	Aesthetic Satisfaction Rate	Calculated Rate	Aesthetic Satisfaction Rate - AIR - Cat II		

Table 7-9 – Proposed Alternatives for new case project – First Arrangement

Input Data for Final Arrangement				Alt1	Alt2	Alt3	Alt4	Alt5
II.1	BT	Bridge Type (Girder, Arch, et	converted to #	30	30	20	20	20
II.2	DT	Structure Type for Deck	converted to #	10	30	10	30	50
II.3	CT	Column Type	converted to #	**10**	**10**	**30**	**30**	**20**
II.4	FT	Foundation Type	converted to #	10	10	10	10	10
II.5	MT	Material Type	converted to #	10	10	10	10	10
II.10	EIC	Estimated Initial Cost - PV	$\$/m^2$	885	885	885	885	885

Engineering judgment is emphasized while proposing alternatives, because the engineering aspects (geometric and structure) have to be verified, especially during the BrIM implementation phase.

7.4.2 BrIM Implementation

Based on the data given in Tables 7-7 through 7-9, sketches and geometric perspectives are produced. The first step is to work with the actual land constraints for each proposed alternative, with architectural innovations, taking into consideration the aesthetic aspects. The five perspectives shown in Figure 7-10 are produced by using Autodesk Revit software, and transferred to the Robot module to conduct preliminary design verifications. After a number of coordination meetings between the architectural and structural designers, the sections presented in Figure 7-11 are delivered to the architect in order to implement the required structural dimensions in his/her perspectives. Afterwards, appropriate volumes and surfaces are extracted from Revit according to the final proposed perspectives. Also, the EIR and AIR are calculated based on Tables 4-7 and 4-8 respectively, and according to the geometric configurations listed in the appendix E. Up to this point, the complete data for the variables of Category II variables are established and these are presented in Table 7-10. Additional information related to the preliminary structural is provided in appendix J.

7.4.3 Final Arrangement

The final arrangement is the last step in extracting the results and analyzing them. In this stage, in order to train the appropriate ANN, the variables included in Categories II, III, and IV from the data module will be considered as input data and the variables of Category V are considered as target values (outputs).

Table 7-10 – Proposed Alternatives for new case project – Cat. II variables after BrIM implementation

Input Data for Final Arrangement				Alt1	Alt2	Alt3	Alt4	Alt5
II.1	BT	Bridge Type (Girder, Arch, et	converted to #	30	30	20	20	20
II.2	DT	Structure Type for Deck	converted to #	10	30	10	30	50
II.3	CT	Column Type	converted to #	**10**	**10**	**30**	**30**	**20**
II.4	FT	Foundation Type	converted to #	10	10	10	10	10
II.5	MT	Material Type	converted to #	10	10	10	10	10
II.6	CV	Volume of Concrete	m^3	4350	4300	5250	5500	5150
II.7	ISW	Industrial Steel Weight	T	0	0	0	0	0
II.8	CS	Exposed Concrete Surfaces	m^2	6150	7250	6050	7250	6350
II.9	SS	Exposed steel surfaces	m^2	0	0	0	0	0
II.10	EIC	Estimated Initial Cost - PV	$/$m^2$	885	885	885	885	885
II.11	EIR	Environment Impact Rate	Calculated Rate	17	14	18	19	18
II.12	AIR	Aesthetic Satisfaction Rate	Calculated Rate	6	5	6	7	6

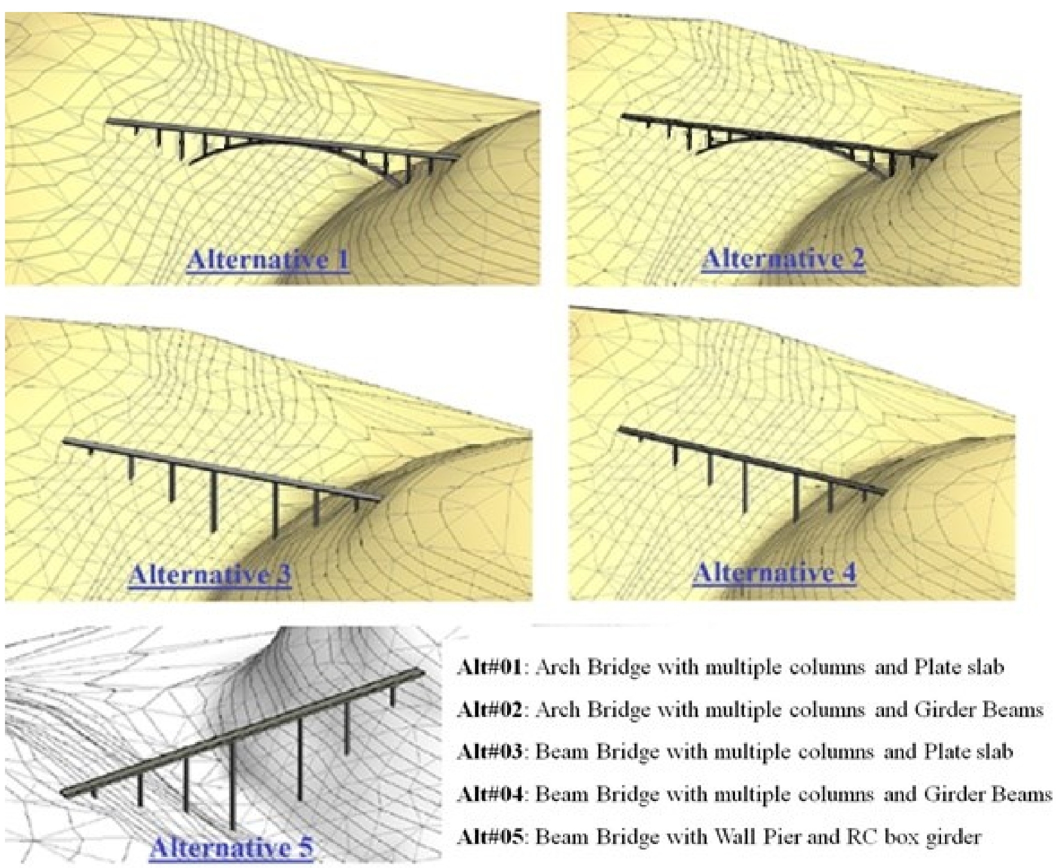


Figure 7-10 – Perspectives for the five alternatives

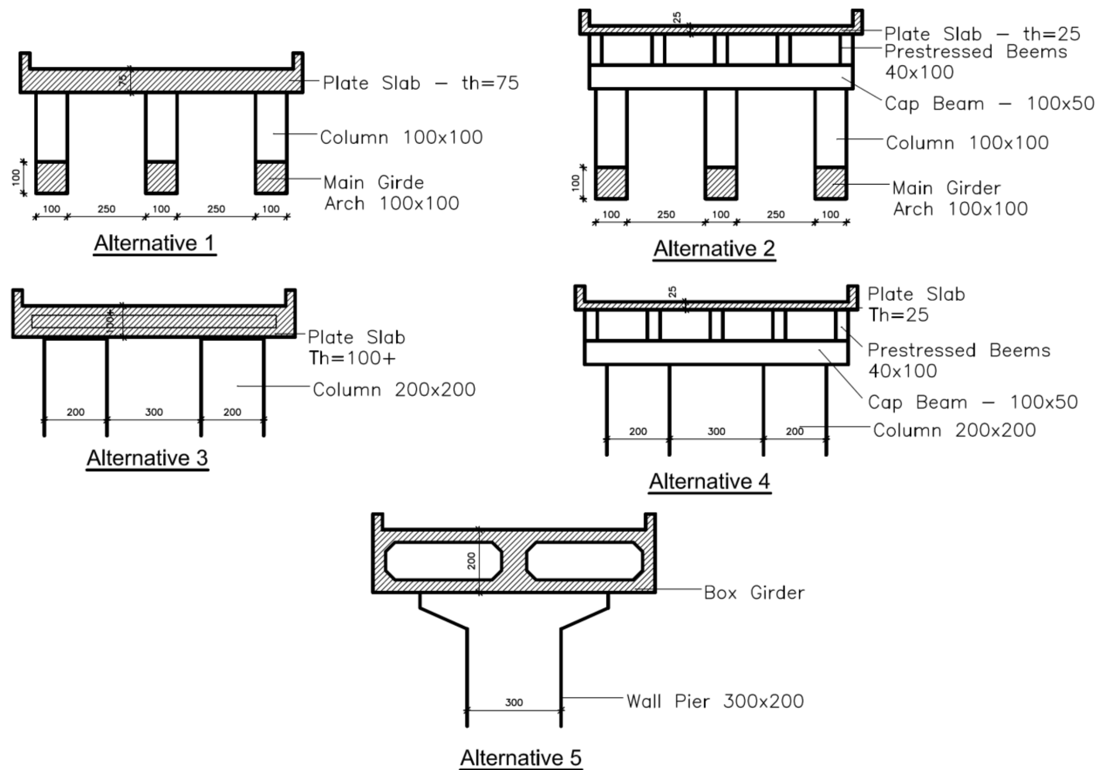


Figure 7-11 – Structural section dimensions for the five alternatives

Tables 7-11 and 7-12 summarize some of those variables, while a complete schedule is provided in Appendix D-7. After training the ANN, verification through testing the existing cases has been conducted and the differences between the target and output values have been highlighted. In Appendix I-2, a complete schedule showing the differences is presented. Table 7-13 shows the input values for new cases (alternatives) to be studied through the trained ANN in order to extract the performance criteria for the different alternatives. The performance criteria for different alternatives are presented in Table 7-14. Obviously, all the necessary verifications, validations, and testing, as defined and discussed in Chapter 6, are implemented in order to assign an optimal level of reliability for the trained ANN, without ignoring that the ANN environment could lead to some probability of dissatisfaction and uncertainty; for that, additional analysis will be conducted in the coming sections to highlight some of them.

Table 7-11 – Input Data for the Final Arrangement – (Refer to Appendix D-7 for complete schedule)

INPUT				001	002	003	004	005	006	…..
II.1	BT	Bridge Type (Girder, Arch, etc…)	converted to #	30	20	20	20	20	20	
II.2	DT	Structure Type for Deck	converted to #	10	40	10	10	10	10	
II.3	CT	Column Type	converted to #	10	30	20	40	30	30	
II.4	FT	Foundation Type	converted to #	10	10	10	10	10	10	
II.5	MT	Material Type	converted to #	10	10	10	10	10	10	
II.6	CV	Volume of Concrete	m^3	2562	1225	3125	625	560	525	
II.7	ISW	Industrial Steel Weight	T	0	0	0	0	0	0	
II.8	CS	Exposed Concrete Surfaces	m^2	4320	21550	3325	556	425	380	
II.9	SS	Exposed steel surfaces	m^2	0	0	0	0	0	0	
II.10	**EIC**	**Estimated Initial Cost - PV**	**$\$/m^2$**	**850**	**1150**	**1250**	**950**	**850**	**850**	
II.11	EIR	Environment Impact Rate	Calculated Rate	9	6	16	17	17	17	
II.12	AIR	Aesthetic Satisfaction Rate	Calculated Rate	8	7	5	4	4	4	
III.1	L	Total Length	m	140	310	215	35	35	32	
III.2	TA	Type of Area to overpass	converted to #	20	20	10	10	10	10	
III.3	RBT	Road-Bridge Type	converted to #	10	20	10	10	10	10	
III.4	Com	Complexity	converted to #	10	10	30	10	10	10	
III.5	TS	Soil Type	converted to #	10	30	10	20	20	20	
III.6	HP	Highest point	m	150	30	7	5.5	5.5	6	
III.7	AP	Availability of Professional Companies in Bridge Construction	#	5	5	3	3	3	3	
IV.1	SN	Number of Span	#	14	7	9	2	2	2	
IV.2	LS	Longest Span	m	140	60	25	18	18	18	
IV.3	NL	Number of Lanes	#	4	6	2	2	2	2	
IV.4	TW	Total Width	m	26	30	12	12	10	10	
IV.5	MS	Max Speed	km/hr	80	100	50	40	40	40	
IV.6	ML	Max Load	T	60	100	60	30	30	30	
IV.7	TRC	Traffic Capacity	Vehicule/day	24352	21572	7588	4792	2014	1556	
IV.8	BG	Bridge Geometric (Straight, Skewed, Curved)	converted to #	10	10	10	20	20	10	

Table 7-12 – Target Data for the Final Arrangement – (Refer to Appendix D-7 for complete schedule)

INPUT				001	002	003	004	005	006	.....
V.1	IC	Actual Initial Cost - PV	$/m^2$	1100	1250	1825	1275	1150	1150	
V.2	OC	Operation & Maintenance Cost over 10	$/m^2$	600	1000	2000	1850	1950	1850	
V.3	DC	Dismantling Cost	$/m^2$	150	400	500	300	350	350	
V.4	EIR-LA	Environment Impact Rate - Local Authorities Evaluation	converted to #	10	20	20	30	20	20	
V.5	AIR-PS	Aesthetic Satisfaction Rate - Public Satisfaction	Based on Q02	5	3	5	7	7	7	
V.6	FS	Functional Satisfaction at first use	converted to #	10	10	20	30	30	30	
V.7	CTM	Actual Construction Time / Estimated	#	2	1.5	2	2	1.75	2	

Table 7-13 – Input Data for new case project – Final Arrangement

Input Data for Final Arrangement				Alt1	Alt2	Alt3	Alt4	Alt5
II.1	BT	Bridge Type (Girder, Arch, etc…)	converted to #	30	30	20	20	20
II.2	DT	Structure Type for Deck	converted to #	10	30	10	30	50
II.3	CT	Column Type	converted to #	10	10	30	30	20
II.4	FT	Foundation Type	converted to #	10	10	10	10	10
II.5	MT	Material Type	converted to #	10	10	10	10	10
II.6	CV	Volume of Concrete	m^3	4350	4300	5250	5500	5150
II.7	ISW	Industrial Steel Weight	T	0	0	0	0	0
II.8	CS	Exposed Concrete Surfaces	m^2	6150	7250	6050	7250	6350
II.9	SS	Exposed steel surfaces	m^2	0	0	0	0	0
II.10	EIC	Estimated Initial Cost - PV	$/m^2$	885	885	885	885	885
II.11	EIR	Environment Impact Rate	Calculated Rate	17	14	18	19	18
II.12	AIR	Aesthetic Satisfaction Rate	Calculated Rate	6	5	6	7	6
III.1	L	Total Length	m	310	310	310	310	310
III.2	TA	Type of Area to overpass	converted to #	20	20	20	20	20
III.3	RBT	Road-Bridge Type	converted to #	10	10	10	10	10
III.4	Com	Complexity	converted to #	10	10	10	10	10
III.5	TS	Soil Type	converted to #	10	10	10	10	10
III.6	HP	Highest point	m	90	90	90	90	90
III.7	AP	Availability of Professional Companies in Bridge Construction	#	5	5	5	5	5
IV.1	SN	Number of Span	#	13	13	8	8	8
IV.2	LS	Longest Span	m	20	20	60	60	60
IV.3	NL	Number of Lanes	#	2	2	2	2	2
IV.4	TW	Total Width	m	9	9	9	9	9
IV.5	MS	Max Speed	km/hr	50	50	50	50	50
IV.6	ML	Max Load	T	50	50	50	50	50
IV.7	TRC	Traffic Capacity	Vehicule/day	6000	6000	6000	6000	6000
IV.8	BG	Bridge Geometric (Straight, Skewed, Curved)	converted to #	10	10	10	10	10

Table 7-14 – Predicted outputs (performance criteria) for new case project case – Final Arrangement

Output (performance criteria) from Trained ANN Matlab				Alt1	Alt2	Alt3	Alt4	Alt5
V.1	IC	Actual Initial Cost - PV	$\$/m^2$	991	986	1157	1194	1131
V.2	OC	Operation & Maintenance Cost ov	$\$/m^2$	3947	4932	3655	4728	5527
V.3	DC	Dismantling Cost	$\$/m^2$	751	708	533	306	178
V.4	EIR-LA	Environment Impact Rate - Local Authorities Evaluation	converted to #	13	14	16	16	23
V.5	AIR-PS	Aesthetic Satisfaction Rate - Public Satisfaction	Based on Q02	4	6	3	3	4
V.6	FS	Functional Satisfaction at first us	converted to #	15	16	44	45	43
V.7	CTM	Actual Construction Time / Estim	#	1.27	1.35	1.65	1.34	1.31

7.5 Results Analysis

Before providing a final decision based on a systematic process, results analysis is needed in order to understand the previous results with their possible level of uncertainty and misleading. For that, Sensitivity Analysis (SA) for some factors is an essential technique to be applied to highlight the uncertainty, and the Level of Realistic is important to provide some validation to the extracted results.

7.5.1 Sensitivity Analysis

The factors that have influenced the decision are investigated by interviewing the experts, then they are well defined and implemented in the data module and exported to the DSS engine to provide the appropriate decision. However, the level of their influence is still unclear as well as the uncertainty that resides in the values assigned to these factors. To overcome this problem, sensitivity analysis is the best tool to apply. For that, within the final arrangement, some factors will be selected to evaluate their influence by assigning different values and by monitoring the variations of the performance criteria. The selected factors to be investigated are: (1) Volume of concrete, (2) Estimated initial cost, (3) Environment Impact Rate, (4) Aesthetic Impact Rate, and (5) Availability of professional companies in bridge construction; stating that the sensitivity analysis will be conducted just for Alternatives 1 and 3, and the values are presented in Table 7-15. Noting that, the decision maker may proceed in the analysis for all the factors and for all the alternatives, because it is up to him/her to make the best selection according to his/her perception by employing the feedback given by the experts during their meetings. After using the trained ANN, for each factor considered and registered, the variations in the performance criteria will be presented. The Sensitivity Analysis (SA) for each factor is carried out without any correlation between them. The variations in the selected performance criteria are recorded as follows: (1) Actual Initial Cost – PV; (2) Operation & Maintenance Cost over 100 Years; (3) Dismantling Cost; (4) Environmental Impact Rate - Local Authorities Evaluation; (5) Aesthetic Satisfaction Rate - Public Satisfaction; (6) Functional Satisfaction at first use; and (7) Actual/Estimated Construction Time. Refer to Appendix I-3 for more details. Referring to figure 7-12, Sensitivity analysis is conducted for the initial cost prediction (performance criteria) by applying different values for the listed factors. For instance, the predicted initial cost increases with the increase of the estimated initial cost. Concerning the environment, it is clearly shown that the environmental protection and the predicted initial cost will increase as well. Other factors, like the concrete volume, do not have important effects, since their curves are either horizontal or parabolic.

7.5.2 Level of Realistic Outcomes

Many traditional methods that provide a graphical solution to selecting an appropriate bridge type or deck type, based on one or more factors, may exist. To evaluate the Realistic Level of the results of the mentioned methods, a comparison of the results and those calculated by the actual DSS is done.

Table 7-15 – Considered Factors and values considered for sensitivity analysis

NEW INPUT - For Alternatives				Alt1	Alt1	Alt1	Alt1	Alt1	Alt2	Alt3	Alt3	Alt3	Alt3	Alt3	Alt4	Alt5
II.1	BT	Bridge Type (Girder, Arch, etc…)	converted to #	30					30	20					20	20
II.2	DT	Structure Type for Deck	converted to #	10					30	10					30	50
II.3	CT	Column Type	converted to #	20					20	20					20	30
II.4	FT	Foundation Type	converted to #	10					10	10					10	10
II.5	MT	Material Type	converted to #	10					10	10					10	10
II.6	CV	Volume of Concrete	m^3	4350	1000	2000	8000	12000	4300	5250	1200	2400	10000	14500	5500	5150
II.7	ISW	Industrial Steel Weight	T	0					0	0					0	0
II.8	CS	Exposed Concrete Surfaces	m^2	6150					7250	6050					7250	6350
II.9	SS	Exposed steel surfaces	m^2	0					0	0					0	0
II.10	EIC	**Estimated Initial Cost - PV**	**$/$m^2$**	885	500	650	1000	1200	885	885	500	650	1000	1200	885	885
II.11	EIR	Environment Impact Rate	Calculated Rate	17	5	10	20	30	17	21	6	12	25	37	22	21
II.12	AIR	Aesthetic Satisfaction Rate	Calculated Rate	6	1	3	8	10	5	6	1	3	8	10	7	6
III.1	L	Total Length	m	310					310	310					310	310
III.2	TA	Type of Area to overpass	converted to #	20					20	20					20	20
III.3	RBT	Road-Bridge Type	converted to #	10					10	10					10	10
III.4	Com	Complexity	converted to #	10					10	10					10	10
III.5	TS	Soil Type	converted to #	10					10	10					10	10
III.6	HP	Highest point	m	90					90	90					90	90
III.7	AP	Availability of Professional Companies in Bridge Construction	#	5	1	3	8	10	5	5	1	3	8	10	5	5
IV.1	SN	Number of Span	#	13					13	8					8	8
IV.2	LS	Longest Span	m	20					20	60					60	60
IV.3	NL	Number of Lanes	#	2					2	2					2	2
IV.4	TW	Total Width	m	9					9	9					9	9
IV.5	MS	Max Speed	km/hr	50					50	50					50	50
IV.6	ML	Max Load	T	50					50	50					50	50
IV.7	TRC	Traffic Capacity	Vehicule/day	6000					6000	6000					6000	6000
IV.8	BG	Bridge Geometric (Straight, Skewed, Curved)	converted to #	10					10	10					10	10

For instance, referring to Figure 4-1, and based on the provided chart, for a span of 310m (~1,000ft), three possibilities have to be analyzed: (1) Truss, (2) Arch, or (3) Cable-stayed bridge, while the decision that will be taken according the proposed DSS will be an Arch bridge. For the other criteria, same analogy is implemented, using a direct verification through similar charts, or by using other types of information depending on the availability of the location/country of the project.

Alt1 / Initial Cost					
Total Volume	1000	2000	4350	8000	12000
Initial Cost	1468	1497	1505	1502	1571
Estimated Cost	500	650	885	1000	1200
Initial Cost	1040	1209	1505	1667	1975
Availability of Profe	1	3	5	8	10
Initial Cost	1680	1548	1505	1835	2125
EIR	5	10	17	20	30
Initial Cost	1856	1694	1505	1446	1356
AIR	1	3	6	8	10
Initial Cost	1939	1565	1505	1619	1730
Different values considered for Sensitivity Analysis					

Alt1 / Initial Cost					
Total Volume	23%	46%	100%	184%	276%
Initial Cost	98%	99%	100%	100%	104%
Estimated Cost	56%	73%	100%	113%	136%
Initial Cost	69%	80%	100%	111%	131%
Availability of Profe	20%	60%	100%	160%	200%
Initial Cost	112%	103%	100%	122%	141%
EIR	29%	59%	100%	118%	176%
Initial Cost	123%	113%	100%	96%	90%
AIR	17%	50%	100%	133%	167%
Initial Cost	129%	104%	100%	108%	115%
The Different percentages considered for Sensitivity Analysis					

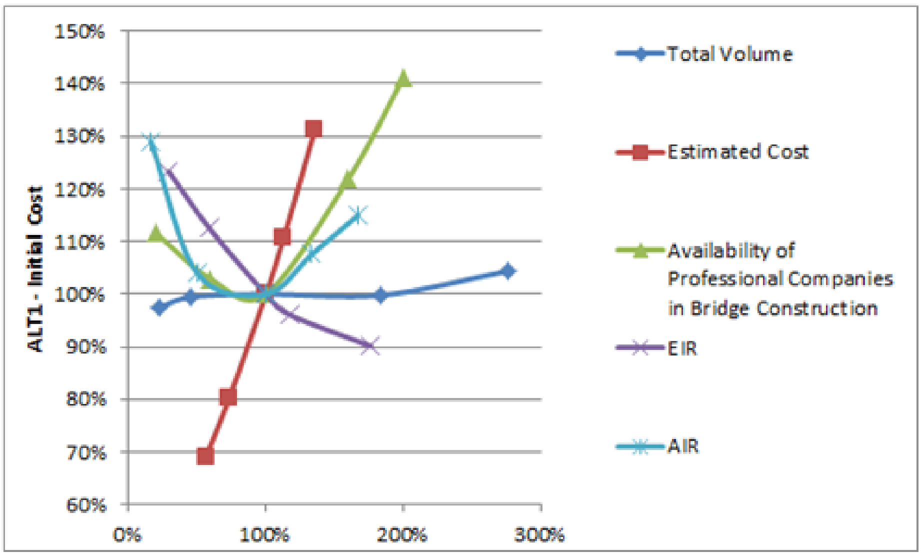


Figure 7-12 – Sensitivity Analysis for the Predicted initial cost criteria

Finally, what will be proposed in this section is based on the information already implemented in the data module. It should be noted that the predicted initial cost (IC), might be compared to the estimated initial cost (EIC), by applying the following steps: 1) calculate the mean and the standard deviation for the EIC/IC ratio of the existing bridges; and 2) compare the new bridge ratio to this mean within an interval of 2σ (2 times standard deviation). The same procedure is conducted and compared to all the predicted performance criteria for a new project with some ratio as presented in Table 7-16. As shown in the Table 7-16, the proposed interval for two standard deviations, we notice that some values fall outside of the proposed interval. Another interval can be adopted, like the 6σ, but the main issue to take into consideration is that we are working at the conceptual design phase, and a misestimation of up to 50% could be acceptable, for it is noted that most of the values in Table 7-16 will be within this range.

