

Integrating 3D CAD and Cost Estimating at the Conceptual Design

Stage of Bridge Projects

By

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

In the Name of Allāh, the Most Gracious, the Most Merciful

To My Parents,

My Father Prof. Khalil Ismail Al-Dosary

My Mother Ibtisam

And to My Life Partner

Shaimaa

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ABSTRACT

Bridge Information Modeling (BrIM), as a concept, has been introduced to enhance the procedures of the whole phases of a bridge life-cycle starting with concept and design, through construction and operation, and ending with maintenance and rehabilitation. Integrating BrIM and design tools will help improve the methods used in designing and constructing bridge projects at early stages taking into considerations their cost and time constraints. The main objective of this research is to develop an integrated model that helps owners, designers and construction managers visualize bridge projects in a 3D mode and accordingly automate the process of generating preliminary cost estimates during the conceptual design stage. To achieve the abovementioned objective, a proposed methodology will be applied where all the aspects needed to develop an efficiently integrated model are realized. Thus, this research describes the proposed methodology that incorporates three modules, which are the core of the integrated model. These modules are: a knowledge based system module, which is used to generate conceptual dimensions and parameters depending on algorithmic and heuristic knowledge gathered from codes, guidelines and design experts; a conceptual cost estimation module, which is used to generate conceptual cost estimate based on the results of the first module; and a 3D-CAD module, which is integrated with the previous modules where users will visualize the proposed bridge in 3D based on the results of the knowledge based module. The successful development of the model would help owners and investors identify the cost and visualize the proposed projects at the early stages of the project life, so they have an idea of the budget required and the aesthetics of the proposed projects. The integrated model is validated through an actual case project to test its workability and output.

ACKNOWLEDGMENT	III
ABSTRACT.....	IV
LIST OF TABLES.....	X
LIST OF FIGURES	XI
GLOSSARY	XVI
CHAPTER ONE	1
INTRODUCTION	1
1.1 General.....	1
1.2 Research Objectives.....	2
1.3 Research Methodology	2
1.3.1 Literature review:.....	2
1.3.2 Data Collection:	3
1.4 Thesis Organization	3
CHAPTER TWO	5
LITERATURE REVIEW	5
2.1 Introduction:.....	5
2.2 Bridge Information Modeling.....	6
2.2.1 Definition.....	6

2.2.2 Applications of Bridge Information Modeling	7
2.3 Cost Estimation	12
2.3.1 Definition and purpose.....	12
2.3.2 Cost Estimation Types	13
2.3.3 Definition and Importance of the Conceptual Cost Estimation	14
2.3.4 Characteristics of the Conceptual Cost Estimation	15
2.3.3 Preparation of the Conceptual Cost Estimate.....	16
2.3.3 Conceptual Cost Estimate Adjustments.....	16
2.4 Bridge Conceptual Design Phase	17
2.4.1 Purpose of the Bridge Conceptual Design.....	18
2.4.2 Requirements and Constraints of the Bridge Conceptual Design	18
2.4.3 Process of Bridge Conceptual Design	19
2.4.4 Bridge Classifications.....	21
2.4.5 Highway Geometric Design Guideline	23
2.4.6 Navigational Waterways Clearances Guideline.....	25
2.4.7 Computer Systems and Conceptual Design	27
2.4.7.1 Knowledge-Based system	28
2.4.5.1.1 Examples of the Implementations of Knowledge-based systems for	
Conceptual design	28
2.6 Summary	31
 CHAPTER THREE	 33
 METHODOLOGY	 33
3.1 Introduction.....	33
3.2 System Components and Architectural.....	33
3.3 Knowledge-Based Module.....	34
3.3.1 Knowledge Base	35
3.3.1.1 Highway Geometric Design Knowledge Base	36
3.3.1.2 Navigational Waterways Clearances Knowledge Base	41
3.3.1.2.1 Small Recreational Vessels.....	41

3.3.1.2.2 Small to Medium Commercial and Cargo Vessels	43
3.3.1.3 Structural Design Knowledge Base	49
3.3.2 Interface	50
3.3.3 Bridge Type Selection	51
3.4 Conceptual Cost Estimating Module	56
3.4.1 Cost Data	56
3.4.3 Adjustments	56
3.4.3.1 Adjustment for Location	56
3.4.3.2 Inflation Adjustment	57
3.4.4 Data Flow.....	57
3.5 3D-CAD Module	59
3.6 Summary	62
CHAPTER FOUR	63
MODEL'S DEVELOPMENT	63
4.1 Introduction.....	63
4.2 Knowledge-Based System Implementation	63
4.2.1 Highway Geometric Knowledge Base Implementation.....	64
4.2.2 Navigational Waterways Clearances Guidelines Implementation	71
4.2.3 Knowledge-Based System Output.....	74
4.3 Bridge Type Selection.....	79
4.4 Conceptual Cost Estimating Module Implementation	87
4.5 3D-CAD Module Implementation	96
4.6 Summary	101
CHAPTER FIVE	102

MODEL'S VALIDATION	102
5.1 Introduction.....	102
5.2 Knowledge-based System.....	104
5.3 Conceptual Cost Estimation Module	111
5.4 3D-CAD Module	116
5.5 Summary	122
CHAPTER SIX	124
CONCLUSION AND FUTURE RECOMMENDATIONS	124
6.1 Conclusion	124
6.2 Research Contributions:.....	125
6.3 Research Limitation:.....	125
6.4 Future Expansion:	126
REFERENCES.....	127
APPENDIX A: TAC (1999) TABLES USED IN THE HIGHWAY GEOMETRIC DESIGN GUIDELINES KNOWLEDGE BASE.....	128
APPENDIX B: NRPD TABLES USED IN THE NAVIGATIONAL WATERWAYS CLEARANCES GUIDELINES KNOWLEDGE BASE	128

APPENDIX C: SAMPLE OF THE BRIDGE DATABASE ACQUIRED FROM MTO... 128

APPENDIX D: STRUCTURAL CODE KNOWLEDGE BASE..... 128

APPENDIX E: SAMPLE OF THE COLLECTED COST DATA..... 128

List of Tables

Table 5. 1 Lakeshore Drive Bridge Information	102
Table 5. 2 Knowledge-Based System Outputs	107

List of Figures

Figure 2. 1 Cost Estimation Matrix for Process Industries (AACE International 2005)	14
Figure 2. 2 Conceptual Cost Estimation Process (Peurifoy et al, 2002)	16
Figure 2. 3 Methodology of the Conceptual Design (Niemeyer, 2003)	20
Figure 3. 1 Main Components of the Model	34
Figure 3. 2 Knowledge-Based Module Process Flow	35
Figure 3. 3 Highway Geometric Design Knowledge Base Flow Process	40
Figure 3. 4 Knowledge Base Process flow of the Navigational Clearances for Recreational Vessels	43
Figure 3. 5 Process flow of obtaining Horizontal Clearances for Small to Medium Vessels	45
Figure 3. 6 Process flow of obtaining Depth Clearances for Small to Medium Vessels	46
Figure 3. 7 Process flow of obtaining Vertical Clearances for Small to Medium Vessels	47
Figure 3. 8 : Process Flow of the Navigational Waterways Clearances Knowledge Base	48
Figure 3. 9 Sample of Existing Bridge Excel Spreadsheet	52
Figure 3. 10 Process Flow of Bridge Type Selection	55
Figure 3. 11 Data flow of the Conceptual Cost Estimation Module	58
Figure 3. 12 Data flow of the 3D-CAD Module	60
Figure 3. 13 Data Flow between the Cost Estimating Module and the 3D-CAD Module	72
Figure 4. 1 Snapshot of the Highway Geometric Design Knowledge Base Selection Form	64
Figure 4. 2 Sample of the Code for the Highway Geometric Design Knowledge Base Drop lists	65
Figure 4. 3 Snapshot of the Road Class Drop List	66

Figure 4. 4 Sample of Declared Variables within the VB.NET Interface for the Highway Geometric Design Knowledge Base	66
Figure 4. 5 Sample of the IF-ELSE Statements in Presenting Knowledge base within the Interface	67
Figure 4. 6 Snapshot of the Design Speed Drop list	68
Figure 4. 7 Snapshot of the Traffic Volume Drop List	68
Figure 4. 8 Snapshot of the Traffic Volume Text Box	69
Figure 4. 9 Snapshot of the Additional Required Entries	69
Figure 4. 10 Snapshot of the Underpass Object Selection Form	70
Figure 4. 11 Sample of Underpass Roads Drop lists Coding	71
Figure 4. 12 Snapshot of the Waterway Information Selection Form	71
Figure 4. 13 Sample of the Code for the Drop Boxes of the Navigational Waterways Guidelines Knowledge Base	72
Figure 4. 14 Sample of Declared Variable of the Navigational Waterways Guidelines Knowledge Base	72
Figure 4. 15 Sample of the IF-ELSE Statements of the Navigational Waterways Clearances Guidelines	73
Figure 4. 16 Snapshot of the Vessel Additional Characteristics and Information Window Form	73
Figure 4. 17 Sample of the Code for the Label	74
Figure 4. 18 Sample of Code used in Calculating Underpass Road Right of Way	75
Figure 4. 19 Snapshot of the Developed VB.NET Interface Forms	76
Figure 4. 20 Snapshot of Bridge Spans Arrangements Form	77
Figure 4. 21 Snapshot of the KBS Output Form	77
Figure 4. 22 Sample of the Code for KBS Output Form Text Boxes	78

Figure 4. 23 Snapshot of filled KBS Output Form	79
Figure 4. 24 Snapshot of Bridge Excel Workbooks	79
Figure 4. 25 Snapshot of Bridge Excel Spreadsheet	80
Figure 4. 26 Sample of Code for the Data Transferred from the VB.NET Interface to the Bridge Excel Workbook	81
Figure 4. 27 Example of Closeness Weights Calculations within Excel Spreadsheet Platform	82
Figure 4. 28 Snapshot of the Input & Output Sheet Containing Maximum Adjusted Weights	83
Figure 4. 29 Sample of Declared Variables for the Adjusted Weights	84
Figure 4. 30 Snapshot of the Bridge Type Selection Form	84
Figure 4. 31 Snapshot of Code for Recommending the Bridge Type	85
Figure 4. 32 Sample of the Code for Bridge Type Selection Form Drop Lists	86
Figure 4. 33 Snapshot of a Filled Bridge Type Selection Form	86
Figure 4. 34 Selecting the Bridge Sub-Category Type	87
Figure 4. 35 Selecting the Bridge Sub-Category Type	87
Figure 4. 36 Created Cost Estimating Module Excel Spreadsheets	88
Figure 4. 37 Snapshot of the Conceptual Cost Estimating Module Excel Spreadsheet	89
Figure 4. 38 Snapshot of the Conceptual Cost Estimating Module Form	90
Figure 4. 39 Sample of the Code for Data Transfer from VB.NET to Excel Spreadsheet	91
Figure 4. 40 Snapshot of the Three Buttons to Generate Cost Estimating Reports	92
Figure 4. 41 Snapshot of the Detailed Cost Estimating Report	93
Figure 4. 42 Snapshot of the Detailed Cost Estimating Report	94
Figure 4. 43 Snapshot of the By-Elements Cost Estimating Report	95
Figure 4. 44 Snapshot of the Summary Cost Estimating Report	95
Figure 4. 45 Snapshot of Generate 3D Bridge Model Button	96

Figure 4. 46 Snapshot of the Window Form of the 3D-CAD Module	97
Figure 4. 47 Snapshot of the Drop List	98
Figure 4. 48 Snapshot of the 3D-CAD Module Form with the Bridge Information	98
Figure 4. 49 Snapshot of Generated 3D Bridge Model Viewed in VB.NET Interface	99
Figure 4. 50 Snapshot of the 3D Bridge Model Viewed in AutoCAD Platform	100
Figure 4. 51 Snapshot of the Bridge 3D Rendering Model	101
Figure 5. 1 Side View of the Actual Bridge (Google Earth™)	103
Figure 5. 2 Actual Bridge Lanes (Google Earth™)	104
Figure 5. 3 Input variables selection	104
Figure 5. 4 Selection of the Underpass Road Information	105
Figure 5. 5 Selection of the Bridge Span Arrangement	106
Figure 5. 6 Knowledge-Based System Outputs	107
Figure 5. 7 Recommended Bridge Types	109
Figure 5. 8 Bridge Type Selection	110
Figure 5. 9 Selecting the Column System Type and Abutment Type	111
Figure 5. 10 Snapshot of the Cost Estimating Module	112
Figure 5. 11 Detailed Cost Estimating Report	113
Figure 5. 12 By-Elements Cost Estimating Report	114
Figure 5. 13 Summarized Cost Estimating Report	114
Figure 5. 14 3D-CAD Module Button	116
Figure 5. 15 Select Bridge Element to View	116
Figure 5. 16 Snapshot of the Whole Bridge 3D Drawing	117
Figure 5. 17 Snapshot of the Whole Bridge 3D Drawing from Different Angle	118

Figure 5. 18 Snapshot of the Columns 3D Drawing	119
Figure 5. 19 Snapshot of the Abutment 3D Drawing	120
Figure 5. 20 Snapshot of the Parapet 3D Drawing	120
Figure 5. 21 Viewing the 3D Drawing within the AutoCAD Platform	121
Figure 5. 22 Rendering View of the 3D Drawing	122

Glossary

2D	Two Dimensions
3D	Three Dimensions
4D	Four Dimensions
AEC	Architecture, Engineering and Construction
AACE	American Association of Cost Estimation
AASHTO LRFD	American Association of State Highway and Transportation Officials Load Resistance Factor Design
AI	Artificial Intelligence
ASTM	American Standards of Testing Materials
AHC1	Wind Effects
AHC2	Navigational Aids and Visibility
B	Vessel Beam
BIM	Building Information Modeling
BrIM	Bridge Information Modeling
BOM	Bill of Materials

BESAT	Bridge Engineering Section of Alberta Transportation
BSC	Bank/Structure Clearance
C_c	Cost of Proposed Project
C_r	Cost of Previous Project
CAD	Computer-Aided Design
CPM	Critical Path Method
CW	Closeness Weight
D	Vessel Draft
D1	Squat Buffer Factor
D2	Trim, Load and other Miscellaneous Factor
D3	Wave Effect (From NWPD Table 5-7)
DBM	Clearance due to Channel Bed Material
DMU	Digital Mock-up
DS	Sedimentation Clearance
F	Future or Present Total Project Cost
H	Vessel Height

HSB	Height Safety Buffer
i	Inflation Rate
I _C	City Index for the Current Project
I _R	City Index for the Previous Project
K	Closeness Factor
KBS	Knowledge-Based System
L ₀	Length of the Proposed Bridge
L _{in}	length of the Existing Bridge i _n
LOB	Line of Balance Method
LF	Length Factor
MLW	Maneuvering Lane Width
n	Number of Years between the Proposed Project and Previous Project
NWPA	Navigational Waterways Protection Act
NWPD	Navigational Waterways Protection Division
P	Past total Project Cost
PDM	Precedence Diagram Method

S_0	Largest Span Length of the Proposed Bridge
S_{in}	Largest Span length of the Existing Bridge i_n
TAC 1999	Transportation Association of Canada Highway Geometric Design Guidelines
TF	Traffic Factor
TWT	Two-Way Traffic Clearance
VBA	Visual Basic Applications
VB.NET	Visual Basic.NET
VF	Velocity Factor
VPS	Virtual Prototyping Systems
W_0	Width of the Proposed Bridge
W_{in}	Width of the Existing Bridge i_n
WBS	Work Breakdown Structure
WE	Wave Effect (From NRPD Table 5-9)

Chapter One

Introduction

1.1 General

Significant advancement and development in automation and communication technologies occurred in recent years, but bridge engineering and its construction management did not fully adapt and integrate these developments (Chen and Shirole, 2008). According to Chen and Shirole (2007), Bridge Information Modeling (BrIM) has potential efficiencies and reasonable advantages to be gained by developing integrated approaches. The concept of BrIM is the same as Building Information Modeling (BIM), but it is closely related with an axis for road or railway design (Katz, 2008). Bridge Information Modeling (BrIM) is widely becoming an effective tool in the bridge engineering and construction industry. Bridge Information Modeling (BrIM) methodology is being used increasingly in the design and construction of complex and large bridges, also (BrIM) aspects such as visualization, detailing, bridge operations management and project delivery are being used in infrastructure projects through the use of AASHTO Ware (Shirole et al. 2009). Integrated approaches of BrIM aspects will not only result in cost reduction, faster delivery and improvement of quality, but also will pave the way towards different project delivery models such as design/build delivery model. However, lot of engineers and researchers are still unaware of the economic benefits of utilizing such technologies in cost estimation at the conceptual design phase of bridge projects (Shirole et al. 2008). Many researchers have studied and applied BrIM on stages of bridge projects such as on detailed design, construction and maintenance. However, BrIM aspects were not implemented at the conceptual stage of a bridge project. This research proposes a methodology to integrate part of the BrIM, which is the three

dimensional computer aided-design 3D CAD models, with cost estimation at the conceptual design stage of bridge projects.

1.2 Research Objectives

In traditional construction projects severe information loss occurs due to lack of efficient communication mechanisms. The concept of BrIM is then proposed to create sufficient integrated information models to fill the gaps of communications between bridge projects stakeholders. Cost estimate plays a crucial role in any construction project, where the success of a construction is measured by its efficient and accurate cost estimate.

The main objective of this research is to develop a methodology to integrate 3D CAD models with cost estimation at the conceptual design stage of bridge projects.

The following list outlines the research sub-objectives:

- study and understand the BrIM concept and applications along with 3D CAD applications;
- study the conceptual cost estimating process and the different types of costs;
- identify the relationship between the 3D CAD and the conceptual cost estimates; and
- develop a model that integrates 3D CAD with the conceptual cost estimates.

1.3 Research Methodology

To accomplish all the above objectives the following procedures are fulfilled:

1.3.1 Literature review:

A comprehensive literature review that covers bridge information modeling, construction cost estimating and conceptual design for bridge project is fulfilled.

1.3.2 Data Collection:

Two types of data are needed in the model development, cost data and existing bridge data. The cost data was collected from actual projects previously constructed. The cost data contains information related to the construction costs for bridge projects in North America. The existing bridge data contains information for all the bridges built in Ontario, and was collected from the Ministry of Transportation of Ontario (MTO).

1.4 Thesis Organization

This thesis is organized in six chapters. A brief description of each is provided as follow:

- **Chapter Two:** presents a comprehensive literature review related to this research. The literature review is divided into three parts, which they are: (1) bridge information modeling, (2) conceptual cost estimating, and (3) bridge conceptual design. The first part focuses on the definition of bridge information modeling and its applications during different stages of bridge projects life cycle. The second part focuses on bridge construction costs estimates, their definitions, their purposes and types. Also it describes the process of generating conceptual cost estimates. The third part reviews the process of bridge conceptual design, which is achieved by identifying the concept of conceptual design of bridge projects. Moreover, it introduces the role and use of different computer systems in designing bridge projects at the conceptual stage.
- **Chapter Three:** describes the methodology that has been used in developing the integrated model, clarifying its components and data flow.
- **Chapter Four:** illustrates the model's development process besides its components and the integration process followed to interrelate them together.

- **Chapter Five:** explains the method used to evaluate the developed model to examine its capability and feasibility by utilizing the model on an existing bridge project located in Ontario.
- **Chapter Six:** presents the thesis conclusions, recommendations for future work expansions and lists the limitations of the current research.

Chapter Two

Literature Review

2.1 Introduction:

Bridges are considered to be important infrastructure components that have great impact on the economy and society. Failing to deliver or maintain bridge projects would lead to major losses for both private and public sectors. Thus, applying BrIM concepts on bridge projects will have the potential to reduce cost, expedite construction and improve quality. Therefore, this chapter provides an extensive literature review of bridge information modeling and its applications throughout a bridge life cycle. In addition, it looks at the integration of BrIM with construction cost estimation at the conceptual design stage of bridge projects.

The first part of this chapter focuses on reviewing the literature related to the concept of BrIM and its applications in different stages of a bridge life cycle. It clarifies the definition and purposes of BrIM to consider during the different stages of a bridge life cycle. In addition, it highlights the importance and the benefits of applying BrIM at the conceptual design stage of bridge projects.

The second part discusses the methods used to generate construction cost estimates for bridge projects at the conceptual design stage. This is accomplished by identifying the concept of cost estimates, defining their purposes and types based on their different levels of accuracy. Moreover, it focuses on conceptual cost estimates by providing a brief review of their definitions, importance, characteristics and methods of preparation.

The third part looks at bridge conceptual design. This is accomplished by identifying the purpose, requirements, constraints and processes of design. In addition it identifies the different

types of bridges. Moreover, it reviews the computer systems used in conceptual design by identifying some examples of computer systems and their implementations on conceptual design of bridges.

2.2 Bridge Information Modeling

This section reviews the different definitions of bridge information modeling. In addition it discusses the applications of bridge information modeling on different stages and phases of projects. This section presents some examples of using the BrIM concept during the design and prefabrication stage, as well as during the planning and construction operations.

2.2.1 Definition

The construction industry has witnessed promising developments in recent decades. Paper-based drawings have been playing the primary role of the presentation of construction documentation in recent decades, while other industries have implemented 3D CAD-based integrated design and manufacturing systems that result in costs reduction, faster delivery and improvements in quality (Shirole et al, 2009). One of the most promising developments in the architecture, engineering and construction (AEC) industries is Building Information Modeling (BIM). As defined by the National Building Information Committee (2013), BIM is “a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life- cycle; defined as existing from earliest conception to demolition.” BIM is changing the product’s delivery that is leading the construction industry to integrate the architecture, structural and mechanical engineering fields (Shirole et al, 2009). The BIM term was popularized by several technology providers, which offered BIM capabilities, such as Bentley Systems, Graphisoft, Autodesk and others. With BIM technology, accurate virtual models of buildings are constructed digitally.

These virtual models are then used to support the design, construction and fabrication activities. BIM technology minimizes the potential errors generated by paper documents, due to design inconsistencies, which cause unexpected field costs, delays and claims between various project parties (Eastman et al, 2011).

By comparing building construction projects with bridge construction projects, one can find that the complexity degree in a bridge or highway construction project is similar to that of a building, although bridge and highway construction involves fewer activities and crew. However, due to the crucial environment and high complexity of the management process involved in bridge and highway construction projects, bridge construction projects have become much more difficult (Shah et al, 2008). Significant advances and developments in automation and communication technologies have occurred in recent years, but the bridge construction engineering and management enterprise have not fully adapted to and integrated these developments (Chen and Shirole, 2006). According to Chen and Shirole (2007), Bridge Information Modeling (BrIM) has weighty potential efficiencies and reasonable advantage to be gained by developing integrated approaches. The concept is the same as BIM but it is closely related with an axis for road or railway design (Katz, 2008). BrIM methodology is being used increasingly in the design and construction of large and complex bridges. Also, BrIM aspects are being used in infrastructure project visualization, detailing, bridge operations management and delivery through the use of AASHTO Ware (Shirole et al, 2009). These integrated approaches will not only result in reduction of costs, faster delivery and improvement of quality, but also will pave the way towards different delivery such as a design/build delivery model (Shirole et al, 2009).

2.2.2 Applications of Bridge Information Modeling

Integrated design and construction of bridges was addressed in many studies and pieces of research, which gave manufacturing industries excellent results and provided improvements. Lee

et al (2012) developed 3D models for specific construction methods used in prefabrication of concrete bridges. The proposed model was needed to enable engineers to make cost-effective decisions. Also, the model ensured adequate collaboration between CAD systems that is not available in 2D drawings, because 2D drawings need additional effort to correct constructability problems due to insufficient information delivery between different engineers. Lee's 3D proposed models not only increase the efficiency of collaboration between different engineers but are also useful for communication between project parties. The CATIA-V5 CAD engine was used in their model to support the 3D geometry models. Their model was based on digital mock-up (DMU) computer-based information technology. Digital mock-up (DMU) technology enables the creation of a 3D virtual environment to model and assemble structures. Also DMU can be used to predict design errors or generated problems that might occur during construction. The model was validated by utilizing a precast concrete box girder bridge construction project by a general contractor. Concrete segment components were modeled and assembled, where the DMU technology improved the quality of the concrete segments and reduced their time and construction cost. Bill of Materials (BOM) conducted to provide information concerning the product parts and the correlation between the parts. The huge sophistication and complexity of construction and fabrication of the reinforced concrete structure was accelerated using this technology. The BOM was assembled through consideration of the sequence of placing the reinforcement bars for the concrete segments by producing a video to enhance the understanding of the segment fabrication. The contractor evaluated the 3D bridge information models by citing a total savings amount of \$2 million. However, the authors mentioned some restrictions on the efficient application of these technologies. The insufficiency of the understanding of these technologies, assurance of positive effects of the technology applications and lack of experienced engineers are considered to be restrictions in using such technologies.

BrIM emerges in a lot of topics in bridge industry such as 4D simulation, virtual construction, computer simulation and virtual prototyping, all of which can be used to accomplish crucial construction work successfully (Shah and Dawood, 2008). The first step of a successful project is planning. Planning is a complex and time-consuming task—even experienced planners find it difficult to produce a perfect plan on the first attempt, so that planners find it necessary to review and update. Thus, using advanced techniques for planning and scheduling the construction of bridge projects will help planners make decisions in a more efficient and appropriate way. 4D CAD was applied on actual bridge and highway projects to provide construction scheduling and resource consumption over time (Zhou and Wan, 2010). 4D CAD technology was also used in testing construction plans and scenarios to improve the constructability of bridge projects. On the other hand, virtual prototyping systems (VPS) is an effective construction planning tool at the operational level related to the dynamic motion of resources such as crew, materials and equipment (Li et al, 2012). VPS helps to avoid collisions between construction plans and activities conflicts through 4D space technique, which optimizes construction and covers the shortcomings of discrete-event simulation. Li et al (2012) described the application of the VPS approach to bridge construction plans in a case study, where the main scope of the work included widening sections of existing carriageways and vehicular bridges and highway structures. The work included the construction of foundations, piers, deck and finishes. The complex topography of the site forced the planners to face several types of problems relating to construction planning and constructability. Concerns, including site safety, cranes and equipment positioning, and site access, were incorporated. The VPS was applied by the planners to allocate plant and equipment resources avoiding mistakes between the amount of plant and activity start-finish times. Also collision analysis was conducted using VPS to help project planners to select suitable construction scenarios by testing different alternatives. The authors listed some limitations of the

VPS in bridge construction. The main limitation of the VPS is that using this modeling technique can be very time-consuming. Also, the VPS does not identify the optimal construction plan. However, planners' feedback indicated that a fully automated platform for the design process is desired since it will open the way for further research in the use of VPS in bridge projects.