Table 7-16 – Level of Realistic

Level of Realistic		Existing Cases		Extremes / 2σ						
factor	Ratio	Mean	St.Dev.	Min	Max	Alt1	Alt2	Alt3	Alt4	Alt5
IC	IC / EIC	1.348	0.138	1.210	1.486	1.120	1.114	1.307	1.349	1.278
OC	OC / IC	1.763	0.450	1.312	2.213	3.983	5.002	3.159	3.960	4.887
DC	DC / IC	0.262	0.078	0.183	0.340	0.758	0.718	0.461	0.256	0.157
EIR-LA	EIR-LA / EIR	1.657	1.431	0.226	3.089	0.765	0.824	0.762	0.727	1.095
AIR-PS	AIR-PS / AIR	1.053	0.533	0.520	1.586	0.667	1.200	0.500	0.429	0.667
FS	FS / BT	1.239	0.535	0.704	1.773	0.500	0.800	2.200	2.250	2.150
CTM	CTM / BT	0.084	0.026	0.058	0.111	0.042	0.068	0.083	0.067	0.066

7.5.3 Final Decision

After this whole analysis, a final step in the process is obviously needed to define a unique final decision. For that, a QFD has to be considered using the values from Table 7-14 with an importance factor for each criterion. This latter could be assigned either by the decision maker itself based on some constraints or by referring to the priority among the performance criteria presented in Appendix D-5, which were defined based on the experts' opinions. For that, the importance factor for each performance criterion will be selected within the interval {1, 2, 3, 4, 5, 6, 7} (1 low importance, 7 high importance). Table 7-16 will calculate the raw score by applying Equation 6-1 for the normalization process and Equation 6-2 for the raw score values and based on these values an appropriate final decision (Alternative) is selected while the others are ranked.

Table 7-17 –Factors and values considered for sensitivity analysis

Normalized performance Criteria				Alt1	Alt2	Alt3	Alt4	Alt5
V.1	IC	Actual Initial Cost - PV	7	8	9	2	1	3
V.2	OC	Operation & Maintenance Cost over 100 Years	6	7	3	9	4	1
V.3	DC	Dismantling Cost	5	1	1	4	7	9
V.4	EIR-LA	Environment Impact Rate - Local Authorities Evaluation	4	9	8	6	6	1
V.5	AIR-PS	Aesthetic Satisfaction Rate - Public Satisfaction	2	3	9	1	1	3
V.6	FS	Functional Satisfaction at first use	1	9	8	1	1	1
V.7	CTM	Actual Construction Time / Estimated	3	9	7	1	7	8
			Raw Score	181	165	118	114	107

7.6 Summary

Any proposed methodology should be subjected to a validation procedure. The objective of validating a research project or an analytical procedure is to determine that the methods used are suitable for the intended goal of the research. Any research methodologies that can be employed to present evidence in support of observations and conclusions or that demonstrate the accuracy of the results can be applied in order to validate the study results and can thus be considered validation methodologies. Internal and external validity have to be considered by indication the interaction between the different variables, if it exists, and the induction and generalizability of research results for prediction purposes. The case study presented in this chapter has been conducted based on 49 expert opinions (Appendix D-5) with data covering 53 bridges spread over 1500 km^2. Among the many validation methodologies, two are covered by the actual research: (a) empirical studies based on model development and evaluation by a statistical analysis as provided in Section 7.3.3 and Appendix D-8; (b) functional demonstration where it is a validation with respect to logic, input, assumptions, and output as shown within the level of realistic outcomes (Section 7.5.2 – Table 7-16). In order to validate the proposed DSS, a real case project is used for a bridge to be constructed in Lebanon between the cities of Bkerke and Zouk. Based on a study that shows the benefit of this new bridge to the public, the site parameters have been collected, and interviews are conducted with experts to define the influence factors to be considered, and other investigations with the public to define the variables in order to establish an appropriate data module covering the existing bridges around the intended area. After interpreting and analyzing the relevant data, suitable tables are extracted and used in the DSS Engine. Two arrangements with BrIM interpretation are carried out to attain the required results, which lead to a list of five alternatives. As mentioned in the thesis, the alternatives to be ranked is proposed and suggested by the decision-maker and it is supposed to be an expert, and based on hints provided by the presented methodology, either by statistical analysis or through the first arrangement of the ANN. For that, the proposed alternatives are valid to be ranked among the valuable propositions. A Sensitivity Analysis (SA) has been used to evaluate the level of influence for each factor on the final results, and a Level of Realistic outcomes procedure is proposed and discussed to highlight the DSS validation. After analyzing the results, a unique final decision is proposed with the necessary comments and suggestions.

Chapter 8
Conclusion, Limitations and Future Works

8.1 Conclusion and Research Contribution

Some Researchers have highlighted the problem of decision-maker subjectivity, and others have mentioned that engineers most often base their decisions on past experience and standard solutions, which is probably the ideal method. This thesis aims to provide a methodology to analyze the subjectivity which is based on the indispensable expert opinion by providing some tools to reinforce and to defend their decision, if needed, and to relate their decision to appropriate performance criteria. For instance, once the decision-maker has proposed a bridge type to be selected, it is important to highlight whether his decision is based on aesthetic criteria, or cost criteria, or a combination of maintenance and cost criteria with other criteria, as is shown in the case study presented in Chapter 7. Also, concerning the other alternatives, how they will be ranked, and based on which performance criteria? For that, the stated methodology will serve the mentioned goals.

This thesis developed a pragmatic method for bridge design at the conceptual design phase, under an array of **objectives**: **(1)** Reduce, control and highlight the subjectivity by moving towards objectivity; **(2)** Provide a clear methodology to categorize and rank the potential alternatives; **(3)** Consider the convenient factors suggested by the experts in an equity and equitable manner; and **(4)** Provide a systematic methodology based on the data of existing projects and expert opinions.

The decision is made by selecting the bridge type at the conceptual design phase, to control and identify the subjectivity which is widely mentioned by many researchers. Investigations through interviews and questionnaires are conducted to clarify the experts' opinions concerning the factors affecting such a decision. The collected factors are implemented into a DSS methodology in order to provide a systematical data manipulation and to work with the particularity of the relevant project location. A bias always exists since the analysis is established based on different opinions, but the decision maker has to identify the principles to judge the alternatives in terms of their consequences in order to control the above-mentioned subjectivity. Moreover, this thesis distinguishes between estimating and forecasting tasks. The “estimating process,” which is a traditional method, is based on an existing preliminary design, with relevant quantities and other information such as unit cost for concrete, and labor cost, in order to provide the “calculated” values. On the other hand, the “forecasting process” is a comparative study with previous cases to provide the “forecasted” values. Referring to the three DSS components, it is to be noticed that the data module is established by a systematic methodology, founded on expert opinions. Some of **the advantages of the three DSS components** are: **(1)** they provide arguments for the decision maker subjectivity; **(2)** they provide flexible and clear steps; and **(3)** they help to adjust any possible subjectivity that might be carried on during the design process. Furthermore, the data analysis provides the decision maker with a possibility to realize the level of uniformity of the collected data. Consequently, the decision maker can identify the data’s homogeneity, heterogeneity, and asymmetrically. After defining the data structure with its appropriate factors, data collection was the next challenging step to deal with. The major challenge is the data interpretation through linguistic converter modules and through the formulations, which are exposed to the subjectivity control leading toward the objectivity processes. This issue clearly shows the abilities of the stated methodology to show that the data contains levels of flexibility to adjust, to modify and, to replace most of the provided modules in order to achieve its goals. It should be noted that during the case project analysis, all the provided modules are subjected to many trial tests in order to attain the most convincing results. In this thesis, considerable attention is dedicated to the data components by exposing all of the data processes, and by providing the flexibility for the decision maker to adjust the data module structure according to the new case constraints, within a systematic methodology. After the data analysis and extraction of the necessary data for the DSS Engine, alternatives for the required decision will be realized as a first arrangement. The proposed alternatives are selected through the ANN environment based on the previous project's data and the approbation of the expert opinion with other alternatives could also be considered. BrIM tools are used to implement the proposed alternatives and any other potential alternatives to benefit from the use of BrIM tools. However, the major problem associated with the analysis is the time consumed to implement these alternatives and to analyze the data acquired from the BrIM tools. For this reason it is preferable to reduce the number of alternatives to a minimum. Thus, another arrangement is launched to obtain the performance criteria and to categorize the alternatives accordingly. The characteristics of the ANN environment such as the training processes, number of neurons to be selected within the hidden layer, verification of the relation between the numbers of the input neurons and the training cases considered, are all considered to be precise tasks. A considerable number of studies found in the literature have been checked to work properly with the ANN, in particular, the topic field, data types, and number of cases considered for training. Even though an extensive analysis has been conducted using the ANN environment, the final verification for accuracy was related to two factors: (1) Training, validation, and testing processes; and (2) Level of Realistic outcomes aiming to generalize the errors. In fact, any engineering data analysis is full of scatter, and it is obvious that compatibility and accuracy of the results are not 100% achieved; therefore, two issues must be taken into consideration: 1) working at the conceptual design phase means that errors up to 50% of accuracy could be acceptable; and 2) the error and accuracy are well highlighted, and any additional modifications applied in the first steps of the methodology may lead to some enhancement. For BrIM tools, their roles are defined by the following targets: (1) to provide the necessary quantities and specifications; (2) to visualize the alternatives in order to verify how realistic the proposed alternatives are; and (3) to minimize as much as possible the modifications and adjustments that may occur during the detailed design phases. The sensitivity analysis, conducted at the end of this study, gives a wide space for the decision maker to evaluate and assess well any decision that could be made, and perceive the range of error that may happen. Superficially and briefly, the notable **contributions** from the present research are characterized by these points: **(1)** the final decision is based on many factors defined according to the individuality of the site, suggested and approved by the experts who provide valuable tools that lead to the appropriate decision; This task has been conducted in a special and critical approach by the way of the collected data and achieved by using appropriate questionnaires in order to figure out the influence of the different expert opinions in the region; **(2)** decision-maker subjectivity is clearly highlighted and controlled, leading to transparency of the subjectivity which is arranged so that it can be compared with other opinions; where the sensitivity analysis and the flexibility of the DSS leads to providing the maximum control of subjectivity; **(3)** the different alternatives are ranked based on the importance of the performance criteria that serve to clarify the importance of each alternative; the importance of the performance criteria could be different between a decision maker and others and this issue makes the DSS have value and may represent a way to analyze the data and provide alternatives based on different points of view; **(4)** the introduction of the use of the BrIM techniques at the conceptual design phase in a manner which maximizes the benefit; this part serves the client in order to figure out the life-cycle cost for different opinions; **(5)** the flexibility of the stated DSS means that appropriate models from other studies can be easily implemented, allowing this DSS to be applied at many other locations through adaptation of the available data and technology; therefore, the means of the DSS flexibility is introduced and highlighted. We do not omit that the way of collecting the needed data as described has a big influence on the realism and objectivity of the results. As per expert opinions, important factors are highlighted; therefore, other decision maker may consent on the results and they could be convinced by the way of its analysis. Site privacy has also considered by the selected existing similar projects for the engine learning processes. The method that was followed to analyze and manipulate these data influences the determination of their accuracy and their level of validity for use in the DSS.

To this end, aside from many of the important concerns of this research, one of the **most significant** lies in the reinforcement provided to the decision maker to defend, fight for, and convince the others of his decision which is based on a systematic methodology.

8.2 Limitations

Like any methodology, providing complete and perfect procedures and solutions is out of the question. Omissions, restrictions, and limitations of many previous research studies have been highlighted, and this thesis provides a methodology to cover as many of these omissions and weaknesses as possible, without expecting that the thesis methodology will provide a complete and perfect solution, and this issue is well highlighted throughout the section on thesis limitations. Despite the prodigious conclusion presented in the previous section, a number of limitations have been detected within the development of the research methodology, as well as within the case project presented. A direct limitation is noticed by the bridge types considered in this research, where some of the bridge types are excluded from the data module, like movable bridges, suspension bridges, and cable-stayed bridges. As the DSS is composed from three components, the limitations will be investigated through them, as well as the weaknesses in their auto-interconnectivity.

Starting with the data limitations, a weakness has been detected with the limited number of existing cases used in forming the data module. Furthermore, a partial problem was encountered during the interpretation of data through the ANN environment, since the data module was not able to define the asymmetrically and heterogeneity of the test case, thus, additional verifications were considered for that purpose. In addition to the above-mentioned problems, the accuracy of the provided data is subject to error. Hence, to overcome this problem, a level of realistic, as defined in Chapter 6 and in the case project in Chapter 7, is verified for this purpose. Also, this problem does not have any impact on the ranking of alternatives, since the processes applied to all of them have the same weaknesses. It should be noted that risk analysis could be applied to overcome this problem, however, this has been proposed as future work.

The weakness of the DSS engine is detected in the ANN itself by using the Matlab V.2015 interface with its limitations. Furthermore, the number of existing cases to train the ANN is not enough compared to the number of input and output neurons. Furthermore, working within an ANN environment is not well developed in this thesis and it is a subject for future work and publications.

Most of the benefits of the BrIM tools are missing in this thesis. For instance, many details that are needed for extracting accurate results from these tools were missing since the thesis focused on the conceptual design phase. Also, the auto-interconnectivity between the geometric and structural parts needs some manual processing, which may lead to the possibility of errors in transferred data. At this point, such limitation is acceptable since the conceptual design phase data was provided with an expected accuracy range between "-50% and +100%."

Further limitations are also encountered due to the missing bridge components in the data, such as the architectural elements and other structural elements. Also indirect limitations have been seen due to politics and security restrictions during the data collection and site investigations.

Obviously any methodology encloses and encompasses some of the limitations mentioned above, but it is important to identify these limitations, and provide either a limited solution within the present methodology or have some vision and perception for future work and enhancement.

8.3 Future Work

The proposed future work is divided into two parts with different directions: Academic and Practice. For each direction, further and advanced works will be conducted to cover the three DSS components: the Data module, the DSS Engine and the BrIM tools implementation.

For the **Academic Direction**, the DSS will be subjected to expansion and extension. *Expansion* is covering more areas and countries by establishing appropriate data structures taking into consideration the particularity of these countries, and conducting the necessary investigations, interviews, and relevant data collection by providing and establishing the needed questionnaires; and *Extension* i attaining more advanced design phases, and adjusting the data structure and its contents for the detailed design phases. As discussed, many modules, like the formulations and linguistic converters, are proposed and used in the data module to help in the manipulation and interpretation of the data; for that, additional modules will be established and incorporated in the data structure to provide a variety of options for the decision maker to select the appropriate decision and conduct further analysis by doing pertinent comparison and rational study. For the DSS engine, additional proposed methods will be added, either to replace or to work in parallel with the AI environment, and also to provide the decision maker, as much as possible, the option to select the appropriate method to limit the subjectivity. Since the ANN has many conditions and restrictions to be verified and interpreted, another approach known as Neuro-Fuzzy could be employed to forecast the performance and at the same time, reduce the subjectivity of the values assigned to the factors under consideration. Neuro-Fuzzy has the potential to make the DSS more comprehensible and provide a wider decision space, in addition to another approach that will help the DSS engine to interpret and to provide more accurate results, such as the Genetic Algorithm (GA), Knowledge-Based System (KBS), or Case-Based Reasoning (CBR). For the BrIM implementation, additional benefits from such tools could occur by providing the decision maker more options to better visualize and understand any decision with more accuracy. This issue could be applied by using advanced tools for the interconnectivity enhancement, and by employing an automatic process, since a fully computerized system will be proposed to help and benefit from a dynamic interface, which leads for more flexibility and more comprehensible results. Being that the collected data is inaccurate and that we are also working with an ANN environment without fulfilling all the appropriate restrictions, it will be useful to propose a risk management analysis to investigate the probability of errors and to highlight the lack of inclusiveness.

As for the **Practice Direction**, it will be worthwhile to benefit from the methodology through professionals and experts that work in government agencies, by using the proposed DSS within real-life in situ works. To start with, agreements will be established between academic institutes and local authority agencies, like municipalities, to implement the methodology and to allow the academic staff to access the data and receive the appropriate feedback. In situ investigations, through questionnaires and public opinion collections and other tasks will be conducted for enhancement purposes and to record the weaknesses of the methodology.

In addition, the DSS could be extended to include advanced studies conducted in the Bridge Management System (BMS) related to the MR&R (Maintenance, Repair & Rehabilitation) optimization plan in the enhancement strategy that will be followed. Due to the flexibility of the methodology, it is possible to benefit from incorporating the associated modules into the DSS, and in such a manner, objectivity is increased and subjectivity is decreased.

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Appendix A – Bridge Characteristics

Parameters / Name	Culvert of Arkadiko Bridge	Alcántara Bridge	Anji Bridge	Iron Bridge	Forth Rail Bridge	Quebec Bridge	Sydney Harbour Bridge	St Louis Bridge	New River Gorge Bridge
Carries	Mycenaean road Tiryns–Epidauros			Pedestrian Trafic	Rail Trafic	3 Lanes of Roadway 1 Rail Line	Trains, Motor Vehicules, Pedes. & Byc	Trafic, Hwy 2	19 US
Crosses		Tagus River	Xiao River	River Severn	Firth of Forth	St Lawrence River	Port Jackson	South Saskatchewan River	New River, 82 CR, CSX
Designer		Caisus Lulius Lacer			John Fowler & Benjamin Baker				
Locale	Arkadiko, Argolis, Greece	Alcántara, Spain	Zhao Country, China	IroonBridge Gorge near Coalbrookdate	Edinburgh, Inchgarvie - Scotland	Quebec City, Levis	Sydney, Australia	St. Louis, Prince Albert 461	Fayetteville, west verginia, US
Design	Corbel arch bridge	Roman Arch Bridge	Open-Spandrel sone	Cast Iron Arch Bridge	Cantilever Bridge	Cantilever Bridge	Through Arch Bridge		Arch
Material	Cyclopean stone	Stone		Iron	Steel	Steel	Steel	Steel	Steel
Total Length	22 m	194 m	50.82 m	60 m.	2,528.7 m.	987 m	1,149 m	380 m	924 m
Width	4.0 m	8 m	9.6 m			29 m	49m		21.1 m - 4 lanes with center divider
Height Clearance below	2.5 m	71 m	7.3 m	18 m.	46 m.		139 m 49 m		267 m
Longest Span	1.0 m	28.8 m	37.37 m	30.5 m.	521.3 m.	549 m	503 m		518.2 m
Number of Spans	1	6	1		19				
Load Limit		52 t							
Start/End of Const./ Opening year	1300-1190 BC	104-106 AD	595-605 CE	1775-1779-1781	~?1875-1890	? - 1917-1919	1923-1932-1932	??-1915-1915	??-??-1977
Heritage Status		Cultural heritage							
Inter-Support Type		Stone- Massive Columns		Stone- Massive Columns	Stone- Massive Columns				
Edge-Support Type	Abutment	Abutment	Abutment	Abutment	Stone- Massive Columns				
Capacity					190-200 train per day				16,200 Veh/day
Depth in Water for Piers									
Cost									

Name / Parameters	George Washington Bridge	Golden Gate Bridge	Messina Bridge	Bendorf Bridge	Stolmasundet Bridge	Stromsund Bridge	Yangpu Bridge	Tatara Bridge	Stonecutters Bridge
Carries	14 lanes (8 upper deck, 6 lower0	6 lanes - Ppedestrian & bicycles	12 lanes	Motorway/freeway Bridge		E45	6 lanes - Inner Ring Road	4 lanes - Byc. & Pedest. Lanes	Dual 3-lanes highway
Crosses	Hudson River	Golden Gate	Sicily / Calabria	Rhine River		Stroms vattudal	Huangpu River	Seto Inland Sea	Rambler Channel
Designer	Othmar Amman, Cass Gilbert	Joseph Strauss, Irving Morrow & Charles Ellis	Messina Co.	Gerd Lohmer Ulrich Finsterwalder Herbert Schambeck		Franz Dischinger			Dissing+Weitling, design competition
Locale	New Jersey & New York City	San Francisco / California	Italy	Mayen-Koblenz, Rhineland-Palatinate Germany	Austevoll, Norway	Swedish	Shangai, China	Hiroshima & Ehime	Tsing Yi & Stonecutters Island
Design	Double-Deck Suspension bridge	Suspension, Truss Arch & Causeways	Suspension Bridge	Box girder bridge hanched	Concrete Box Girder	Cable-Stayed	Cable-Stayed	Cable-Stayed	Cable-Stayed
Material	Steel	Steel		Concrete	Concrete				
Total Length	1,450 m	2,737.4 m	3,660 m	1,029 m		332 m	8,354 m	1,480 m	1,596 m
Width	36 m	27.4 m		30.86 m			30.35 m	30.6 m	
Height Clearance below	184 m 65 m	227.4 m 67.1 m					223 m 48 m	26 m	298 m 73.5 m
Longest Span	1,100 m	1,280.2 m	3,300 m	208 m	296.1 m	182 m	602 m	890 m	1,018 m
Number of Spans	3	3	3	7	3	3		3	
Load Limit									
Start/End of Const./ Opening year	1927-1931 1st phase upper - 1962	1933 - 1937 - 1937	2010 - under construction 11 y.	1960 - 1962 - 1965	?? - 1998	??-??-1956		??-??-1999	2004-2009-2009
Heritage Status									
Inter-Support Type	Steel Tower	Steel Tower	Tower			Tower	Tower	Tower	
Edge-Support Type									
Capacity	289,329 Veh/day (2008)	118,000 Veh/day	140,000 Veh/day 200 trains				100,000 Veh/day 2006		
Depth in Water for Piers			120 m						
Cost									

Appendix B – Important Data and Valuable Information Websites

"About Bridges"	:	http://www.nireland.com/bridgeman/index.htm
"Structurae"	:	http://en.structurae.de/
" Iron Bridge"	:	http://en.wikipedia.org/wiki/The_Iron_Bridge
"Forth Rail Bridge"	:	http://en.wikipedia.org/wiki/Forth_Bridge
"Messina Bridge"	:	http://bridgepros.com/projects/Strait_of_Messina_Bridge/

Appendix C – MnDOT Structural Element List

MnDOT Structural Element List

#	Element Description
Concrete Decks	
12	Top of Concrete Deck with Uncoated Rebar (No Overlay)
13	Bituminous Overlay (Concrete Deck)
14	Bituminous Overlay with Membrane (Concrete Deck) Deck Each 1-5 33
18	Latex, Epoxy, or Thin Overlay (Concrete Deck) Deck Each 1-5 33
22	Low Slump Overlay (Concrete Deck with Uncoated Rebar) Deck Each 1-5 32
26	Top of Concrete Deck with Epoxy Reinforcement (No Overlay) Deck Each 1-5 32
27	Top of Concrete Deck with Cathodic Protection System Deck Each 1-5 32
377	Low Slump Overlay (Concrete Deck with Epoxy Rebar) Deck Each 1-5 32
429	Top of Conc. Deck w/Epoxy Rebar top mat only (No Overlay) Deck Each 1-5 32
430	Low Slump Overlay (Conc. Deck w/Epoxy Rebar top mat only) Deck Each 1-5 32
Concrete Slabs	
38	Top of Concrete Slab with Uncoated Rebar (No Overlay) Deck Each 1-5 32
39	Bituminous Overlay (Concrete Slab) Deck Each 1-5 33
40	Bituminous Overlay with Membrane (Concrete Slab) Deck Each 1-5 33
44	Latex, Epoxy, or Thin Overlay (Concrete Slab) Deck Each 1-5 33
48	Low Slump Overlay (Concrete Slab with Uncoated Rebar) Deck Each 1-5 32
52	Top of Concrete Slab with Epoxy Reinforcement (No Overlay) Deck Each 1-5 32
53	Top of Concrete Slab with Cathodic Protection System Deck Each 1-5 32
378	Low Slump Overlay (Concrete Slab with Epoxy Rebar) Deck Each 1-5 32
405	Top of CIP Concrete Voided Slab (No Overlay) Deck Each 1-5 32
406	Low Slump Overlay (CIP Concrete Voided Slab) Deck Each 1-5 32
431	Top of Conc. Slab w/Epoxy Rebar top mat only (No Overlay) Deck Each 1-5 32
432	Low Slump Overlay (Conc. Slab w/Epoxy Rebar top mat only) Deck Each 1-5 32

Timber Decks & Slabs

Other Deck Types

Deck Joints

Roadway Approaches

Bridge Railings

Painted Steel Elements

Weathering Steel Elements

413 Weathering Steel Arch Spandrel Column Superstructure Each 1-4 46

424 Weathering Steel Gusset Plate Truss Connection Superstructure Each 1-4 46

426 Weathering Steel Pinned Truss Connection Superstructure Each 1-4 46

428 Weathering Steel Pier Cap (Superstructure) Superstructure LF 1-4 46

Reinforced Concrete Elements

105 Reinforced Concrete Box Girder Superstructure LF 1-4 47

110 Reinforced Concrete Girder or Beam Superstructure LF 1-4 47

116 Reinforced Concrete Stringer Superstructure LF 1-4 47

144 Reinforced Concrete Arch Superstructure LF 1-4 47

155 Reinforced Concrete Floor beam Superstructure LF 1-4 47

205 Reinforced Concrete Column Substructure Each 1-4 47

210 Reinforced Concrete Pier Wall Substructure LF 1-4 47

215 Reinforced Concrete Abutment Substructure LF 1-4 47

220 Reinforced Concrete Footing Substructure Each 1-4 47

227 Reinforced Concrete Piling Substructure Each 1-4 47

234 Reinforced Concrete Pier Cap/Bearing Cap Substructure LF 1-4 47

375 Precast Concrete Channels Superstructure LF 1-4 47

385 Reinforced Concrete Arch Spandrel Column Superstructure Each 1-4 47

387 Reinforced Concrete Wingwall Substructure Each 1-4 47

414 Reinforced Concrete Arch Spandrel Wall Superstructure LF 1-4 47

Prestressed or Post-Tensioned Concrete Elements

104 Prestressed Concrete Box Girder Superstructure LF 1-4 48

109 Prestressed Concrete Girder or Beam Superstructure LF 1-4 48

115 Prestressed Concrete Stringer Superstructure LF 1-4 48

143 Prestressed Concrete Arch Superstructure LF 1-4 48

154 Prestressed Concrete Floorbeam Substructure LF 1-4 48

204 Prestressed Concrete Column Substructure Each 1-4 48

226 Prestressed Concrete Piling Substructure Each 1-4 48

233 Prestressed Concrete Pier Cap/Bearing Cap Substructure LF 1-4 48

374 Prestressed Concrete Double, Quad, Bulb, or Inverted Tees Superstructure LF 1-4 48

Timber Elements

Masonry, Other, or Combination Material Elements

Other Structural Elements

Culvert Elements

Smart Flags

Other Items

985 Slopes & Slope Protection Substructure Each 1-3 82

986 Curb & Sidewalk Deck Each 1-3 82

987 Roadway over Culvert Culvert

988 Miscellaneous Items Miscellaneous

Appendix D – Forms

The structures of the survey and questionnaires were established based on some procedures presented in previous research mentioned in the literature review, further to the research needs, coupled to the common tips that should be followed during the preparation of a questionnaire. Questionnaires were established based on direct questions to get the required data. Common rules have to be followed in such a task. Referring to many references, the main considerations are summarized by the following tips:

(a) Determine the purpose of the questionnaire; the required data to be defined.

(b) Decide who should be asked and investigated.

(c) Select the appropriate method for data collection (email, phone, interviews).

(d) Choose measurement scale and scoring.

(e) Avoid loaded questions by reducing the amount of the required information and by simplifying the questions as much as possible.

(f) Make sure that the investigated people are professional and efficiently serve the purpose of the questionnaire.

(g) Check the reliability of the provided data and make sure that the collected data will be treated equitably by conducting an evaluation to verify if the collected data serve their purposes; and many other considerations such as the title of the questionnaire and the use of non-threatening questions.

Two questionnaires were established for the research purposes and used and presented in the case study.

The first questionnaire (Q#01), addressed to experts, aimed to collect data concerning the factors having influence on the bridge performance and on the bridge type to be selected. For this purpose, emails were sent to the most important associations concerned with bridge design and management, but since I was working in an environment that is not familiar with such investigations, few replies were received. For this reason, direct contacts were conducted later and eight companies consented to asking their professional to participate in the questionnaire. A total of 49 participants participated in the questionnaire. The number of participants, as well as the method of collection of the required statistical data is among the research limitations mentioned in Chapter 8. The factors mentioned in this questionnaire are either selected from among a pool of proposed factors or they are new factors proposed by the participants.

The second questionnaire (Q#02) is addressed to the public in order to collect their feedback concerning their satisfaction with bridges from an aesthetic point view. These investigations are spread over the existing bridges found in the research area. The five aesthetic criteria mentioned in the questionnaire were selected based on previous investigations and research.

D-1 – Questionnaire Q01 – Page 1/2

Questionnaire Q01

Subject:	Criteria Affecting the Bridge Design and Performance	#
Addressed To:	Private & Public Agencies and Companies	
Date:		***Type:*** (2)
Company name:		*Gov./CM/Cons.*
Participant name /Function:		

Q01-A *(Soft Factors)*

A new Bridge type is going to be selected; in your opinion, what are the Criteria that might define the bridge performance.

Rate each provided Criteria from 1 to 10 respecting its importance level

(Hint: refer to the back-sheet for some proposed criterias)

Criteria	Rate	Criteria	Rate	Criteria	Rate

Q01-B *(Hard Factors)*

A new Bridge type is going to be selected; in your opinion, what are the factors that have influence on the bridge performance Criteria.

Rate each provided factor from 1 to 10 respecting its influence level.

(Hint: refer to the back-sheet for some proposed factors)

Factors	Rate	Factors	Rate	Factors	Rate

NB:
1. It is preferable to participate more than one participant (decision-maker, Senior Engineer) from one Company/Agency
2. Gov.: Government Agency; CM: Construction Management or Main Contractor; Cons.: Consultant Agency
3. Use another sheet if more space is needed.

D-2 – Questionnaire Q01 – Page 2/2

Soft Factors (items, criteria, variables) - Defined as performance Criterias

Economy; Workability; Aesthetics; Transportability; Environment Impact; Functionality; Benefit; Safety; Initial Cost; Operation & Maintenance Cost; Dismantling Cost; time of construction;

Hard Factors (items, criteria, variables) - Defined as influence factors

Site Location; Bridge span lengths; Ground condition; Structural system; Main span length; Estimated cost; Year of Decision; Year of Construction; Operation Year; Bridge Type; Structure Type for Deck; Column Type; Foundation Type; Material Type; Material quantities, exposed areas; Environment Impact Rate; Aesthetic Satisfaction Rate; Bridge Geometric ; Total Length; Type of Area to overpass; Road-Bridge Type; Plan Layout Complexity; Soil Type; Highest point; Number of bidden companies; Number of Span; Longest Span; Number of Lanes; Total Width; Max Speed; Type of Loading; Traffic Capacity; Scale; Site Access; Geographic Information; Space Usage; Site Layout, Material Selection; Weather conditions; Cultural;

Participiant Nots:

D-3 – Questionnaire Q02

Questionnaire Q02

Subject:	Aesthetic Impact Rate - Public Satisfaction	#
Addressed To:	Public & Users	
Date:		
Student's Group #		
Bridge Investigated: Bridge #		

Traffic Monitoring **(Number of Vehicules)**

Week 1	**Mo**		**Fr**		**Week 2**	**Mo**		**Fr**		**Week 3**	**Mo**		**Fr**		**Results - Daily Av. Traffic**
	Tu		**Sat**			**Tu**		**Sat**			**Tu**		**Sat**		
	We		**Sun**			**We**		**Sun**			**We**		**Sun**		
	Th					**Th**					**Th**				

Aesthetic Criteria:	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**
Proportion and geometry																				
Environmental																				
Structural harmony																				
Focus of attention																				
Weathering and surface finish																				

Aesthetic Criteria:	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**
Proportion and geometry																				
Environmental																				
Structural harmony																				
Focus of attention																				
Weathering and surface finish																				

Notes & Comments

Aesthetic Criteria

I: Importance factor related to the selected criteria based on the participant opinion
1: low importance; 10: highest importance rate

V: Rated Criteria of the the participant. 1: low acceptable rate; 10: high acceptable rate

D-4 – Questionnaire Q01 – Participant #001

Questionnaire Q01

Subject:	Criteria Affecting the Bridge Design and Performance	#
Addressed To:	Private & Public Agencies and Companies	001
Date:	Nov. 2015	***Type:*** (2)
Company name:		*Gov./CM/Cons.*
Participant name /Function:	Toufic Khoury - Senior Bridge Engineer	***CM***

Q01-A *(Soft Factors)*

A new Bridge type is going to be selected; in your opinion, what are the Criteria that might define the bridge performance.
Rate each provided Criteria from 1 to 10 respecting its importance level
(Hint: refer to the back-sheet for some proposed criterias)

Criteria	Rate	Criteria	Rate	Criteria	Rate
Economy	2	Operation & Maintenance Cost over	6	Aesthetic Satisfaction Rate - Public Satisfaction	5
Transportability	2	Dismantling Cost	4	Functional Satisfaction at first use	5
Safety	5	Time of construction	4	Actual Construction Time / Estimate	6
Initial Cost	7	Environment Impact Rate - Local Authorities Evaluation	6		

Q01-B *(Hard Factors)*

A new Bridge type is going to be selected; in your opinion, what are the factors that have influence on the bridge performance Criteria.
Rate each provided factor from 1 to 10 respecting its influence level.
(Hint: refer to the back-sheet for some proposed factors)

Factors	Rate	Factors	Rate	Factors	Rate
Material Selection	6	Operation Year	3		
Space Usage	5	Number of Span	5		
Weather conditions	2	Longest Span	5		
Scale	4	Site Access	5		
Ground condition	1	Number of Lanes	4		
Road-Bridge Type	8	Total Width	7		
Type of Area to overpass	6	Max Speed	5		
Complexity	4	Site Layout	4		
Soil Type	4	Traffic Capacity	5		
Highest point	6	Year of Decision	2		
Year of Construction	1	Bridge Geometric (Straight, Skewed, Curved)	5		
Availability of Professional Companies in Bridge Construction	5	Cultural	1		

NB:
1. It is preferable to participate more than one participant (decision-maker, Senior Engineer) from one Company/Agency
2. Gov.: Government Agency; CM: Construction Management or Main Contractor; Cons.: Consultant Agency
3. Use another sheet if more space is needed.

D-5 – Summary Schedule for Expert Opinions

D-5 (a)

Q01 - Summary Results

ID	Factors (Cat. 3 &4)	#01	#02	#03	#04	#05	#06	#07	#08	#09	#10	#11	#12	#13	#14	#15	#16	#17	#18	#19
1	Site Location				5	1	6	8		3	3		3		5			4	2	
2	Bridge Type (Girder, Arch, etc…)																			
3	Material Selection	6		4		3		5		7		6			5	4	3	6		8
4	Foundation Type																			
5	Space Usage	5		6		4		6			7		3			5			8	
6	Material Type																			
7	Volume of Concrete																			
8	Weather conditions	2		3		4		5		3		5		6		3		2		4
9	Industrial Steel Weight																			
10	Scale	4			5			3			6			5		4		2		
11	Exposed Concrete Surfaces																			
12	Ground condition	1		2		3		3		4	5		5	4	7			7		2
13	Exposed steel surfaces																			
14	Aesthetic Satisfaction Rate																			
15	Total Length			5		6		8		4		6	5		7			3		6
16	Structure Type for Deck																			
17	Road-Bridge Type	8	6		6	6		9	5		3	5		6		7		8	9	6
18	Type of Area to overpass	6	7	6	8	3	6	5	9	6	7	5	9		4	8		9	6	5
19	Geographic Information		5	6		3			2			4			3			5		1
20	Complexity	4	6	8	6		5	6	3		5	5		7			7		5	5
21	Environment Impact Rate																			
22	Soil Type	4	5		6		5	2		3			5	4		3	6		5	7
23	Highest point	6	7	8	6	5			9	6	5		4	8		3	6		5	8
24	Year of Construction	1	2	3		5	2		1	2	5	6	5	9	8	4		2	3	6
25	Availability of Professional Companies in Bridge Construction	5		6		4		2		3		5			6		7		6	5
26	Operation Year	3		6	5	4	3	2		6	5		3		2	6			5	2
27	Number of Span	5	6		4		3	5		6	4		7	6	5	8	3	2		
28	Longest Span	5		6	7	6	8	6		3	5	6	5		6	5	4	8	6	3
29	Site Access	5		6		5		2			3		4				9			3
30	Number of Lanes	4	6	4	5	6	4		5	5		3	4		6		7		6	5
31	Estimated cost		2	3		3		6		5		6		3		3		5	3	
32	Total Width	7	5	5	6	3	4		6	3		6	4		4		6		5	6
33	Column Type																			
34	Max Speed	5		6	5		7		6			5	6	4			5	6		
35	Site Layout	4		5		6		5		3		6	5			4		5		
36	Max Load		4	6		6	5		5	6		7		5		4			6	
37	Traffic Capacity	5	4		6		4		5	7		6		8			5		9	
38	Year of Decision	2		5		6	5	8	6	6				5	6		5		3	2
39	Bridge Geometric (Straight, Skewed, Curved)	5	4	4	3		5	4		3	4	7		6	4	5		4		3
40	Cultural	1		2		3	4		5		3		2		6			9		4

ID	Criteria (Cat. 5)	#01	#02	#03	#04	#05	#06	#07	#08	#09	#10	#11	#12	#13	#14	#15	#16	#17	#18	#19
a	Economy	2		3			6			5	4			6	3			5		2
b	Workability		3		3		6	4		4		6		3			5		4	
c	Transportability	2		3		5	7		3		5		3	4			3		3	
d	Functionality		8			5	4		5	6			5	2		1			7	
e	Benefit				3		5		4			6			8		5			8
f	Safety	5			3		6			5		4			3		7			5
g	Initial Cost	7		6	8		6	7		5		6	7	6	8		6	6		7
h	Operation & Maintenance Cost over 100 Years	6		5	7		5	6		4		5	6	5	7		5	5		6
i	Dismantling Cost	4		3	5		6	3		5		6	5	8	6		8	6		5
j	Time of construction	4		3		5			6				4		2			6		
k	Environment Impact Rate - Local Authorities Evaluation	6		5		5			6		7		4		2		9	6		
l	Aesthetic Satisfaction Rate - Public Satisfaction	5		6		4			6		5			8		5		6		7
m	Functional Satisfaction at first use	5		6		4		5		6		5			4		5	6	5	4
n	Actual Construction Time / Estimated	6		4	5			6	7		6	8		5		7		8		4

D-5(b)

Q01 - Summary Results

ID	Factors (Cat. 3 &4)	#20	#21	#22	#23	#24	#25	#26	#27	#28	#29	#30	#31	#32	#33	#34	#35	#36	#37	#38
1	Site Location	6	7		5	6	5		8		2	1		5		2	4	2		
2	Bridge Type (Girder, Arch, etc…)																			
3	Material Selection			3	5			2		4			6		4			2		
4	Foundation Type																			
5	Space Usage	4			2		6		5		7		5			6	4			5
6	Material Type																			
7	Volume of Concrete																			
8	Weather conditions	5		2	3	5		4	2	3			3		2		5	4	5	
9	Industrial Steel Weight																			
10	Scale	3			5			4			5			6		3		4		2
11	Exposed Concrete Surfaces																			
12	Ground condition		4		5		5	2	5		3						6	5	2	4
13	Exposed steel surfaces																			
14	Aesthetic Satisfaction Rate																			
15	Total Length	5			9		5		8		2		1		5	2			4	5
16	Structure Type for Deck																			
17	Road-Bridge Type		6	5	7		8	3		2	5		6		8	7			6	
18	Type of Area to overpass		2	4	5	7	5	6			8	5	4	2	5		7	6		3
19	Geographic Information			3			7				5			3			1			5
20	Complexity		6			5	7		2		5		6	5		6	5	7	2	
21	Environment Impact Rate																			
22	Soil Type	4		6	5		3		4		6		5	7		6		5		4
23	Highest point		4	6		8	5	6	6	7	6	8	6			5	4	5	6	8
24	Year of Construction						2					5			3		2	5	4	
25	Availability of Professional Companies in Bridge Construction	4		3		5	3	6	4	5	3	5	6	3	4	8	3	2	5	4
26	Operation Year	5	6			3	5		2		3	6	5	4				4	5	
27	Number of Span	5	3	6		4		6		5	2		3		7		5	6		
28	Longest Span	5	4			6				8	6					6	5	4		
29	Site Access	5		8			5		2		3			4		5			4	
30	Number of Lanes	4		4	2		6	5	5			5	4			4		4		6
31	Estimated cost		5	5	6	3	2		5	4	9		2	2		5		5	6	
32	Total Width	4		3	1		5	7	4			4				5		6		5
33	Column Type																			
34	Max Speed		5	6		6	7		8		5	3		5	4		6	6		
35	Site Layout	6		3		5		4	6			3		8		7			5	
36	Max Load	3		4		6			7		3	5		8		6		7		9
37	Traffic Capacity		6		5		8		6	6		5	4		5	6		6		5
38	Year of Decision	5		6				6		5			7		2	5	3		6	
39	Bridge Geometric (Straight, Skewed, Curved)	5	6	4	3	5	7			6	5		4		6	3			5	
40	Cultural		5		2		3		6		4		1			2			5	

ID	Criteria (Cat. 5)	#20	#21	#22	#23	#24	#25	#26	#27	#28	#29	#30	#31	#32	#33	#34	#35	#36	#37	#38
a	Economy	4			3		5			8	7			3		6		5		
b	Workability		4		6		5		4	5			6		3	5		4		6
c	Transportability			5			3		4		5			5			2		4	
d	Functionality	6	2		6			4		3			5			7			4	5
e	Benefit			7			6		5		4		5		5			5	7	
f	Safety		3			4			6			5			3			5		4
g	Initial Cost		5		6		7	7	8		5		6	7		6		8	7	
h	Operation & Maintenance Cost over 100 Years		4		5		6	6	7		5		6	6		5		7	6	
i	Dismantling Cost		4		5		6	7	7		4		6	5		4		6	5	
j	Time of construction	7			5					6			1		2			3		4
k	Environment Impact Rate - Local Authorities Evaluation	7	8		5			8		6		8	1		2		8	3		4
l	Aesthetic Satisfaction Rate - Public Satisfaction			3		5		4	6			3	2	5			6	4		5
m	Functional Satisfaction at first use		2	5	3	5	6	7	5	4			6			6	5	4		6
n	Actual Construction Time / Estimated	8				8		6		7		4			6	7		5		8

D-5(c)

Q01 - Summary Results

ID	Factors (Cat. 3 &4)	#39	#40	#41	#42	#43	#44	#45	#46	#47	#48	#49	Total	Rates
1	Site Location	4		5			5		6		8	2	123	0.88
2	Bridge Type (Girder, Arch, etc…)												0	0.00
3	Material Selection	5	4			3		5	2	4	2	5	113	0.81
4	Foundation Type												0	0.00
5	Space Usage		4		6		7		2	5		6	118	0.84
6	Material Type												0	0.00
7	Volume of Concrete												0	0.00
8	Weather conditions		3	7	5	4	6	2		3		2	112	0.80
9	Industrial Steel Weight												0	0.00
10	Scale			5	4		3	3		5	4		85	0.61
11	Exposed Concrete Surfaces												0	0.00
12	Ground condition	3			5	5	5			5	5		112	0.80
13	Exposed steel surfaces												0	0.00
14	Aesthetic Satisfaction Rate												0	0.00
15	Total Length		6			5	8	8	6	9	7	6	151	1.08
16	Structure Type for Deck												0	0.00
17	Road-Bridge Type	5		9		5	4	8	5	9	7		199	1.42
18	Type of Area to overpass	5	7	5	3	4	5		6	5	8	2	228	1.63
19	Geographic Information			6		3		4		7		5	78	0.56
20	Complexity	5	8		6			2		4			153	1.09
21	Environment Impact Rate												0	0.00
22	Soil Type	2		4	6	5		4	2	5	6	7	151	1.08
23	Highest point		6	8		6	5	5	6			8	220	1.57
24	Year of Construction	6	3	2				5	2		1	2	106	0.76
25	Availability of Professional Companies in Bridge Construction	6	2				3	5	5	7	6	2	158	1.13
26	Operation Year	3	5		2	5	3	6	4			3	131	0.94
27	Number of Span	5		4	6		5	7		6		3	152	1.09
28	Longest Span	5		6	5	4	6	8	6	5	6	8	192	1.37
29	Site Access	3		5			2		4			4	91	0.65
30	Number of Lanes		8		7	5		2	3		4	5	153	1.09
31	Estimated cost		6		8		2		1	2	3	3	123	0.88
32	Total Width		7		6	4		3	5		6	6	151	1.08
33	Column Type												0	0.00
34	Max Speed	5	6		7		5		5		4	2	150	1.07
35	Site Layout	6		5	7		4		6	6	7		131	0.94
36	Max Load		5		6	3		4	5	7		8	150	1.07
37	Traffic Capacity		3	4			6		6	5	7		152	1.09
38	Year of Decision		5		4	5	2	3	6	5		5	139	0.99
39	Bridge Geometric (Straight, Skewed, Curved)	4			6		4		6		5	4	149	1.06
40	Cultural		6		5			2	4	3		4	91	0.65
									Average				140.07	

ID	Criteria (Cat. 5)	#39	#40	#41	#42	#43	#44	#45	#46	#47	#48	#49	Total	Rates
a	Economy	6		4			3		5		4		99	0.75
b	Workability			5	6	7			5		5	4	118	0.90
c	Transportability			6	3	2	5	4			4	5	95	0.72
d	Functionality			3		6		6			6		106	0.81
e	Benefit		6		5	6		6	7		2		115	0.87
f	Safety			8			5		6	6		7	100	0.76
g	Initial Cost	6	5	7		7		6	8		5		201	1.53
h	Operation & Maintenance Cost over 100 Years	5	5		5	6		5	4		3		168	1.28
i	Dismantling Cost	4	6			5		4	5		4		157	1.19
j	Time of construction		5			6			5		4		78	0.59
k	Environment Impact Rate - Local Authorities Evaluation		5	8		6		8	5		4	8	154	1.17
l	Aesthetic Satisfaction Rate - Public Satisfaction	7	8		5	8		6		6	7	8	150	1.14
m	Functional Satisfaction at first use		4	7		5	5			3	5		148	1.12
n	Actual Construction Time / Estimated		7		4		6		4		7		153	1.16
									Average				131.6	

D-6 – Questionnaire Q02 – Gr.02 – Bridge ID10

Questionnaire Q02

Subject:	Aesthetic Impact Rate - Public Satisfaction	#
Addressed To:	Public & Users	
Date:	5-Dec-16	***AIR-PS***
Student's Group#	Gr. 02	**7**
Bridge Investigated: Bridge #	ID 10	

Traffic Monitoring **(Number of Vehicules)**

Week	Day	Vehicles	Day	Vehicles
Week 1	**Mo**	13450	**Fr**	14055
	Tu	12450	**Sat**	7500
	We	11750	**Sun**	13250
	Th	11450		
Week 2	**Mo**	11800	**Fr**	13240
	Tu	15200	**Sat**	9150
	We	14250	**Sun**	13750
	Th	12250		
Week 3	**Mo**	14560	**Fr**	14650
	Tu	13150	**Sat**	8670
	We	13200	**Sun**	14750
	Th	11540		

Results - Daily Av. Traffic
12575

Aesthetic Criteria:	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**
Proportion and geometry	10	8	9	10	4	8	8	10	8	10	8	10	8	10	8	9	8	8	8	6
Environmental	8	10	8	8	8	9	8	10	9	10	9	7	8	8	10	9	9	8	7	9
Structural harmony	9	10	6	10	9	8	8	9	8	10	8	10	9	8	9	10	6	8	9	6
Focus of attention	8	9	9	6	9	10	9	8	9	9	8	8	8	10	9	7	9	9	8	7
Weathering and surface finish	8	9	10	7	8	6	10	9	8	7	8	9	5	8	6	10	10	9	9	9
	8		7		6		8		8		7		7		7		7		6	