Aside from all the efforts to conduct research on bridge construction, computer simulation has been applied to bridge deck construction as a case study (Said et al, 2009). The authors mentioned that using the Critical Path Method (CPM) or Precedence Diagram Method (PDM) as traditional planning and scheduling methods, will provide a large number of repetitive activities. They also mentioned that using the Line of Balance Method (LOB), as an example of a repetitive scheduling method, will also create uncertainty and interaction amongst involved resources. The authors considered computer simulation to be a powerful planning tool for complex, stochastic and repetitive bridge deck construction. The case study presented a bridge that has been constructed in Cairo, Egypt, using the newly developed system, which is called Bridge_Sim. The duration of the deck construction was estimated by considering all the data required, such as material quantities, material unit costs, and activity durations. Associated total cost and different scenarios for crew formations and construction sequence in the construction plans are also considered.

Another application of computer simulation technology was conducted on cable-stayed bridges to estimate the productivity rates of different combinations of crews (Abraham and Halpin, 1998). Many studies are conducted on bridge construction management and planning, either at the operational or the project planning level by using modern technologies to enhance the productivity of construction and to provide a faster, more cost-effective and safer construction environment.

A lot of researchers have been studying and discussing the operation of construction equipment using computer-aided design software and modern technologies for very complex and complicated bridge projects. Park et al (2009) applied 3D CAD for effective derrick crane operations in a case project concerning cable-stayed bridge construction. In their case project, a 3D CAD model was applied during the operation stage, wherein it showed, in detail, the movement of the equipment and materials throughout the construction operation. The operation stage requires more in-depth knowledge of the whole construction operation. The case study presented the application of a 3D CAD model to show the operation of a derrick crane in constructing the Cheongpoong Grand Bridge, which is a cable-stayed bridge. The derrick crane was selected for use because of its light weight and its compatibility with the bridge construction methodology. A collision check of structural members during construction was provided using a 3D model where the difficulty of visualizing the status of the facility to be built using traditional 2D drawings was resolved. Also space analysis to unload materials was conducted so that engineers can effectively use the space for loading, unloading and installing the crane. The derrick crane was the major piece of equipment used in the project. However, analyzing the safety of using the derrick crane in installing objects was crucial. Thus, analysis of the crane operations was conducted using the 3D CAD model. The entire path of the crane, when in motion, was visualized during the envelope analysis before the physical construction starts. Using a 3D CAD model in the case project led the authors to conclude that this technique can prevent reworks, while improving the productivity of bridge construction.

Technology developments that have occurred during recent decades have encouraged many researchers to develop modern methods to improve productivity in different fields of construction. Modern technology and bridge information modeling (BrIM) were used in many bridge projects during both the project and operational stages. Other researchers are currently

looking at the application of BrIM project tasks such as planning, scheduling, safety, construction operations and maintenance. Most BrIM applications have been implemented on projects after their design stage where the related information and data are available. However, applying and using the BrIM concept during the project conceptual stage has not captured the attention of researchers. Applying the concept during this stage will lead to developing effective and powerful applications and models that will save time and cost. However, this research will focus on integrating the 3D CAD part of BrIM with conceptual cost estimating; thus, the conceptual design stage is the focus of this research study.

2.3 Cost Estimation

2.3.1 Definition and purpose

One of the most difficult and crucial tasks in construction management is estimating the construction cost of a project. Construction cost estimating has influence on maintaining a contractor's success in insuring his/her profit. Cost estimating is defined as a report of the approximate quantity of material, cost and time needed to complete the construction of a project (Carr, 1989). Rad (2001) defines cost estimating as the art and science of using historical data and experience to forecast the total cost and duration of a project.

Many factors affect the cost-estimating task such as project site and environmental risk. The methods used to do cost estimates depend on the project stage; this is due to the change in the amount of information available from one stage to another. The main purpose of cost estimating is to provide detailed information that helps stakeholders to make major decisions related to the profitability of the project within a specified budget and the required time. Westeny (1997) summarizes the purposes of cost estimation as follows:

- Provides an evaluation and assessment of the capital cost for a specific work.

- Creates the basis for planning and monitoring project progress.
- Provides necessary information required for the preparation of project schedule such as durations, resources and tasks.
- Gives financial input necessary to prepare cash flow.

2.3.2 Cost Estimation Types

According to Stewart (1982), cost estimates are divided into two major types, which are the approximate and the detailed estimates. Butcher and Demmers (2003) also divided construction cost estimates into two types: approximated conceptual cost estimates, which are utilized in the predesign stage, as well as the detailed estimates, which are utilized during the post-design stage. Peurifoy et al (2002), however, categorized construction cost estimates into three types: back of the envelope estimates, preliminary or conceptual estimates, and full funding estimates. On the other hand, Halpin (1985) classified construction cost estimates into four types, which are: the conceptual estimate, preliminary estimate, engineer's estimate, and bid estimate. Holm et al (2005) also classified construction cost estimates into four types as follows: preliminary cost estimate, elemental cost estimate, unit price estimate, and detailed cost estimation. These four types represent the estimating process, which starts with the conceptual and ends with the bid estimate.

In 2005 AACE International classified cost estimates into five classes. Each estimate class is identified by the project stage, purpose, preparation effort and level of accuracy. Figure 2.1 illustrates the five classes of estimate.

	<i>Primary Characteristic</i>	<i>Secondary Characteristic</i>			
ESTIMATE CLASS	MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES Expressed as % of complete definition.	END USAGE Typical purpose of estimate	METHODOLOGY Typical estimating method	EXPECTED ACCURACY RANGE Typical +/- range relative to index of 1 (i.e. Class 1 estimate) ^(a)	PREPARATION EFFORT Typical degree of effort relative to least cost index of 1 ^(b)
Class 5	0% to 2%	Screening or feasibility	Stochastic (factors and/or models) or judgment	4 to 20	1
Class 4	1% to 15%	Concept study or feasibility	Primarily stochastic	3 to 12	2 to 4
Class 3	10% to 40%	Budget authorization or control	Mixed but primarily stochastic	2 to 6	3 to 10
Class 2	30% to 75%	Control or bid/tender	Primarily deterministic	1 to 3	5 to 20
Class 1	65% to 100%	Check estimate or bid/tender	Deterministic	1	10 to 100

Figure 2. 1 Cost Estimation Matrix for Process Industries (AACE International 2005)

As shown in Figure 2.1, the conceptual cost estimate has an expected accuracy range of 3 to 12 and a preparation effort of 2 to 4. Expected accuracy range of 1 means the estimate has the highest level of accuracy, while expected accuracy range of 20 means the estimate has the lowest level of accuracy. Preparation effort value of 1 represents the typical degree of effort relative to the lowest effort needed in preparing the cost estimate, while preparation effort of 100 represents the highest degree of effort required to prepare the estimate.

2.3.3 Definition and Importance of the Conceptual Cost Estimation

Limited information is available prior to any design. However, it is necessary to the owner to assess the economic feasibility of a proposed project before continuing with it. Thus it is crucial to prepare and use an approximate cost estimate during the feasibility study. A conceptual cost estimate is the first effort made to predict the cost of the project. It is usually performed at the beginning of the project, where significant experience and judgment are needed to develop a reliable conceptual cost estimate. Conceptual cost estimation is defined as the prediction of project costs that is performed before the availability of a significant amount of information and

the completion of the work scope definition with the purpose of using it as the basis for important project decisions such as budget setting, allotment of funds and project continuity decisions. The importance of the conceptual cost estimate is that it assists the overall cost control by providing the first check against the budget (Pratt, 2004). It also indicates cost overruns at the early stages of the project, which help in reviewing the design for possible alternatives. Adrian (1993) listed the purposes of conceptual cost estimates as follows:

- Provides help to owners during the economic feasibility study.
- Assists designers in controlling the budget of the design.
- Helps the owner in establishing the funding of the project.

2.3.4 Characteristics of the Conceptual Cost Estimation

Each type of cost estimate has some unique characteristics due to the time needed in process, data available and time required by the process. Peurifoy et al (2002) identified three characteristics of the conceptual cost estimate. The first characteristic is that conceptual cost estimation is a mixture of art, visualizing the project and the construction detailed sequence and adjusting them into new conditions, and science, making use of the costs of past works. The second characteristic is that the accuracy of the estimate is highly related to the level of the information available by the scope of the project. The third characteristic is that it is limited to its resources, which are available information, time and cost. The information is restricted in detail and precision due to the fact that the estimate is developed in the early stage of the project. Time and cost are also restricted due to the need to screen several alternative designs and to define the feasibility of the project as quickly as possible.

2.3.3 Preparation of the Conceptual Cost Estimate

Generally, preparation of a conceptual cost estimate involves a sequence of activities (Peurifoy et al, 2002). The first activity that needs to be achieved is to study the scope of the project and to produce an estimating plan. The estimating plan contains information about cost analysis of previous similar projects, sketch plans of the proposed project and brief specifications of services for the proposed project. Next, historical data of similar past projects is to be collected. This activity is very critical because availability of any unsuitable selected data will undesirably affect the estimate. After that, adjustments are applied to the selected data to be suitable and compatible to the scope of the project. The consequential cost estimate is then submitted, describing in detail all the information, assumptions, procedures, and adjustments to management for decision-making. Figure 2.2 illustrates the conceptual cost estimation process.

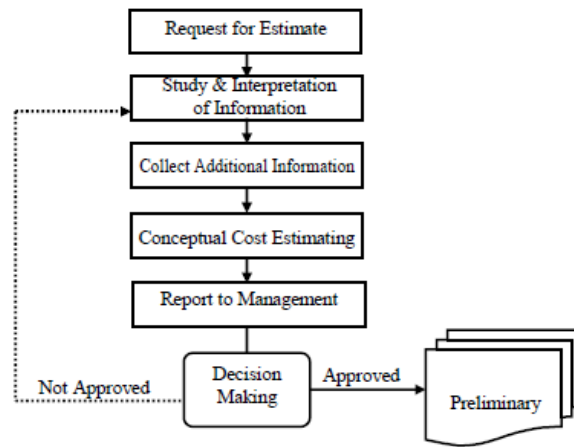


Figure 2. 2 Conceptual Cost Estimation Process (Peurifoy et al, 2002)

2.3.3 Conceptual Cost Estimate Adjustments

It is important to adjust the cost of similar previous projects to be suitable for the proposed project. There are two types of cost adjustments: time adjustment and location adjustment.

To have a reliable cost estimate it is important to have no difference in time between the historical project data and the proposed project. In the case of a time difference, it is necessary to

adjust the cost data in order to have no time difference between the two projects. The time adjustment should represent the inflation or deflation of cost with respect to time. The inflation and deflation are due to differences in labor rates, material costs and interest rates (Peurifoy et al, 2002). In order to measure the difference, data index numbers are used as a means of expressing the difference. The index can be used to adjust previous cost information, calculate an equivalent compound interest rate and to forecast future projects. Various organizations publish indices that show the economic trends of the construction industry with respect to time. Using time adjustment indices, similar types of work from the past to the present or future period can be forecasted (Adrian, 1993).

Similarly to the time adjustment, cost estimation reliability will not be available if there is a difference in location between the past project and the proposed project, unless location adjustment is applied. The reason is that price levels differ from one region of the country to another. The factors affecting the variation in construction cost according to location are the construction cost of labor, material, and equipment in addition to other factors such as weather, climate, mobilization, labor availability, and productivity. Indices that measure the difference in cost with respect to geographical location are published by many organizations (Migiliaccio et al, 2013).

2.4 Bridge Conceptual Design Phase

This section reviews the bridge conceptual design phase by providing a brief review on the purpose, requirements, constraints, process and types of bridges. Also examples of implementations of computer systems for conceptual design are presented.

2.4.1 Purpose of the Bridge Conceptual Design

The purpose of the bridge conceptual design phase is to develop alternatives and solutions for a bridge crossing an obstacle such as a stream, road or other facility, and then to find the most appropriate one in order to provide an optimal solution (BESAT, 2014). In order to choose the optimal solution, a consideration of all relevant issues should be considered along with examining several alternatives. In other words, the aim of the conceptual design phase is to answer, within a specified time, the question of how to select the best alternative which can meet the requirements, needs and constraints of the project.

2.4.2 Requirements and Constraints of the Bridge Conceptual Design

According to BESAT (2014), it is required by the designers to balance between the requirements and constraints in the process of the development of alternatives. It also requires some judgments and the preparation of a solid defense of the recommended alternatives and proposals. In addition, significant communication between the bridge conceptual design team and the roadway design team is essential. Constraints that should be involved in the conceptual design are: structure safety, economy, constructability, inspectability, durability, sustainability, aesthetics, and compatibility with environment and landscape (Nedev et al, 2011). Specifying design demands and intentions are considered to be one of the most crucial tasks of bridge conceptual design, because they are usually changing during the process of the conceptual design. As stated by Dekker (2000) shortage of time is one of the obstacles to designers, because they have to produce a suitable and optimal structure with limited time and information. In addition there is no specific formula or unique solution the designers have to follow, but it is based on the designer's experience and the requirements dictated by the project. If the designer has experience and past knowledge, inconsistency in the alternatives constrains will be clear and noticeable. Also, the designer will be able to improve the solution and reduce the time required by

neglecting some alternatives and reducing the number of possibilities. Troitsky (2000) mentioned that the designer's past experience and knowledge will reflect on the designer's creativity, imagination and visualization, which are necessary to plan and design a bridge. He also mentioned that in order to determine the fundamental function and performance of the bridge, the designer must first visualize and imagine the bridge. Holgate (1986) suggested the use of computer applications to effectively create, compare and visualize alternatives. By using computer applications the designer can create number of alternatives in a short period of time. In addition the designer can compare and visualize the components of each alternative, such as deck cross section, piers and abutments to check its compatibility, applicability and economy.

2.4.3 Process of Bridge Conceptual Design

The process of bridge conceptual design has been identified in different ways by researchers. Dekker (2000) mentioned that it is very complicated to define or to outline the process of the conceptual design. According to Troitsky (2000) there are two steps the designer should consider when doing conceptual design. The first step is to create bridge alternatives. The second step is to check and sketch the alternatives. After achieving these two steps, the designer should examine all the proposed alternatives putting in mind all the parameters and constraints of the project. Kroll (2001) proposed a general methodology of the conceptual design process that is summarized into the following four steps: (1) need identification, (2) technology identification, (3) parameter analysis, and (4) concept selection. The major function of the need identification step is to discover what the real need is, and to analyze the need such that the best alternative should meet its requirements and not be prevented by the way the need is described. The major function of the second step is to develop initial ideas by recognizing critical issues. The third step's main function is to develop initial applicable solutions. Finally, the main function of the fourth step is to compare and evaluate the solutions against each other to determine the most

suitable alternative. On the other hand, Niemeyer (2003) proposed methodology that consists of five steps to use for the conceptual design. Figure 2.3 summarizes the said methodology.

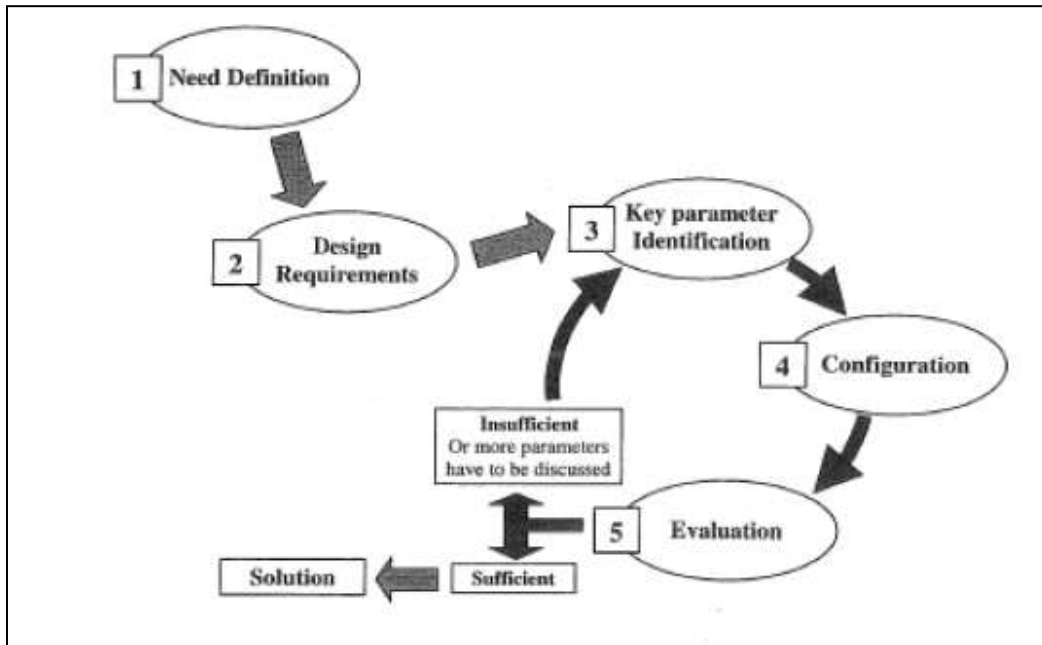


Figure 2. 3 Methodology of the Conceptual Design (Niemeyer, 2003)

The first step is the need definition. The designer has to identify basic needs by identifying the type of traffic that will run on the bridge and the location where it will be located. Then the needs should be analyzed to help in setting the limitations of the project such as budget and bridge type. This is a very critical step, because the risk of changing the whole design might be increased if the needs are incorrectly identified. The second step is the design requirements. In this step all hard requirements are clarified and minimum needed functions and constraints are summarized. Hard requirements are the parameters that every alternative has to satisfy, such as number of lanes or required bridge heights, etc. In addition, all the technical aspects such as codes and legal requirements are discussed. The third step is the key parameter identification. The main function of the third step is to simplify the tasks to produce simple problems. This can be implemented by removing the less important ideas, then trying to solve the most critical problems to be able to continue developing the concept further. The fourth step is the

configuration of the conceptual idea. In this step, more detailed information with sketches, preliminary calculation and explanations of the conceptual idea are developed. Some parameters and materials are defined to be used in the evaluation of the physical configuration. The fifth step is the alternative evaluation. In this step the proposed alternatives are evaluated according to different parameters and factors.

2.4.4 Bridge Classifications

In order to fully understand bridge conceptual design it is essential to know the different types and classifications of bridges. Tang (2007) has made his assumptions, which led him to divide bridge evolution into two major periods within the last four thousand years: the Arch Era and the Contemporary Era. These two eras encompass all types of bridges starting with the very primitive arch bridge formed from natural stone for pedestrians, passing through ordinary bridges with a medium span length, up to the more recent bridges, such as cable-stayed and suspension cable bridges. Finally, Tang (2007) classified bridges within four types: Girder Bridges, Cable-Stayed Bridges, Arch Bridges and Suspension Bridges. According to Taly (1997) the necessity of categorizing bridges in several ways has increased because bridges have developed from simple beam bridges to advanced suspension and cable-stayed bridges. Also, he mentioned that bridges can be classified as follows:

- Construction material.
 - Classifying bridges based on their superstructure construction material such as timber, concrete, steel, etc. However, a combination of materials is frequently used in a bridge superstructure. For instance, a combination of reinforced concrete deck and steel girders can be used for bridge superstructure.
- Span lengths.

- Classifying bridges based on three span length ranges. These ranges are short span (10m to 40m), medium span (40m to 120m) and long span (over 120m) (Bakht et al , 1982).
- Structural forms.
 - Structural system or form refers to the bridge load resisting mechanism. The bridge load resisting mechanism is the way loads are transferred from the deck to the foundation. In this viewpoint, bridges can be classified as, (1) slab on stringer bridges; (2) orthotropic bridges; (3) truss bridges; (4) rigid frame bridges; (5) cantilever bridges; (6) cable stayed bridges ; (7) suspension bridges (Taly, 1997),.
- Span types.
 - Bridges can be classified by span type used with respect to the support system used. Span types can be classified into two types: simply supported and continuously supported.
- Load path characteristics.
 - Classifying bridges based on load path or distribution in the bridge superstructure. There are two types of load paths and they are: a one-dimensional system, which distributes the load in one dimension only, and a two-dimensional system, which distributes the load in a perpendicular direction.
- Usage.
 - Classifying bridges based on the purpose of usage. For example, bridges can be classified as highway bridges, railway bridges, airport runway bridges, pipeline bridges, and conveyor bridges.
- Position.
 - Classifying bridges as stationary or fixed in place.

- Deck type.
 - Classifying bridges based on the number of decks. Commonly, bridges have only one deck. However, some bridges have double decks one above the other.

Work Breakdown Structures (WBS) are used in organizing and presenting bridge elements, components, and construction work in a logical order. ASTM Standard Classification for Bridge Elements UNIFORMAT II (E2103) covers most highway bridges, railroad bridges and pedestrian bridges. The elements in the classification are major physical components that are common within constructed entities. According to the ASTM E2103, using this classification will ensure consistency in the economic evaluation of bridge construction projects. Also, this standard can be used to prepare budgets and to establish elemental cost plans prior to the start of design. In addition, it is stated that the classification is consistent with typical costing practices used at the conceptual design phase. This classification divides the classification of bridge elements into four hierarchal levels: Level 1-Major Group Elements, Level 2-Group Elements, Level 3-Individual Elements, and Level 4-Subclassification Elements. Moreover, the classification provides descriptions and units of measure for the elements to provide means for calculating the size or magnitude of each element.

2.4.5 Highway Geometric Design Guideline

The Transportation Association of Canada Geometric Design Guideline 1999 (TAC 1999) is used by designers in Canada as a source of a highway geometric design guideline. The purpose of using this guideline is to get assistance in generating conceptual road features and dimensions considering all the highway design factors such as mobility, environmental impacts, safety, capital cost, aesthetics, maintenance cost and vehicle operational cost. Sample of the road features and dimensions are lane width, left shoulder width, right shoulder width, median width,

bike path width, transit lane width, pedestrian path width and parapet width. The guideline utilizes the concept of design domain in presenting design parameters and guidelines. According to TAC (1999), the design domain concept is a range of values that a design parameter might take. If the lower values of the design domain are considered, generally the design will be considered to be less efficient or less safe, and will also cost less to construct. On the other hand, if the higher values of the design domain are considered, then the design will be considered to be more efficient or safer, but may cost more. This guideline assists designers in applying the design domain concept by providing numerical guidance, in the form of tables and graphs. In addition, it provides a commentary on the nature of the design domain, quantitative evaluation data of safety performance, and worked examples of the applications of the design domain.

To define the required road design features, a proper classification for the type of road should be defined. Proper classification will assist in establishing the geometric design features of the road (TAC, 1999). The TAC (1999) road design classification system contains ten primary divisions as follows:

- Rural Areas
 - Local
 - Collector
 - Arterial
 - Freeway
- Urban Areas
 - Lane
 - Local
 - Collector
 - Arterial
 - Expressway
 - Freeway

If adding bikeways is desired, cycling facilities should be designed consistently with the highway regulations and guidelines. Based on TAC (1999), there are four types for bikeways: (1) shared

roadways, (2) shoulder bikeways, (3) bike lanes, and (4) bike paths. The guideline provides commentaries on the type of bikeways that can be used with each type of road classification. Shared bikeways are most suited to local urban and suburban roads. Shoulder bikeways are always one-way in the same direction as the adjacent outside travel lane, and they are more suitable for rural roads. Bike lanes are more suitable to high-flow roads with high design speed, 80 km/h or above. Mostly, they are one-way in the same direction as the adjacent outside travel lane. Bike paths are bike lanes with physical separator from roadways. They are most suitable for high speed arterials, expressways, or freeways. Bike paths can be shared with pedestrians.

2.4.6 Navigational Waterways Clearances Guideline

The Navigable Waters Protection Act (NWPA), established by Transport Canada, is responsible for protecting the public right of navigation in all navigable waters in Canada. Any company or government agency that proposes to construct or repair any work within the limits of navigable waterway must obtain approval through the NWPA (TAC, 1999). A document developed by Transport Canada Navigational Waterways Protection Division (TC NWPD) in 2006, is used as a guideline in determining minimum navigational clearances. This guideline insures the provision of minimum required navigational clearances that allow safe passage under bridges and culvert structures for all types of vessels. If the bridge crosses a navigational waterway, it is important to know the minimum required navigational clearances in order to be able to identify the bridge's span arrangements.

The purpose of the navigational clearances requirement is to find three types of clearances.

These clearances are as follows:

- Minimum horizontal navigational clearance,
- Minimum depth navigational clearance, and

- Minimum vertical navigational clearance,

It is important to know the different classifications of vessels in order to be able to find the clearances. The guideline divides the vessels into three main classes:

- Small Recreational Vessels:
 - Canoe
 - Kayak
- Recreational and Small to Medium Commercial and Cargo Vessels:
 - Powered Inflatable Vessel
 - Small/Medium Sail Vessel
 - Large Sail Vessel
 - Small/Medium Powered Pleasure Vessel
 - Harbour Tug
 - Small/Medium Fishing Vessel
 - Large Fishing Vessel
- Large Vessels:
 - Lake Freighter
 - Container Transport
 - Crude Carriers
 - Cruise Ships

The guideline provides Table 2-1, Table 2-2 and Table 2-3, which summarize the vessel classifications for recreational vessels, small to medium vessels and large vessels respectively. All the tables are illustrated in Appendix B. In addition to the vessel classification, it is important to categorize the waterways based on their characteristics. Also, the guideline provides

categorizations of waterways in Canada, which are summarized in Table 3-1, in Appendix B, Classes of Waterways in Canada. The waterway classifications in Canada are as follows:

- Small rivers/streams and lakes with limited access
- Large rivers and lakes with good access
- Controlled Waterways
- Great Lakes
- Harbours
- Coastal
- Ocean/Marine

2.4.7 Computer Systems and Conceptual Design

Pahl and Beitz (1988) and Lansdown (1989) mentioned the importance of developing logical strategies, and creating a structured procedure for the design process of a bridge to ensure rational and economic design results. However, only the following structured procedure in the design will not be enough. According to Miles et al (1994), it has been shown that the human brain is unable to deal with the massive amounts of data which are generated from complex design processes, and this leads to mistakes occurring. On the other hand, computers are virtuous in storing large amounts of data. If an error is found in a computer system, it can be corrected and that error should never repeated. In addition, developing a computer design system will reduce the problem caused by the knowledge overload. This can be accomplished by recording all the information in all design stages. Starting in the 1950s, developers started to use artificial intelligence (AI) in developing engineering design computer software (Miles et al, 1994). Simply, artificial intelligence is the simulation of human intelligence. Gradually, the applications of AI were merged with several practices to form the bases of the knowledge-based systems

(KBS). As defined by Schoen et al (1988), KBS is a computer system that uses knowledge to solve complex problems. KBS represents knowledge explicitly by rules and logical statements, such as IF-THEN rules, rather than implicitly representing knowledge by codes, in the way of any conventional computer system.