Aesthetic Criteria:	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**	**I**	**V**
Proportion and geometry	8	8	10	8	10	8	9	8	10	8	9	6	8	8	9	10	9	10	8	9
Environmental	8	7	8	10	9	10	7	8	8	9	8	10	6	8	8	8	8	8	9	8
Structural harmony	9	6	8	10	9	10	8	8	10	9	8	8	8	4	9	7	8	8	7	10
Focus of attention	8	8	8	10	9	9	9	8	9	10	8	10	8	9	8	8	9	10	6	7
Weathering and surface finish	10	9	10	8	8	8	8	8	8	8	8	10	8	8	8	7	8	9	8	8
	6		8		8		6		8		7		6		7		7		6	

Notes & Comments

Aesthetic Criteria

I: Importance factor related to the selected criteria based on the participant opinion
1: low importance; 10: highest importance rate

V: Rated Criteria of the the participant. 1: low acceptable rate; 10: high acceptable rate

D-7 – Summary Schedule for Data

Types	Groups	Categorys		Abreviations	Parameters	Units	Bridge Name	Halat Bridge	Fouad Chhab Bridge
Bridge Components	Administrative Info	Category I	I.1	ID	Bridge ID	NA	001	002	003
			I.2	BN	Bridge Name	NA	Casino - Jounieh	Halat Highway	Fouad Chhab Bridge
			I.3	GD	General Description	NA	NA	Re constructed 2006	NA
			I.4	BL	Bridge Location	NA	Jounieh - Lebanon	Halat - Lebanon	Jounieh
			I.5	YD	Year of Decision made	year	1963	1970	1959
			I.6	YS	Starting Year of Construction	year	1964	1971	1960
			I.7	YC	Ending Year of Construction	year	1965	1973	1962
			I.8	YO	Year Put in Operation	year	1965	1973	1963
	Geometric & Structure Info	Category II	II.1	BT	Bridge Type (Girder, Arch, etc…)	converted to #	30	20	20
			II.2	DT	Structure Type for Deck	converted to #	10	40	10
			II.3	CT	Column Type	converted to #	10	30	20
			II.4	FT	Foundation Type	converted to #	10	10	10
			II.5	MT	Material Type	converted to #	10	10	10
			II.6	CV	Volume of Concrete	m^3	2562	1225	3125
			II.7	ISW	Industrial Steel Weight	T	0	0	0
			II.8	CS	Exposed Concrete Surfaces	m^2	4320	21550	3325
			II.9	SS	Exposed steel surfaces	m^2	0	0	0
			II.10	EIC	Estimated Initial Cost - PV	$\$/m^2$	850	1150	1250
			II.11	EIR	Environment Impact Rate	Calculated Rate	9	6	16
			II.12	AIR	Aesthetic Satisfaction Rate	Calculated Rate	8	7	5
Hard Factors	Uncontrolled Variables	Category III	III.1	L	Total Length	m	140	310	215
			III.2	TA	Type of Area to overpass	converted to #	20	20	10
			III.3	RBT	Road-Bridge Type	converted to #	10	20	10
			III.4	Com	Complexity	converted to #	10	10	30
			III.5	TS	Soil Type	converted to #	10	30	10
			III.6	HP	Highest point	m	150	30	7
			III.7	AP	Availability of Professional Companies in Bridge Construction	#	5	5	3
	Controlled Variables	Category IV	IV.1	SN	Number of Span	#	14	7	9
			IV.2	LS	Longest Span	m	140	60	25
			IV.3	NL	Number of Lanes	#	4	6	2
			IV.4	TW	Total Width	m	26	30	12
			IV.5	MS	Max Speed	km/hr	80	100	50
			IV.6	ML	Max Load	T	60	100	60
			IV.7	TRC	Traffic Capacity	Vehicule/day	24352	21572	7588
			IV.8	BG	Bridge Geometric (Straight, Skewed, Curved)	converted to #	10	10	10
Soft Factors	Performance Criteria	Category V	V.1	IC	Actual Initial Cost - PV	$\$/m^2$	1100	1250	1825
			V.2	OC	Operation & Maintenance Cost over 100 Years	$\$/m^2$	600	1000	2000
			V.3	DC	Dismantling Cost	$\$/m^2$	150	400	500
			V.4	EIR-LA	Environment Impact Rate - Local Authorities Evaluation	converted to #	10	20	20
			V.5	AIR-PS	Aesthetic Satisfaction Rate - Public Satisfaction	Based on Q02	5	3	5
			V.6	FS	Functional Satisfaction at first use	converted to #	10	10	20
			V.7	CTM	Actual Construction Time / Estimated	#	2	1.5	2

D-7 – Summary Schedule for Data – Cont'd

Categorys		Abreviations	Apotres Bridge	Soldini Bridge	Sarba Brdige	Yasouaa AlMalak Old Bridge	Yasouaa AlMalak New Bridge	Nahr AlKaleb Upper Bridge
Category I	I.1	ID	004	005	006	007	008	009
	I.2	BN	Apotres Bridge	Soldini Bridge	Sarba Brdige	Yasouaa AlMalak Old Bridge	Yasouaa AlMalak New Bridge	Nahr AlKaleb Upper Bridge
	I.3	GD	NA	NA	NA	Rehabilitated	NA	NA
	I.4	BL	Jounieh	Ghadir	Sarba Brdige	Zouk	Zouk	Nahr AlKaleb
	I.5	YD	1959	1959	1959	1965	1995	1996
	I.6	YS	1961	1961	1961	1966	2000	1999
	I.7	YC	1962	1962	1962	1968	2002	2004
	I.8	YO	1963	1963	1963	1969	2003	2005
Category II	II.1	BT	20	20	20	20	20	20
	II.2	DT	10	10	10	60	60	60
	II.3	CT	40	30	30	30	20	20
	II.4	FT	10	10	10	10	10	20
	II.5	MT	10	10	10	10	10	10
	II.6	CV	625	560	525	3250	8325	4225
	II.7	ISW	0	0	0	0	0	0
	II.8	CS	556	425	380	2550	11250	4020
	II.9	SS	0	0	0	0	0	0
	II.10	EIC	950	850	850	1250	1350	1425
	II.11	EIR	17	17	17	20	16	17
	II.12	AIR	4	4	4	4	8	7
Category III	III.1	L	35	35	32	143	634	384
	III.2	TA	10	10	10	10	10	10
	III.3	RBT	10	10	10	10	10	20
	III.4	Com	10	10	10	20	30	10
	III.5	TS	20	20	20	30	30	60
	III.6	HP	5.5	5.5	6	6	30	14.5
	III.7	AP	3	3	3	5	6	4
Category IV	IV.1	SN	2	2	2	10	23	14
	IV.2	LS	18	18	18	20	40	35
	IV.3	NL	2	2	2	2	2	2
	IV.4	TW	12	10	10	12	10	9
	IV.5	MS	40	40	40	50	60	80
	IV.6	ML	30	30	30	60	60	60
	IV.7	TRC	4792	2014	1556	9678	13568	11352
	IV.8	BG	20	20	10	30	30	30
Category V	V.1	IC	1275	1150	1150	1725	1850	1725
	V.2	OC	1850	1950	1850	3250	3000	2250
	V.3	DC	300	350	350	550	600	550
	V.4	EIR-LA	30	20	20	10	20	20
	V.5	AIR-PS	7	7	7	3	3	5
	V.6	FS	30	30	30	20	30	40
	V.7	CTM	2	1.75	2	2	1.75	2

D-7 – Summary Schedule for Data – Cont'd

Categorys		Abreviations	Antelias Neccache Bridge	Nahr Almot 1 Bridge	Nahr Al mot 2 Bridge	Dora Bridge	Karantine Bridge	Achrafieh Borj Hammoud Bridge
Category I	I.1	ID	010	011	012	013	014	015
	I.2	BN	Antelias Neccache Bridge	Nahr Almot 1 Bridge	Nahr Al mot 2 Bridge	Dora Bridge	Karantine Bridge	Achrafieh Borj Hammoud Bridge
	I.3	GD	NA	NA	NA	NA	NA	NA
	I.4	BL	Naccache	Nahr Elmot	Nahr Elmot	Dora	Karantine	Karantina
	I.5	YD	1997	1992	1992	1999	1965	1970
	I.6	YS	2001	1996	1996	2003	1966	1971
	I.7	YC	2003	1999	1999	2004	1968	1972
	I.8	YO	2003	2000	2000	2004	1969	1973
Category II	II.1	BT	20	20	20	20	20	20
	II.2	DT	60	60	60	60	50	10
	II.3	CT	20	30	20	30	30	40
	II.4	FT	10	10	10	10	10	10
	II.5	MT	10	10	10	10	10	10
	II.6	CV	12450	12750	6240	17250	8650	2250
	II.7	ISW	0	0	0	0	0	0
	II.8	CS	14550	15250	7250	18150	9550	2100
	II.9	SS	0	0	0	0	0	0
	II.10	EIC	1100	1100	1250	1075	1150	950
	II.11	EIR	13	17	14	13	11	13
	II.12	AIR	6	7	7	6	5	4
Category III	III.1	L	493	653	573	624	196	106
	III.2	TA	10	10	10	10	10	10
	III.3	RBT	10	10	10	20	20	10
	III.4	Com	30	10	30	10	20	10
	III.5	TS	30	20	30	30	20	20
	III.6	HP	8	7	5.5	6	5	5
	III.7	AP	4	4	4	5	3	3
Category IV	IV.1	SN	18	15	13	11	5	6
	IV.2	LS	45	56	53	60	40	20
	IV.3	NL	2	3	2	6	8	4
	IV.4	TW	24	18	8.5	26	42	18
	IV.5	MS	60	60	60	100	100	40
	IV.6	ML	60	60	60	60	60	30
	IV.7	TRC	12575	9758	11245	28254	29457	7865
	IV.8	BG	30	30	30	30	10	10
Category V	V.1	IC	1425	1350	1550	1375	1450	1350
	V.2	OC	2500	2500	2500	2250	3000	2500
	V.3	DC	400	350	550	450	500	400
	V.4	EIR-LA	30	20	20	20	10	20
	V.5	AIR-PS	7	5	3	5	5	5
	V.6	FS	30	30	50	30	30	30
	V.7	CTM	2	2	2	1.5	1.25	1.25

D-7 – Summary Schedule for Data – Cont'd

Categorys		Abreviations	Achrafieh Jdeideh Bridge	Ghazir Bridge	Nahr Ibrahim Upper Bridge	Nahr Ibrahim Lower Bridge	Jbeil Main Bridge	Jbeil Secondary Bridge
Category I	I.1	ID	016	017	018	019	020	021
	I.2	BN	Achrafieh Jdeideh Bridge	Ghazir Bridge	Nahr Ibrahim Bridge	Nahr Ibrahim Bridge HW	First Jbeil Bridge	Second Jbeil Bridge
	I.3	GD	NA	Str Deficiency	NA	NA	NA	NA
	I.4	BL	Nborj Hammoud	Ghazir	NA	NA	Jbeil	Jbeil
	I.5	YD	1995	1960	1960	1960	1970	1970
	I.6	YS	2002	1960	1961	1962	1971	1971
	I.7	YC	2006	1961	1963	1962	1972	1972
	I.8	YO	2007	1962	1963	1963	1972	1972
Category II	II.1	BT	20	20	20	20	20	20
	II.2	DT	60	10	10	10	10	10
	II.3	CT	30	30	40	30	40	40
	II.4	FT	10	10	10	10	10	10
	II.5	MT	10	10	10	10	10	10
	II.6	CV	48550	450	825	4150	1525	1475
	II.7	ISW	0	0	0	0	0	0
	II.8	CS	52650	425	875	5250	1450	1450
	II.9	SS	0	0	0	0	0	0
	II.10	EIC	1450	1000	800	900	1050	1050
	II.11	EIR	13	16	17	10	16	19
	II.12	AIR	4	4	5	5	4	4
Category III	III.1	L	1734	30	61	153	120	115
	III.2	TA	10	10	10	10	10	10
	III.3	RBT	20	10	10	20	10	10
	III.4	Com	20	10	10	10	10	10
	III.5	TS	30	20	30	50	20	20
	III.6	HP	8	5	5.75	20	6	6
	III.7	AP	5	3	3	2	4	4
Category IV	IV.1	SN	53	2	4	4	8	8
	IV.2	LS	50	15	16	51	20	20
	IV.3	NL	5	2	2	6	2	2
	IV.4	TW	24	10	8	30	8.5	8.5
	IV.5	MS	80	60	50	100	60	60
	IV.6	ML	80	60	30	60	60	60
	IV.7	TRC	13578	5354	2456	19546	5486	5224
	IV.8	BG	30	10	10	10	30	30
Category V	V.1	IC	1850	1550	1150	1350	1350	1350
	V.2	OC	3500	2500	2000	2500	2050	2050
	V.3	DC	550	300	200	350	350	350
	V.4	EIR-LA	30	20	20	30	20	20
	V.5	AIR-PS	7	9	5	3	4	5
	V.6	FS	30	20	10	1	20	20
	V.7	CTM	2	1.5	1.5	1.7	1.75	1.75

D-7 – Summary Schedule for Data – Cont'd

Categorys		Abreviations	Akeiby Bridge	Bouar Bridge	Safra Bridge	Tabarja Brdige	Metro Bridge	Sahel Alma Bridge
Category I	I.1	ID	022	023	024	025	026	027
	I.2	BN	Mardoumet Bridge	Bouar Bridge	Safra Bridge	Tabarja Brdige	Metro Bridge	Sahel Alma Bridge
	I.3	GD	NA	NA	NA	NA	NA	NA
	I.4	BL	Bouar/Akaiby	Bouar	Safra	Tabarja	Maamelten	Sahel Alma
	I.5	YD	1960	1960	1960	1965	1960	1960
	I.6	YS	1961	1961	1961	1966	1960	1961
	I.7	YC	1963	1961	1961	1967	1962	1962
	I.8	YO	1963	1963	1963	1967	1963	1962
Category II	II.1	BT	20	20	20	20	20	20
	II.2	DT	10	10	10	10	30	30
	II.3	CT	40	40	40	40	40	30
	II.4	FT	10	10	10	10	10	10
	II.5	MT	10	10	10	10	10	10
	II.6	CV	763	675	950	575	4250	775
	II.7	ISW	0	0	0	0	0	0
	II.8	CS	860	775	1050	650	5250	950
	II.9	SS	0	0	0	0	0	0
	II.10	EIC	**800**	**800**	**900**	**750**	**1150**	**900**
	II.11	EIR	18	16	16	17	13	13
	II.12	AIR	4	4	4	4	5	3
Category III	III.1	L	53	55	68	48	153	25
	III.2	TA	10	10	10	10	20	10
	III.3	RBT	10	10	10	10	20	20
	III.4	Com	10	10	10	10	10	10
	III.5	TS	20	10	10	10	40	30
	III.6	HP	5.5	5.5	5	6	10	6
	III.7	AP	3	3	3	3	5	3
Category IV	IV.1	SN	4	4	4	4	3	2
	IV.2	LS	15	18	20	16	70	15
	IV.3	NL	2	2	2	2	4	4
	IV.4	TW	8	7.5	10	6.5	24	25.5
	IV.5	MS	50	30	50	30	100	100
	IV.6	ML	30	30	60	30	60	60
	IV.7	TRC	1251	1153	2151	2224	30542	31049
	IV.8	BG	10	10	20	10	10	10
Category V	V.1	IC	1150	1350	1150	1100	1550	1200
	V.2	OC	2150	2025	3000	2150	3000	2950
	V.3	DC	200	250	300	225	500	250
	V.4	EIR-LA	20	20	30	20	20	20
	V.5	AIR-PS	5	6	5	5	2	8
	V.6	FS	10	30	20	20	20	20
	V.7	CTM	1.5	1.25	1.5	1.25	1.2	1.5

D-7 – Summary Schedule for Data – Cont'd

Categorys		Abreviations	Roumieh Bridge	Beit Misk Bridge	Akeiby Bridge HW	Kartaba Bridge	Fidar Bridge	Third Jbeil Bridge
Category I	I.1	ID	028	029	030	031	032	033
	I.2	BN	Roumieh Bridge	Beit Misk Bridge	Mar Elias Bridge	Kartaba Bridge	Fidar Bridge	Third Jbeil Bridge
	I.3	GD	NA	NA	NA	NA	NA	NA
	I.4	BL	Roumieh	Beit Misk	Akaiby	Akaiby	Fidar	Jbeil
	I.5	YD	2005	2005	1960	1960	1961	1965
	I.6	YS	2012	2010	1961	1961	1962	1966
	I.7	YC	2013	2010	1961	1961	1963	1967
	I.8	YO	2013	2011	1961	1961	1963	1968
Category II	II.1	BT	20	20	10	20	20	20
	II.2	DT	40	20	10	10	10	10
	II.3	CT	40	30	10	40	40	40
	II.4	FT	10	10	10	10	10	10
	II.5	MT	10	10	10	10	10	10
	II.6	CV	375	425	275	725	1050	850
	II.7	ISW	0	0	0	0	0	0
	II.8	CS	350	375	335	705	1220	650
	II.9	SS	0	0	0	0	0	0
	II.10	EIC	875	950	1200	855	850	700
	II.11	EIR	19	15	16	18	13	17
	II.12	AIR	5	5	4	5	5	4
Category III	III.1	L	22	52	7	62	122	70
	III.2	TA	10	10	10	10	10	10
	III.3	RBT	10	10	20	10	10	10
	III.4	Com	10	10	10	10	10	10
	III.5	TS	10	10	20	20	30	10
	III.6	HP	5.5	5	4	5	5.75	5.5
	III.7	AP	5	4	3	3	3	3
Category IV	IV.1	SN	1	2	1	4	8	4
	IV.2	LS	22	26	7	15	15.5	18
	IV.3	NL	2	1	6	2	2	1
	IV.4	TW	9	6	30	8	8	6
	IV.5	MS	50	50	100	50	50	40
	IV.6	ML	60	60	60	30	30	30
	IV.7	TRC	553	1257	19254	6752	1258	798
	IV.8	BG	10	30	10	20	30	10
Category V	V.1	IC	1125	1200	1850	1125	1250	950
	V.2	OC	1500	2000	3000	2425	2625	1500
	V.3	DC	250	300	250	200	200	250
	V.4	EIR-LA	30	30	10	20	20	20
	V.5	AIR-PS	7	5	7	4	5	7
	V.6	FS	20	30	20	20	30	40
	V.7	CTM	1.25	1.25	1.25	1.5	1.6	1.4

D-7 – Summary Schedule for Data – Con t'd

Categorys		Abreviations	Deerine Bridge	Harisa Haret Sakher Bridge	Harisa Deerine Bridge	Zouk Bridge	Dbayye First Bridge Main Part	Dbayye First Bridge East Part
Category I	I.1	ID	034	035	036	037	038	039
	I.2	BN	Deerine Bridge	Harisa Haret Sakher Bridge	Harisa Deerine Bridge	Zouk Bridge	Dbayye First Bridge	Dbayye First Bridge
	I.3	GD	NA	NA	NA	NA	NA	NA
	I.4	BL	Jounieh	Haret sakher	Haret Sakher	Kaslik	Dbayyeh	Dbayyeh
	I.5	YD	1960	1985	1985	1959	1992	1992
	I.6	YS	1961	1995	1995	1960	1999	1999
	I.7	YC	1962	1997	1997	1961	2002	2002
	I.8	YO	1963	1998	1998	1962	2003	2003
Category II	II.1	BT	10	20	10	20	20	20
	II.2	DT	10	30	10	30	40	20
	II.3	CT	40	40	40	40	30	20
	II.4	FT	10	10	10	10	10	10
	II.5	MT	10	10	10	10	10	10
	II.6	CV	625	475	425	510	3215	955
	II.7	ISW	0	0	0	0	0	0
	II.8	CS	955	675	415	490	4150	1050
	II.9	SS	0	0	0	0	0	0
	II.10	EIC	900	1250	1100	1050	1100	950
	II.11	EIR	12	16	17	16	16	18
	II.12	AIR	5	5	5	4	6	6
Category III	III.1	L	25	22	14	14	123	93
	III.2	TA	10	10	10	10	10	10
	III.3	RBT	20	20	10	20	10	10
	III.4	Com	10	10	10	10	10	10
	III.5	TS	20	10	10	10	30	20
	III.6	HP	7.5	6	6	6	10	6
	III.7	AP	3	6	6	3	5	5
Category IV	IV.1	SN	1	1	2	1	6	5
	IV.2	LS	25	22	7	14	30	20
	IV.3	NL	4	2	2	4	4	1
	IV.4	TW	24	14	13	22	20	6.5
	IV.5	MS	100	80	50	80	60	50
	IV.6	ML	60	60	30	60	60	60
	IV.7	TRC	26570	5247	6254	29523	8325	3487
	IV.8	BG	10	20	10	10	10	10
Category V	V.1	IC	1450	1450	1620	1550	1350	1550
	V.2	OC	2250	1500	2000	3000	2250	2500
	V.3	DC	300	350	400	300	500	350
	V.4	EIR-LA	20	20	20	20	20	10
	V.5	AIR-PS	6	5	5	8	5	3
	V.6	FS	20	20	30	20	20	20
	V.7	CTM	1.5	2	2.25	2	1.5	1.5

D-7 – Summary Schedule for Data – Cont'd

Categorys		Abreviations	Dbayye First Bridge West Part	Dbayye Second Bridge Main Part	Dbayye Second Bridge East Part	Dbayye Second Bridge West Part	Antelias Bridge	Nahr ElKalb Bridge	NahrEmot Baabdat Brdige
Category I	I.1	ID	040	041	042	043	044	045	046
	I.2	BN	Dbayye First Bridge	Dbayye Second Bridge	Dbayye Second Bridge	Dbayye Second Bridge	Antelias Bridge	Nahr ElKalb Bridge	NahrEmot Baabdat Brdige
	I.3	GD	NA	NA	NA	NA	NA	NA	NA
	I.4	BL	Dbayyeh	Dbayyeh	Dbayyeh	Dbayyeh	Antelias	Nahr ElKalb	Nahr Elmot
	I.5	YD	1992	1992	1992	1992	2006	1960	1999
	I.6	YS	1999	1999	1999	1999	2009	1962	2004
	I.7	YC	2002	2002	2002	2002	2010	1964	2005
	I.8	YO	2003	2003	2003	2003	2010	1965	2006
Category II	II.1	BT	20	20	20	20	20	20	20
	II.2	DT	20	40	20	20	60	30	50
	II.3	CT	20	30	20	20	30	40	30
	II.4	FT	10	20	20	20	10	20	10
	II.5	MT	10	10	10	10	10	10	10
	II.6	CV	550	1925	625	425	10550	5250	675
	II.7	ISW	0	0	0	0	0	0	0
	II.8	CS	655	2050	755	495	11250	4250	625
	II.9	SS	0	0	0	0	0	0	0
	II.10	EIC	950	1175	1175	1175	1350	1100	950
	II.11	EIR	17	18	14	13	11	16	15
	II.12	AIR	7	7	7	7	6	7	7
Category III	III.1	L	42	75	82	54	322	104	83
	III.2	TA	10	10	10	10	10	30	10
	III.3	RBT	10	10	10	10	20	20	10
	III.4	Com	10	20	20	20	10	10	10
	III.5	TS	20	50	50	50	30	50	10
	III.6	HP	6	4.85	6	5	7	6	6.5
	III.7	AP	5	6	6	6	5	4	5
Category IV	IV.1	SN	3	2	4	3	13	3	3
	IV.2	LS	15	40	25	20	30	40	32
	IV.3	NL	1	2	1	1	8	8	2
	IV.4	TW	6.5	20	7.25	7.25	32	37	7
	IV.5	MS	50	50	50	50	100	100	50
	IV.6	ML	60	60	60	60	80	60	30
	IV.7	TRC	3268	8598	7352	5678	17582	31552	2598
	IV.8	BG	10	10	10	10	10	30	10
Category V	V.1	IC	1550	1325	1325	1325	1850	1450	1250
	V.2	OC	2500	2000	2000	2000	3500	3500	4000
	V.3	DC	350	550	450	450	500	400	250
	V.4	EIR-LA	10	20	20	20	20	20	20
	V.5	AIR-PS	2	3	2	3	3	5	3
	V.6	FS	20	20	20	20	20	20	30
	V.7	CTM	1.25	1.5	1.5	1.5	1.5	1.75	1.5

D-7 – Summary Schedule for Data – Cont'd

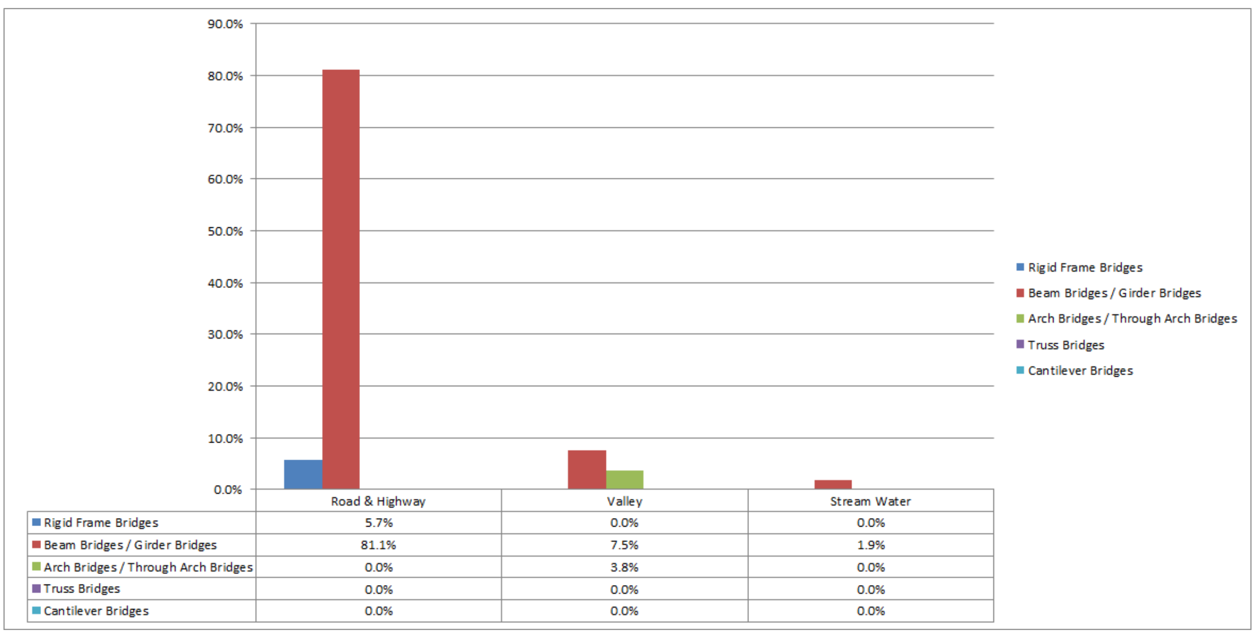
Categorys		Abreviations	NahrElmot Nabeih Bridge	Jouret Elballout Bridge	Ballout Broummana Bridge	Jal-el-Dib Old Steel Bridge	Fiat Steel Bridge	Mdeirej Bridge	Jadra Bridge
Category I	I.1	ID	047	048	049	050	051	052	053
	I.2	BN	NahrElmot Nabeih Bridge	Jouret Elballout Bridge	Ballout Broummana Bridge	Jal-el-Dib Old Steel Bridge	Fiat Steel Bridge	Mdeirej Bridge	Jadra Bridge
	I.3	GD	NA	NA	NA	Removed after 33 yrs	NA	NA	Arch/Straight
	I.4	BL	Nabeih	jouret Elballout	Broummana	Jal-el-Dib	Sen El Fil	Sawfar	Jadra
	I.5	YD	1998	1999	1995	1978	1978	1992	1975
	I.6	YS	2002	2003	2001	1979	1980	1996	1980
	I.7	YC	2003	2004	2003	1980	1981	1998	1982
	I.8	YO	2005	2005	2004	1981	1982	1998	1983
Category II	II.1	BT	20	20	20	20	20	20	30
	II.2	DT	40	40	30	30	30	40	20
	II.3	CT	40	40	40	20	20	30	30
	II.4	FT	10	10	10	10	10	10	10
	II.5	MT	10	10	10	30	30	10	10
	II.6	CV	1150	320	385	325	670	18550	3250
	II.7	ISW	0	0	0	950	2050	0	0
	II.8	CS	950	280	360	0	0	16750	5750
	II.9	SS	0	0	0	3150	11250	0	0
	II.10	EIC	850	850	800	1550	1550	1950	1250
	II.11	EIR	17	17	18	5	3	15	9
	II.12	AIR	7	5	5	5	6	6	5
Category III	III.1	L	43	23	27	103	319	430	160
	III.2	TA	20	10	10	10	10	20	20
	III.3	RBT	20	10	10	20	20	20	20
	III.4	Com	10	10	10	10	10	10	10
	III.5	TS	10	10	10	40	30	10	10
	III.6	HP	25	5.5	5.5	6	6	71	42
	III.7	AP	5	5	5	3	3	2	3
Category IV	IV.1	SN	1	1	2	8	16	11	10
	IV.2	LS	43	23	14	20	25	45	30
	IV.3	NL	4	2	2	3	4	6	6
	IV.4	TW	20	7	9	10	13.5	32	32
	IV.5	MS	80	50	50	80	80	100	100
	IV.6	ML	60	30	30	30	30	80	60
	IV.7	TRC	7534	1258	2485	11253	14259	7582	12562
	IV.8	BG	10	10	10	10	10	10	10
Category V	V.1	IC	1050	1100	1050	1950	1850	2550	1925
	V.2	OC	2500	2500	2500	3500	4500	5000	3500
	V.3	DC	300	300	300	200	150	1250	750
	V.4	EIR-LA	30	30	30	30	30	20	20
	V.5	AIR-PS	7	5	5	7	9	3	7
	V.6	FS	20	30	20	40	30	20	8
	V.7	CTM	1.25	1.25	1.5	1.25	1.5	2	2

D-8 – Statistically Relation between Factors from Cat III & IV with Bridge Type BT

			III.2 - TA - Type of Area to overpass					
			10	20	30			
		Number of Bridges	Road & Highway	Valley	Stream Water			
II.1 - BT	10	Rigid Frame Bridges	3	0	0	0	0	0
	20	Beam Bridges / Girder Bridges	43	4	1	0	0	0
	30	Arch Bridges / Through Arch Bridges	0	2	0	0	0	0
	40	Truss Bridges	0	0	0	0	0	0
	50	Cantilever Bridges	0	0	0	0	0	0
								53

			III.2 - TA - Type of Area to overpass					
			10	20	30			
		Number of Bridges	Road & Highway	Valley	Stream Water	0	0	0
II.1 - BT	10	Rigid Frame Bridges	5.7%	0.0%	0.0%	0.0%	0.0%	0.0%
	20	Beam Bridges / Girder Bridges	81.1%	7.5%	1.9%	0.0%	0.0%	0.0%
	30	Arch Bridges / Through Arch Bridges	0.0%	3.8%	0.0%	0.0%	0.0%	0.0%
	40	Truss Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	50	Cantilever Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
								100.0%

Schedules for Statistically Relation Between TA & BT



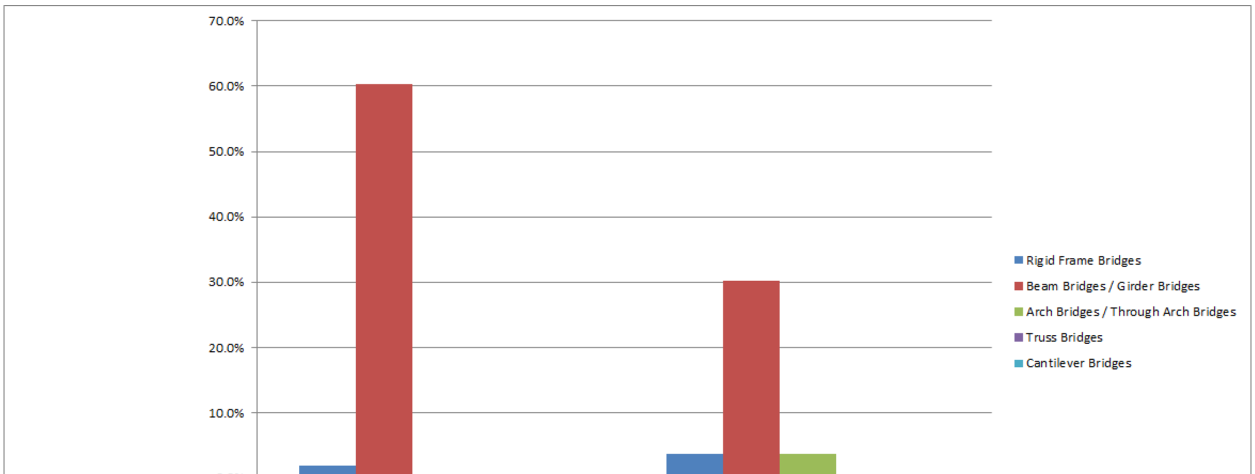
Graphical Presentation for Statistically Relation Between TA & BT

D-8 – Statistically Relation between Factors from Cat III & IV with Bridge Type BT – Cont'd

II.1 - BT		III.3 - RBT - Road Bridge Type 10 Non-HighWay Bridge	20 Highway Bridge				
	Number of Bridges						
10	Rigid Frame Bridges	1	2	0	0	0	0
20	Beam Bridges / Girder Bridges	32	16	0	0	0	0
30	Arch Bridges / Through Arch Bridges	0	2	0	0	0	0
40	Truss Bridges	0	0	0	0	0	0
50	Cantilever Bridges	0	0	0	0	0	0
							53

II.1 - BT		III.3 - RBT - Road Bridge Type 10 Non-HighWay Bridge	20 Highway Bridge	0	0	0	0
	Number of Bridges						
10	Rigid Frame Bridges	1.9%	3.8%	0.0%	0.0%	0.0%	0.0%
20	Beam Bridges / Girder Bridges	60.4%	30.2%	0.0%	0.0%	0.0%	0.0%
30	Arch Bridges / Through Arch Bridges	0.0%	3.8%	0.0%	0.0%	0.0%	0.0%
40	Truss Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
50	Cantilever Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
							100.0%

Schedules for Statistically Relation Between RBT & BT



	Non-HighWay Bridge	Highway Bridge
Rigid Frame Bridges	1.9%	3.8%
Beam Bridges / Girder Bridges	60.4%	30.2%
Arch Bridges / Through Arch Bridges	0.0%	3.8%
Truss Bridges	0.0%	0.0%
Cantilever Bridges	0.0%	0.0%

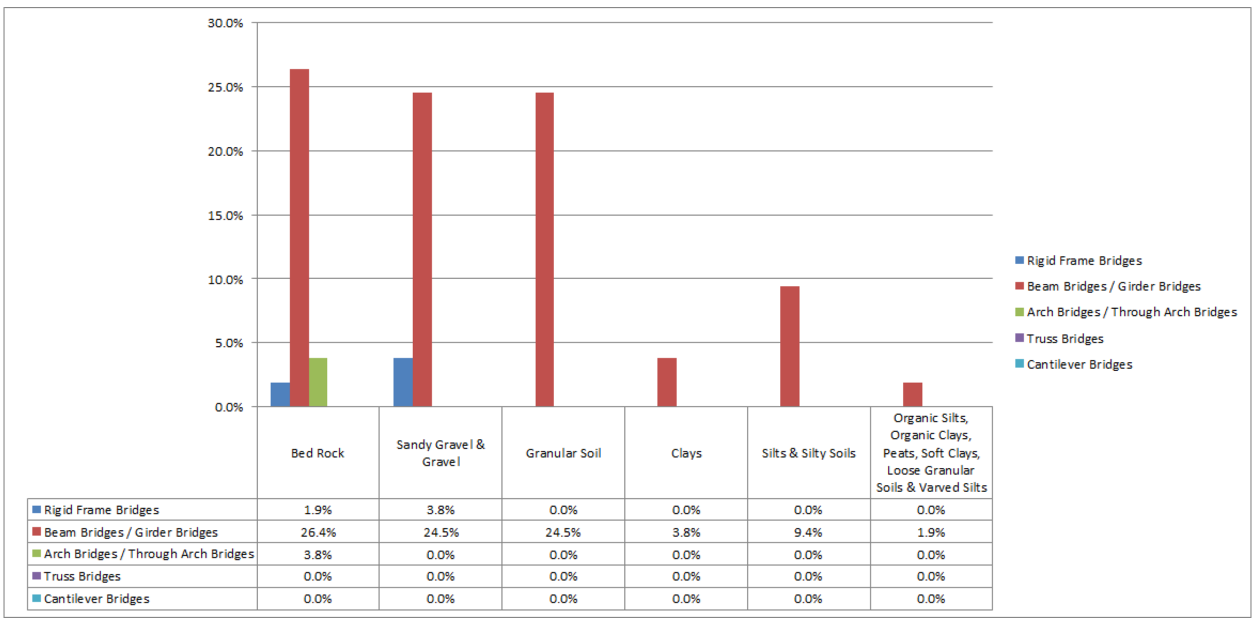
Graphical Presentation for Statistically Relation Between RBT & BT

D-8 – Statistically Relation between Factors from Cat III & IV with Bridge Type BT – Cont'd

			III.5 - ST - Soil Types					
			10	20	30	40	50	60
		Number of Bridges	Bed Rock	Sandy Gravel & Gravel	Granular Soil	Clays	Silts & Silty Soils	Organic Silts, Organic Clays, Peats, Soft C
II.1 - BT	10	Rigid Frame Bridges	1	2	0	0	0	0
	20	Beam Bridges / Girder Bridges	14	13	13	2	5	1
	30	Arch Bridges / Through Arch Bridges	2	0	0	0	0	0
	40	Truss Bridges	0	0	0	0	0	0
	50	Cantilever Bridges	0	0	0	0	0	0
								53

			III.5 - ST - Soil Types					
			10	20	30	40	50	60
		Number of Bridges	Bed Rock	Sandy Gravel & Gravel	Granular Soil	Clays	Silts & Silty Soils	Organic Silts, Organic Clays, Peats, Soft C
II.1 - BT	10	Rigid Frame Bridges	1.9%	3.8%	0.0%	0.0%	0.0%	0.0%
	20	Beam Bridges / Girder Bridges	26.4%	24.5%	24.5%	3.8%	9.4%	1.9%
	30	Arch Bridges / Through Arch Bridges	3.8%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	Truss Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	50	Cantilever Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
								100.0%

Schedules for Statistically Relation Between ST & BT



	Bed Rock	Sandy Gravel & Gravel	Granular Soil	Clays	Silts & Silty Soils	Organic Silts, Organic Clays, Peats, Soft Clays, Loose Granular Soils & Varved Silts
Rigid Frame Bridges	1.9%	3.8%	0.0%	0.0%	0.0%	0.0%
Beam Bridges / Girder Bridges	26.4%	24.5%	24.5%	3.8%	9.4%	1.9%
Arch Bridges / Through Arch Bridges	3.8%	0.0%	0.0%	0.0%	0.0%	0.0%
Truss Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cantilever Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

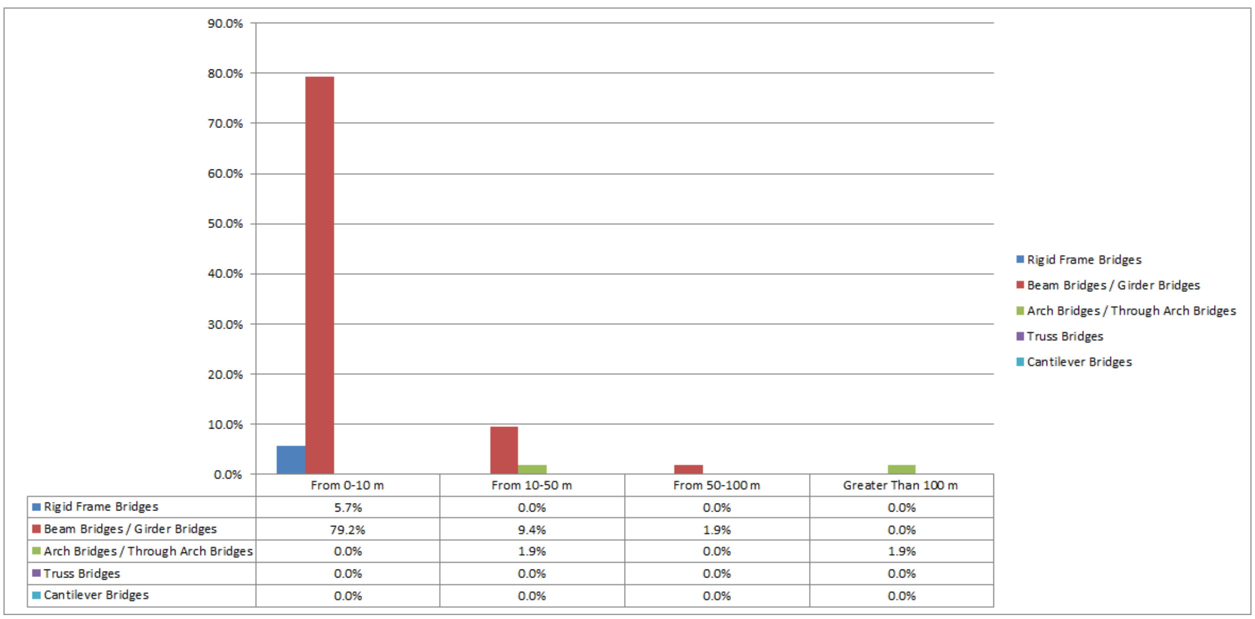
Graphical Presentation for Statistically Relation Between ST & BT

D-8 – Statistically Relation between Factors from Cat III & IV with Bridge Type BT – Cont'd

			III.6 - HP - Highest point					
		Number of Bridges	From 0-10 m	From 10-50 m	From 50-100 m	Greater Than 100 m		
II.1 - BT	10	Rigid Frame Bridges	3	0	0	0	0	0
	20	Beam Bridges / Girder Bridges	42	5	1	0	0	0
	30	Arch Bridges / Through Arch Bridges	0	1	0	1	0	0
	40	Truss Bridges	0	0	0	0	0	0
	50	Cantilever Bridges	0	0	0	0	0	0
								53

			III.6 - HP - Highest point					
		Number of Bridges	From 0-10 m	From 10-50 m	From 50-100 m	Greater Than 100 m	0	0
II.1 - BT	10	Rigid Frame Bridges	5.7%	0.0%	0.0%	0.0%	0.0%	0.0%
	20	Beam Bridges / Girder Bridges	79.2%	9.4%	1.9%	0.0%	0.0%	0.0%
	30	Arch Bridges / Through Arch Bridges	0.0%	1.9%	0.0%	1.9%	0.0%	0.0%
	40	Truss Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	50	Cantilever Bridges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
								100.0%

Schedules for Statistically Relation Between HP & BT



Graphical Presentation for Statistically Relation Between HP & BT

Appendix E – Aesthetic Characteristics (MDOT, 2005)

1. **Ratio of deck span to depth**

   Span Length/Deck Depth > 20 will start to be better.

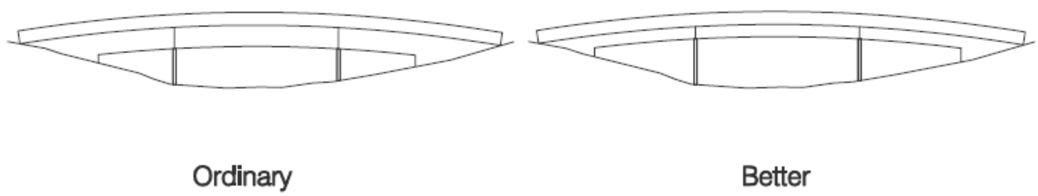
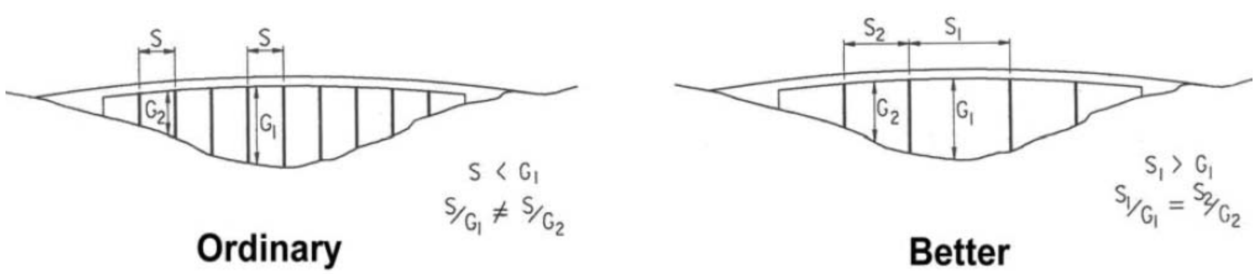


Figure E-1 - Ratio of deck span to depth

2. **Ratio of deck span to pier height, Consistency of Span Numbers**

Based on the Indication on the mentioned description, factors will be rated between 1 & 10 and will be input in the appropriate table row.

The proportions of the major elements of the bridge are the strongest determinants of its visual impact. For pier placement, the key proportion is span versus vertical clearance, or, a better way to look at it, span versus the overall shape of the space beneath the bridge. Generally, the bridge will look better the more the horizontal dimension of this space (the span) exceeds the vertical dimension



Emphasizing horizontal proportions in pier placement and keeping the S/G ratio constant

Figure E-2 - Ratio of deck span to pier height

3. **Ratio of deck depth to pier width**

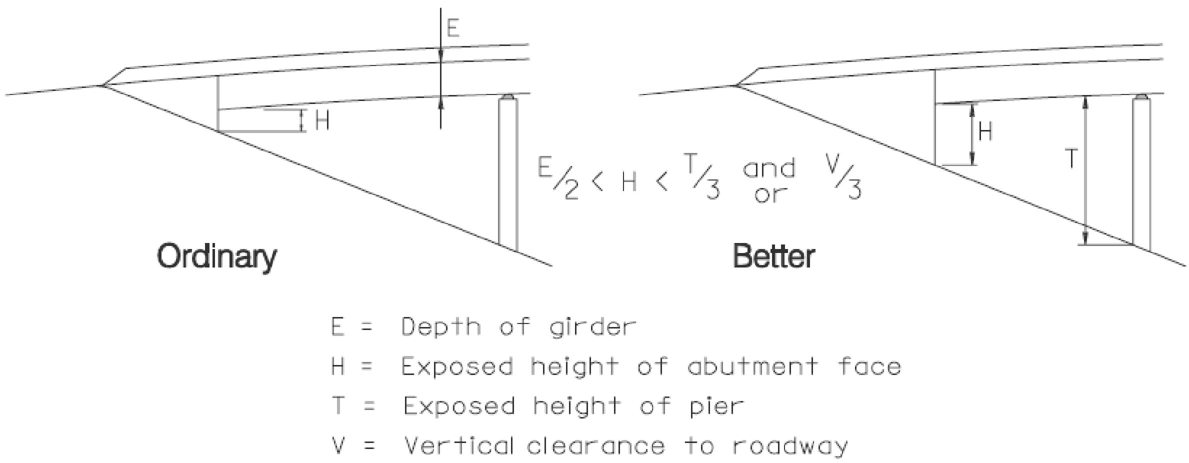


Figure E-3 - Ratio of deck depth to pier width

4. **Deck curvature in elevation**

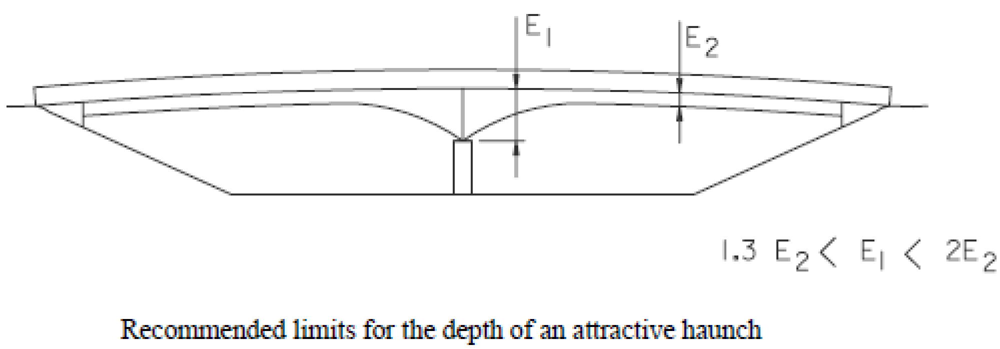


Figure E-4 – Deck Curvature in elevation

5. **Deck super-elevation**

It is depend on the different elevation between the start – end points – So it is related to the longitudinal slope value. (10 if slope = 0)

6. Bridge skew Angle

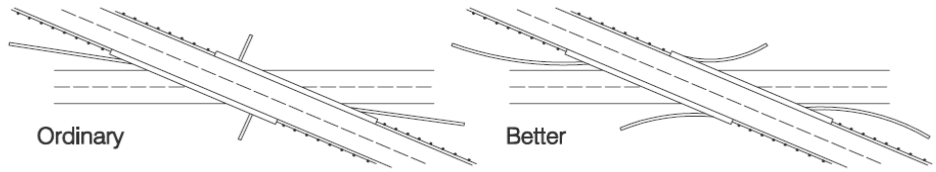


Figure E-5 – Bridge Skew Angle

7. Integrity to surrounding topography

Rating from 0 to 10 based on well integrated as Arch with the surrounding topography

8. Structure Impression (strength through form,)

Strong or weak structure appearance (0 to 10)

9. Clear Display

Bridge block the clear view or it is light for eyes (0 to 10)

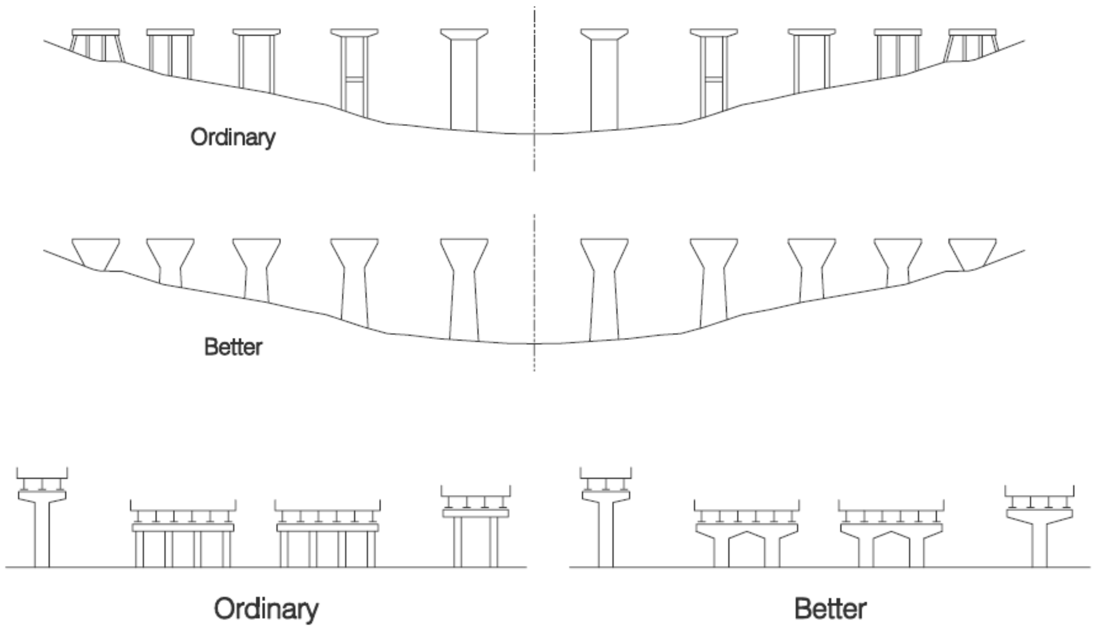
10. Lighting, Shade, Shadow.