2.4.7.1 Knowledge-Based system

According to Miles et al (1994), the conceptual design area has been resistant to the introduction of computer systems. However, developers were able, by the development of the KBS, to provide systems that undertake conceptual design needs. According to the definition of the KBS, it consists of two main parts: the knowledge and the interface engine. Two types of knowledge are used in the KBS: algorithmic and heuristic. The algorithmic knowledge represents equations based on Newtonian physics, while the heuristic knowledge represents rules of thumb which are based on experience. On the other hand, the interface engine presents the knowledge via logical statements and IF-THEN rules. Miles (1994) briefly summarizes the benefits of implementing KBS at the conceptual design stage:

- Provides rapid evaluation of options during conceptual design in much greater detail.
- Provides defined design methodology which will ensure the evaluation and exploration of all features in appropriate detail.
- Provides assistance for designers who are lacking the knowledge or experience.
- Provides help to designers with the cognitive overload occurrence.

2.4.5.1.1 Examples of the Implementations of Knowledge-based systems for Conceptual design

Soh (1989) produced a prototype system for the conceptual design of fixed offshore steel structures. The domain of the system is shallow water fixed steel structures. The fixed steel

structures are built and fabricated on shore, then towed out and fixed in their positions. The fixing procedure is to inserting steel piles through the legs of the lower part of structure. The initial goal of this project was to develop a prototype system to test the applicability of KBS to offshore conceptual design. Then the concept of the prototype was extended to be coupled with other software. The system aimed to assist inexperienced designers who need the help of senior engineers in the topology of the structure and the preliminary size of members. The knowledge base for this prototype is the experience and knowledge of researcher, Soh, himself. Also, the system contains information gathered from different design codes and handbooks of steel structures. Then, the knowledge is presented in a mixture of dBaseIII, Cliper and C programming language interface engines implementing IF statements and logical rules. The system was further developed by adding a graphical modeler and editor component. This component improved the KBS by adding the feature of visual examination for members. As described by Miles (1994), integrating graphical editor component with the KBS analysis package was introduced because it was recognized that KBS is considerably less useful than when it is coupled to other software or components with complementary abilities.

Manos et al (2011) proposed a methodology for implementing KBS for the preliminary design of the seismic isolation of bridges. In Europe, seismic isolation of bridges is performed according to the Eurocode 8, which refers to the basic requirements and compliance criteria, analysis procedures and the verification of the isolating system. The proposed methodology is based on the current design provisions of Eurocode 8, but is complemented by additional criteria, set according to expert judgment, laboratory testing and recent research findings, while using a combined cost/performance criterion to select from a database of available bearing products on the international market. Eurocode 8 is a The model also offers the advantage that all possible selections of bearing sections are considered potential design solutions as opposed to the

common preliminary design procedure, which because of time and complexity constraints investigates some of the design alternatives. The methodology is also implemented in software whose efficiency is validated through parametric numerical analyses as well as by using the case of a real bridge.

Miles and Moore (1989) proposed another example of implementing KBS for conceptual design. They proposed implementing KBS for conceptual design of road bridges. They developed a system which is intended for inexperienced young civil engineers and aims to assist young civil engineers in gaining more understanding of conceptual bridge design process. The conceptual design stage was chosen in implementing KBS because the conceptual stage of bridge design has been ignored by engineering software developers and programmers. In addition, practical experience is not passed to inexperienced young bridge engineers. However, most young engineers have less understanding of the conceptual design process. Thus, the conceptual design stage was made the aim for developing a KBS. The developers suggested limiting the domain of the system to cover road bridges crossing another road, because it seemed that the domain would otherwise be extremely large. However, it was recognized that the domain could always be extended at a later stage. Regarding the sources of knowledge, the developers rely on information derived from books, papers, and code of practice such as British Standards and Department of Transport guidelines. In addition, information about conceptual bridge design was collected from experts. They involved a number of bridge design experts in the knowledge elicitation. The knowledge base was structured into a tree structure, which is split into six sections. The six sections are: (1) road geometry, (2) site topography, (3) pier positioning, (4) bridge characteristics and bridge width, (5) end supports and wing walls, (6) deck material and constructions. The knowledge base sections directly follow the approach adopted by the bridge design experts. After gathering all the information, the system was developed in the PROLOG

language. Prolog is a general purpose logic programming language associated with artificial intelligence and computational linguistics. The PROLOG language logic is expressed in terms of relations, represented as facts and rules. The style of the system follows the format of the rule-based system representation, which implements logical relationships and IF-ELSE format. The system was distributed in a number of bridge design offices to be reviewed and evaluated. The system was evaluated by reviewers and no major gaps or mistakes were found, and this showed that it was practically complete. As future expansions, Miles and Moore (1989) suggested to include graphics and to build more interaction with other computer systems such as CAD systems and intelligent databases.

2.6 Summary

This chapter has reviewed previous theories and practical works related to the concept of integration of bridge information modeling with conceptual cost estimation at the conceptual design stage. First, it reviewed the concept of bridge information modeling and some examples of implementing bridge information modeling on different stages of bridge construction. This part helped in accomplishing the first research objective, which is studying and understanding the concept of BrIM and its applications. Also, it helped to narrow the research and to focus on integrating 3D CAD with cost estimating at the conceptual design stage. Second, this chapter highlighted cost estimation by reviewing the definition, the purpose, and types. It also presented a further review on the conceptual cost estimating definition, purpose, characteristics, preparations and adjustments. This part assisted in accomplishing the second research objective, which is understanding the definition of cost estimation and identifying the purpose and types of cost estimation. Finally, this chapter addressed the bridge conceptual design phase by identifying its purpose, requirements, constraints and bridge type classifications. Also, this chapter covered the advantages of implementing the Knowledge-Based System on conceptual design, which will

be used in the research methodology, by presenting some examples of implementations of the system on the conceptual design phase.

Chapter Three

Methodology

3.1 Introduction

This chapter explains the proposed methodology to be used in developing and implementing the integrated 3D-CAD with cost estimation model at the conceptual design stage. Based on the literature review conducted in chapter 2, it is important to follow the sequence of the conceptual bridge design in order to create a computer information system. Also, it is important to develop an efficient connection between excel spreadsheets, programming languages and interface. This chapter explains the methodology, its components and architecture. The Knowledge-Based System will be explained by identifying the knowledge base and the interface. All the modules of the proposed model will be explained to present the data flow of the adopted methodology.

3.2 System Components and Architectural

The proposed methodology that integrates 3D-CAD and cost estimation for bridges at the conceptual design stage requires following the steps used to design the bridge at the conceptual stage. This can be achieved by identifying all the necessary bridge-related parameters and information needed for the conceptual design. The integrated model consists of the following three main modules (1) knowledge-based module; (2) cost estimation module; and (3) 3D visualization module. The knowledge-based module is used to generate preliminary dimensions/parameters, and to recommend bridge type alternatives. The cost estimation module consists of a comprehensive cost database that is used to generate cost estimates for the selected alternatives. The 3D-CAD module utilizes three-dimensional (3D) drawings in modeling bridges. Figure 3.1 illustrates the components of the proposed model.

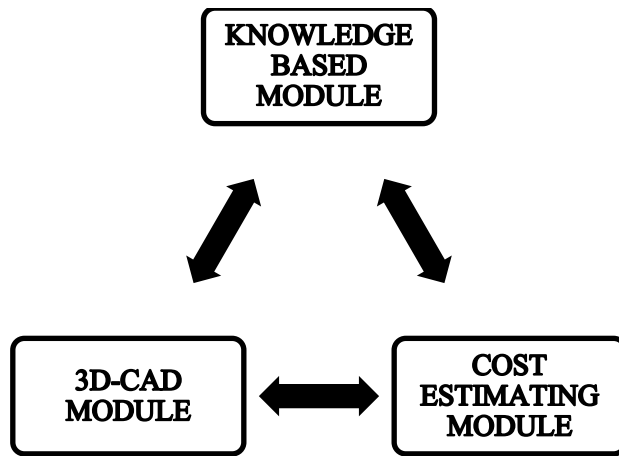


Figure 3. 1 Main Components of the Model

3.3 Knowledge-Based Module

Little information is available at the conceptual design stage of a bridge. Thus, the main purpose of utilizing the Knowledge-Based System (KBS) module is to generate preliminary dimensions and parameters which can be used in the conceptual cost estimating module. The main procedure of the KBS involves three steps, (1) user's input variables; (2) knowledge base analysis; (3) KBS output variables. The first step requires the user to identify objective variables rather than subjective variables. The reason behind this is that objective evaluation criteria require objective feedback or measures, which are available to both experienced and inexperienced designers. On the other hand, subjective criteria require subjective feedback or experience judgment, which can be available only for the experienced designer. The objective variables, which should be identified by the user, are bridge length, road type, required number of lanes, location and overpass object information. The second step is to use the user's input variables in consulting the system's stored knowledge base. Two types of knowledge are to be consulted, algorithmic knowledge and heuristic knowledge. The algorithmic knowledge is based on highway geometric design guidelines, navigational waterway guidelines and bridge structural design code, while the heuristic knowledge is based on rules of thumb gathered from bridge

design experts and engineers. The knowledge base is consulted and restored through the interface IF-THEN rules. Finally, the third step is to present the output variables to the user, and to provide the user with the flexibility to make any desired changes. These variables are bridge cross-sectional dimensions, element dimensions and span arrangements. These variables are then used in the process of bridge type selection, which will be used later in both the conceptual cost estimating module and 3D-CAD module. Figure 3.2 illustrates the process flow of the knowledge-based system module.

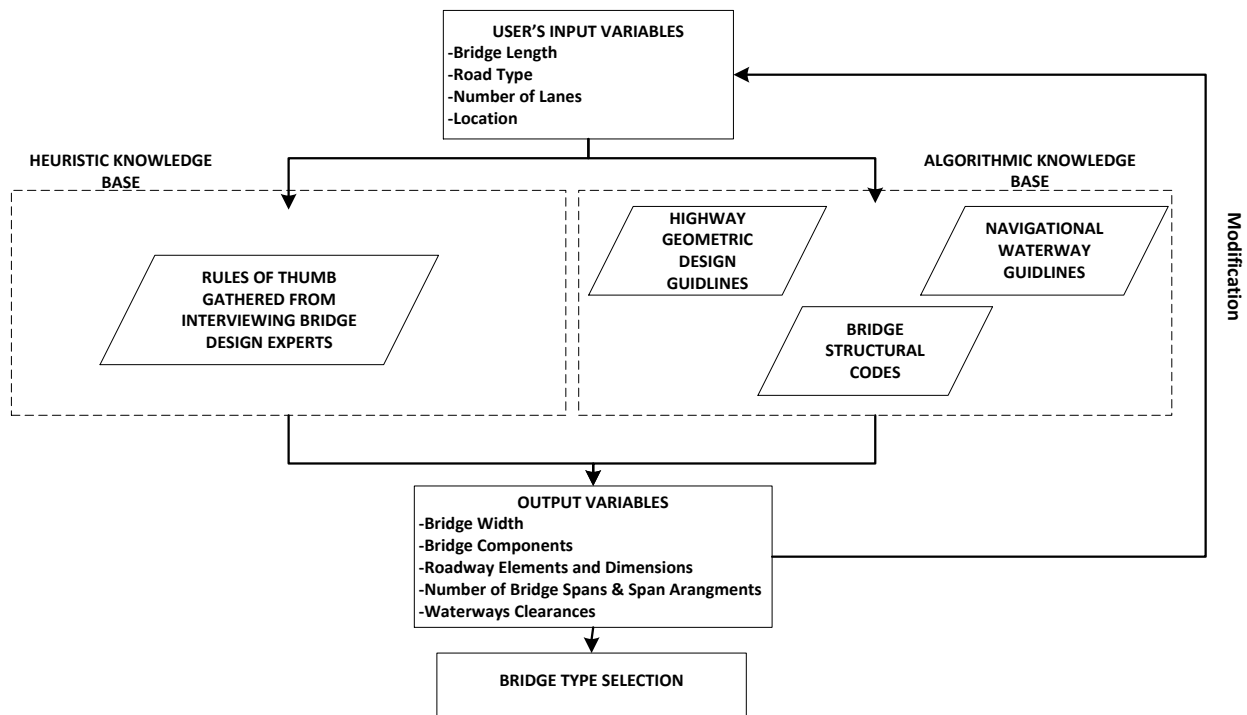


Figure 3. 2 Knowledge-Based Module Process Flow

3.3.1 Knowledge Base

As described previously, there are two types of knowledge, algorithmic knowledge and heuristic knowledge. This section introduces the collected algorithmic and heuristic knowledge bases used to create the KBS. The algorithmic knowledge base depends on three major resources, which are:

(1) Highway Geometric Design Guidelines; (2) Navigational Waterways Guidelines; (3) Bridge Structural Design Code. The heuristic knowledge base depends on bridge design experts as a resource for knowledge. Two bridge design experts were interviewed to gather information, which is not available in books or design codes. The selection process of the experts and the types of heuristic knowledge are explained in the succeeding section 3.3.1.3

3.3.1.1 Highway Geometric Design Knowledge Base

As mentioned in Chapter 2, the TAC (1999) road design classification system contains ten primary divisions. According to TAC (1999), proper classification of road type will assist in establishing the geometric design features of the road such as lane width, left shoulder width, right shoulder width, median width, bike path width, transit lane width, pedestrian path width and parapet width. Once the road classification is properly specified, road features can be obtained using Table 1.3.4.1 Characteristics of Rural Roads and Table 1.3.4.2 Characteristics of Urban Roads. These tables are shown in Appendix A. Using these tables, values of design speeds and traffic volumes can be found.

Design speed, traffic volumes and the road classification are considered the basic parameters for finding the lane width. The guideline provides tables for each road classification, which can be used to find the lane width. For example, if the road is classified as two-lane rural road, Table 2.2.2.1 Lane Widths for Two-Lane Rural Roadways is used to find the lane width, while, if the road is classified as multilane rural road, Table 2.2.2.2 Lane Widths for Multilane Rural Roadways is used to obtain the lane width. On the contrary, if the road is classified as urban road, Table 2.2.2.3 Lane Widths for Urban Roadways is used to obtain the lane width. All these tables are shown in Appendix A. In regards to transit lane width; the guideline provides a commentary explaining the procedure. It mentions that the transit lane width should be the same as the adjacent lane or 0.2 m less, but not less than 3.5 m. However, if the transit lane is next to a

contraflow lane, then the transit lane width should be between 3.7 m and 4.0 m where design speed is equal to or less than 60 km/h.

To find the shoulder width, the guideline provides tables to find the shoulder width for each road classification. For urban local and collector roads, Table 2.2.10.1 Horizontal Clearance at Bridges on Local and Collector Urban Roads is used to obtain the left and right shoulder widths, while, for urban arterial roads, Figure 2.2.10.3 Horizontal Clearance on Bridge on Urban Arterial Roads (Overpass) is used to obtain the widths of the left and right shoulders. For urban freeway roads, Figure 2.2.10.4 Horizontal Clearances on Bridges on Urban Freeways (Overpass) is used to obtain the widths of the left and right shoulders. However, for rural roads, the guideline provides Table 2.2.10.2 Horizontal Clearance at Bridges on Rural Roads to assist designers in obtaining the widths of the left and right shoulders. All these tables and figures are illustrated in Appendix A. Median width can also be obtained from these tables. Concrete barriers are usually used as median for the divided roads. Thus, from these tables median width can be obtained by adding the 0.4 m barrier width to the 0.2 m barrier face width.

With regard to sidewalk width, the guideline provides heuristic commentaries to obtain the width of sidewalks. The commentaries mention that the typical minimum sidewalk width is 1.5 m. Also, an additional lateral clearance width of 0.5 m is to be added when the sidewalk is neighbouring fences, barriers or any similar facility. In addition, adding a left side barrier is compulsory if the design speed is 100 km/h, or if the road classification is expressway or freeway.

Beside these commentaries, the guideline provides tables to assist designers in obtaining bikeway widths. For obtaining a bike path lane width, Table 3.4.6.1 Bike Path Lane Width is used. For obtaining bike lane and shared lane widths, Table 3.4.6.2 Bike Lane and Shared Street

Lane Width is used. All the aforementioned tables are included in Appendix A. For the shoulder bikeways, the guideline provides a commentary mentioning that widths required for shoulder bikeways are the same as those required for exclusive bike paths.

The TAC (1999) guideline provides a commentary about the vertical clearances in section 2.1.3.4 Vertical Alignment. This commentary provides application heuristics for vertical clearances for roads, railways, pedestrian overpasses, waterways, and airways. The guideline recommends using a minimum vertical clearance for vehicular bridges of 5.0 m over travelled lanes and shoulders. The guideline recommends that designers consider 100 to 200 mm above the minimum value to make provision for future overlays of the roadway surface. For railways, the guideline recommends using 7.163 m as a vertical clearance, measured from the base of the rail elevation to the underside of the overpass structure.

One of the major outputs required from the KBS is to generate suggestions and recommendations for the span arrangements. If the underpass object is a road or a highway, the highway regulations and guidelines should be consulted to check the possibility of constructing a support or a pier within the underpass's right of way. To implement this, the TAC (1999) Horizontal Clearances for Underpass guideline was used in the knowledge base. Left and right shoulder widths of the underpasses are obtained from these guidelines. These widths represent the required width for shoulders to have in order to be able to construct a pier. Once these widths are obtained, they must be compared with the actual values and thus check to see if the required shoulder widths are less than or equal to the actual shoulder widths. Thus, for urban arterial roads, Figure 2.2.10.1 Horizontal Clearances at Bridges on Urban Arterial Roads (Underpass) is used to obtain the required shoulder widths, while Figure 2.2.10.2 Horizontal Clearances at Bridges on Urban Freeways Roads (Underpass) is used to obtain the required shoulder widths for urban freeways. Acquiring the horizontal clearance of the underpass road will provide an

indication of the possibility of constructing a pier without needing to reconstruct or widen the underpass road. This indication can be used to suggest the arrangement of the spans.

After gathering all this information, logical relationships and IF-THEN rules are ready to be created. Figure 3.3 summarizes all the information used in developing the highway geometric design knowledge base.

TAC (1999) Tables and Figures

INPUT VALUES

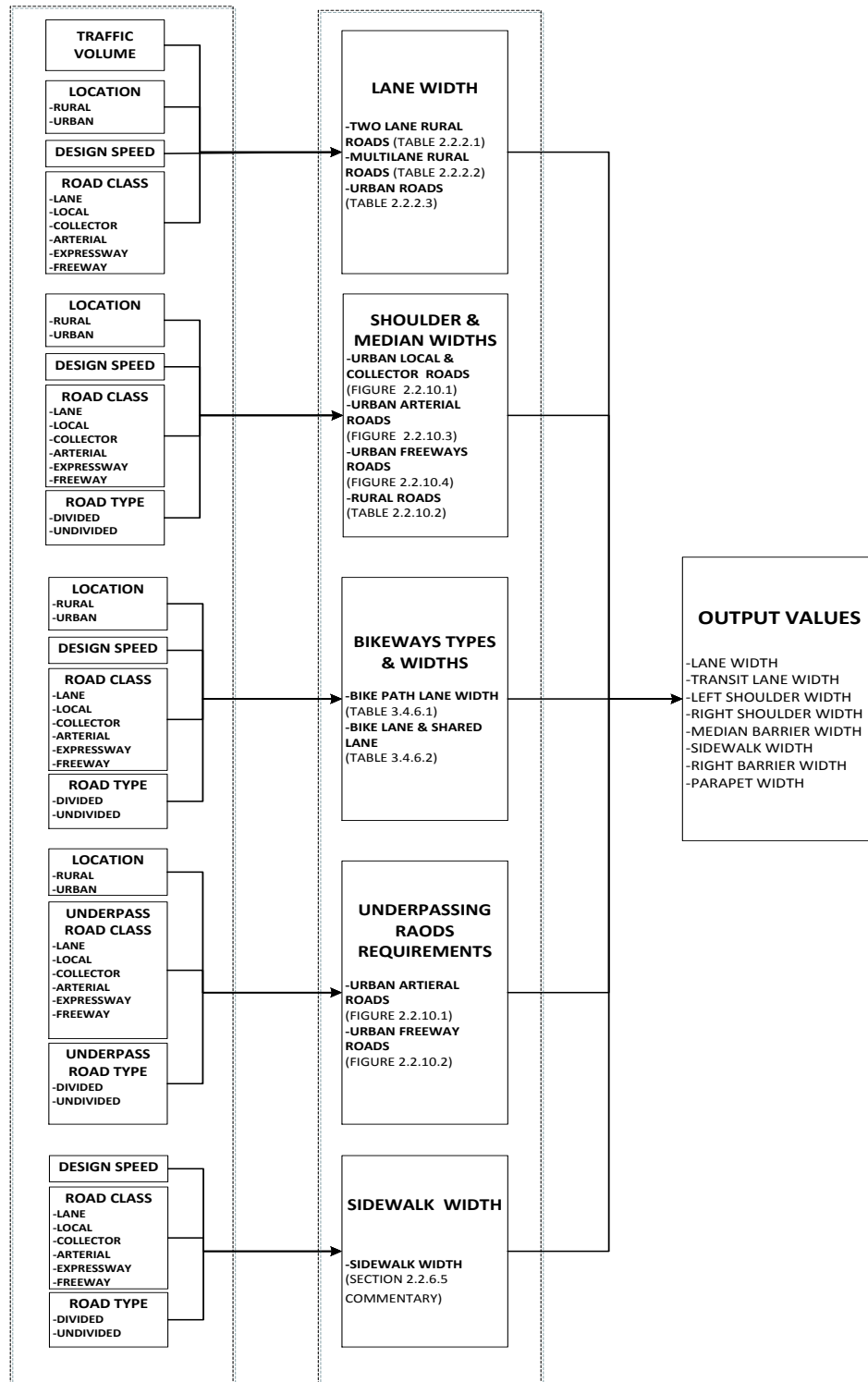


Figure 3. 3 Highway Geometric Design Knowledge Base Flow Process

3.3.1.2 Navigational Waterways Clearances Knowledge Base

As mentioned previously in Chapter 2, the NWPD guideline divides the vessels into three main classes. The guideline provides Table 2-1, Table 2-2 and Table 2-3, that summarize the vessel classifications for recreational vessels, small to medium vessels and large vessels respectively. The tables are illustrated in Appendix B.

3.3.1.2.1 Small Recreational Vessels

For small recreational vessels, the horizontal navigational clearance is dependent on a base width of 3.0 m. Also, the horizontal navigable clearance is dependent on three factors which are the length factor (LF), velocity factor (VF), and the traffic factor (TF) (NWPD, 2006). The effect of these three factors is not cumulative, and only the one with the largest adjusted width is to be used. The velocity factor is meant to measure the relation between the vessel's velocity and its stability. High velocity will reduce the stability of the vessel. NWPD guideline provides Table 4-1 Stream velocity Ranges and Applicable Velocity factors (VF) to help designers to obtain velocity factor. The length factor is only required when considering the installation of a water-crossing structure under which navigation is expected to occur. The length factor is based on the need to maintain a certain apparent area of the opening at the end of the structure, which is the size that the opening appears to be when viewed through the structure from 10 m upstream of the structure. This apparent area, as seen through the structure, is considered to be the minimum necessary to provide a perceived level of comfort and safety for navigation through the structure. The NWPD guideline provides Table 4-2, Structure Length and Corresponding Equivalent Areas and Length Factor (LF), to obtain the length factor. All the tables are illustrated in Appendix B. The traffic factor is used when there is two-way traffic in the waterway. In such a case, the traffic factor is equal to 1.35, while a factor of 1.0 is used in case of one-way traffic.

After identifying the different values of each factor, the horizontal clearance formula provided by the NWPD guideline, as shown in Equation 3.1, is used to determine the minimum horizontal clearance required for safe navigation by small recreational vessels.

$$\textit{Minimum Horizontal Clearance Required} = \textit{the Greatest of} \begin{cases} 3.0 \text{ m} \times VF \\ 3.0 \text{ m} \times TF \\ 3.0 \text{ m} \times LF \end{cases} \quad [3.1]$$

In reference to the depth navigational clearance for small recreational vessel, the NWPD guideline requires a depth of 0.3 m as the minimum depth for a safe navigation by canoes and kayaks. This depth is to be measured from the normal water level, which is defined by the Ontario Ministry of Transportation as the average summer water level.

To determine the minimum height clearance required by small recreational vessels, the NWPD guideline requires a minimum height of 1.5 m to be used. The minimum height is required to be modified by using the length factor (LF). From Table 4-2, Structure Length and Corresponding Equivalent Areas and Length Factor (LF), the length factor can be obtained. The minimum height required is then determined using Equation 3.2 provided by the NWPD guideline as follows:

$$\textit{Minimum Height Required} = 1.5 \text{ m} \times LF \quad [3.2]$$

where, LF = Length Factor

The minimum required height is measured from the high water level condition, which is obtained from the Ordinary High Water Level (OHWL) provided by the Ontario Ministry of Transportation. Figure 3.4 shows the process of using all information gathered from the NWPD in developing the recreational vessels navigational clearances knowledge base.