Geometric Forms, parapets, shadow of the bridge on other surround elements bad or good effect? (From 0 to 10)

11. Relationship with the substructure

Fixed and rigid with the piers; appropriate and rational dimensions between super and substructure.

12. Pier Dimension Ratios



Families of piers varying by length

Figure E-6 – Pier Dimension Ratios

13. Color & Textures

Using Cladding and appropriate texture with the environment, harmonic color with the surround.

14. Architectural Elements Consistency

Verifying the Consistency between the Main Girder, Bracing, and any other structural elements with Architecture insight.

Appendix F – Linguistic Converter Modules

F.1 - Bridge Type (Girder, Arch, etc…)

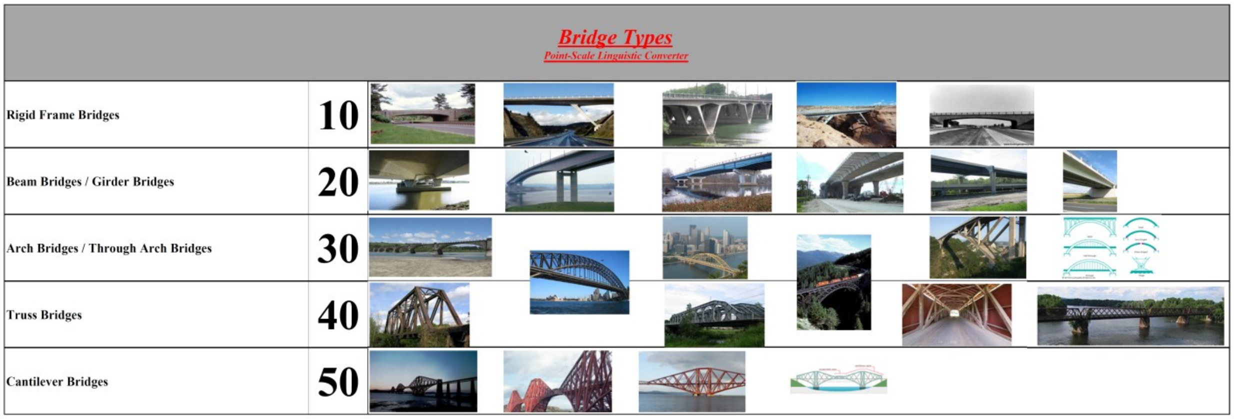


Figure F-1 – Bridge Types

F.2 - Structure Type for Deck

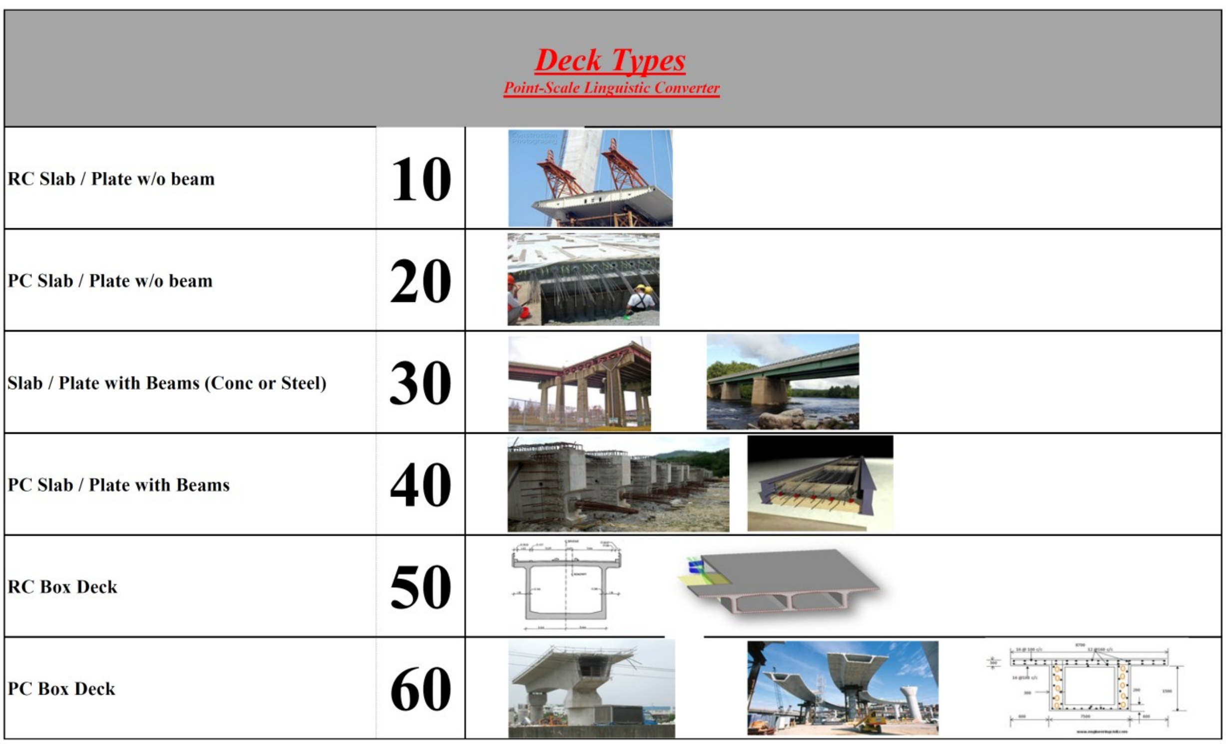


Figure F-2 - Deck Types

F.3 - Column Type

Column Types Point-Scale Linguistic Converter		
W/O Columns - Natural Abutment / or supported by ends	10	
Single Column Pier	20	  
Multi-Column Piers	30	  
Wall Pier	40	  

Figure F-3 – Column Types

F.4 - Foundation Type

Foundation Types Point-Scale Linguistic Converter	
Shallow Foundation	10
Deep Foundation	20

Figure F-4 – Foundation Types

F.5 - Material Type

Material Types Point-Scale Linguistic Converter		
Concrete	10	
Concrete/Steel Mixte	20	
Steel	30	

Figure F-5 – Material Types

F.6 - Type of Area to Overpass

Types of Area to Overpass Point-Scale Linguistic Converter		
Road & Highway	10	
Valley	20	
Stream Water	30	

Figure F-6 – Types of Area to Overpass

F.7 - Road-Bridge Type

Road-Bridge Types Point-Scale Linguistic Converter		
Non-HighWay Bridge	10	
Highway Bridge	20	

Figure F-7 – Road-Bridge Types

F.8 – Complexity

Complexity Point-Scale Linguistic Converter		
Simple Direction	10	
Two perpendicular Direction	20	
Multiple Section-Directions	30	

Figure F-8 – Complexity

F.9 - Soil Types

Soil Types Point-Scale Linguistic Converter	According to IBC
Bed Rock	10
Sandy Gravel & Gravel	20
Granular Soil	30
Clays	40
Silts & Silty Soils	50
Organic Silts, Organic Clays, Peats, Soft Clays, Loose Granular Soils & Varved Silts	60

Figure F-9 – Soil Types

F.10 - Bridge Geometric (Straight, Skewed, Curved)

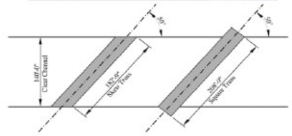
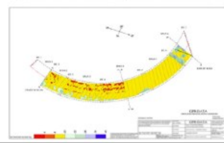
Bridge Geometric Types Point-Scale Linguistic Converter		
Straight	10	
Skewed	20	
Curved	30	

Figure F-10 – Bridge Geometrics

F.11 - Environment Impact Rate - Local Authorities Evaluation

Environment Impact Rate - Local Authority Evaluation - EIR-LA Point-Scale Linguistic Converter		
Low Damage	10	Rating provided by the Government Authorities based on their Own evaluation of Bridge Environment impact
Medium Damage	20	
High Damage	30	

Figure F-11 – EIR-LA

F.12 - Functional Satisfaction at first use

Functional Requirements *Point-Scale Linguistic Converter*		
Low Functionality	**50**	Rating provided by the Government Authorities base on their Own evaluation of Bridge Functionality
Slightly Accepted Functionality	**40**	
Average Functionality	**30**	
Good Functionality	**20**	
Higher Functionality	**10**	

Figure F-12 – Functional Satisfaction

Appendix G – Bank of Photos – Existing Bridges (Sample)


46- Nahrmot Baabdat Bridge 7


46- Nahrmot Baabdat Bridge 8


46- Nahrmot Baabdat Bridge 9


6- Nahrmot Baabdat Bridge 1


6- Nahrmot Baabdat Bridge 1


6- Nahrmot Baabdat Bridge 1:


6- Nahrmot Baabdat Bridge 1:


47- NahrElmot Nabeih Bridge


48- Jouret ElBallout Bridge 1


48- Jouret ElBallout Bridge 2


48- Jouret ElBallout Bridge 3


48- Jouret ElBallout Bridge 4


48- Jouret ElBallout Bridge 5


48- Jouret ElBallout Bridge 6


48- Jouret ElBallout Bridge 7


9- Ballout Broummana Bridge


9- Ballout Broummana Bridge


9- Ballout Broummana Bridge


9- Ballout Broummana Bridge


9- Ballout Broummana Bridge


9- Ballout Broummana Bridge


9- Ballout Broummana Bridge


50- Jal-el-Dib Old Steel Bridge


51- Fiat Steel Bridge

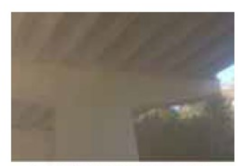

52- Mdeyrej Bridge


53- Jadra Bridge


01- Casino Bridge


02- Halat Bridge-Fidar 1


02- Halat Bridge-Fidar 2


02- Halat Bridge-Fidar 3


02- Halat Bridge-Fidar 4


03- Fouad Chehab Bridge 1


03- Fouad Chehab Bridge 2


03- Fouad Chehab Bridge 3


03- Fouad Chehab Bridge 4

Appendix H – Autodesk Software Products for the Bridge Lifecycle

	DESIGN				CONSTRUCTION				O&M			
	Architecture	Preliminary Design	Structural Analysis	Contract Documents	Staging Visualization	Estimating	Scheduling	Fabrication	Rating	Routing	Management	Inspection
Infrastructure Modeler		X										
AutoCAD Civil 3D		X	X	X				X				
Revit Architecture	X			X								
Revit Structure		X	X	X				X				
Bridge Modeler		X										
Revit MEP				X								
3ds Max Design					X							
Navisworks					X		X	X				
Quantity Take-off						X						
BIM 360 Field (Vela)								X				

Appendix I – Case Study Results

I-1 First Arrangement Target Values verses Testing Values

Target				001	002	003
II.1	BT	Bridge Type (Girder, Arch, etc	converted to #	30	20	20
			Training results / Testing	29.36	20.44	20.09
II.2	DT	Structure Type for Deck	converted to #	10	40	10
			Training results / Testing	10.6346	56.9266	10.0712
II.3	CT	Column Type	converted to #	**10**	**30**	**20**
			Training results / Testing	10.1851	30.3264	18.7745
II.4	FT	Foundation Type	converted to #	10	10	10
			Not Applied - Not Needed			
II.5	MT	Material Type	converted to #	10	10	10
			Training results / Testing	10.0004	10.0000	10.0005
II.6	CV	Volume of Concrete	m^3	2562	1225	3125
			Not Applied - to be calculated			
II.7	ISW	Industrial Steel Weight	T	0	0	0
			Not Applied - to be calculated			
II.8	CS	Exposed Concrete Surfaces	m^2	4320	21550	3325
			Not Applied - to be calculated			
II.9	SS	Exposed steel surfaces	m^2	0	0	0
			Not Applied - to be calculated			
II.1(	EIC	Estimated Initial Cost - PV	$/m^2$	850	1150	1250
			Training results / Testing	854	1128	1228
II.1	EIR	Environment Impact Rate	Calculated Rate	9	6	16
			Not Applied - to be calculated			
II.1:	AIR	Aesthetic Satisfaction Rate	Calculated Rate	8	7	5
			Not Applied - to be calculated			

		004	005	006	007	008	009	010	011	012
II.1	BT	20	20	20	20	20	20	20	20	20
		19.10	19.67	19.84	23.63	27.90	19.85	24.40	19.61	18.92
II.2	DT	10	10	10	60	60	60	60	60	60
		10.083	10.1774	10.1603	59.6255	59.9981	59.9844	59.955	58.9485	59.3766
II.3	CT	**40**	**30**	**30**	**30**	**20**	**20**	**20**	**30**	**20**
		39.025	39.0721	37.5437	38.2424	31.409	28.4362	25.5056	29.5842	21.0497
II.4	FT	10	10	10	10	10	20	10	10	10
II.5	MT	10	10	10	10	10	10	10	10	10
		10.0002	10.0002	10.0004	10.0001	10.0006	10.0002	10.0001	10.0001	10.0001
II.6	CV	625	560	525	3250	8325	4225	12450	12750	6240
II.7	ISW	0	0	0	0	0	0	0	0	0
II.8	CS	556	425	380	2550	11250	4020	14550	15250	7250
II.9	SS	0	0	0	0	0	0	0	0	0
II.1(	EIC	950	850	850	1250	1350	1425	1100	1100	1250
		857	847	816	1242	1353	1494	1248	1087	1242
II.1	EIR	17	17	17	20	16	17	13	17	14
II.1:	AIR	4	4	4	4	8	7	6	7	7

		013	014	015	016	017	018	019	020	021
II.1	BT	20	20	20	20	20	20	20	20	20
		10.01	11.41	20.14	19.94	20.27	20.22	19.70	19.56	19.53
II.2	DT	60	50	10	60	10	10	10	10	10
		59.8178	48.1066	10.0711	59.998	10.0302	10.1121	10.4258	10.346	10.3639
II.3	CT	**30**	**30**	**40**	**30**	**30**	**40**	**30**	**40**	**40**
		30.7911	25.7275	38.5186	18.0054	26.9727	32.6969	31.1846	36.8499	36.9161
II.4	FT	10	10	10	10	10	10	10	10	10
II.5	MT	10	10	10	10	10	10	10	10	10
		10.0000	10.0000	10.0005	10.0002	10.0003	10.0009	10.0003	10.0001	10.0001
II.6	CV	17250	8650	2250	48550	450	825	4150	1525	1475
II.7	ISW	0	0	0	0	0	0	0	0	0
II.8	CS	18150	9550	2100	52650	425	875	5250	1450	1450
II.9	SS	0	0	0	0	0	0	0	0	0
II.1(	EIC	1075	1150	950	1450	1000	800	900	1050	1050
		1517	1299	906	1448	824	826	913	1026	1024
II.1	EIR	13	11	13	13	16	17	10	16	19
II.1:	AIR	6	5	4	4	4	5	5	4	4

		022	023	024	025	026	027	028	029	030
II.1	BT	20	20	20	20	20	20	20	20	10
		20.00	20.19	20.21	20.47	19.78	10.54	18.67	19.70	11.06
II.2	DT	10	10	10	10	30	30	40	20	10
		10.1649	10.2357	10.1636	10.1123	26.7393	26.3285	38.498	22.1265	10.3069
II.3	CT	**40**	**40**	**40**	**40**	**40**	**30**	**40**	**30**	**10**
		36.0582	38.1165	37.2944	37.7699	38.2372	32.949	32.5012	33.2517	38.821
II.4	FT	10	10	10	10	10	10	10	10	10
II.5	MT	10	10	10	10	10	10	10	10	10
		10.0008	10.0005	10.0002	10.0005	10.0082	10.0002	10.0004	10.0001	10.0001
II.6	CV	763	675	950	575	4250	775	375	425	275
II.7	ISW	0	0	0	0	0	0	0	0	0
II.8	CS	860	775	1050	650	5250	950	350	375	335
II.9	SS	0	0	0	0	0	0	0	0	0
II.1(	EIC	800	800	900	750	1150	900	875	950	1200
		810	804	859	807	1148	906	908	984	1200
II.1	EIR	18	16	16	20	13	13	19	15	16
II.1:	AIR	4	4	4	4	5	3	5	5	4

I-1 First Arrangement Target Values verses Testing Values – cont’d

		031	032	033	034	035	036	037	038	039
II.1	BT	20	20	20	10	20	10	20	20	20
		18.58	19.50	19.96	10.95	19.48	21.19	19.73	20.00	20.19
II.2	DT	10	10	10	10	30	10	30	40	20
		10.0232	10.0954	10.245	10.4161	29.3025	10.3732	11.9184	37.2909	27.6169
II.3	CT	40	40	40	40	40	40	40	30	20
		38.0495	38.7207	35.8944	37.5817	39.0684	36.7249	38.9399	28.5989	18.1125
II.4	FT	10	10	10	10	10	10	10	10	10
II.5	MT	10	10	10	10	10	10	10	10	10
		10.0002	10.0001	10.0014	10.0002	10.0010	10.0007	10.0003	10.0004	10.0004
II.6	CV	725	1050	850	625	475	425	510	3215	955
II.7	ISW	0	0	0	0	0	0	0	0	0
II.8	CS	705	1220	650	955	675	415	490	4150	1050
II.9	SS	0	0	0	0	0	0	0	0	0
II.1(	EIC	855	850	700	900	1250	1100	1050	1100	950
		858	845	779	941	1230	885	980	932	952
II.1	EIR	18	13	17	12	16	24	16	16	18
II.1	AIR	5	5	4	5	5	5	4	6	6

		040	041	042	043	044	045	046	047	048
II.1	BT	20	20	20	20	20	20	20	20	20
		19.26	19.76	20.65	19.75	14.87	10.00	21.06	19.93	20.04
II.2	DT	20	40	20	20	60	30	50	40	40
		20.8451	39.5544	20.3597	20.349	59.0393	31.5537	46.3029	40.9079	37.0366
II.3	CT	20	30	20	20	30	40	30	40	40
		20.6156	28.9447	18.682	20.9435	30.1472	39.6679	31.313	39.0055	34.937
II.4	FT	10	20	20	20	10	20	10	10	10
II.5	MT	10	10	10	10	10	10	10	10	10
		10.0004	10.0004	10.0004	10.0004	10.0000	10.0007	10.0006	10.0005	10.0006
II.6	CV	550	1925	625	425	10550	5250	675	1150	320
II.7	ISW	0	0	0	0	0	0	0	0	0
II.8	CS	655	2050	755	495	11250	4250	625	950	280
II.9	SS	0	0	0	0	0	0	0	0	0
II.1(	EIC	950	1175	1175	1175	1350	1100	950	850	850
		940	1151	1152	1184	1342	1104	928	863	899
II.1	EIR	17	18	14	13	11	16	15	17	17
II.1	AIR	7	7	7	7	6	7	7	7	5

		049	050	051	052	053
II.1	BT	20	20	20	20	30
		19.70	19.49	19.60	25.01	29.02
II.2	DT	30	30	30	40	20
		18.357	32.8811	33.0178	35.2792	20.0809
II.3	CT	40	20	20	30	30
		36.4869	21.8622	24.8309	30.9059	37.6836
II.4	FT	10	10	10	10	10
II.5	MT	10	30	30	10	10
		10.0006	29.9988	29.9991	10.0003	10.0006
II.6	CV	385	325	670	18550	3250
II.7	ISW	0	950	2050	0	0
II.8	CS	360	0	0	16750	5750
II.9	SS	0	3150	11250	0	0
II.1(	EIC	800	1550	1550	1950	1250
		866	1547	1546	1296	1251
II.1	EIR	18	5	3	15	9
II.1	AIR	5	5	6	6	5

I-2 Final Arrangement Target Values verses Testing Values

Target				001	002	003	004
V.1	IC	Actual Initial Cost - PV	$/m^2	1100	1250	1825	1275
		Training results / Testing		1627.53	1250.00	1825.00	1275.00
V.2	OC	Operation & Maintenance Cost over 100 Y	$/m^2	600	1000	2000	1850
		Training results / Testing		596.5	1018.6	1647.9	1862.7
V.3	DC	Dismantling Cost	$/m^2	150	400	500	300
		Training results / Testing		149.415	557.450	505.002	301.122
V.4	EIR-LA	Environment Impact Rate - Local Authorities Evaluation	converted to #	10	20	20	30
		Training results / Testing		10.2493	20.1096	20.5707	30.4162
V.5	AIR-PS	Aesthetic Satisfaction Rate - Public Satisfaction	Based on Q02	5	3	5	7
		Training results / Testing		5	3.38963	5	7
V.6	FS	Functional Satisfaction at first use	converted to #	10	10	20	30
		Training results / Testing		9.9857	19.2813	20.4937	30.4639
V.7	CTM	Actual Construction Time / Estimated	#	2	1.5	2	2
		Training results / Testing		2.00820	1.50302	2.03792	1.98483

		005	006	007	008	009	010	011	012	013	014	015
V.1	IC	1150	1150	1725	1850	1725	1425	1350	1550	1375	1450	1350
		1150.00	1150.00	2267.19	1762.13	1725.00	1425.00	1800.79	1550.00	1375.00	1770.06	1350.00
V.2	OC	1950	1850	3250	3000	2250	2500	2500	2500	2250	3000	2500
		2883.4	2841.9	3271.7	3036.0	2297.8	1299.1	2483.6	1124.3	2318.1	2997.3	2718.4
V.3	DC	350	350	550	600	550	400	350	550	450	500	400
		351.441	352.829	533.708	602.754	548.500	326.083	330.508	547.322	416.144	496.746	400.999
V.4	EIR-LA	20	20	10	20	20	30	20	20	20	10	20
		22.3860	20.1381	10.1204	20.0127	20.3416	27.4624	22.8873	32.1534	19.9806	26.0246	20.7825
V.5	AIR-PS	7	7	3	3	5	7	5	3	5	5	5
		7	6.8612	3	3	5	3.3302	5	3	4.85426	5	5
V.6	FS	30	30	20	30	40	30	30	50	30	30	30
		30.3716	31.5956	20.2564	29.3480	41.3155	29.7242	29.9429	47.7194	29.4758	29.8071	25.9442
V.7	CTM	1.75	2	2	1.75	2	2	2	2	1.5	1.25	1.25
		1.82844	1.93263	2.05146	1.77195	1.96525	1.99454	1.88220	2.02474	1.47992	1.25255	1.45083