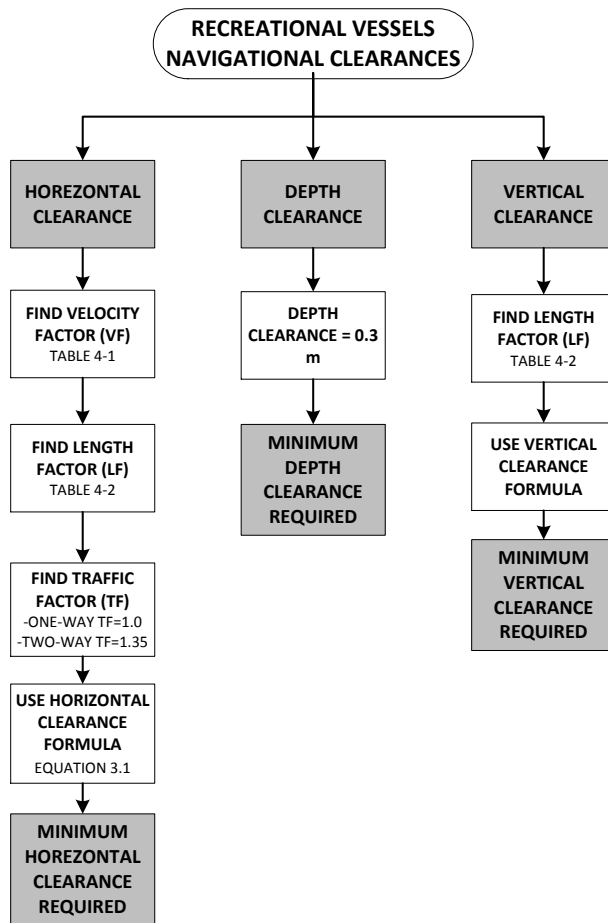


Figure 3. 4 Knowledge Base Process flow of the Navigational Clearances for Recreational Vessels

3.3.1.2.2 Small to Medium Commercial and Cargo Vessels

Generally, if a vessel is less than 25m in length, it is considered to be within the small to medium commercial and cargo vessel classification. The NWPD guideline provides horizontal clearance guidelines, which accommodate the effects of vessel maneuverability, bank suction, structure clearance and factor in buffer safety. All the factors are given as a multiplier to the target vessel beam. Thus, to find the minimum horizontal clearance the following steps are followed:

1. Define the vessel beam (B), which can be obtained by defining the type of vessel as classified in (NWPD) Table 2-2

2. Obtain the Maneuvering Lane Width (MLW) by using (NWPD) Table 5-1 “Recreational and Small Commercial Vessel Maneuvering Lane Width Requirement”
3. Obtain Bank Suction Clearance (BSC) by using (NWPD) Table 5-2 “Bank and Structure Clearance for Reactional and Small to Medium Commercial and Cargo Vessels”
4. Provide an additional horizontal clearance safety buffer to account for crosswinds, and for lack of visibility. This can be done using (NWPD) Table 5-4 “Horizontal Clearance Safety Buffer due to Crosswinds (AHC1)”, and (NWPD) Table 5-5 “Horizontal Clearance Safety Buffer due to Navigational Aids and Visibility (AHC2)”
5. Apply the NWPD horizontal clearance formulas shown in equation 3.3 for one-way traffic, and equation 3.4 for two-way traffic.

$$\text{Horizontal Clearance for One Way Traffic} = MLW + (2 \times BSC) + (2 \times AHC1) + (2 \times AHC2) \quad [3.3]$$

where, MLW= Maneuvering Lane Width, from Table 5-1

BSC= Bank/Structure Clearance, from Table 5-2

AHC1= Wind Effects, from Table 5-4

AHC2= Navigational Aids and Visibility, from Table 5-5

$$\text{Horizontal Clearance for Two Way Traffic} = (2 \times MLW) + (2 \times BSC) + TWT + (2 \times AHC1) + (2 \times AHC2) \quad [3.4]$$

where, TWT= Two-Way Traffic Clearance.

MLW= Maneuvering Lane Width, Table 5-1.

BSC= Bank/Structure Clearance, Table 5-2.

AHC1= Wind Effects, Table 5-4.

AHC2= Navigational Aids and Visibility, Table 5-5.

All these tables and equations are going to be used in developing the knowledge base of the navigational waterways. Figure 3.5 illustrates the process of obtaining the horizontal navigational clearance for small to medium vessels.

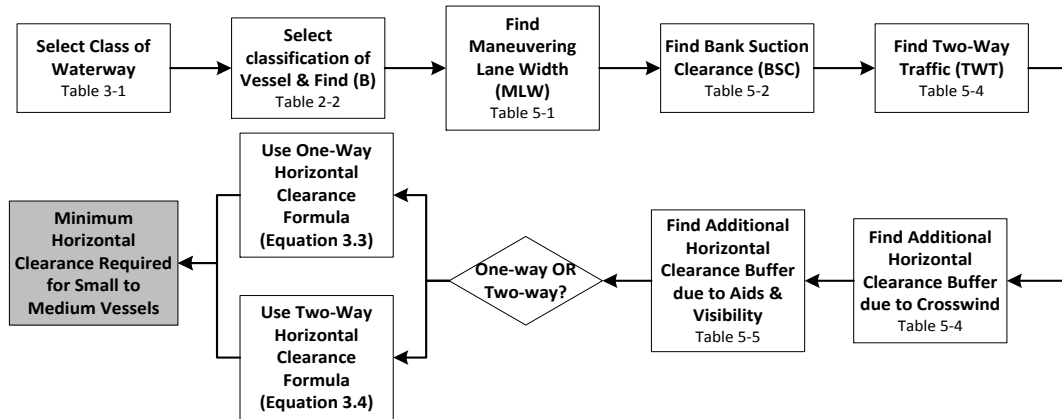


Figure 3. 5 Process flow of obtaining Horizontal Clearances for Small to Medium Vessels

The NRPD guideline provides a method for finding the depth navigational clearance for small to medium vessels. The depth clearance is measured from the minimum low water level, which is the normal water level defined by the Ontario Ministry of Transportation as the average summer water level. To be able to find the depth, the vessel draft should be defined. The vessel draft is the distance between the waterline and the lowest point on the hull below the waterline, which can be obtained from Table 2-2. Figure 5-2 in (Appendix B) illustrates the depth navigational clearance diagram. Once the vessel draft is obtained, additional depth is to be added to the vessel draft due to factors such as squat, wave effects, sedimentation and channel bed material. Figure 3.6 shows the process of identifying the depth clearance for small/medium vessels. All the tables mentioned in the figure are illustrated in Appendix B.

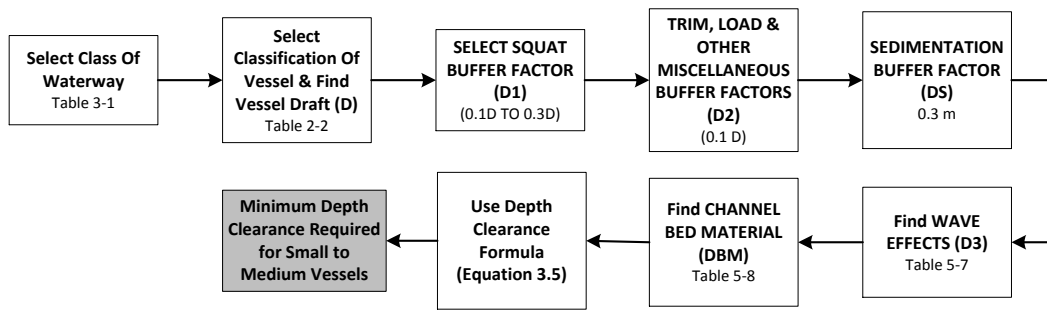


Figure 3. 6 Process flow of obtaining Depth Clearances for Small to Medium Vessels

After obtaining all depth factors, the minimum depth clearance required for small to medium commercial and cargo vessels can be calculated using Equation 3.5 provided by the NWPD guideline.

$$\text{Minimum Depth Clearance Required} = D + D1 + D2 + D3 + DS + DBM \quad [3.5]$$

where, D = Target Vessel Draft, from Table 2-2

D1 = Squat Buffer Factor, value of (0.1 D to 0.3 D)

D2 = Trim, Load and Other Miscellaneous Factor, value of (0.1 D)

D3 = Wave Effect, from Table 5-7

DS = Sedimentation Clearance, value of (0.3 m)

DBM = Clearance due to Channel Bed Material, from Table 5-8

The vertical navigational clearance protects the vessel from hitting the overhead structures. The NWPD guideline provides a way to determine the vertical clearances, which accounts for vessel height, wave effects and speed effects. The vertical clearance is measured from the maximum height of the water level. To determine the vertical navigational clearance, the vessel height must be known. The vessel height is the distance between the waterline and the vessel's highest point above the waterline. The height of the ballast condition has to be used, which refers to the condition when the vessel is completely unloaded. Once the vessel height is obtained, additional vertical clearance to account for waves should be added to the vessel height. Table 5-9 "Height

Clearance due to Wave Effects” is used to obtain the additional clearance. However, the wave effect factor depends on the vessel draft, which is obtained using Table 2-2. In addition to the wave effect, NWPD provides additional height safety buffer (HSB) of 0.9 m to account for the removable items attached to the top of the vessel, such as radar and flags. Figure 5-2 in Appendix B illustrates the height navigational clearance diagram. Then, the minimum vertical clearance required formula, provided by the NWPD guideline, is used to calculate the minimum vertical clearance required as shown in Equation 3.6.

$$\text{Minimum Vertical Clearance Required} = H + WE + HSB \quad [3.6]$$

where, H = Target Vessel Height.

WE= Wave Effects, from Table 5-9

HSB= Height Safety Buffer, value of (0.9 m)

Figure 3.7 shows the process of identifying the vertical clearance for small/medium vessels.

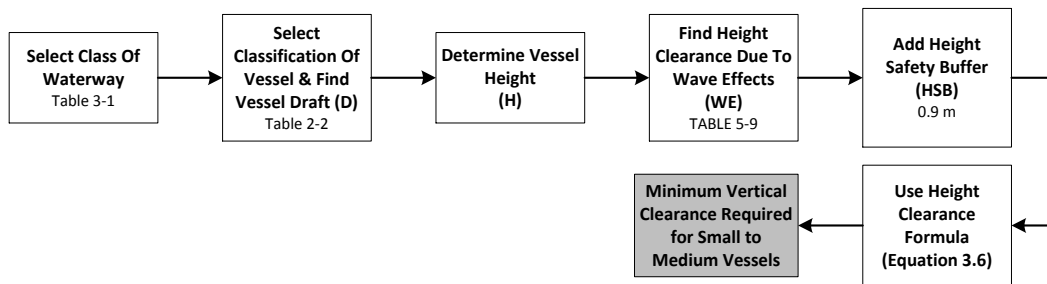


Figure 3.7 Process flow of obtaining Vertical Clearances for Small to Medium Vessels

The process flow of the navigational waterways clearances knowledge base is shown in Figure 3.8. All the tables mentioned in Figure 3.8 are illustrated in Appendix B.

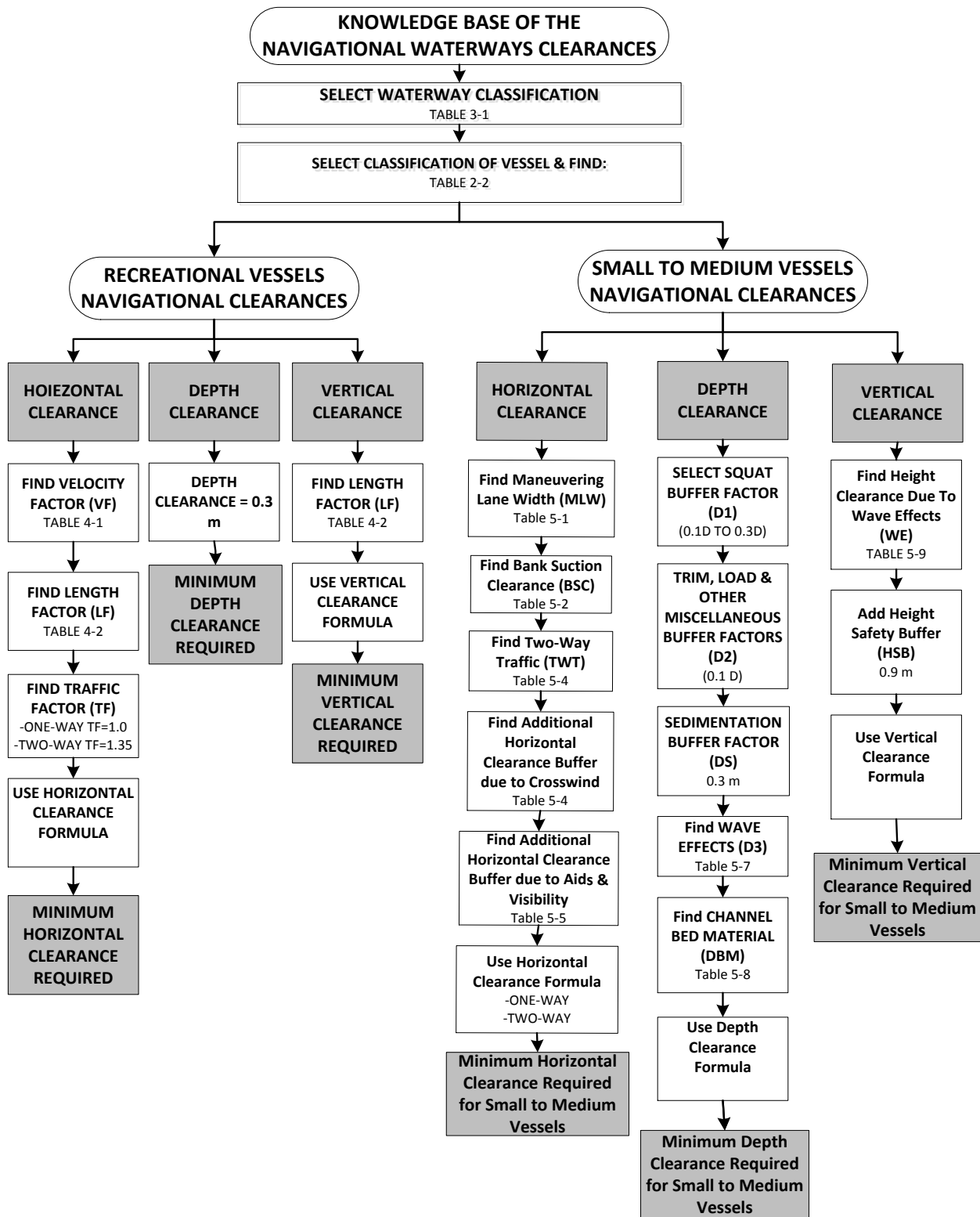


Figure 3. 8 : Process Flow of the Navigational Waterways Clearances Knowledge Base

3.3.1.3 Structural Design Knowledge Base

Little structural design information is available at the conceptual design stage. In addition, there is no specific formula or unique solution the designers have to follow; structural design is based mainly on the designer's experience and knowledge. Thus, collecting information from bridge design experts is the only source for developing the structural design knowledge base. In this research it was decided to interview two bridge design experts to elicit information and knowledge for developing the structural design knowledge base. The reason for selecting two experts in developing the knowledge base is that it has been found that interviewing multiple, more than one, experts is highly beneficial and is recommended for knowledge base development (Moore, 1991). Interviewing more than one expert has been found to provide less chance of missing vital information, and to reduce the length of the overall knowledge elicitation process. Care is taken in choosing experts who have long experience in bridge design. The selected experts are currently practicing bridge design to insure that their expertise will be relevant and useful; otherwise, there would be a risk that their knowledge is out of date. One of the selected experts is currently working in the public sector, Head of structural department of Ministry of Transportation of Canada, and the other expert is currently working in the private sector, Senior structural engineer in an international consultancy engineering company. The meeting involved an interview with the expert, in which the research was explained in full, ensuring the expert understood the intended capabilities of the proposed model, the degree of co-operation which would be necessary, and the format that the model would take. Providing information about the type of knowledge that would be required allowed the problem-solving methodology employed by the experts to be quantified. The experts recommended using AASHTO LRFD Bridge Design Specifications (2014) as the source of the algorithmic knowledge base. AASHTO LRFD (2014) Table 2.5.2.6.3-1 "Traditional Minimum Depths for

Constant Depth Superstructure" is used to obtain the span depth ratio. The table is included in Appendix D. The span-depth ratio is provided as an optional criterion to be used by designers to avoid undesirable structural effects due to structural deformation. The span depth ratio can be used to obtain the minimum depth of bridge deck. However, bridge design experts suggested adding 100 mm or 150 mm to the depth obtained by using the span depth ratio.

Other heuristic information concerning bridge components was collected and gathered by interviewing the two bridge design experts. The information was gathered through asking the experts questions about the type and preliminary dimensions for all the bridge components, such as the choice of bridge deck, decisions concerning the supporting structure, the number of spans, and type of material for the bridge components. The collected information is stored in an Excel spreadsheet for later use in the conceptual cost estimating module. Sample of the collected information is included in Appendix D. This can assist the designer or user to generate preliminary dimensions for the bridge components.

3.3.2 Interface

In developing the interface for the model, a programming language with the capability to integrate and exchange information with MS Excel and AutoCAD with high data recall efficiency should be used. In addition, it should have the capability to develop a user friendly interface that can assist the user in entering the input values into the system. Furthermore, the programming language should have the ability to execute logical statements and rules in the format of If-Else in order to implement the knowledge base.

To fulfill all these requirements, Visual Basic .NET (VB.NET) is chosen as a programming language to develop the interface of the model. VB.NET has the capability to integrate with

other applications through Visual Basic for Applications (VBA), which can be used in controlling many aspects of other host applications such as Microsoft Office and AutoCAD.

After gathering all the required knowledge bases, the next step is to create If-Else rules and logical statements using the programming language. This step is accomplished simply by creating If-Else rules and logical statements that represents the process flows of the knowledge bases. It is important to keep in mind while developing the interface to provide guidance to the user in the process of inserting and selecting variables.

3.3.3 Bridge Type Selection

It is necessary to select the bridge type prior to starting the process of developing conceptual cost estimating of the bridge project. Various aspects need to be considered when selecting an appropriate bridge type in the conceptual design stage. A few criteria such as cost, aesthetics and the durability of bridges can only be judged and balanced by experienced designers. However, due to the lack of information and data at the conceptual design phase the selection process is somehow difficult. Many artificial intelligence decision support systems are available, which can be used to help in selecting the bridge type, such as fuzzy logic, neural networks and cognitive simulation. However, the design experts interviewed recommended to selecting the bridge type depending on existing bridges.

Historical data of all existing bridges in Ontario was collected from the Ministry of Transportation of Ontario (MTO). The data contains information about 2,784 bridges in Ontario. The information includes (1) bridge structural type; (2) bridge sub-structural type; (3) total bridge length; (4) total bridge width; (5) bridge span arrangement; and (6) material. The structural bridge types available in the database are (1) beam/girder; (2) arch; (3) frame; (4) slab; (5) temporary modular; and (6) truss. After collecting the data, a validation and consolidation

process is applied to remove any repetitive or incomplete information. The data is presented in an Excel workbook. The data was divided based on the bridge span number. Each Excel workbook contains sheets that represent bridge types. Figure 3.9 illustrates a sample of Existing Bridge Excel workbook.

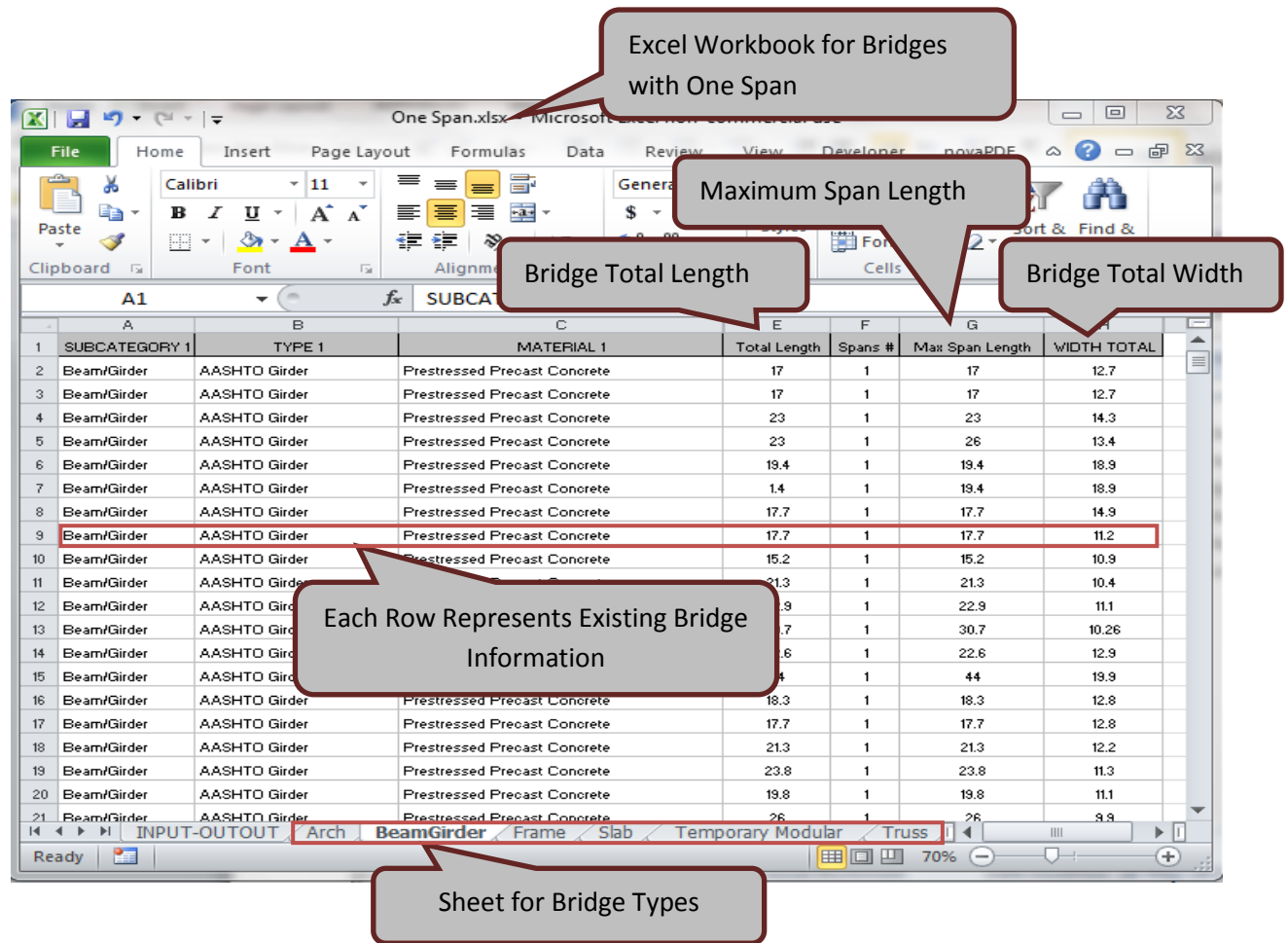


Figure 3. 9 Sample of Existing Bridge Excel Spreadsheet

The criterion of selecting bridge type is based on comparing the user's input variables with the variables of an existing bridge, and selecting a bridge type that matches the user's input variables. As shown previously in Figure 3.2, the output variables of the knowledge base system are used as input variables for the bridge type selection process. These variables are (1) bridge length, (2) largest span length, (3) bridge width and (4) number of spans. In addition, the user is required to

specify a value of Closeness Factor (K), which is a factor used in quantifying the similarity between the proposed bridge variables with existing bridge variables. Based on the number of spans, the existing bridge Excel spreadsheet is selected to be used in selecting the bridge type. The variables of bridge length, bridge width and largest span length are used to calculate the closeness weights. Closeness Weights, which are the ratios between the input variables and the existing bridge variables, are then to be calculated using the following equations:

$$\text{Closeness Weight of Bridge Width} = \frac{W_0}{W_{i_n}} \quad [3.7]$$

$$\text{Closeness Weight of Bridge Length} = \frac{L_0}{L_{i_n}} \quad [3.8]$$

$$\text{Closeness Weight of Bridge Span Length} = \frac{S_0}{S_{i_n}} \quad [3.9]$$

Where, W_0 = Width of the proposed bridge

W_{i_n} = Width of the existing bridge i_n

L_0 = Length of the proposed bridge

L_{i_n} = Length of the existing bridge i_n

S_0 = Largest Span length of the proposed bridge

S_{i_n} = Largest Span length of the existing bridge i_n

The next step is to calculate the adjusted closeness weight, to see how close the proposed variables are to the existing bridge variable. The adjusted closeness weight has a range value between one and zero. Adjusted closeness weight value 1.0 means that the proposed bridge variables exactly match the existing bridge variables, while adjusted closeness weight of value zero represents that the proposed bridge variables do not match the existing bridge variables.

The following equation is used to calculate the adjusted closeness weight:

$$Adjusted\ closeness\ weight = \begin{cases} Closeness\ Weight \geq 2, & 0 \\ Closeness\ Weight \geq 1, & 2 - Closeness\ Weight \\ Closeness\ Weight < 1, & 1 - Closeness\ Weight \end{cases} \quad [3.10]$$

All of these steps are then repeated for all the bridge cases within the same Excel sheet. As mentioned above, each Excel sheet represents a bridge type. Once adjusted closeness weights are calculated for all the bridge cases within an Excel sheet, the maximum value of the adjusted closeness weights is found and to be compared with the closeness factor K. If the maximum closeness weight is found to be bigger than the closeness factor K, then the bridge type is recommended to the user. If the maximum closeness weight is found to be smaller than the closeness factor K, then the existing bridge type is rejected. All these calculations are repeated with all the bridge types available in the Existing Bridge Excel workbook. Figure 3.10 shows the process flow of the bridge type selection process.