		016	017	018	019	020	021	022	023	024	025	026
V.1	IC	1850	1550	1150	1350	1350	1350	1150	1350	1150	1100	1550
		1850.00	1550.00	1116.74	1350.00	1350.00	1319.58	1150.00	1005.59	1046.21	1012.87	1550.00
V.2	OC	3500	2500	2000	2500	2050	2050	2150	2025	3000	2150	3000
		3514.5	2454.0	1994.4	2571.0	1733.9	1668.3	2142.4	2002.8	943.9	2132.3	2976.0
V.3	DC	550	300	200	350	350	350	200	250	300	225	500
		546.784	302.865	202.537	347.185	350.818	349.667	231.211	240.262	283.664	225.925	496.611
V.4	EIR-LA	30	20	20	30	20	20	20	20	30	20	20
		30.0010	20.5861	20.1811	29.6267	19.1209	18.7663	20.7647	20.6469	28.7898	20.8254	19.7194
V.5	AIR-PS	7	9	5	3	4	5	5	6	5	5	2
		7	9	5	3	3.26467	3.5943	5.42347	6	6.7648	5	2
V.6	FS	30	20	10	1	20	20	10	30	20	20	20
		49.9468	20.3905	10.0543	1.9583	17.6295	20.0863	11.0761	30.5884	20.6615	20.9390	31.0656
V.7	CTM	2	1.5	1.5	1.7	1.75	1.75	1.5	1.25	1.5	1.25	1.2
		1.89790	1.82442	1.49504	1.51818	1.79100	1.75213	1.51512	1.28530	1.50693	1.25427	1.22022

		027	028	029	030	031	032	033	034	035	036	037
V.1	IC	1200	1125	1200	1850	1125	1250	950	1450	1450	1620	1550
		1200.00	939.48	1017.92	1850.00	1359.14	1250.00	950.00	1450.00	1450.00	1620.00	1550.00
V.2	OC	2950	1500	2000	3000	2425	2625	1500	2250	1500	2000	3000
		2971.5	1519.8	1967.7	3091.4	2405.5	2642.3	1477.0	2284.7	1153.4	2011.7	3028.2
V.3	DC	250	250	300	250	200	200	250	300	350	400	300
		248.874	252.317	298.947	165.812	201.944	203.146	233.937	301.516	335.771	402.504	279.261
V.4	EIR-LA	20	30	30	10	20	20	20	20	20	20	20
		19.0776	28.3528	29.2349	9.4254	24.0668	19.6956	21.5734	19.5822	20.2502	19.8864	19.4384
V.5	AIR-PS	8	7	5	7	4	5	7	6	5	5	8
		5.5741	7	5	7	4	5	4.3249	6	5	5	8
V.6	FS	20	20	30	20	20	30	40	20	20	30	20
		20.0817	20.3187	35.7216	23.6463	20.6073	28.5412	40.1763	20.1659	20.1822	34.5884	20.3384
V.7	CTM	1.5	1.25	1.25	1.25	1.5	1.6	1.4	1.5	2	2.25	2
		1.47288	1.37935	1.29583	1.42843	1.52960	1.61874	1.41524	1.47186	2.06077	2.20030	1.94290

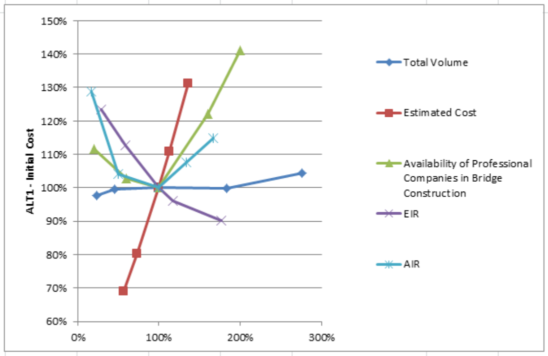
		038	039	040	041	042	043	044	045	046	047	048
V.1	IC	1350	1550	1550	1325	1325	1325	1850	1450	1250	1050	1100
		1350.00	1550.00	1550.00	1325.00	1325.00	1325.00	1850.00	1823.71	1250.00	1352.15	1100.00
V.2	OC	2250	2500	2500	2000	2000	2000	3500	3500	4000	2500	2500
		2278.7	2544.4	2357.3	2056.6	2057.3	1961.9	3453.2	3510.6	3994.1	2606.8	2772.8
V.3	DC	500	350	350	550	450	450	500	400	250	300	300
		448.732	352.207	353.802	547.256	450.901	450.543	556.636	393.386	255.462	305.475	302.641
V.4	EIR-LA	20	10	10	20	20	20	20	20	20	30	30
		19.4430	10.3695	10.4822	20.1935	18.9346	19.7926	19.9845	19.9038	20.3882	26.1133	28.8078
V.5	AIR-PS	5	3	2	3	2	3	3	5	3	7	5
		4.83635	3	2	2.93864	2	2.992033	3	5	3.044867	8.3383	5
V.6	FS	20	20	20	20	20	20	20	20	30	20	30
		19.5854	20.1745	14.8541	19.7842	13.3131	12.0824	17.0990	1.0003	30.3970	19.9727	31.8259
V.7	CTM	1.5	1.5	1.25	1.5	1.5	1.5	1.5	1.75	1.5	1.25	1.25
		1.50927	1.53158	1.28738	1.70370	1.56287	1.53367	1.48816	1.75381	1.43415	1.21666	1.44031

		049	050	051	052	053
V.1	IC	1050	1950	1850	2550	1925
		1050.00	1911.69	1850.00	2550.00	1925.00
V.2	OC	2500	3500	4500	5000	3500
		2537.4	3533.2	7811.5	4997.6	4291.1
V.3	DC	300	200	150	1250	750
		301.396	324.562	151.118	1249.227	749.915
V.4	EIR-LA	30	30	30	20	20
		27.1490	29.7328	28.6909	19.9175	20.1930
V.5	AIR-PS	5	7	9	3	7
		5	7	4.5665	3	7
V.6	FS	20	40	30	20	8
		29.9637	40.1782	30.2453	19.9216	7.8726
V.7	CTM	1.5	1.25	1.5	2	2
		1.38297	1.23781	1.48704	1.99196	1.97829

I-3 Sensitivity Analysis (SA) for performance criteria versus factors – for Alt 1 & 3

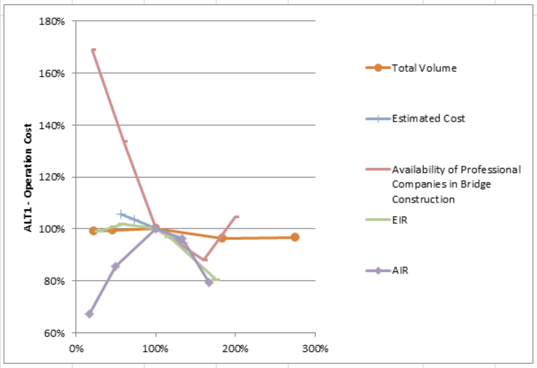
Alt1 / Initial Cost					
Total Volume	1000	2000	4350	8000	12000
Initial Cost	1468	1497	1505	1502	1571
Estimated Cost	500	650	885	1000	1200
Initial Cost	1040	1209	1505	1667	1975
Availability of Profe	1	3	5	8	10
Initial Cost	1680	1548	1505	1835	2125
EIR	5	10	17	20	30
Initial Cost	1856	1694	1505	1446	1356
AIR	1	3	6	8	10
Initial Cost	1939	1565	1505	1619	1730

Alt1 / Initial Cost					
Total Volume	23%	46%	100%	184%	276%
Initial Cost	98%	99%	100%	100%	104%
Estimated Cost	56%	73%	100%	113%	136%
Initial Cost	69%	80%	100%	111%	131%
Availability of Profe	20%	60%	100%	160%	200%
Initial Cost	112%	103%	100%	122%	141%
EIR	29%	59%	100%	118%	176%
Initial Cost	123%	113%	100%	96%	90%
AIR	17%	50%	100%	133%	167%
Initial Cost	129%	104%	100%	108%	115%



Alt1 / Operation Cost					
Total Volume	1000	2000	4350	8000	12000
Operation Cost	3917	3928	3947	3805	3821
Estimated Cost	500	650	885	1000	1200
Operation Cost	4175	4094	3947	3869	3729
Availability of Profe	1	3	5	8	10
Operation Cost	6666	5281	3947	3479	4135
EIR	5	10	17	20	30
Operation Cost	3912	4018	3947	3836	3177
AIR	1	3	6	8	10
Operation Cost	2656	3380	3947	3796	3126

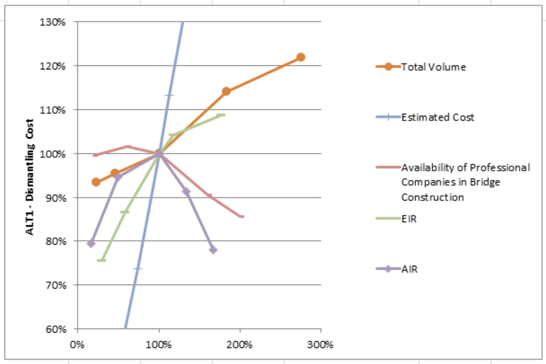
Alt1 / Operation Cost					
Total Volume	23%	46%	100%	184%	276%
Operation Cost	99%	100%	100%	96%	97%
Estimated Cost	56%	73%	100%	113%	136%
Operation Cost	106%	104%	100%	98%	94%
Availability of Profe	20%	60%	100%	160%	200%
Operation Cost	169%	134%	100%	88%	105%
EIR	29%	59%	100%	118%	176%
Operation Cost	99%	102%	100%	97%	80%
AIR	17%	50%	100%	133%	167%
Operation Cost	67%	86%	100%	96%	79%



I-3 Sensitivity Analysis (SA) for performance criteria versus factors – for Alt 1 & 3 Cont'd

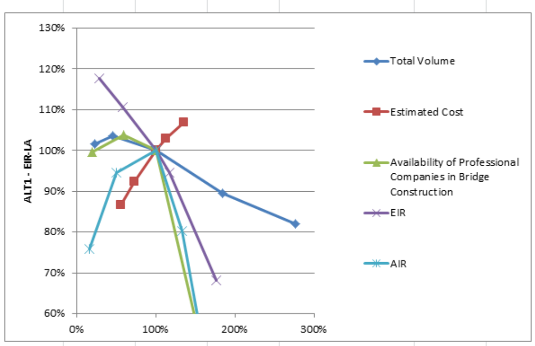
Alt1 / Dismantling Cost					
Total Volume	1000	2000	4350	8000	12000
Dismantling Cost	701	716	751	856	915
Estimated Cost	500	650	885	1000	1200
Dismantling Cost	437	554	751	851	1027
Availability of Profe	1	3	5	8	10
Dismantling Cost	747	763	751	680	643
EIR	5	10	17	20	30
Dismantling Cost	568	650	751	783	816
AIR	1	3	6	8	10
Dismantling Cost	597	710	751	686	586

Alt1 / Dismantling Cost					
Total Volume	23%	46%	100%	184%	276%
Dismantling Cost	93%	95%	100%	114%	122%
Estimated Cost	56%	73%	100%	113%	136%
Dismantling Cost	58%	74%	100%	113%	137%
Availability of Profe	20%	60%	100%	160%	200%
Dismantling Cost	99%	102%	100%	91%	86%
EIR	29%	59%	100%	118%	176%
Dismantling Cost	76%	87%	100%	104%	109%
AIR	17%	50%	100%	133%	167%
Dismantling Cost	79%	95%	100%	91%	78%



Alt1 / EIR-LA					
Total Volume	1000	2000	4350	8000	12000
EIR-LA	13.2	13.45	13	11.63	10.67
Estimated Cost	500	650	885	1000	1200
EIR-LA	11.26	12	13	13.39	13.89
Availability of Profe	1	3	5	8	10
EIR-LA	12.95	13.5	13	6.5	0
EIR	5	10	17	20	30
EIR-LA	15.28	14.39	13	12.3	8.85
AIR	1	3	6	8	10
EIR-LA	9.85	12.3	13	10.44	5.86

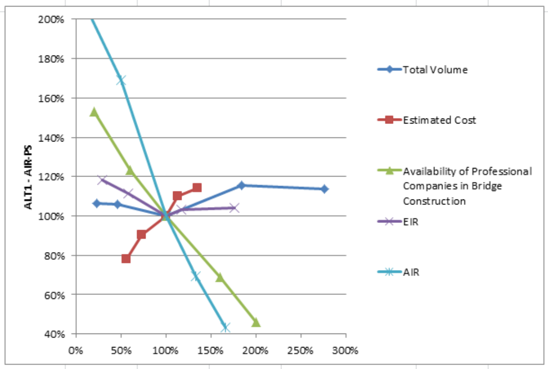
Alt1 / EIR-LA					
Total Volume	23%	46%	100%	184%	276%
EIR-LA	102%	103%	100%	89%	82%
Estimated Cost	56%	73%	100%	113%	136%
EIR-LA	87%	92%	100%	103%	107%
Availability of Profe	20%	60%	100%	160%	200%
EIR-LA	100%	104%	100%	50%	0%
EIR	29%	59%	100%	118%	176%
EIR-LA	118%	111%	100%	95%	68%
AIR	17%	50%	100%	133%	167%
EIR-LA	76%	95%	100%	80%	45%



I-3 Sensitivity Analysis (SA) for performance criteria versus factors – for Alt 1 & 3 Cont'd

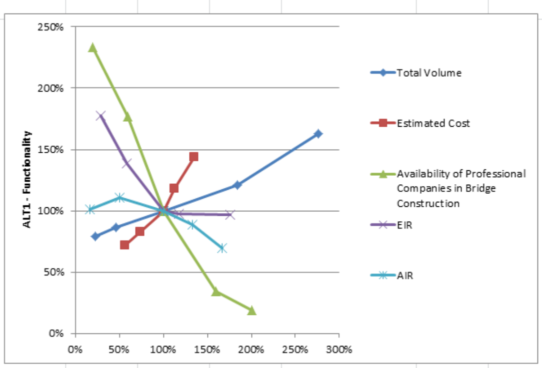
Alt1 / AIR-PS					
Total Volume	1000	2000	4350	8000	12000
AIR-PS	4.25	4.23	4	4.62	4.55
Estimated Cost	500	650	885	1000	1200
AIR-PS	3.12	3.62	4	4.4	4.57
Availability of Profe	1	3	5	8	10
AIR-PS	6.12	4.93	4	2.76	1.84
EIR	5	10	17	20	30
AIR-PS	4.74	4.46	4	4.12	4.17
AIR	1	3	6	8	10
AIR-PS	8.06	6.76	4	2.77	1.74

Alt1 / AIR-PS					
Total Volume	23%	46%	100%	184%	276%
AIR-PS	106%	106%	100%	116%	114%
Estimated Cost	56%	73%	100%	113%	136%
AIR-PS	78%	91%	100%	110%	114%
Availability of Profe	20%	60%	100%	160%	200%
AIR-PS	153%	123%	100%	69%	46%
EIR	29%	59%	100%	118%	176%
AIR-PS	119%	112%	100%	103%	104%
AIR	17%	50%	100%	133%	167%
AIR-PS	202%	169%	100%	69%	44%



Alt1 / Funct					
Total Volume	1000	2000	4350	8000	12000
Funct	11.92	12.96	15	18.2	24.4
Estimated Cost	500	650	885	1000	1200
Funct	10.82	12.45	15	17.68	21.61
Availability of Profe	1	3	5	8	10
Funct	35	26.48	15	5.16	2.83
EIR	5	10	17	20	30
Funct	26.67	20.8	15	14.63	14.49
AIR	1	3	6	8	10
Funct	15.16	16.58	15	13.27	10.43

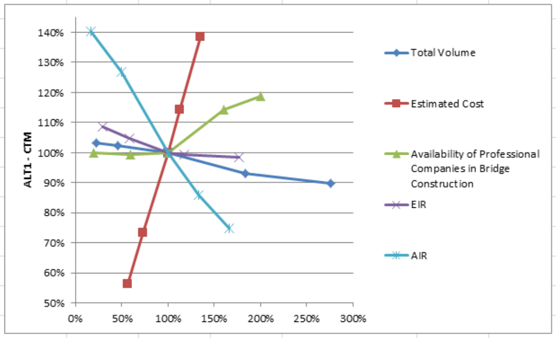
Alt1 / Funct					
Total Volume	23%	46%	100%	184%	276%
Funct	79%	86%	100%	121%	163%
Estimated Cost	56%	73%	100%	113%	136%
Funct	72%	83%	100%	118%	144%
Availability of Profe	20%	60%	100%	160%	200%
Funct	233%	177%	100%	34%	19%
EIR	29%	59%	100%	118%	176%
Funct	178%	139%	100%	98%	97%
AIR	17%	50%	100%	133%	167%
Funct	101%	111%	100%	88%	70%



I-3 Sensitivity Analysis (SA) for performance criteria versus factors – for Alt 1 & 3 Cont'd

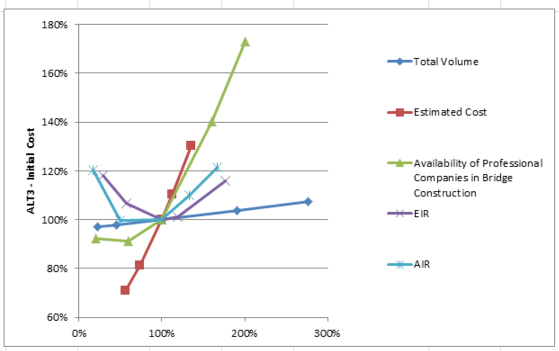
Alt1 / CTM					
Total Volume	1000	2000	4350	8000	12000
CTM	1.31	1.3	1.27	1.18	1.14
Estimated Cost	500	650	885	1000	1200
CTM	0.715	0.93	1.27	1.45	1.76
Availability of Profe	1	3	5	8	10
CTM	1.27	1.26	1.27	1.45	1.51
EIR	5	10	17	20	30
CTM	1.38	1.33	1.27	1.26	1.25
AIR	1	3	6	8	10
CTM	1.78	1.61	1.27	1.09	0.95

Alt1 / CTM					
Total Volume	23%	46%	100%	184%	276%
CTM	103%	102%	100%	93%	90%
Estimated Cost	56%	73%	100%	113%	136%
CTM	56%	73%	100%	114%	139%
Availability of Profe	20%	60%	100%	160%	200%
CTM	100%	99%	100%	114%	119%
EIR	29%	59%	100%	118%	176%
CTM	109%	105%	100%	99%	98%
AIR	17%	50%	100%	133%	167%
CTM	140%	127%	100%	86%	75%



Alt3 / Initial Cost					
Total Volume	1200	2400	5250	10000	14500
Initial Cost	1217	1228	1255	1302	1349
Estimated Cost	500	650	885	1000	1200
Initial Cost	889	1021	1255	1384	1633
Availability of Profe	1	3	5	8	10
Initial Cost	1156	1145	1255	1761	2172
EIR	6	12	21	25	37
Initial Cost	1482	1339	1255	1269	1454
AIR	1	3	6	8	10
Initial Cost	1508	1252	1255	1380	1522

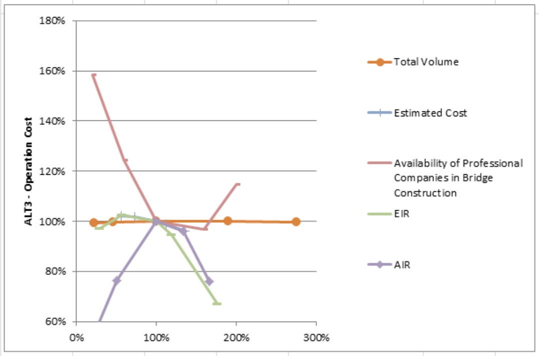
Alt3 / Initial Cost					
Total Volume	23%	46%	100%	190%	276%
Initial Cost	97%	98%	100%	104%	107%
Estimated Cost	56%	73%	100%	113%	136%
Initial Cost	71%	81%	100%	110%	130%
Availability of Profe	20%	60%	100%	160%	200%
Initial Cost	92%	91%	100%	140%	173%
EIR	29%	57%	100%	119%	176%
Initial Cost	118%	107%	100%	101%	116%
AIR	17%	50%	100%	133%	167%
Initial Cost	120%	100%	100%	110%	121%



I-3 Sensitivity Analysis (SA) for performance criteria versus factors – for Alt 1 & 3 Cont'd

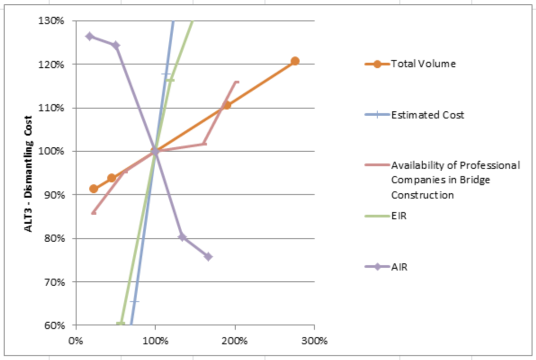
Alt3 / Operation Cost					
Total Volume	1200	2400	5250	10000	14500
Operation Cost	3626	3637	3655	3661	3640
Estimated Cost	500	650	885	1000	1200
Operation Cost	3729	3715	3655	3611	3516
Availability of Profe	1	3	5	8	10
Operation Cost	5792	4540	3655	3536	4192
EIR	6	12	21	25	37
Operation Cost	3555	3745	3655	3464	2458
AIR	1	3	6	8	10
Operation Cost	1869	2794	3655	3508	2778

Alt3 / Operation Cost					
Total Volume	23%	46%	100%	190%	276%
Operation Cost	99%	100%	100%	100%	100%
Estimated Cost	56%	73%	100%	113%	136%
Operation Cost	102%	102%	100%	99%	96%
Availability of Profe	20%	60%	100%	160%	200%
Operation Cost	158%	124%	100%	97%	115%
EIR	29%	57%	100%	119%	176%
Operation Cost	97%	102%	100%	95%	67%
AIR	17%	50%	100%	133%	167%
Operation Cost	51%	76%	100%	96%	76%



Alt3 / Dismantling Cost					
Total Volume	1200	2400	5250	10000	14500
Dismantling Cost	487	500	533	589	643
Estimated Cost	500	650	885	1000	1200
Dismantling Cost	240	349	533	628	794
Availability of Profe	1	3	5	8	10
Dismantling Cost	457	508	533	542	618
EIR	6	12	21	25	37
Dismantling Cost	197	323	533	620	774
AIR	1	3	6	8	10
Dismantling Cost	674	663	533	428	404

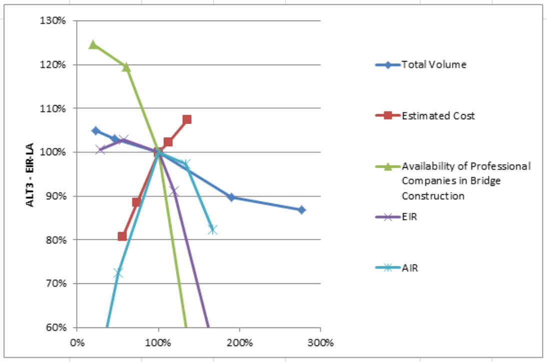
Alt3 / Dismantling Cost					
Total Volume	23%	46%	100%	190%	276%
Dismantling Cost	91%	94%	100%	111%	121%
Estimated Cost	56%	73%	100%	113%	136%
Dismantling Cost	45%	65%	100%	118%	149%
Availability of Profe	20%	60%	100%	160%	200%
Dismantling Cost	86%	95%	100%	102%	116%
EIR	29%	57%	100%	119%	176%
Dismantling Cost	37%	61%	100%	116%	145%
AIR	17%	50%	100%	133%	167%
Dismantling Cost	126%	124%	100%	80%	76%



I-3 Sensitivity Analysis (SA) for performance criteria versus factors – for Alt 1 & 3 Cont'd

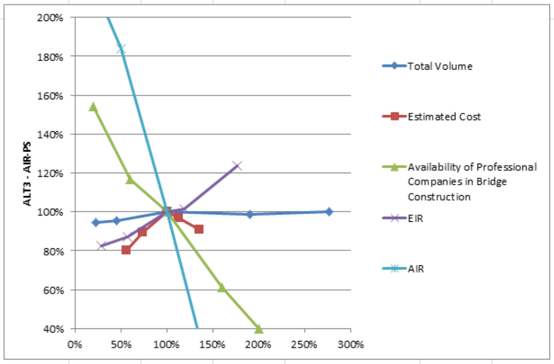
Alt3 / EIR-LA					
Total Volume	1200	2400	5250	10000	14500
EIR-LA	16.8	16.51	16	14.36	13.89
Estimated Cost	500	650	885	1000	1200
EIR-LA	12.9	14.16	16	16.37	17.19
Availability of Profe	1	3	5	8	10
EIR-LA	19.95	19.11	16	4.67	0
EIR	6	12	21	25	37
EIR-LA	16.1	16.47	16	14.59	7.94
AIR	1	3	6	8	10
EIR-LA	6.7	11.59	16	15.57	13.16