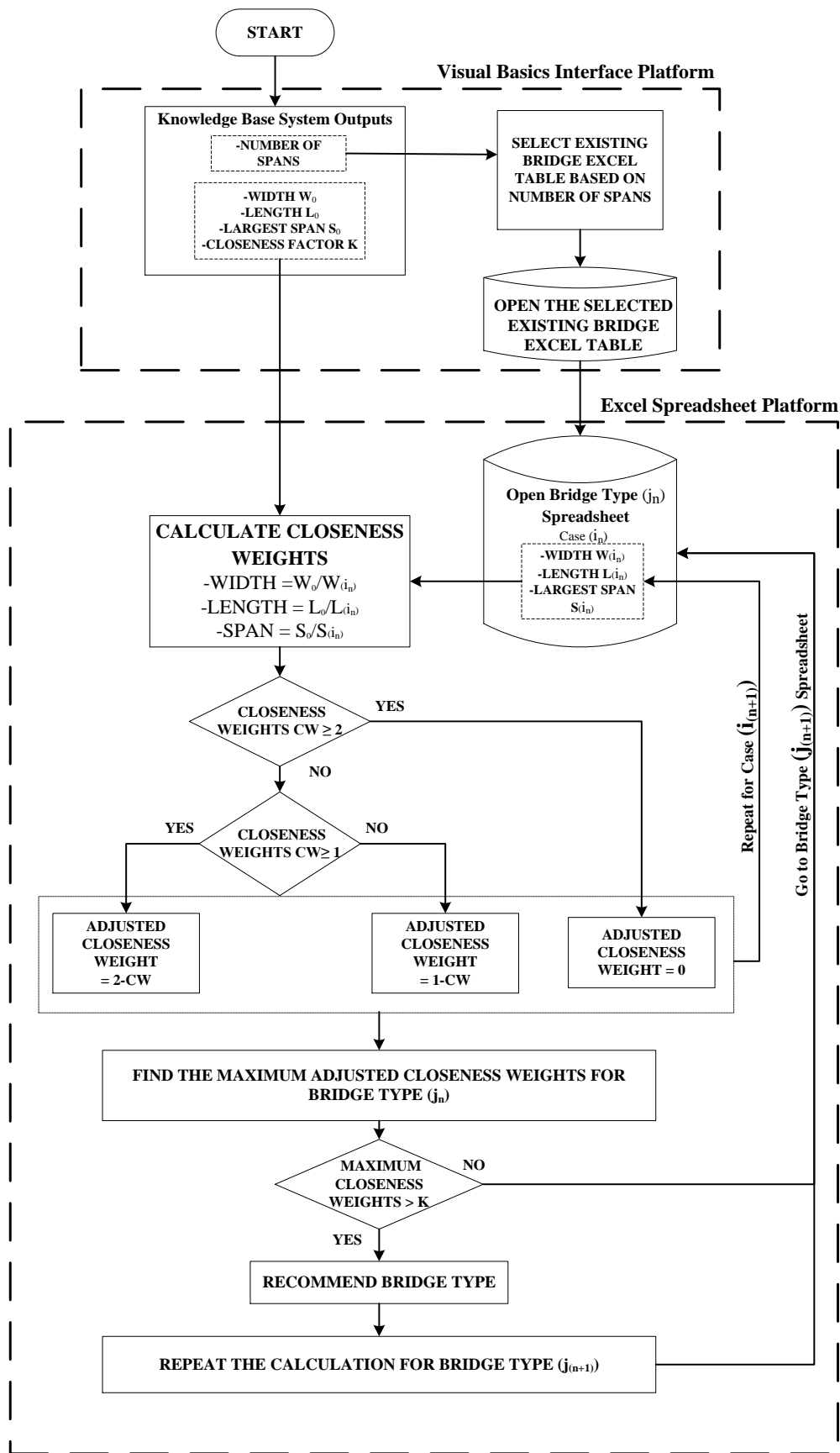


Figure 3. 10 Process Flow of Bridge Type Selection

3.4 Conceptual Cost Estimating Module

It is necessary to define the dimensions and to select the bridge design type before one can estimate the cost. Thus the output of both the knowledge-based system and the bridge type selection process are considered as input variables in the conceptual cost estimation module.

3.4.1 Cost Data

Preparing a cost estimate greatly depends on the accuracy of the collected data. Thus, data collection has to be carried out before developing the cost estimating module. Since published cost data is not available for bridges, the only remaining alternative source of cost data is collecting the cost data from previously constructed bridge projects. In-house cost data is considered to be the best choice in this case; however, cost data of previously constructed bridge projects can be used for the research purposes. The cost data collection process was conducted before developing the module. The resources of the collected data were from different previously constructed bridge projects in North America. Samples of the collected cost data are illustrated in Appendix E. Using the ASTM (E2103) standards and the collected cost data, a bridge elements and components Excel spreadsheet for each type of bridge is created. These Excel spreadsheets are used to calculate the estimated conceptual cost for the project by entering the dimensions and parameters obtained from the KBS.

3.4.3 Adjustments

It is important to adjust the cost of previous similar projects for time and location so that they are suitable for the proposed project.

3.4.3.1 Adjustment for Location

In order to adjust the cost according to the location, R. S. Means (2012) cities indices are used for this purpose. R.S. Means adjustment for location Equation [3.6] is used as follows:

$$C_c = C_r \left(\frac{I_c}{I_R} \right) \quad [3.6]$$

where C_c = cost of proposed project

C_r = cost of previous project

I_c = city index for the current project

I_R = city index of the previous project.

3.4.3.2 Inflation Adjustment

Once the location adjustments are applied to the costs, inflation adjustment can easily be applied by entering the inflation rate and the number of the years for which the project cost is needed.

R.S. Means adjustment for time Equation [3.7] is used to calculate the inflation adjustment as follows:

$$F = P \times (1 + i)^n \quad [3.7]$$

where F = Future or present total project cost

P = past total project cost, taken from the location adjustment equation

i = inflation rate

n = number of years between the proposed project and the previous project

3.4.4 Data Flow

Once the cost adjustments are applied, conceptual cost estimating reports can be generated.

Three different types of reports are to be generated, which are: (1) detailed cost estimating report, (2) sub-classification cost estimating report, and (3) summary cost estimating report. The purpose of generating three types of reports is to explain the cost allocation clearly by generating a cost estimate for each work group such as, superstructure, substructure, and site work, etc.

Figure 3.11 summarizes the data flow of the conceptual cost estimation module.

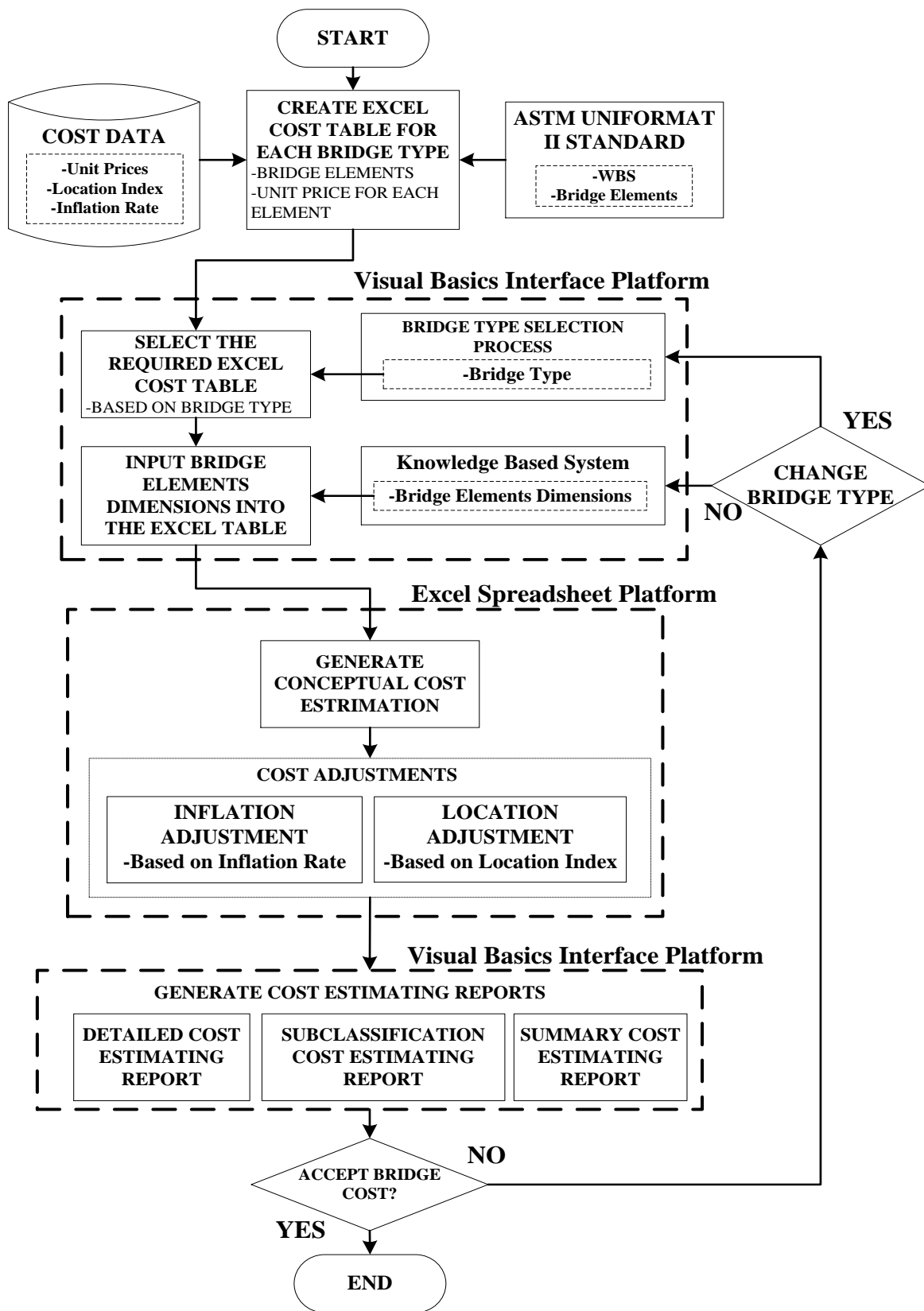


Figure 3. 11 Data flow of the Conceptual Cost Estimation Module

3.5 3D-CAD Module

The purpose of the 3D-CAD module is to visualize the information of each bridge element and to present it in a 3D model. It is important that the generated 3D model contain visual properties that allow the user to identify the texture and color of the material in order to visualize the realistic aesthetics of the bridge. To do that, AutoCAD is utilized as a visualization tool, because its capabilities suit the purpose of the module.

AutoCAD has the ability to exchange information with many applications with high efficiency in performing data recall. In addition, AutoCAD has the ability to assign properties such as material type and color to objects. This ability gives the 3D object a realistic visualization, which can assist the user in judging the aesthetics of the bridge elements. Moreover, AutoCAD has the ability to add the effect of lightning on the 3D object to visualize the light and shade effect, which is one of the bridge aesthetics principles. Besides all these abilities, utilizing AutoCAD as a visualization tool will allow the user to orient the 3D bridge model and visualize it from different views.

As shown in Figure 3.1, both the conceptual cost estimating and the visualization modules share the same input variables, which are the output variables of the KBS and the bridge type selection process. Thus, the 3D-CAD module can also use the Excel spreadsheets created from combining the cost data and the ASTM standards of bridge element classification. An exchange of information between the two modules is provided. In other words, if any changes or modifications with the generated 3D bridge model result in changes in the Excel spreadsheet, it will lead to changes in the conceptual cost estimation reports. To implement this data exchange, it is important to create a link between the visualization tool, AutoCAD, and the Excel spreadsheets of the model. Figure 3.12 illustrates the data flow of the 3D-CAD module.

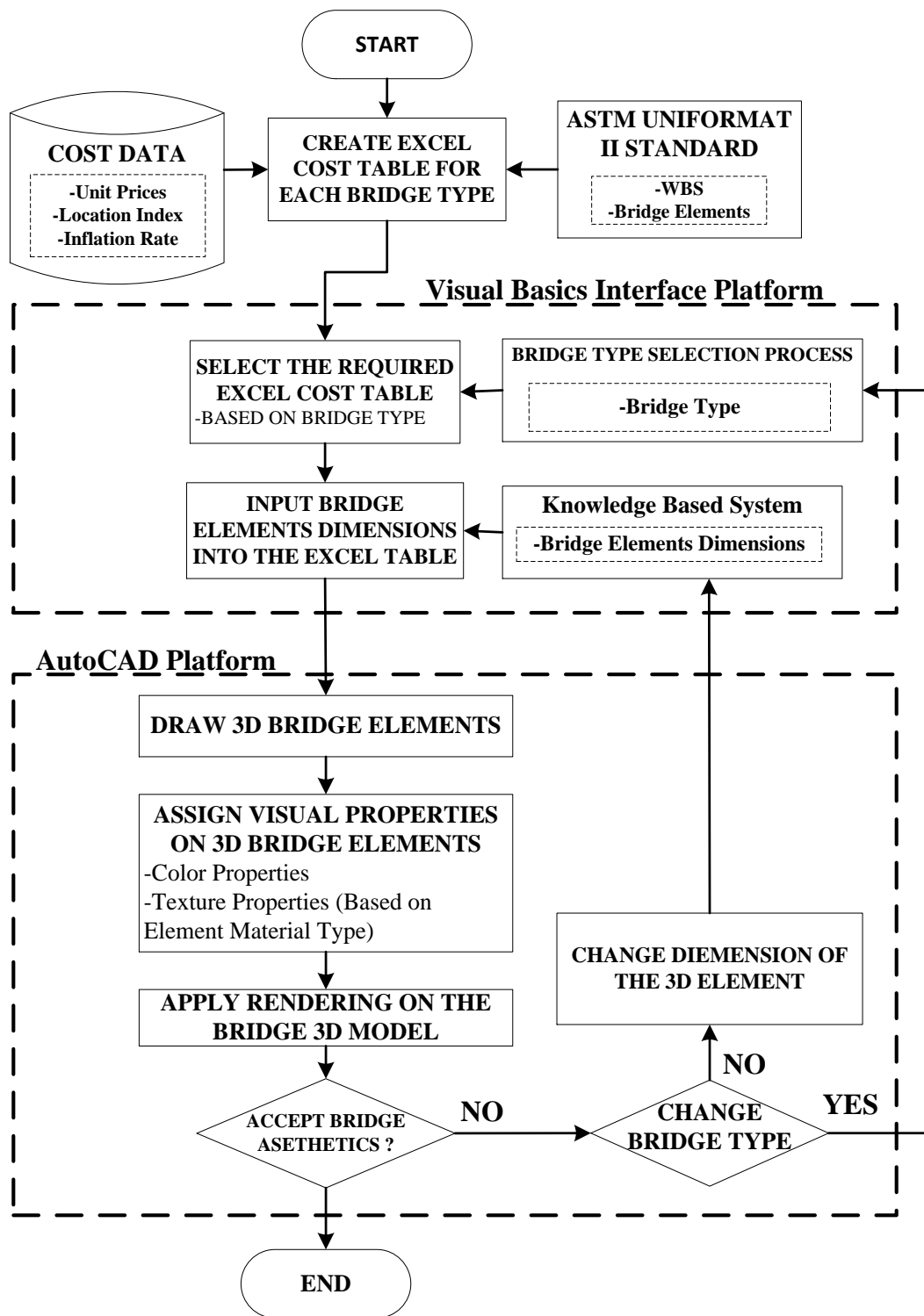


Figure 3. 12 Data flow of the 3D-CAD Module

Figure 3.13 illustrates the data flow between the cost estimating module and the 3D-CAD module.

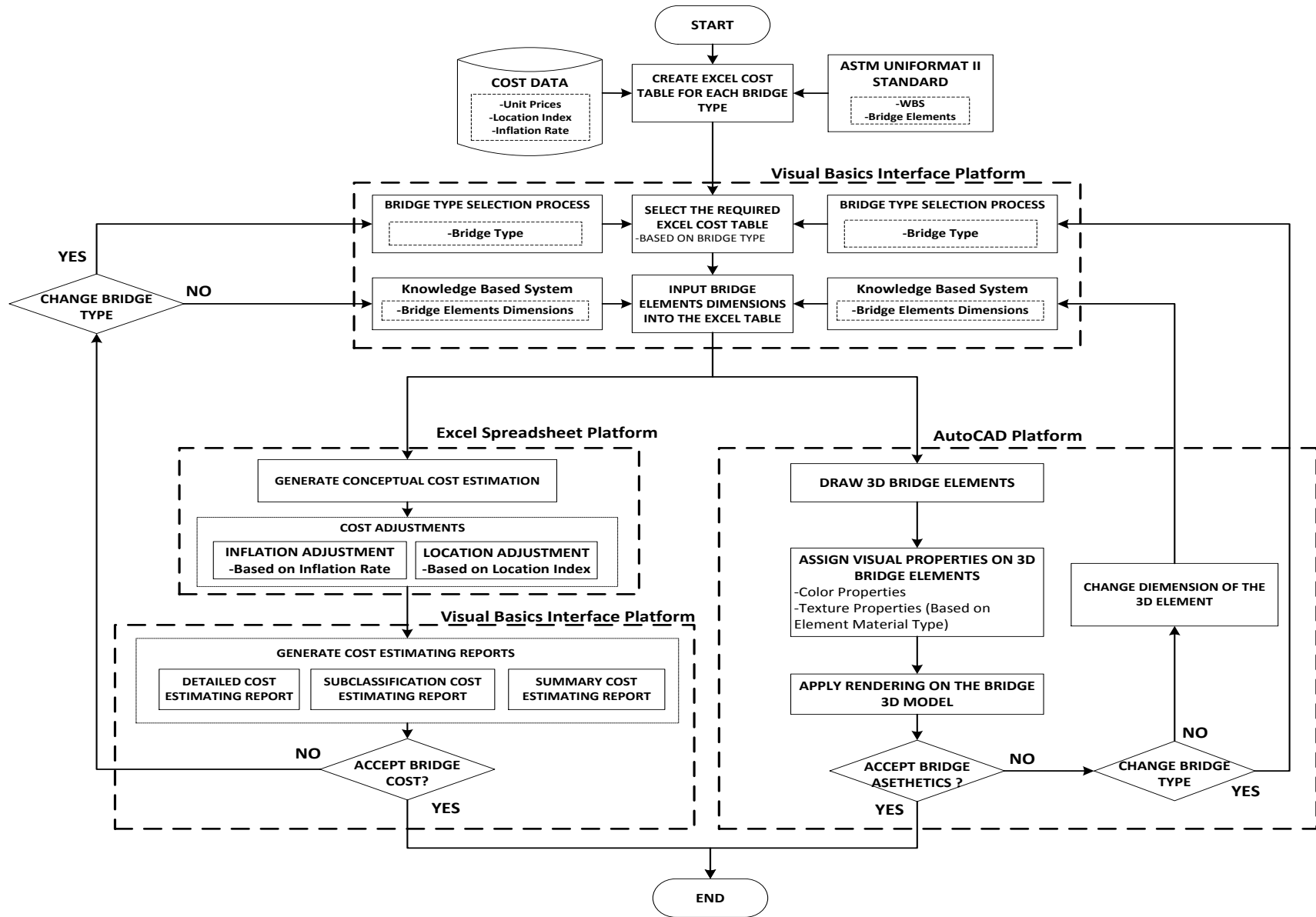


Figure 3. 13 Data Flow between the Cost Estimating Module and the 3D-CAD Module

3.6 Summary

This chapter presented the methodology used in developing a model that integrates conceptual cost estimating with 3D CAD. The model's architecture consists of three main modules and they are: (1) Knowledge-Based System, (2) conceptual cost estimation module, and (3) 3D-CAD module. The knowledge-based system was presented by defining the knowledge bases used in the model. In addition, the bridge type selection process was introduced by presenting the flow process of bridge type selection. Then, the conceptual cost estimating module was presented by defining the collected cost data and the data flow of the module. Finally, the process flow of the 3D-CAD module was presented, and the integration between the conceptual cost estimating module and the 3D-CAD module was explained. A data flow chart was presented to explain the integration process.

Chapter Four

Model's Development

4.1 Introduction

This chapter describes the model's development process. The process followed in developing the model consists of three main steps: (1) developing the knowledge-based system, (2) developing the conceptual cost estimating module, and (3) developing the 3D-CAD module. The development of the knowledge-based system is presented by showing the development of the interface and the implementation of the knowledge base rules. The conceptual cost estimating module development is presented by establishing the process of the collecting data and the process of developing Excel spreadsheets used in the module. The development of the 3D-CAD module is presented by showing the process of the visualization process and the implementation of the 3D-CAD module integration with the conceptual cost estimating module.

4.2 Knowledge-Based System Implementation

The Knowledge-Based System (KBS) consist of two main components, the knowledge base and the interface. This section will present the development of the knowledge base within Visual Basic .NET. The knowledge base consists of three main sources of information, which are: (1) highway geometric design guidelines, (2) navigational waterways guidelines, and (3) bridge structural design code. To implement the knowledge base, the following two steps are followed:

1. Develop an interface using VB.NET according to the order of the knowledge bases process flow.
2. Write programming code for VB.NET by:
 - Converting knowledge base tables and information representation to IF-ELSE rules in the VB.NET language.

- Representing formulas and equations in the VB.NET language to perform the calculations.

These two steps will be followed in developing the interface of the knowledge-based system.

4.2.1 Highway Geometric Knowledge Base Implementation

In developing the highway geometric design knowledge base, Figure 3.3 is followed. According to the process flow of the knowledge base, the user should first identify the road classification in order to determine roadway elements and dimensions. Thus, the interface was developed accordingly, as shown in Figure 4.1. The variables are presented in a form of drop lists. The drop lists present a list of choices to the user from which he/she selects an item.

The form contains the following parameters and their associated callouts:

- Country (Callout: Country)
- Province (Callout: Province/state)
- City (Callout: City List)
- Location (Callout: Location (Rural/Urban))
- Road Class (Callout: Road Class: -Local, -Collector, -Arterial, -Expressway, -Highway)
- One Way / Two Way (Callout: Traffic Type (one way/two way))
- Road Type (Callout: Road Type (Divided / Undivided))
- Design Speed (Callout: Design Speed)
- Traffic Volume (Veh/hr) (Callout: Traffic Volume)
- Average Annually Daily Traffic (Veh/hr)

Figure 4. 1 Snapshot of the Highway Geometric Design Knowledge Base Selection Form

Once the interface is developed, writing code for each of the drop lists is required. It is important to provide the user the guidance to enter the required information. To accomplish that, items of the drop lists are added and modified according to the users' entries. In other words, the items of

the second drop list will be changed according to the selected items of the first drop list. For instance, if the user chose "Canada" in the Country drop list, the Province drop list will present Canadian provinces to the user as items, while, if the item "United States" was chosen from the Country drop list, the name of the second drop list will be changed to "States", and it will present a list of states as items. The same procedure is used for the other drop lists, Table 1.3.4.1 and Table 1.3.4.2 from TAC (1999) are followed to assign the items of the drop lists. Figure 4.2 shows an example of the drop list coding, while the whole code of the model is illustrated in Appendix F.

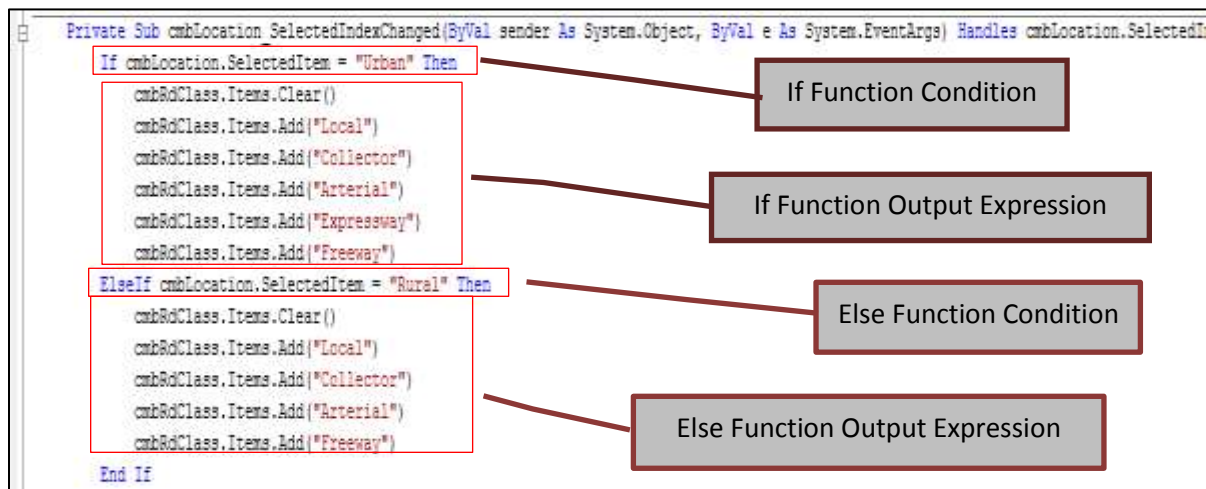


Figure 4. 2 Sample of the Code for the Highway Geometric Design Knowledge Base Drop lists

The model instantly modifies the items of the drop lists based on the user's selections. For example once the location type is selected, the model will then instantly modify the selection items of the road class drop list. Figure 4.3 shows the road class drop list.

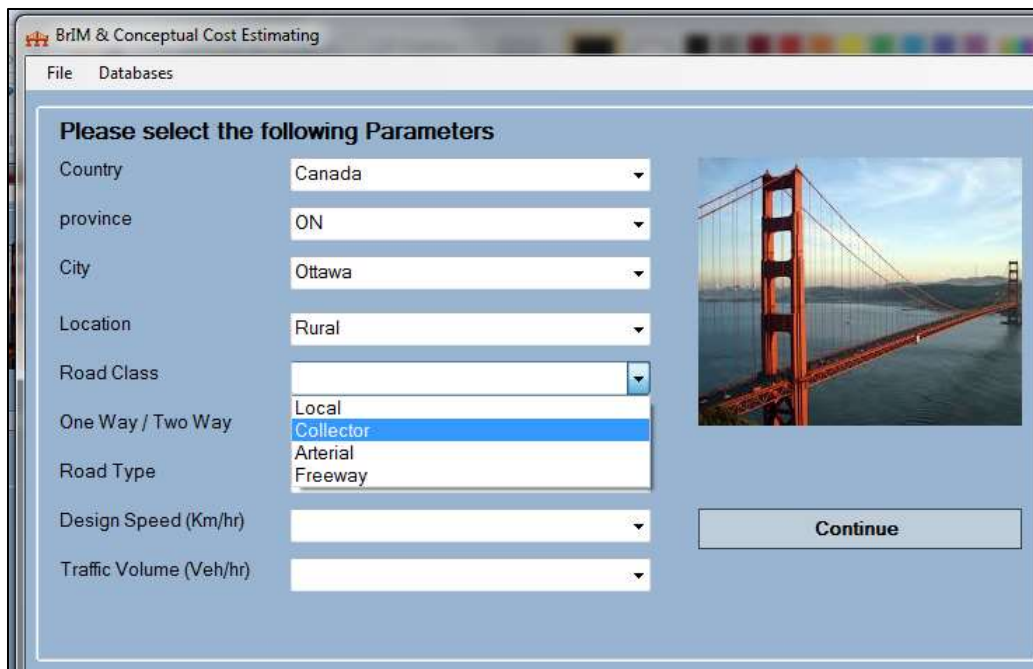


Figure 4. 3 Snapshot of the Road Class Drop List

Once the VB.NET interface for the highway geometric design knowledge base is developed, the next step is to employ IF-ELSE functions in implementing the knowledge base. The procedure in this step is to convert all the information mentioned in Figure 3.3 to IF-ELSE and logical statements within the interface. The first step is to declare variables to the VB.NET interface engine to be recalled later in the statements. Samples of the declared variables to the VB.NET are showed in Figure 4.4.



Figure 4. 4 Sample of Declared Variables within the VB.NET Interface for the Highway Geometric Design Knowledge Base

All the declared variables and the logical operations are used in presenting the information of Figure 3.3 within the interface. Figure 4.4 shows an example of presenting the TAC (1999) "Table 2.2.10.2 Right Shoulder Width for Rural Roads" as IF-ELSE rules. IF-Sub Conditions, which are IF conditions within the expressions of another IF statement, are also utilized in presenting the information of the knowledge base within the interface. The whole code of the model is included in Appendix F.

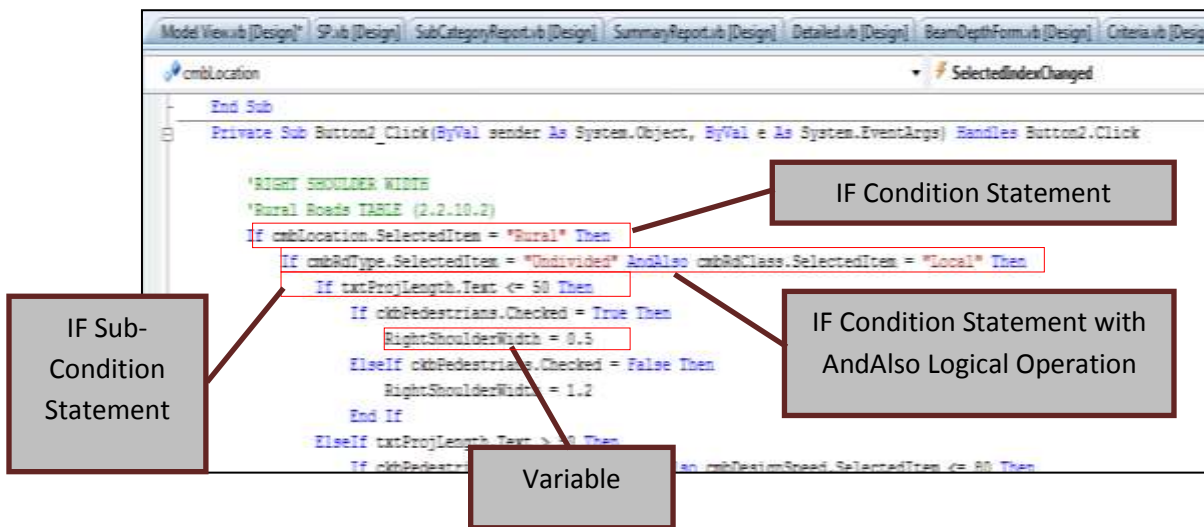


Figure 4. 5 Sample of the IF-ELSE Statements in Presenting Knowledge base within the Interface

The system will modify items of the design speed and traffic volume drop lists according to the information presented in TAC (1999) Table 1.3.4.1 and Table 1.3.4.2 as shown in Figure 4.6 and Figure 4.7 respectively.

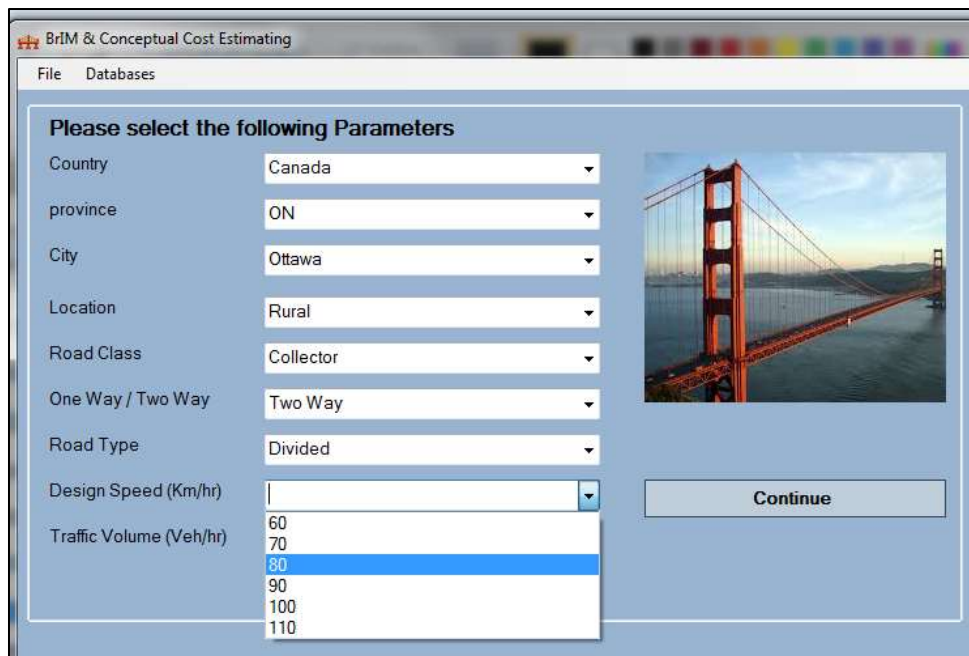


Figure 4. 6 Snapshot of the Design Speed Drop list

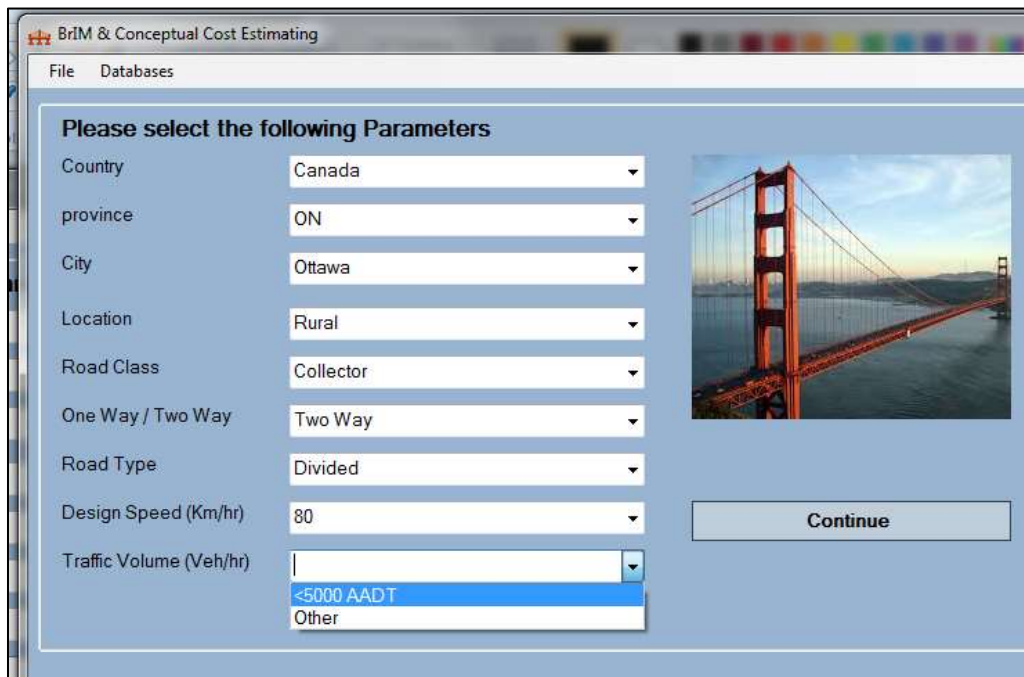


Figure 4. 7 Snapshot of the Traffic Volume Drop List

If the user selects the item "Other" from the traffic volume drop list, a text box will appear for the user to insert the desired traffic volume, as shown in Figure 4.8.

Design Speed (Km/hr)	80	Continue
Traffic Volume (Veh/hr)	Other	
Average Annually Daily Traffic (Veh/hr)		

Insert the value of Traffic Volume Required

Figure 4. 8 Snapshot of the Traffic Volume Text Box

Once all the information is entered and stored, clicking the button "Continue" button will show the user another set of entries. Figure 4.9 shows a snapshot of the next set of entries needed by the model.

Figure 4. 9 Snapshot of the Additional Required Entries

As shown in Figure 4.9, the user then has to insert the length and number of lanes in the text boxes. Also the user can specify the availability of any type of special lanes by clicking on the checkboxes. Once the user clicks the Continue button, the system will execute some of the knowledge-based conditions and functions to obtain some values. A selection form will then appear to the user to provide more information about the underpass object. The selection form

contains two required information selection forms, which are Underpass Road Information and Waterway Information, as shown in Figure 4.10. The user is requested to select the type of overpass object from the Overpass Object drop list. According to the user's selection, one of the two required information selection forms will be enabled.

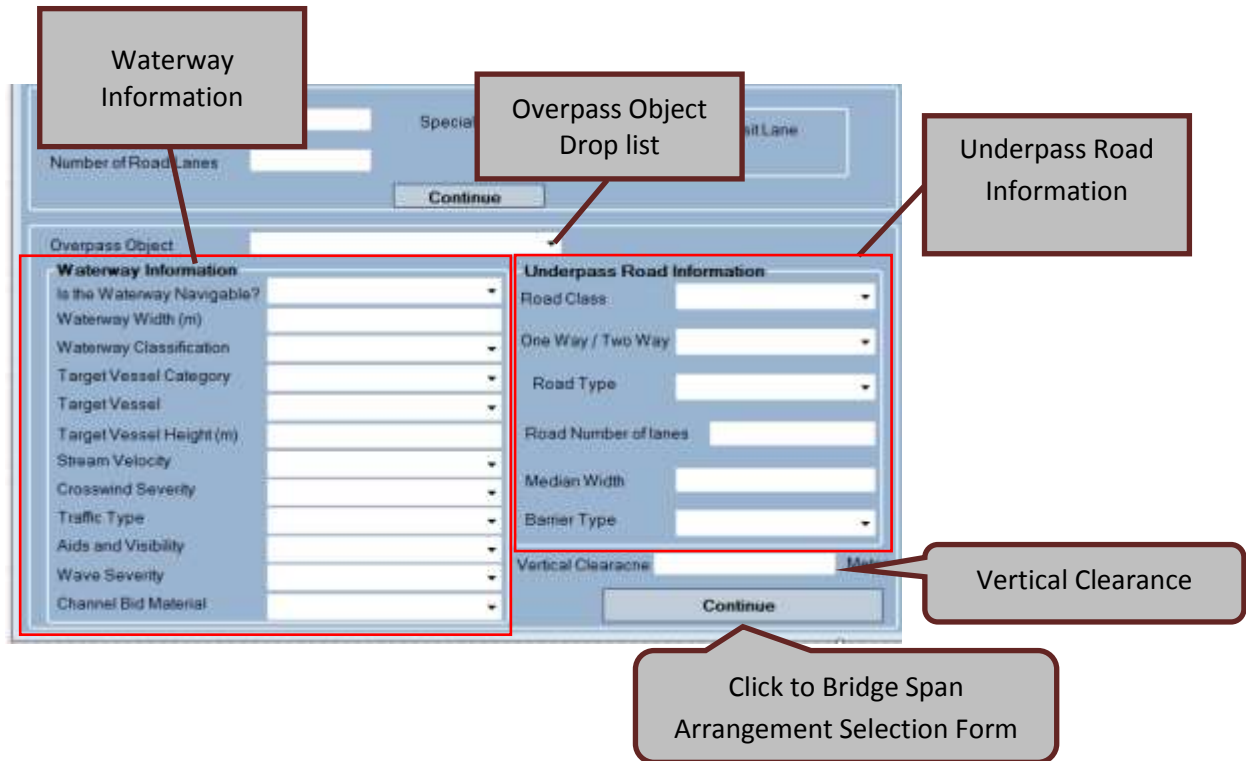


Figure 4. 10 Snapshot of the Underpass Object Selection Form

The Underpass Road Information selection form requires information regarding underpass roads. Drop lists are added to the group box in order to collect information about the underpass. The information of TAC (1999) Figure 2.2.10.1 and Figure 2.2.10.2 are followed in coding the drop lists. Figure 4.11 shows an example of the drop list coding. The whole code of the model can be found in Appendix F. Once the user provides all the required information, the model will instantly show the required vertical clearance for the bridge according to the user's selections.

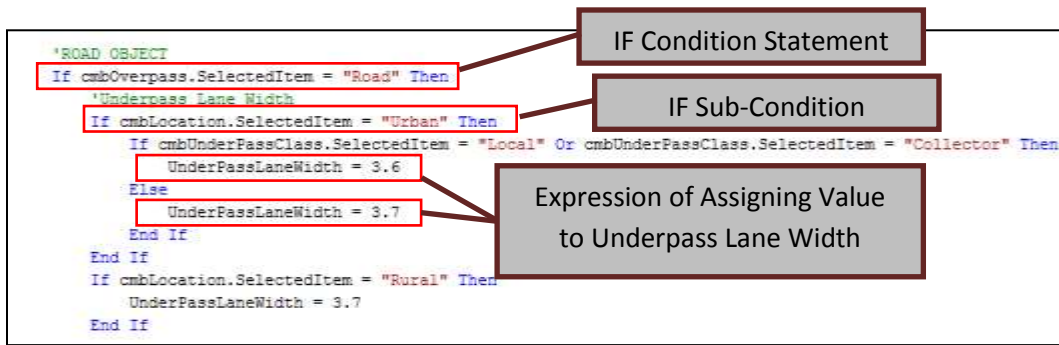


Figure 4. 11 Sample of Underpass Roads Drop lists Coding

4.2.2 Navigational Waterways Clearances Guidelines Implementation

The Waterway Information selection form utilizes drop lists and text boxes in presenting information about the navigational waterways knowledge base. The drop lists and text boxes are organized based on the sequence of the navigational waterways guidelines procedures. Figure 4.12 shows a snapshot of the Waterway Information selection form.

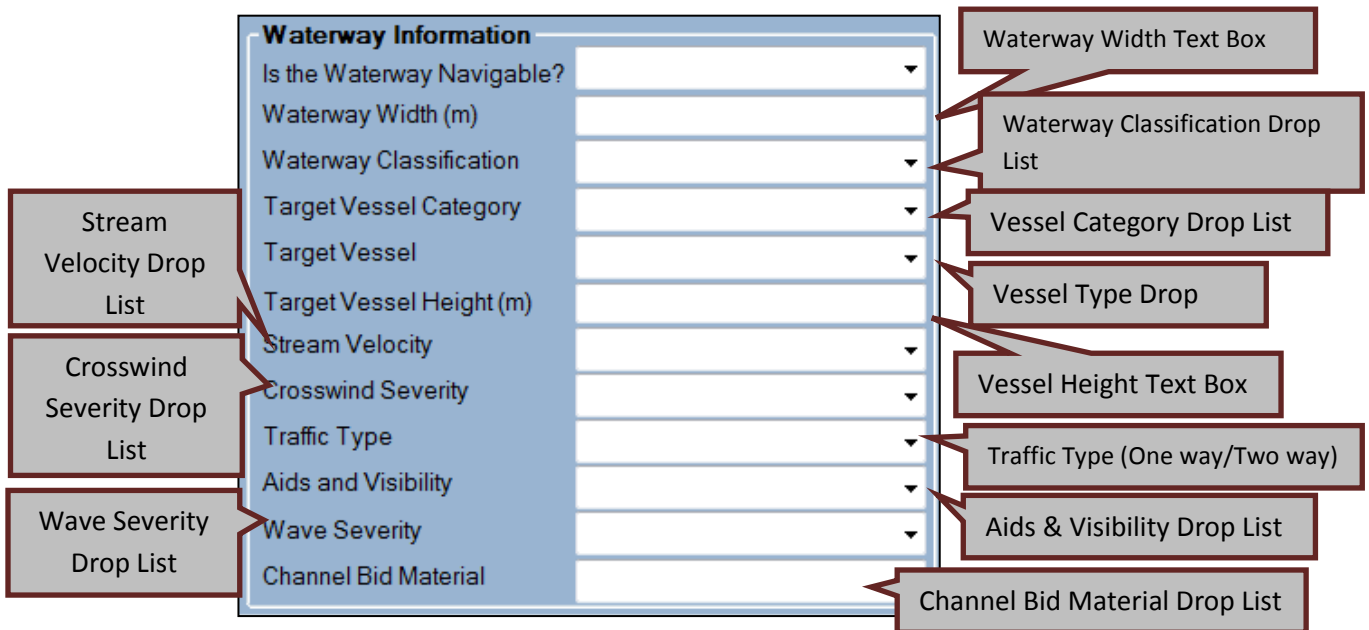


Figure 4. 12 Snapshot of the Waterway Information Selection Form

It is important to provide the user guidance in entering the input variables. Similar to the procedure used in implementing the knowledge base of the highway geometric design guidelines, items of the drop lists are added and modified according to the users' entries. The

items of the second drop list will be modified according to the selected items of the first drop list. All the tables mentioned in Figure 3.8 are followed in assigning items to the drop lists. Figure 4.13 shows a drop list coding sample.

```

Private Sub cmbWaterClassification_SelectedIndexChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmbWaterClassification.SelectedIndexChanged
    If cmbWaterClassification.SelectedItem = "Small Rivers/Streams and Lakes" Then
        cmbVesselCategory.Items.Clear()
        cmbVesselCategory.Items.Add("Recreational Vessels")
        txtVesselHeight.Enabled = False
        cmbStreamVelocity.Enabled = True
        cmbTrafficType.Enabled = True
        cmbCrosswind.Enabled = False
        cmbAidsVisibility.Enabled = True
        cmbWaveSeverity.Enabled = False
    End If
End Sub

```

Condition: If Item "Small Rivers/Streams and Lakes" is selected Then Execute the Expressions

Expression of Adding Item "Recreational Vessels" to Drop Box "Vessel Category"

Figure 4. 13 Sample of the Code for the Drop Boxes of the Navigational Waterways Guidelines Knowledge Base

The next step is to declare all the variables needed for the interface so they will be used later in the IF-ELSE statements and the logical operation expressions, as shown in Figure 4.14.

```

Public W As Integer
Public B As Integer
Public D As Integer
Public H As Integer
Public VF As Integer
Public LF As Integer
Public IF As Integer
Public MLW As Integer
Public BSC As Integer
Public ANCL As Integer
Public ANCF As Integer
Public WE As Integer
Public SE As Integer
Public Mini_H_Clearance As Integer
Public Mini_V_Clearance As Integer
Public waterlevel As Integer

```

Declared Variables of the Navigational Waterways Knowledgebase to the VB.NET Interface

Figure 4. 14 Sample of Declared Variable of the Navigational Waterways Guidelines Knowledge Base

Once variables are declared, the IF-ELSE conditions and logical operations can be implemented. All the tables mentioned in Figure 3.8 were followed in writing the code of the IF-ELSE rules within the VB.NET interface. Figure 4.15 shows an example of the knowledge base IF-ELSE statements.

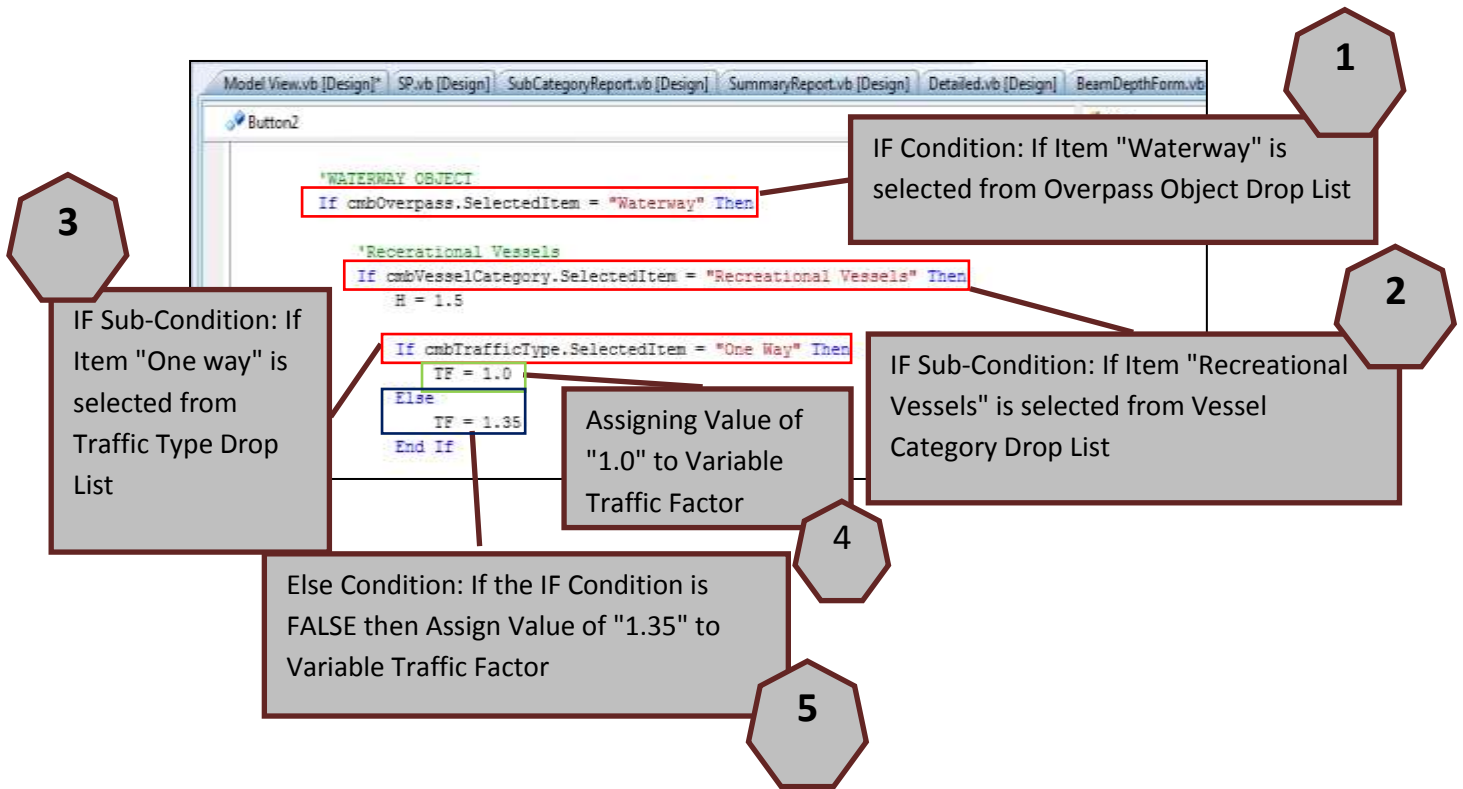


Figure 4. 15 Sample of the IF-ELSE Statements of the Navigational Waterways Clearances Guidelines

If the user selects the category of small/medium vessels as an item of the Vessel Category Drop List, then additional information is required from the user to be entered. This additional information is the vessel's beam and draft. Another form is assigned to collect this required information. Figure 4.16 shows a snapshot of that form.

The screenshot shows the 'BeamDepthForm' window with the following elements and callouts:

- Maximum Water Level (m)**: A text box for entering the maximum water level.
- Please Specify the Following Characteristics of the Target Vessel**: A heading for the vessel characteristics section.
- Vessel's Beam Within**: A text box for entering the vessel's beam.
- Vessel's Draft Within**: A text box for entering the vessel's draft.
- Continue**: A button to proceed to the next step.
- Labels to guide the user**: A callout pointing to the vessel characteristics section.
- Maximum Water Level Text Box**: A callout pointing to the top text box.
- Vessel Beam Text Box**: A callout pointing to the beam text box.
- Vessel Draft Text Box**: A callout pointing to the draft text box.
- Click to return back to the Previous Form**: A callout pointing to the 'Continue' button.

Figure 4. 16 Snapshot of the Vessel Additional Characteristics and Information Window Form

Labels will change instantly according to the user's selection of the vessel type. For instance, the model will show the user a text label "Vessel's Beam within (1.5-2.1) m" if the user selected vessel type "Powered Inflatable Vessel" from the Vessel Type Drop List. This guidance is developed based on NRPD Guideline Table 2-3. Figure 4.17 shows a sample of the code assigned to the label.

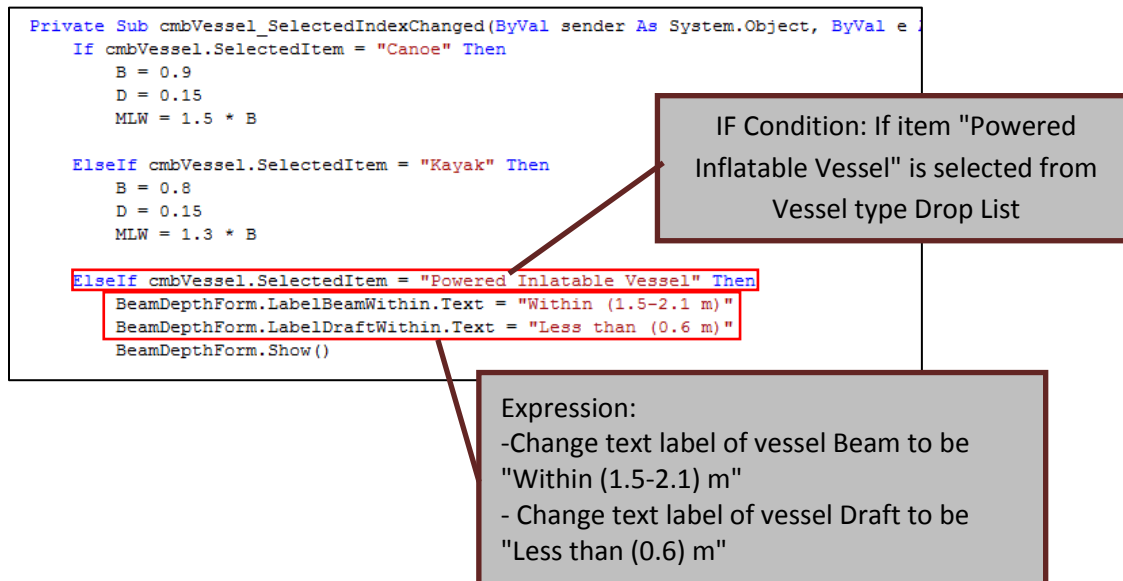


Figure 4. 17 Sample of the Code for the Label

4.2.3 Knowledge-Based System Output

This section presents the procedure followed in obtaining and presenting the KBS outputs within the VB.NET interface. It is necessary to state the purpose of using KBS, which is to provide assistance and guidance to users by recommending parameters and dimensions rather than generating specific values. Moreover, it is important to recognize that the highway geometric design guidelines adapt the concept of the design domain in providing the range of variables to designers, which indicates that there is no a specific value for a variable. Thus, it is mandatory to

provide the user flexibility in changing and modifying the output values in order to meet the concept of design domain.