Alt3 / EIR-LA					
Total Volume	23%	46%	100%	190%	276%
EIR-LA	105%	103%	100%	90%	87%
Estimated Cost	56%	73%	100%	113%	136%
EIR-LA	81%	89%	100%	102%	107%
Availability of Profe	20%	60%	100%	160%	200%
EIR-LA	125%	119%	100%	29%	0%
EIR	29%	57%	100%	119%	176%
EIR-LA	101%	103%	100%	91%	50%
AIR	17%	50%	100%	133%	167%
EIR-LA	42%	72%	100%	97%	82%



Alt3 / AIR-PS					
Total Volume	1200	2400	5250	10000	14500
AIR-PS	2.84	2.86	3	2.96	3
Estimated Cost	500	650	885	1000	1200
AIR-PS	2.41	2.69	3	2.9	2.72
Availability of Profe	1	3	5	8	10
AIR-PS	4.63	3.5	3	1.83	1.2
EIR	6	12	21	25	37
AIR-PS	2.48	2.62	3	3.04	3.71
AIR	1	3	6	8	10
AIR-PS	6.64	5.52	3	1.19	0

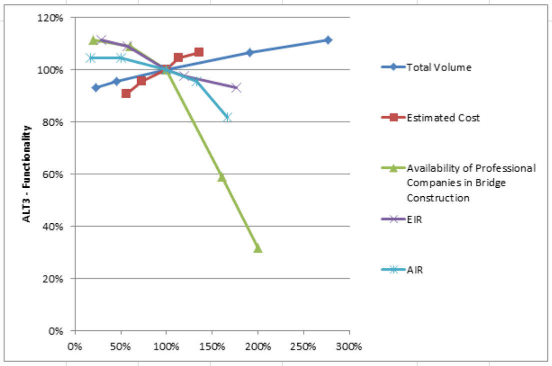
Alt3 / AIR-PS					
Total Volume	23%	46%	100%	190%	276%
AIR-PS	95%	95%	100%	99%	100%
Estimated Cost	56%	73%	100%	113%	136%
AIR-PS	80%	90%	100%	97%	91%
Availability of Profe	20%	60%	100%	160%	200%
AIR-PS	154%	117%	100%	61%	40%
EIR	29%	57%	100%	119%	176%
AIR-PS	83%	87%	100%	101%	124%
AIR	17%	50%	100%	133%	167%
AIR-PS	221%	184%	100%	40%	0%



I-3 Sensitivity Analysis (SA) for performance criteria versus factors – for Alt 1 & 3 Cont'd

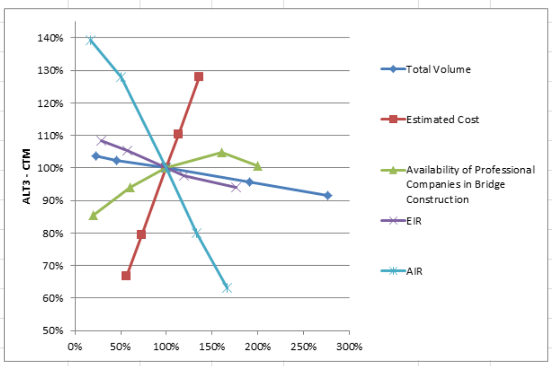
Alt3 / Funct					
Total Volume	1200	2400	5250	10000	14500
Funct	41	42	44	47	49
Estimated Cost	500	650	885	1000	1200
Funct	40	42	44	46	47
Availability of Profe	1	3	5	8	10
Funct	49	48	44	26	14
EIR	6	12	21	25	37
Funct	49	48	44	43	41
AIR	1	3	6	8	10
Funct	46	46	44	42	36

Alt3 / Funct					
Total Volume	23%	46%	100%	190%	276%
Funct	93%	95%	100%	107%	111%
Estimated Cost	56%	73%	100%	113%	136%
Funct	91%	95%	100%	105%	107%
Availability of Profe	20%	60%	100%	160%	200%
Funct	111%	109%	100%	59%	32%
EIR	29%	57%	100%	119%	176%
Funct	111%	109%	100%	98%	93%
AIR	17%	50%	100%	133%	167%
Funct	105%	105%	100%	95%	82%



Alt3 / CTM					
Total Volume	1200	2400	5250	10000	14500
CTM	1.71	1.69	1.65	1.58	1.51
Estimated Cost	500	650	885	1000	1200
CTM	1.1	1.31	1.65	1.82	2.11
Availability of Profe	1	3	5	8	10
CTM	1.41	1.55	1.65	1.73	1.66
EIR	6	12	21	25	37
CTM	1.79	1.74	1.65	1.61	1.55
AIR	1	3	6	8	10
CTM	2.3	2.11	1.65	1.32	1.04

Alt3 / CTM					
Total Volume	23%	46%	100%	190%	276%
CTM	104%	102%	100%	96%	92%
Estimated Cost	56%	73%	100%	113%	136%
CTM	67%	79%	100%	110%	128%
Availability of Profe	20%	60%	100%	160%	200%
CTM	85%	94%	100%	105%	101%
EIR	29%	57%	100%	119%	176%
CTM	108%	105%	100%	98%	94%
AIR	17%	50%	100%	133%	167%
CTM	139%	128%	100%	80%	63%



Appendix J – Preliminary Structural Analysis

This Appendix is dedicated to covering a brief presentation related to the BrIM implementation, especially the structural design part at the conceptual design phase.

The alternatives are designed under two types of loads: Permanent loads (Self weight, dead load) for 7 cm wearing surface equivalent to 1.54 KN/m2 and Transient loads based on the AASHTO standard covering truck design with its related loads spread over the bridge deck with its different types, locations, and characteristics by defining the lane load, tandem load, and braking forces (Figures J-1 & J-2). At the conceptual design phase, all previous considerations are covered by the different loads implemented in the appropriate software.

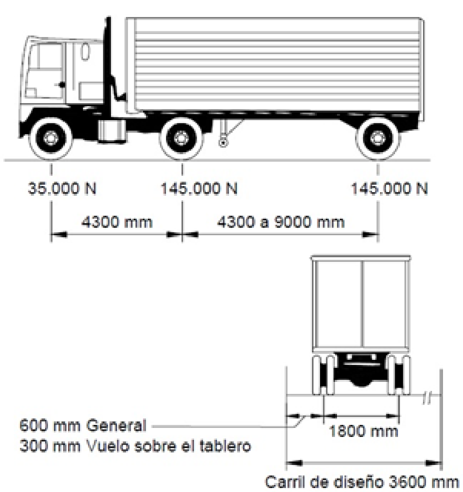


Figure 0-1 – Truck Design

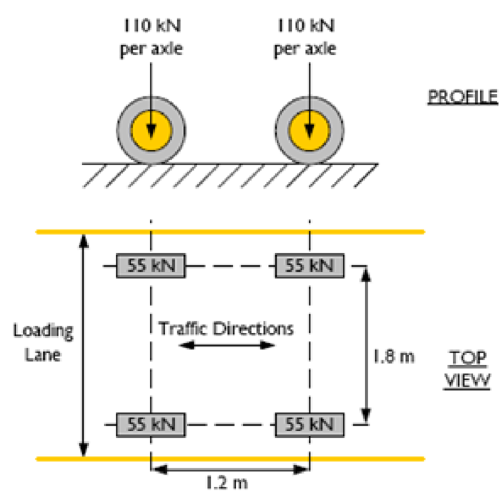
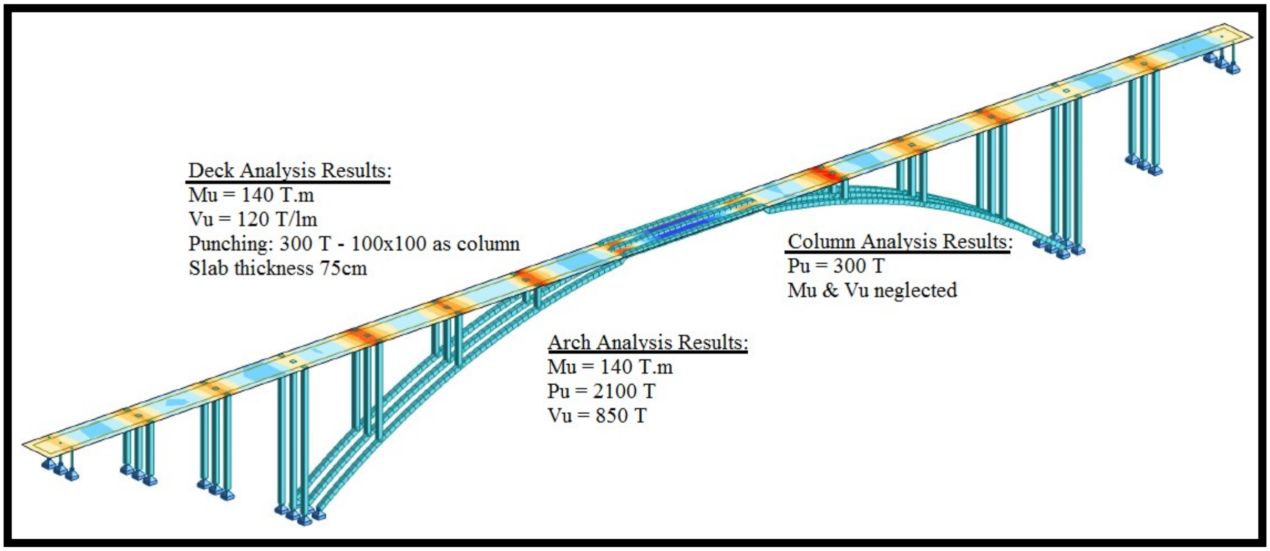


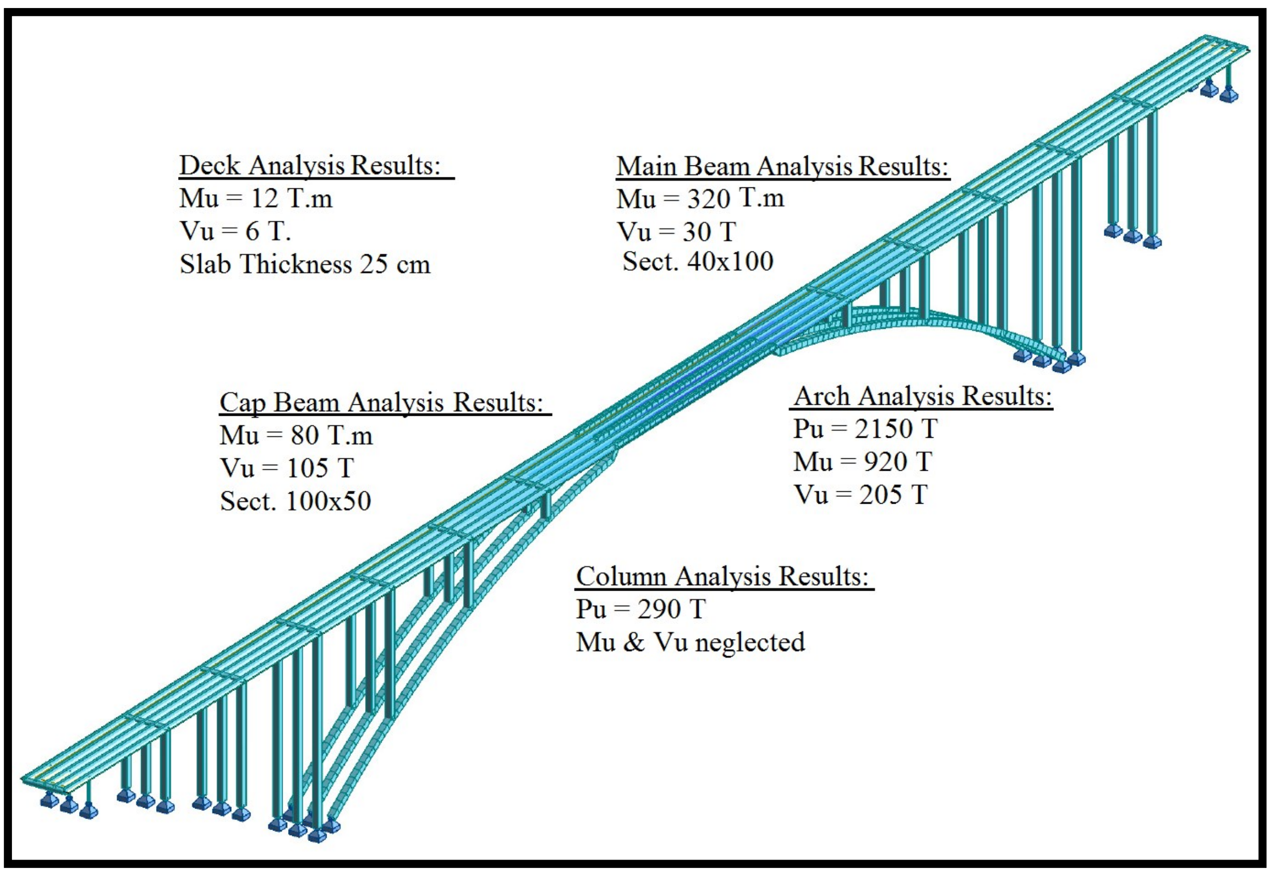
Figure J-2 – Tandem Design

The Autodesk Robot is used for the purpose of design for the different alternatives, based on the loads defined previously, according to the proposed alternatives. The different alternatives are directed by the architect and implemented in the Revit software based on perspective constraint. After the coordination between the Architect and the Structural engineer, the elements' dimensions are established and verified through the aforementioned software. Based on the bridge characteristics for the different alternatives presented in Figure 7-11, the Autodesk Robot software is launched for a preliminary structural verification. The results are summarized and presented as follows:

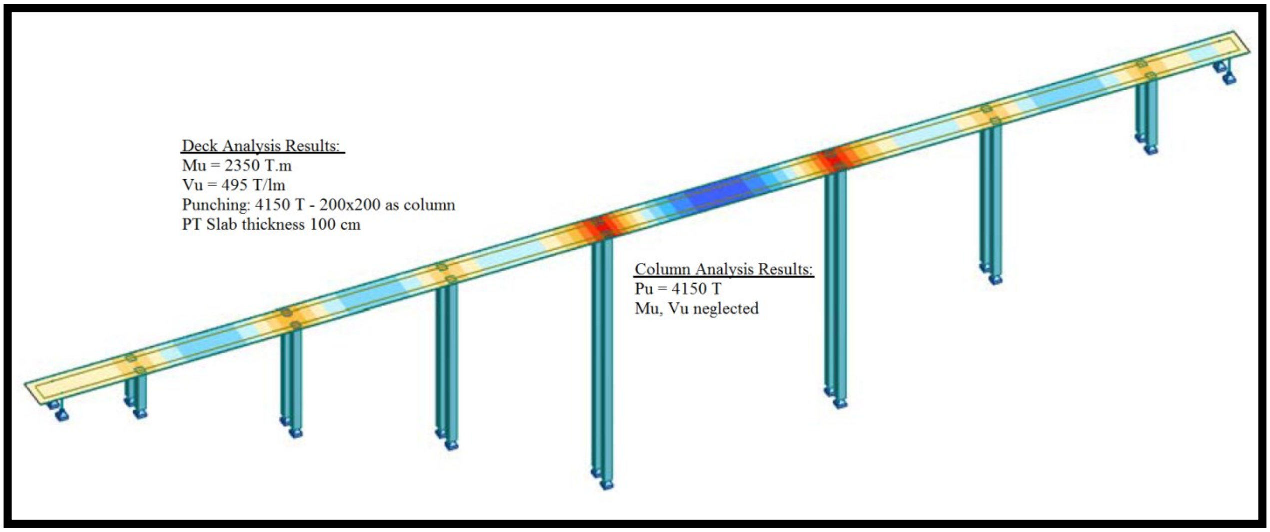
Alternative 1:



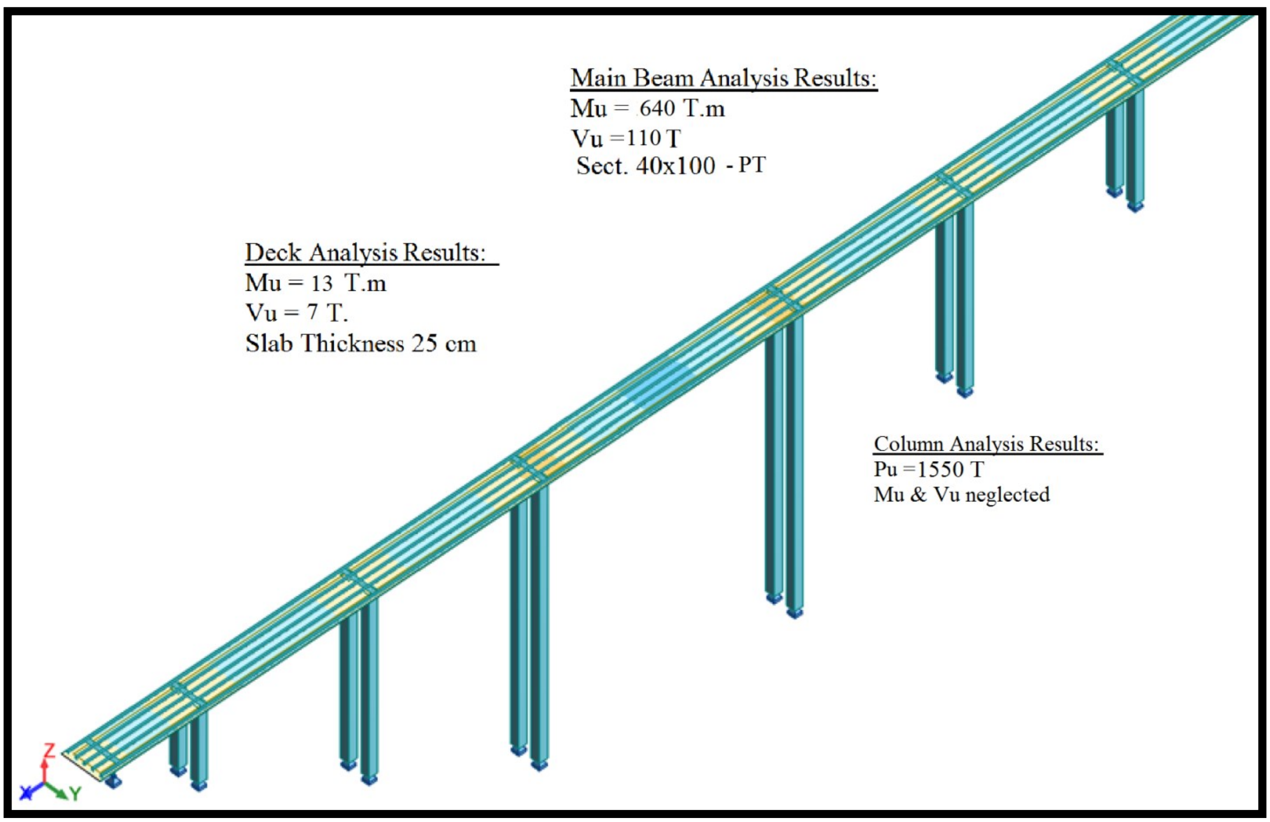
Alternative 2:



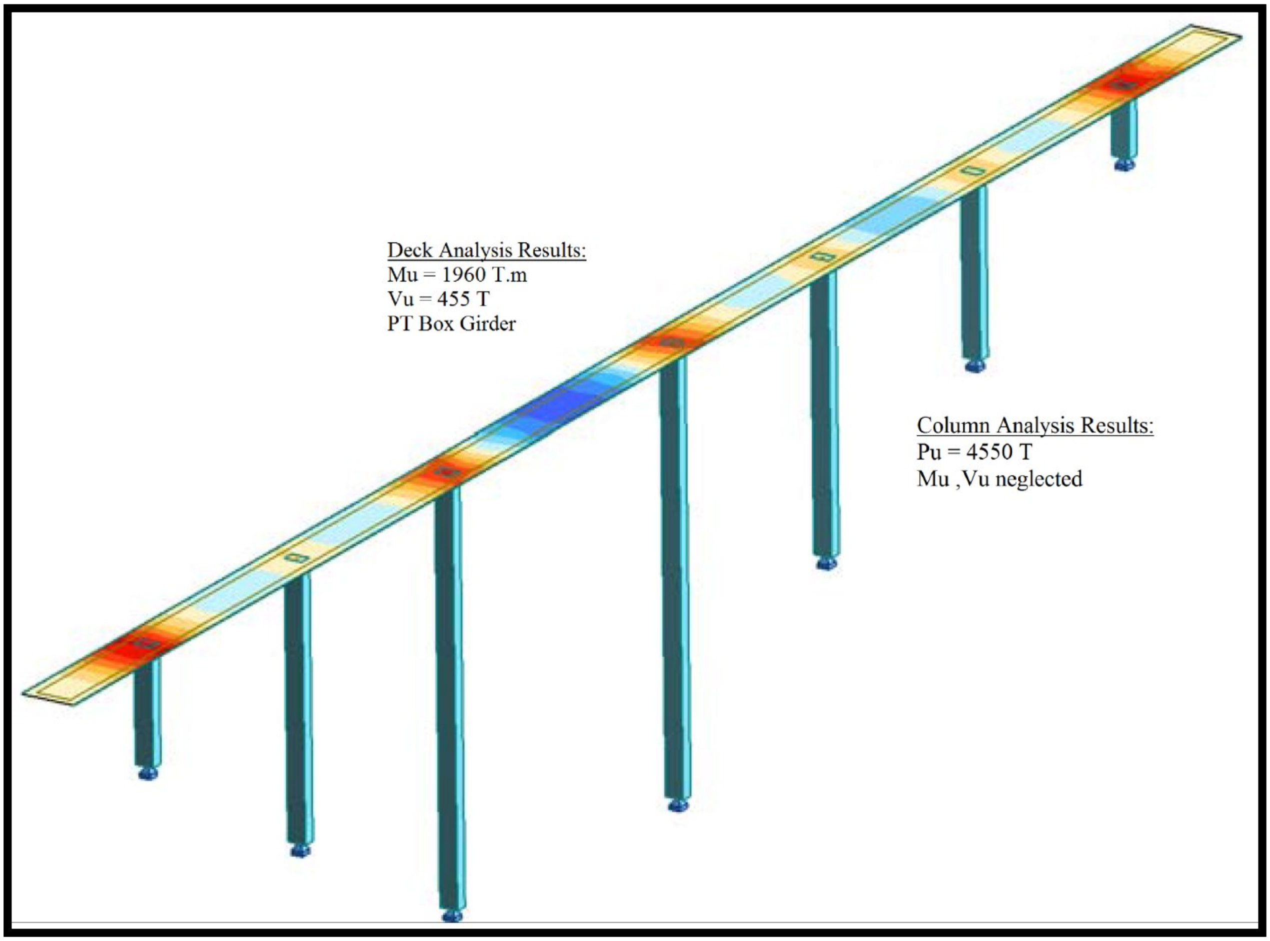
Alternative 3:



Alternative 4:



Alternative 5:



Based on the ACI318-11 Standard, the Reinforced Concrete elements (Beam sections, Columns and Slabs) have been verified. For Columns, and as preliminary design, the axial loads should be covered by the following verifications:

Slenderness according to KL/r < 22

Capacity Pu < 0.6Ag.f'c

For Beams and Slabs, the internal forces such as ultimate moment (Design moment), shear, and axial loads have been verified by designing the appropriate sections and verifying the required reinforcement ratio which should be less than 50% of the balanced ratio b.

For deflection analysis, other required verification such as seismic and wind forces are not included in this phase.

Appendix K – Publications

Otayek Elie, Jrade Ahmad and AlKass Sabah, 2012 "Integrated Decision Support System for Bridges at Conceptual Design Stage", CIB W78-2012 Conference, the 29th International Conference on Applications of IT in the AEC Industry Beirut, Lebanon 17-19 October 2012.

Otayek Elie, Jrade Ahmad and AlKass Sabah, 2013 "Integrating the Artificial Intelligence techniques into Bridge Information Modeling (BrIM)", CSCE 2013 Annual Conference, Montreal, Canada May 29 – June 1, 2013.

Otayek Elie and Jrade Ahmad, 2016 "Optimization for Bridge Type Selection Using Artificial Neural Networks", CSCE SCGC Resilient Infrastructure, London, UK STR-996 June 1 - June 4, 2016.