The next step after assigning values to the variables is to write the equations within the interface. Some variables such as horizontal and vertical clearances need to be calculated using formulas and equations. These equations and formulas are incorporated in the VB.NET interface by using IF-ELSE conditions and logical operations to cover all the cases of the proposed project. Figure 4.18 shows a sample of the code used in calculating the underpass right of way width.

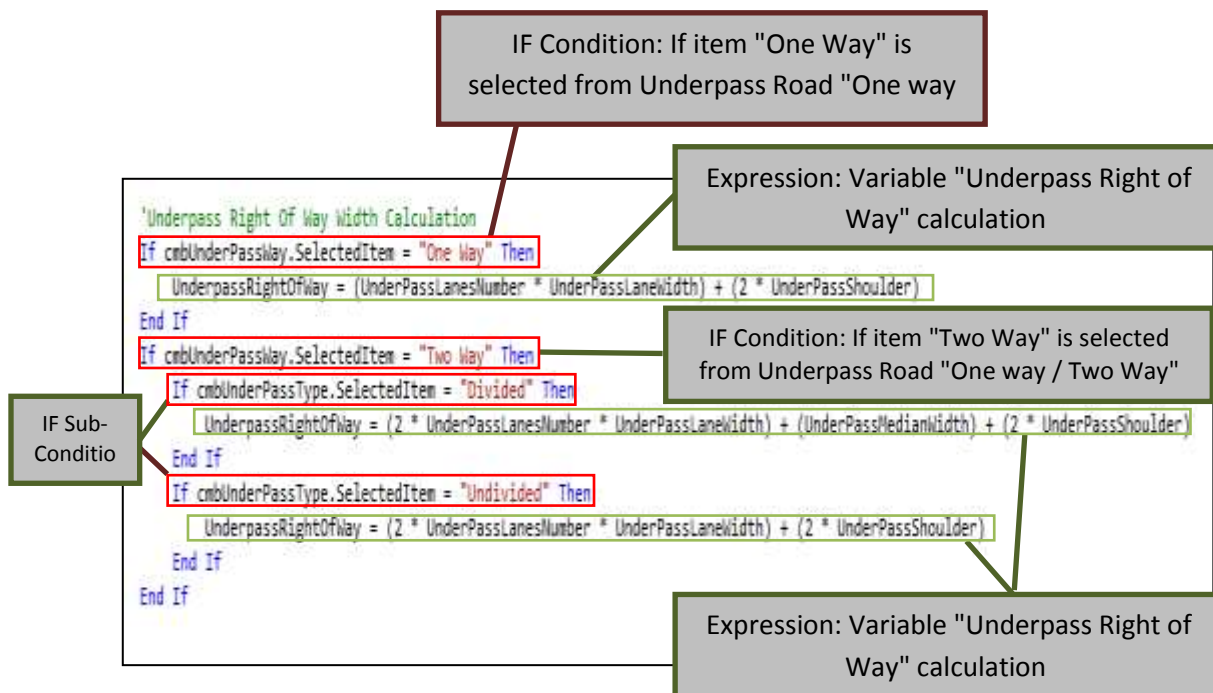


Figure 4. 18 Sample of Code used in Calculating Underpass Road Right of Way

The next step is to assign objects within the interface to present the output variables. Two forms were developed to organize the output variables. The first form contains objects that present information about the bridge span arrangements, while the second form contains objects and controls that present information about the output variables of the KBS. Figure 4.19 shows a snapshot of the VB.NET interface forms, which were developed. The user has to click on the Continue button to view the frames.

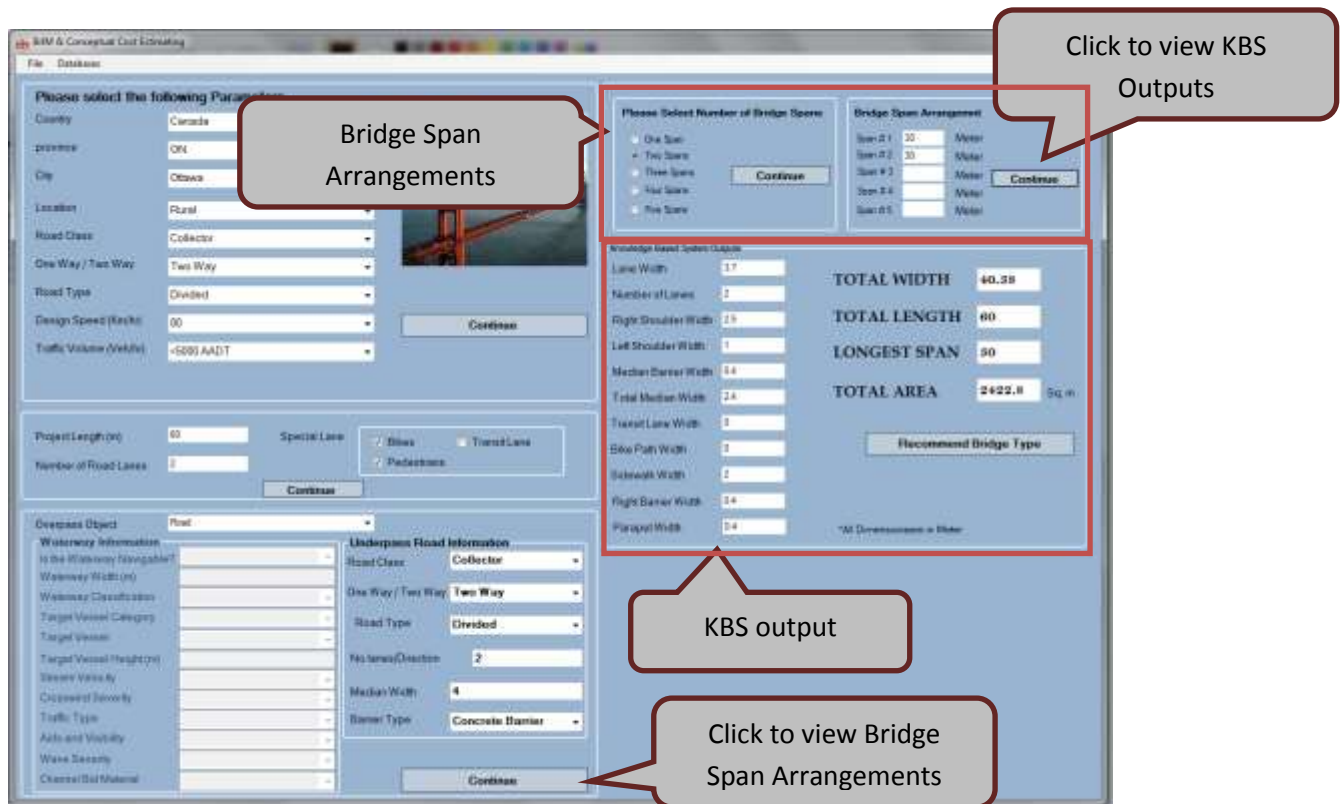


Figure 4. 19 Snapshot of the Developed VB.NET Interface Forms

The Bridge Span Arrangements form contains two groups of information to organize the sequence of the bridge span arrangement output. The first group of information contains radio buttons, which are used to make the user to choose only one of the several options. These radio buttons represent the number of spans suggested to be used. Although the proposed methodology does not restrict the number of bridge spans, it was decided to limit the number of spans to a maximum of five in developing this model. The second group of information contains text boxes corresponding to the number of spans selected by the user. The user has the flexibility of changing the span arrangements by inserting the desired arrangement in the text boxes. Figure 4.20 shows a snapshot of group bridge span arrangements.

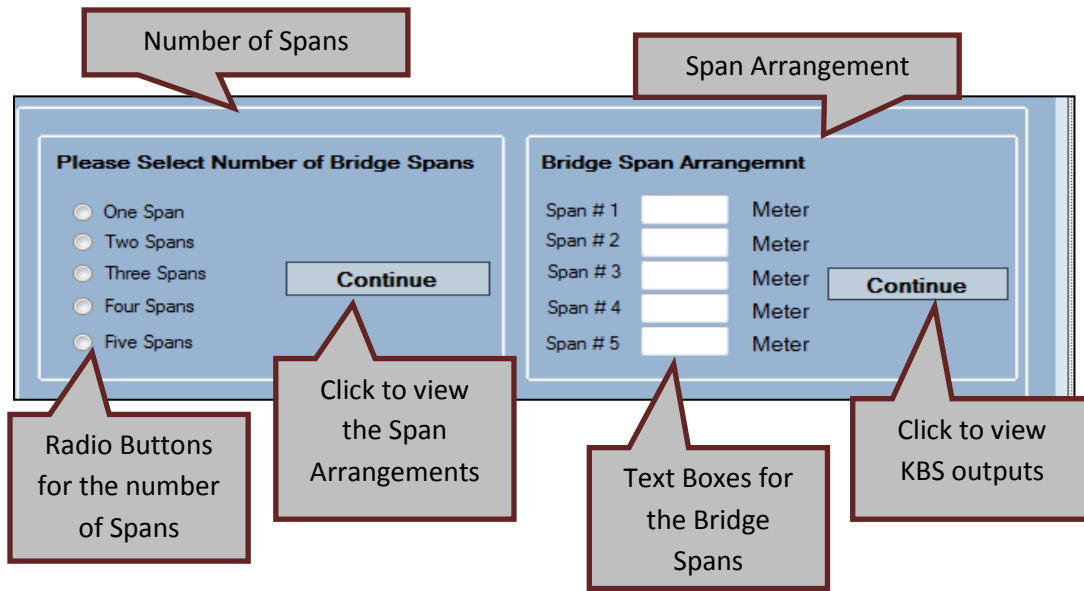


Figure 4. 20 Snapshot of Bridge Spans Arrangements Form

The KBS Output Form presents the output variables using text boxes. Text boxes are used to provide the user flexibility in modifying the output values of the variables if any modification is desired. Figure 4.21 shows a snapshot of KBS Output Form.

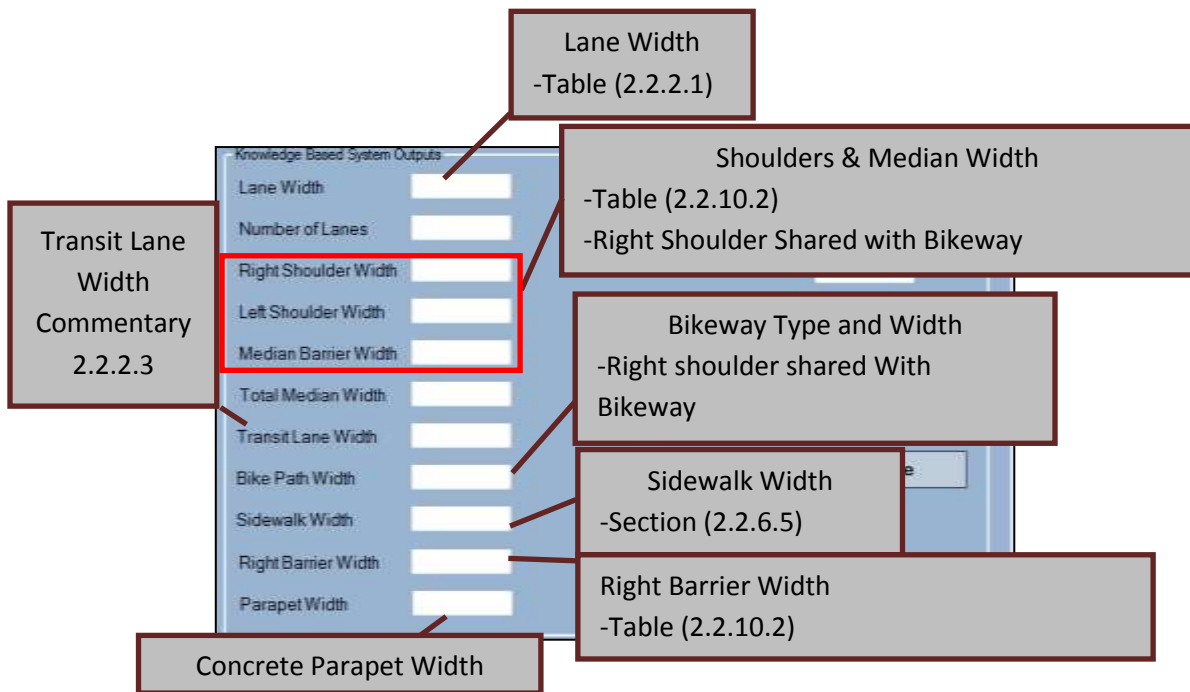


Figure 4. 21 Snapshot of the KBS Output Form

After developing the interface of the KBS, the next step is to write code for all text boxes to present the values of the variables. Figure 4.22 shows a sample of the code used for the KBS Output form text boxes.

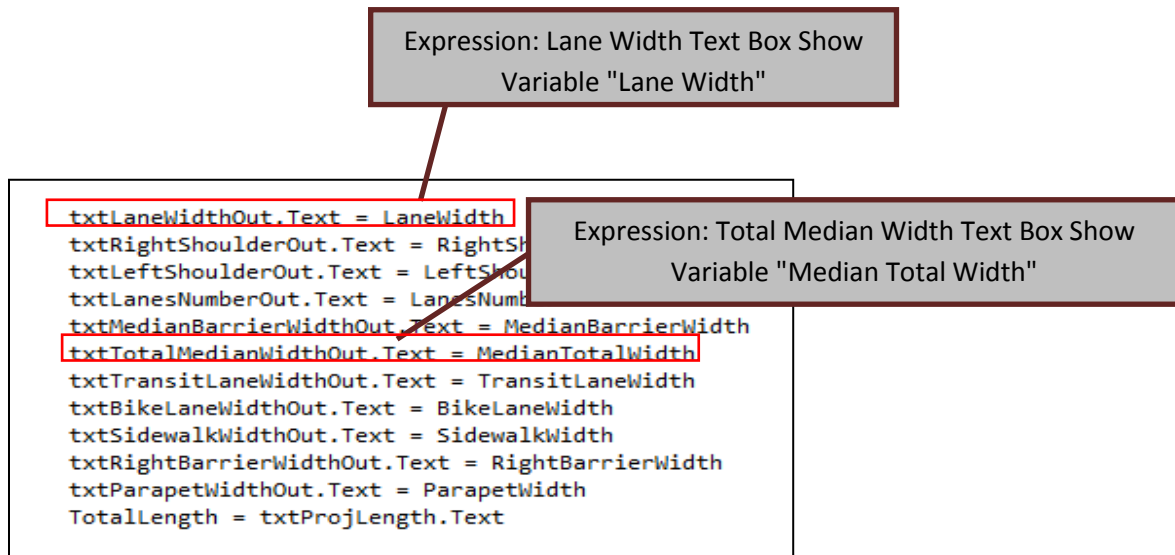


Figure 4. 22 Sample of the Code for KBS Output Form Text Boxes

Output variables are then to be used in the bridge type selection subsystem, the conceptual cost estimation module, and the 3D-CAD module as input values. Figure 4.23 shows a snapshot of a filled KBS Output Form.

Knowledge Based System Outputs			
Lane Width	3.7	TOTAL WIDTH	40.38 m
Number of Lanes	2	TOTAL LENGTH	60 m
Right Shoulder Width	2.5	LONGEST SPAN	30 m
Left Shoulder Width	1	TOTAL AREA	2422.8 Sq. m
Median Barrier Width	0.4	Recommend Bridge Type	
Total Median Width	2.4		
Transit Lane Width	0	*All Dimensions are in Meter	
Bike Path Width	0		
Sidewalk Width	2		
Right Barrier Width	0.4		
Parapet Width	0.4		

Figure 4. 23 Snapshot of filled KBS Output Form

4.3 Bridge Type Selection

The bridge type selection depends on the information from existing bridges. Data for Ontario Bridges was collected from the Ministry of Transportation of Ontario (MTO). Samples of the collected data are illustrated in Appendix C. The first step after collecting the data was to validate and consolidate all the collected information to discard any repetitive, incomplete and incorrect information. Then, the data is divided into Excel workbooks based on the number of spans. Figure 4.24 and Figure 4.25 respectively show samples of the collected bridge information and classifications.



Figure 4. 24 Snapshot of Bridge Excel Workbooks

As shown in Figure 4.25, the bridge Excel workbooks are divided into sheets according to the bridge type. Each sheet represents the information of one bridge type, such as arch bridges, beam / girder bridges, frame, slab, temporary modular, and truss. Another sheet is created for input and output variables.

	A	B	C	E	F	G	H
1	SUBCATEGORY 1	TYPE 1	MATERIAL 1	Total Length	Spans #	Max Span Length	WIDTH TOTAL
2	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	17	1	17	12
3	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	17	1	17	12
4	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	23	1	23	14.5
5	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	23	1	26	14.5
6	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	19.4	1	19.4	12.5
7	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	1.4	1	19.4	12.5
8	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	17.7	1	17.7	11.2
9	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	17.7	1	17.7	11.2
10	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	15.2	1	15.2	10.9
11	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	21.3	1	21.3	10.4
12	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	22.9	1	22.9	11.1
13	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	30.7	1	30.7	10.26
14	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	22.6	1	22.6	12.9
15	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	44	1	44	19.9
16	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	18.3	1	18.3	12.8
17	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	17.7	1	17.7	12.8
18	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	21.3	1	21.3	12.2
19	Beam/Girder	AASHTO Girder	Prestressed Precast Concrete	23.8	1	23.8	11.3

Figure 4. 25 Snapshot of Bridge Excel Spreadsheet

The output values of the KBS are used as input values for the bridge type selection process. Based on the selected number of bridge spans, the KBS output values are to be transferred from the VB.NET interface to the bridge Excel workbook. For example, if the user selects "One" as the number of bridge spans, the KBS output values will be inserted in the One Span Bridge Excel workbook. Figure 4.26 shows sample of the code for the data transferred from VB.NET interface to the Bridge Excel workbook.

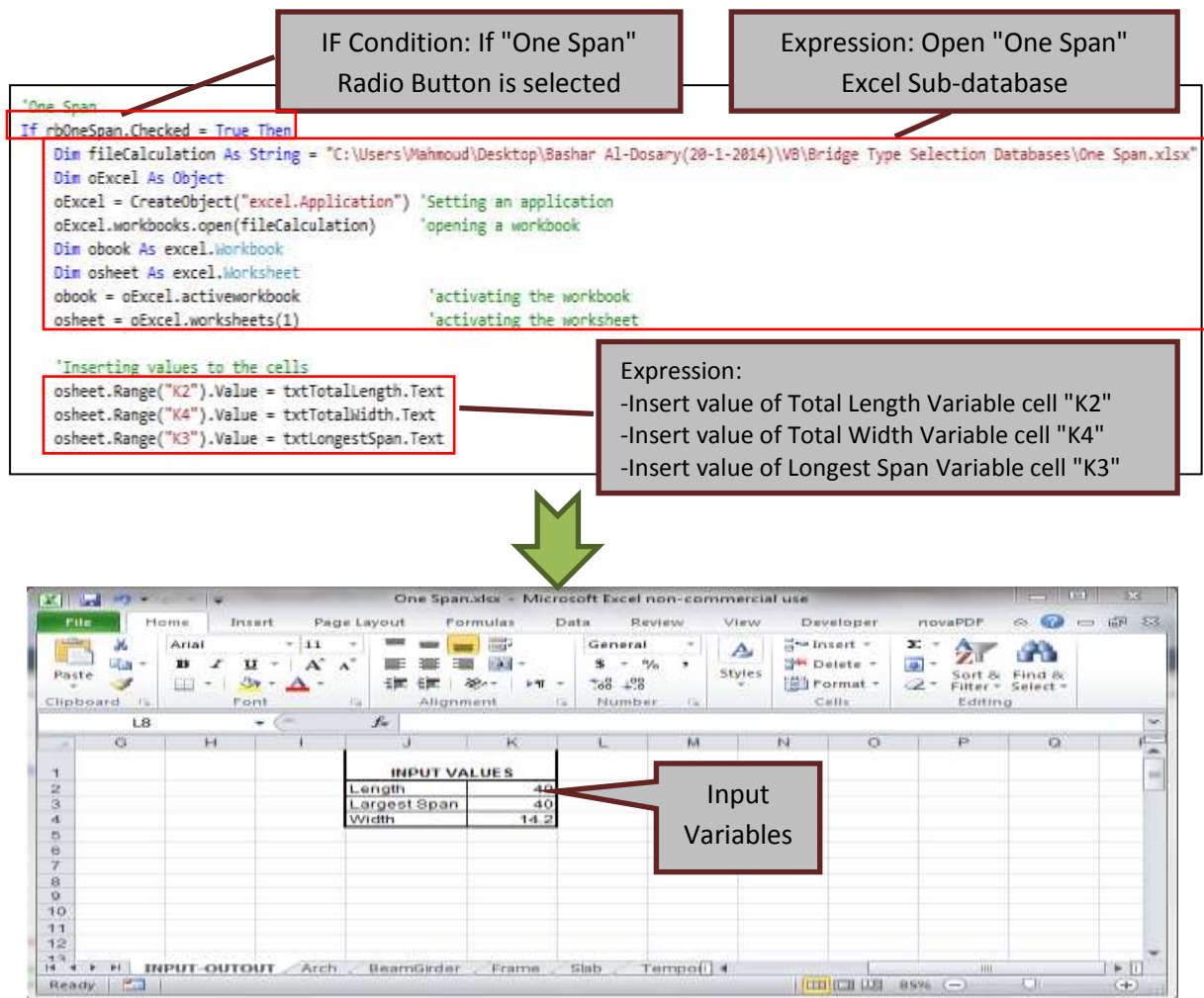


Figure 4. 26 Sample of Code for the Data Transferred from the VB.NET Interface to the Bridge Excel Workbook

The next step is to calculate the Closeness Weights and Adjusted Closeness Weights for all the bridges stored in the Excel workbook. Closeness weights and adjusted closeness weights are calculated for bridge length, width and its largest span length. Figure 4.27 shows an example of the closeness weights and the adjusted weights coefficient calculation.

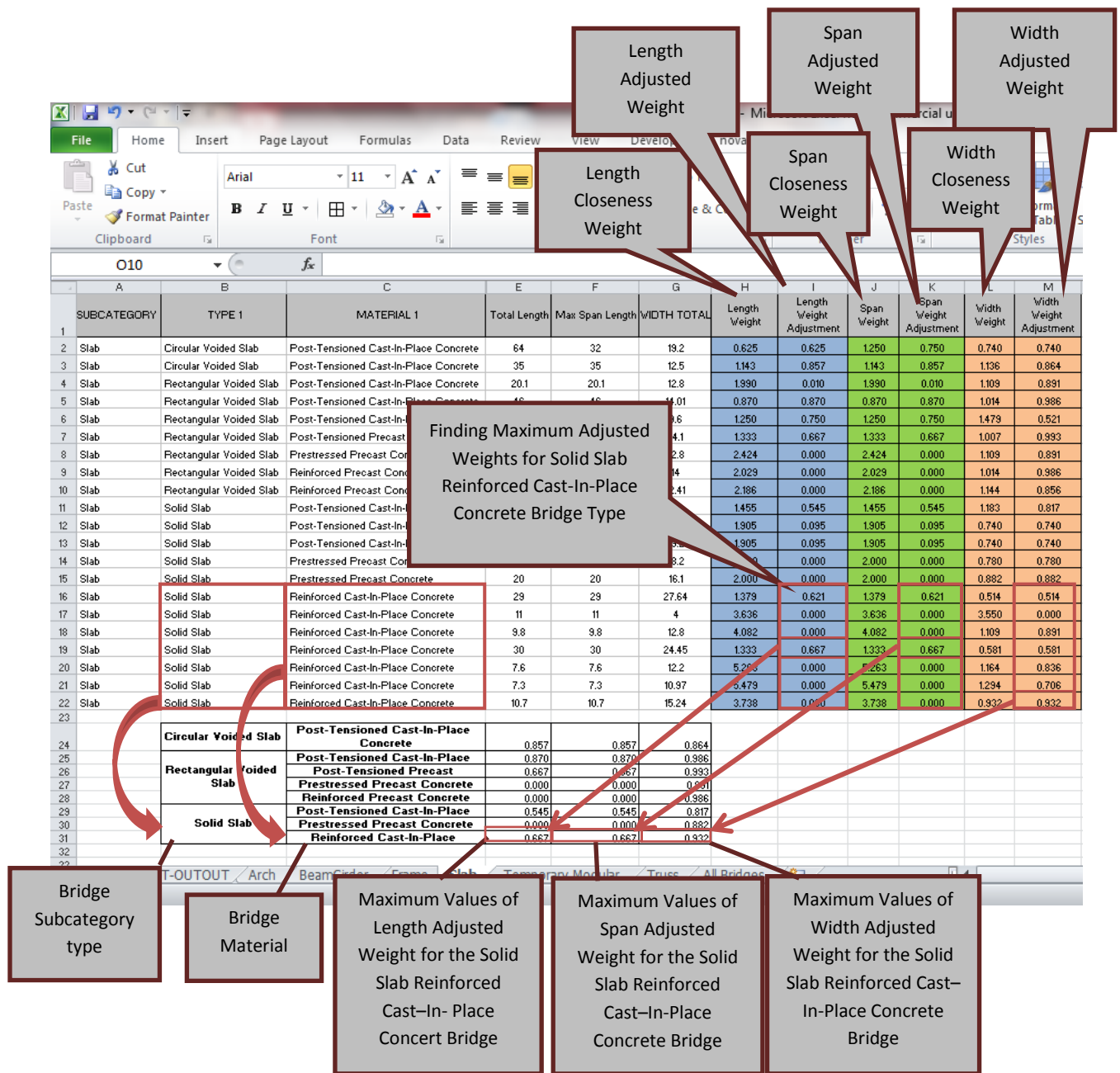


Figure 4. 27 Example of Closeness Weights Calculations within Excel Spreadsheet Platform

As shown in Figure 4.27, the maximum adjusted weights for each bridge type are found. This calculation process is then applied to all the bridge type sheets. Figure 4.28 shows a snapshot of the Input & Output sheet containing the maximum adjusted closeness coefficient.

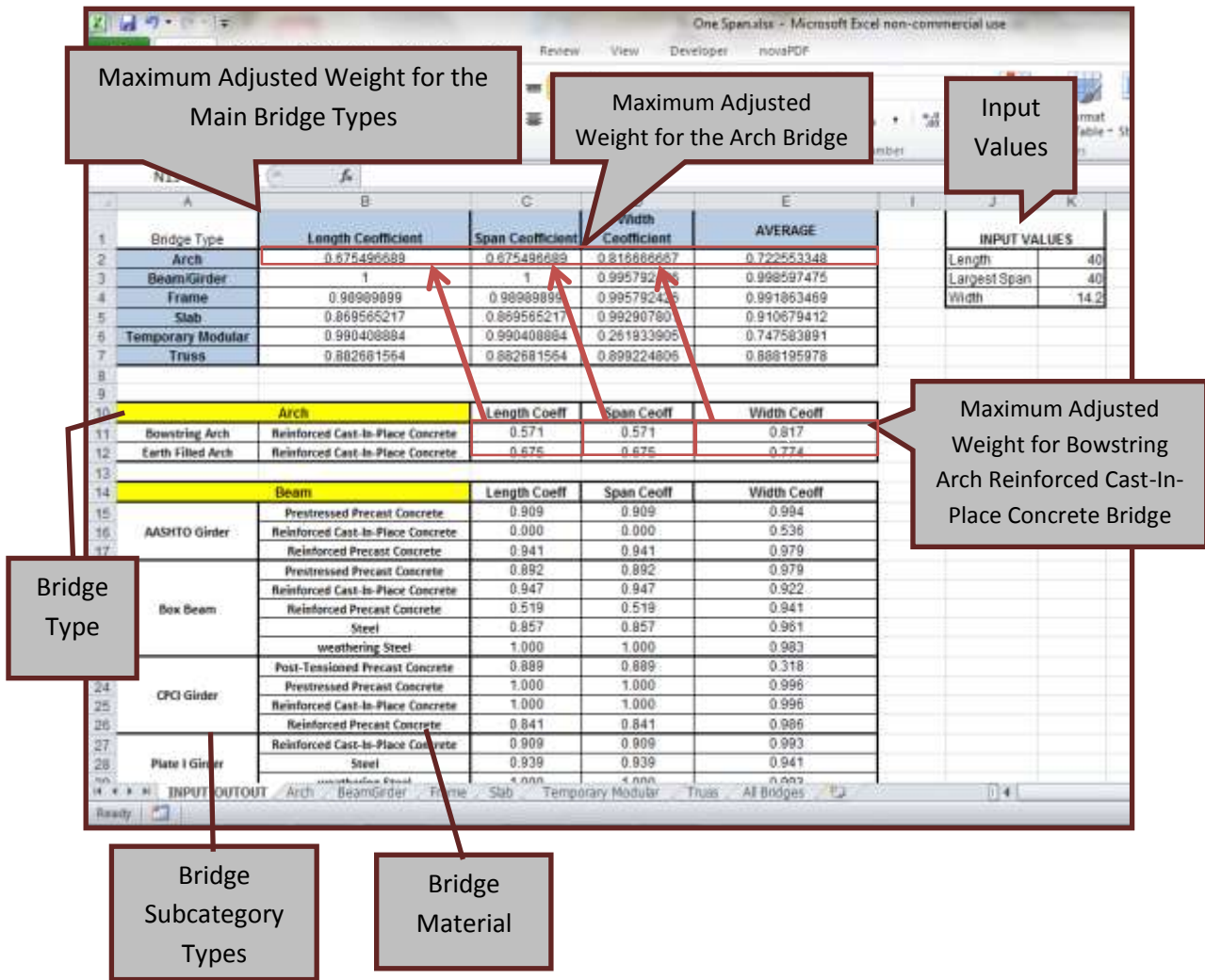


Figure 4. 28 Snapshot of the Input & Output Sheet Containing Maximum Adjusted Weights

After collecting all the maximum values of the adjusted weights, the maximum adjusted value for each bridge main type is found, as shown in Figure 4.28. All these calculated values are then to be transferred to the VB.NET interface. To implement this, identifying variables within the interface is first required. A variable is assigned, within the interface, for each adjusted weight in the Input and Output Sheet. Figure 4.29 shows sample of the assigning code.

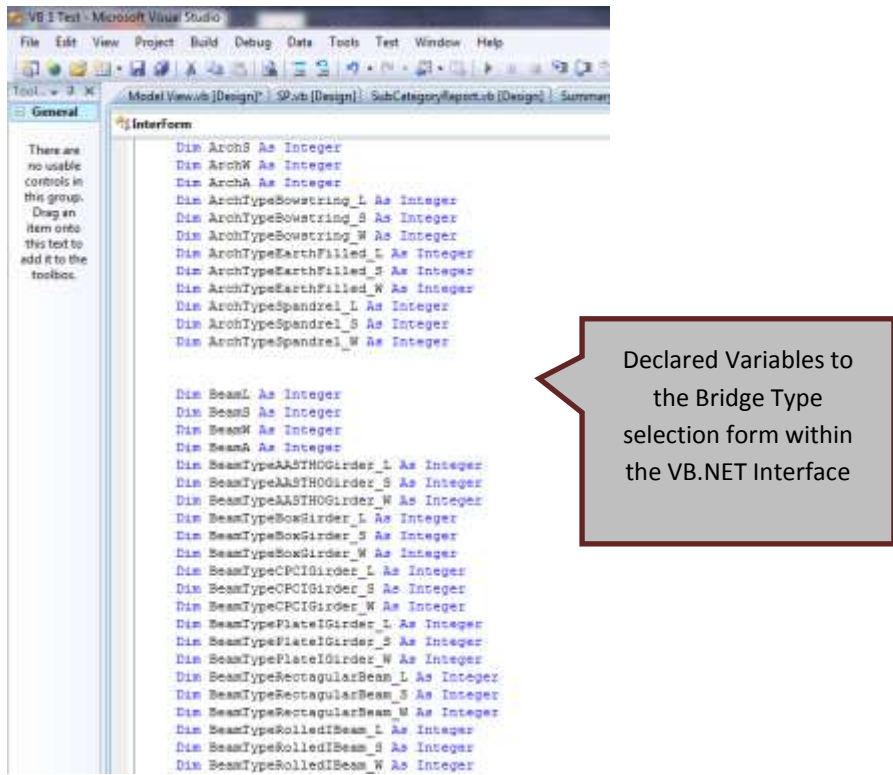


Figure 4. 29 Sample of Declared Variables for the Adjusted Weights

Afterwards, a form is added to the interface to organize the information for the bridge type selection process. Figure 4.30 shows a snapshot of the bridge type selection form.

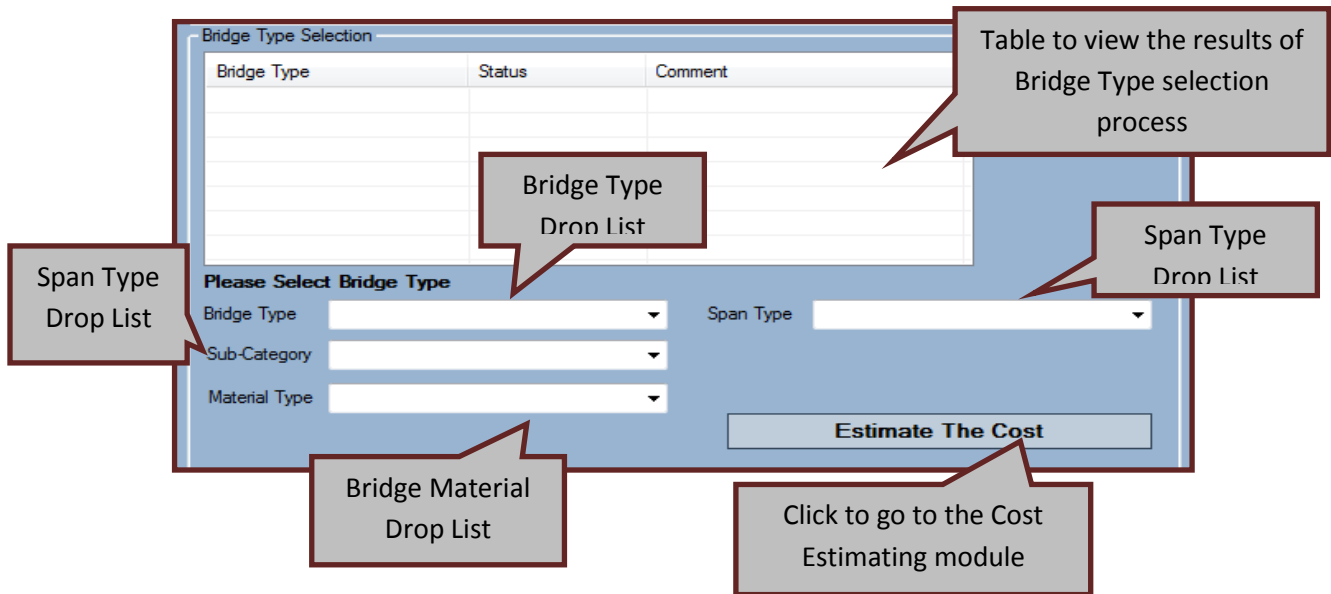


Figure 4. 30 Snapshot of the Bridge Type Selection Form

As shown in Figure 4.30, a table is assigned to present a list of the recommended bridge types to the user. The table contains three columns: bridge type, status, and comment. The status column is used to inform the user if the bridge type is recommended or not. The comment column is added to provide the user with an explanation of why it is not recommending the bridge type. Drop lists are added for the user to select one of the recommended bridge types. IF-ELSE rules and logical operators are used in the process of recommending bridge types. Figure 4.31 shows a snapshot of the code used in recommending the bridge type. AASHTO LRFD Table 2.5.2.6.3-1 is used for the span type drop list to obtain the span depth ratio.

```

If ArchL < 0.8 Or ArchS < 0.8 Or ArchW < 0.8 Then
  If ArchL < 0.8 Then
    ListView1.Items(0).SubItems.AddRange(New String() {"Not Recommended", "Length Coefficient is less than 80%"})
  ElseIf ArchS < 0.8 Then
    ListView1.Items(0).SubItems.AddRange(New String())
  ElseIf ArchW < 0.8 Then
    ListView1.Items(0).SubItems.AddRange(New String())
  End If
Else
  ListView1.Items(0).SubItems.AddRange(New String())
  cmbBridgeType.Items.Add("Arch")
End If

```

IF Condition with logical operations

IF Sub-Condition

Expression: Write "Not recommended" for the statue of Arch Bridge and "Length Coefficient is less than 80%" for the Comment

Figure 4. 31 Snapshot of Code for Recommending the Bridge Type

Figure 4.32 shows a snapshot of the code for bridge type selection drop list.

```

Private Sub cmbBridgeType_SelectedIndexChanged(ByVal sender As Object, ByVal e As EventArgs) Handles cmbBridgeType.SelectedIndexChanged
    If cmbBridgeType.SelectedItem = "Arch" Then
        cmbSubcategory.Items.Clear()
        If ArchTypeBowstring L >= 0.8 And ArchTypeBowstring S >= 0.8 And ArchTypeBowstring W >= 0.8 Then
            cmbSubcategory.Items.Add("Bowstring Arch")
        End If
        If ArchTypeEarthFilled L >= 0.8 And ArchTypeEarthFilled S >= 0.8 And ArchTypeEarthFilled W >= 0.8 Then
            cmbSubcategory.Items.Add("Earth Filled Arch")
        End If
    End If
End Sub

```

IF Condition: If Bridge type item "Arch" is selected

If cmbBridgeType.SelectedItem = "Arch" Then

If ArchTypeBowstring L >= 0.8 And ArchTypeBowstring S >= 0.8 And ArchTypeBowstring W >= 0.8 Then

cmbSubcategory.Items.Add("Bowstring Arch")

IF Sub-Condition: If Adjusted Coefficients of Bowstring Arch Bridge type is larger than 80% t

Expression: Add item "Bowstring Arch" to the Bridge Subcategory Drop List

Figure 4. 32 Sample of the Code for Bridge Type Selection Form Drop Lists

Figure 4.33 shows a snapshot of a filled bridge type selection form. Once the recommended bridge types are shown, the user has then to select the bridge subcategory type and bridge material as shown in Figure 4.34 and Figure 4.35.

Bridge Type	Status	Comment
Arch	Not Recommended	Width Coefficient is less than 80%
Beam / Girder	Recommended	
Frame	Recommended	
Slab	Recommended	
Temporary Modular	Not Recommended	Width Coefficient is less than 80%
Truss	Not Recommended	Width Coefficient is less than 80%

Please Select Bridge Type

Bridge Type: [Dropdown menu]

Sub-Category: [Dropdown menu with 'Slab' selected]

Material Type: [Dropdown menu]

Estimate The Cost

Figure 4. 33 Snapshot of a Filled Bridge Type Selection Form

Bridge Type Selection

Bridge Type	Status	Comment
Arch	Not Recommended	Width Coefficient is less than 80%
Beam / Girder	Recommended	
Frame	Recommended	
Slab	Recommended	
Temporary Modular	Not Recommended	Width Coefficient is less than 80%
Truss	Not Recommended	Width Coefficient is less than 80%

Please Select Bridge Type

Bridge Type: Slab

Sub-Category: [Dropdown]

Material Type:

- Circular Voided Slab
- Rectangular Voided Slab
- Solid Slab

Estimate The Cost

Selecting Bridge Sub-Category Type

Figure 4. 34 Selecting the Bridge Sub-Category Type

Bridge Type Selection

Bridge Type	Status	Comment
Arch	Not Recommended	Width Coefficient is less than 80%
Beam / Girder	Recommended	
Frame	Recommended	
Slab	Recommended	
Temporary Modular	Not Recommended	Width Coefficient is less than 80%
Truss	Not Recommended	Width Coefficient is less than 80%

Please Select Bridge Type

Bridge Type: Slab

Sub-Category: Solid Slab

Material Type:

- Post-Tensioned Cast-In-Place Concrete

Estimate The Cost

Selecting Bridge Material Type

Click to open the Conceptual Cost Estimating Window Form

Figure 4. 35 Selecting the Bridge Sub-Category Type

4.4 Conceptual Cost Estimating Module Implementation

The output variables of both the knowledge-based system and the bridge type selection process are used as input variables for the conceptual cost estimating module. The first step in the conceptual cost estimating development module is to create an Excel spreadsheet for each bridge type. The databases should be created according to the collected cost data and the ASTM

UNIFORMAT II Standards. In each Excel spreadsheet, bridge elements associated with cost should be defined. Figure 4.36 and Figure 4.37 respectively show examples of created cost estimating Excel spreadsheets.

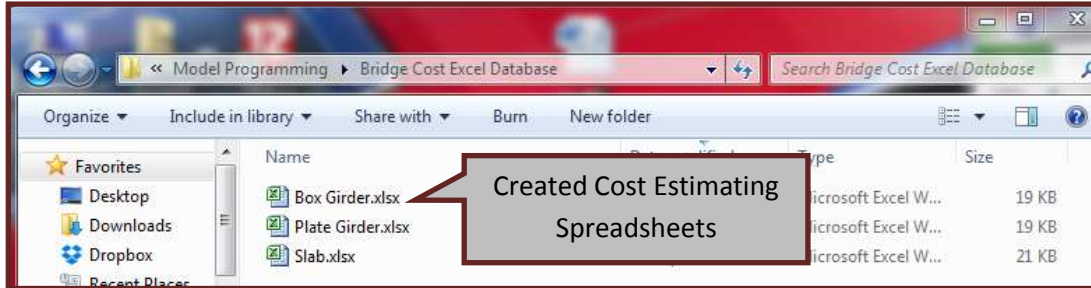


Figure 4. 36 Created Cost Estimating Module Excel Spreadsheets

The image shows a screenshot of an Excel spreadsheet titled "Slab.xlsx - Microsoft Excel non-commercial use". The spreadsheet is organized into columns labeled A through G. Callouts point to various parts of the spreadsheet: "Major Group Elements" points to column A, "Group Elements" to column B, "Individual Elements" to column C, "Sub-classification Elements" to column D, "Unit" to column E, "Quantity" to column F, "Unit Cost" to column G, and "Cost" to column H. A "Total Cost" callout points to the bottom right of the spreadsheet.

	A	B	C	D	E	F	G	H
1	Substructure	<i>Walls</i>	Walls	Cast-in-Place Concrete	Cubic Meter	112	2316	\$ 259,410
2			Columns	Cast-in-Place Concrete	Cubic Meter	16.8	2316	\$ 38,912
3			Cap Beams	Cast-in-Place Concrete	Cubic Meter	20	2895	\$ 57,899
4		<i>Abutments</i>	Stem	Cast-in-Place Concrete	Cubic Meter	112	1390	\$ 155,632
5			Wing walls	Cast-in-Place Concrete	Cubic Meter	28	1390	\$ 38,908
6	Superstructure	<i>Span Assemblies</i>	Bearing	Elastomeric	Each	5	2292	\$ 11,460
7		<i>Deck</i>	Structural Surface	Cast-in-Place Concrete	Cubic Meter	510	781	\$ 398,182
8				Reinforcement Bars	Kg	47430	0.672	\$ 31,855
9			Wearing Surface	Bituminous Concrete Driveway	Squared Meter	600	200	\$ 120,259
10	Protection	<i>Structure Protection</i>	Expansion Joints	Strip-Seal	Linear Meter	60	71	\$ 4,255
11			Protective Coats	Preparation and Application	Squared Meter	600	122	\$ 73,470
12			Drainage Systems	Scuppers, Drain Pipes & Buries Drains	Percentage of the Total Cost	0.04	0.047	\$ 48,170
13		<i>Traffic Protection</i>	Barriers	Parapet	Linear Meter	30	43	\$ 1,288
14				Railing	Linear Meter	30	74	\$ 2,216
15				Median	Linear Meter	30	56	\$ 1,680
16				Curb	Meter	30	182	\$ 5,456
17				Guardrail	Linear Meter	30	54	\$ 1,612
18				Sidewalk	Squared Meter	60	13	\$ 803
19			Traffic Controls	Signals, Arms, Base Plate & Conduits	Percentage of the Total Cost	0.05	0.050	\$ 60,212
20		<i>Other Protection</i>	Lighting	Signals, Arms, Base Plate & Conduits	Linear Meter	30	32	\$ 953
21			Signage	Sign Board, Supports & Conduits	Percentage of the Total Cost	0.015	0.015	\$ 18,064
22	Site Work	<i>Site Preparations</i>	Clearing & Grubbing		Percentage of the Total Cost	0.008	0.008	\$ 9,875
23			Earthworks		Percentage of the Total Cost	0.004	0.004	\$ 4,335
24			Mobilization		Percentage of the Total Cost	0.1	0.100	\$ 120,425
25		<i>Approach Construction</i>	Approach Slab		Percentage of the Total Cost	0.008	0.008	\$ 9,634
26					subtotal			\$ 1,474,964
27					contingency	20%		\$ 294,993
28					Overhead and Profit	15%		\$ 221,245
29					Tax	13%		\$ 191,745
30					Total			\$ 2,182,947

Figure 4. 37 Snapshot of the Conceptual Cost Estimating Module Excel Spreadsheet

Once the cost estimating Excel spreadsheets are created, the second step is to develop a form within the VB.NET interface for the conceptual cost estimating module. Figure 4.38 shows a snapshot of the conceptual cost estimating module form.

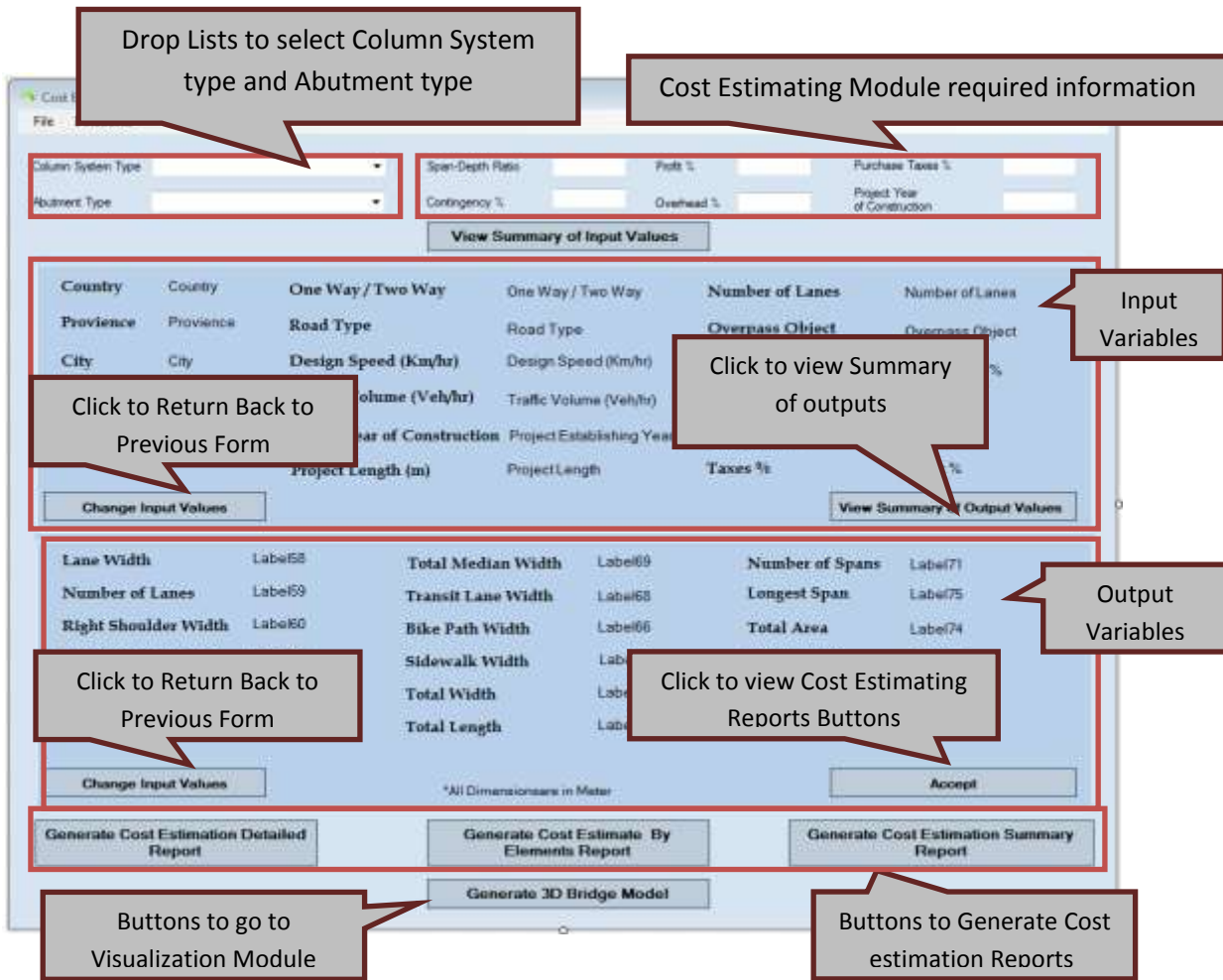


Figure 4. 38 Snapshot of the Conceptual Cost Estimating Module Form

The user has to insert information regarding cost estimation values such as percentage of contingency, profit percentage, overhead percentage, purchase taxes percentage and project year of construction. The user then can click the button "View Summary of Input Variables" to view a summary of input variables that are going to be used in the cost estimating.

The user can go back to the first form if any modifications are desired by clicking on the button "Change Input Values." If no modifications are desired and all the input variables are accepted, the user can click on the button "Accept" to continue and select the type of cost estimation report to be generated.

After developing the interface, the next step is to write code to perform the selection of the proper cost estimation Excel spreadsheet in order to transfer the data from the VB.NET interface to the Excel spreadsheet. The Excel spreadsheet selection will be based on the bridge type. IF-ELSE statements and logical operators are used in the code for transferring the data from the interface to the selected Excel spreadsheet. Figure 4.39 shows a sample of the code for data transfer from the VB.NET interface to the Excel spreadsheet.

```

Private Sub Button8_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Button8.Click
    If InterForm.cmbSubcategory.SelectedItem = "Slab" Then
        'EXCEL CONNECTION
        Dim fileCalculation As String = "C:\Users\Mahmoud\Desktop\Bashar Al-Dosary(28-1-2014)\VB\Bridge Cost Excel Database\Slab.xlsx"
        Dim oExcel As Object
        oExcel = CreateObject("excel.Application") 'Setting an application
        oExcel.workbooks.open(fileCalculation) 'opening a workbook
        Dim obook As Excel.Workbook
        Dim osheet As Excel.Worksheet
        obook = oExcel.activerworkbook 'activating the workbook
        osheet = oExcel.worksheets(1) 'activating the worksheet

        'Inserting values to the cells
        osheet.Range("j1").Value = InterForm.txtTotalLength.Text
        osheet.Range("j2").Value = InterForm.txtTotalWidth.Text
        osheet.Range("j3").Value = InterForm.VerticalClearance
        osheet.Range("j5").Value = InterForm.txtTotalMedianWidthOut.Text
        osheet.Range("j7").Value = InterForm.txtSidewalkWidthOut.Text
        osheet.Range("j19").Value = InterForm.txtLongestSpan.Text
    End If
End Sub

```

IF Condition: If item "Slab" from is selected Bridge Subcategory drop list

Expression: Open Database "Slab"

Expression: Inserting Values to the Excel Spreadsheet

Figure 4. 39 Sample of the Code for Data Transfer from VB.NET to Excel Spreadsheet

The next step is to perform the cost adjustments. Both the location adjustment and inflation adjustments are implemented within the cost Excel spreadsheet.

The final step is to create three forms to present the three types of cost estimation reports. A new form is created for each type of cost estimation report. As shown in Figure 4.40, three buttons are added to open the cost estimating reports.

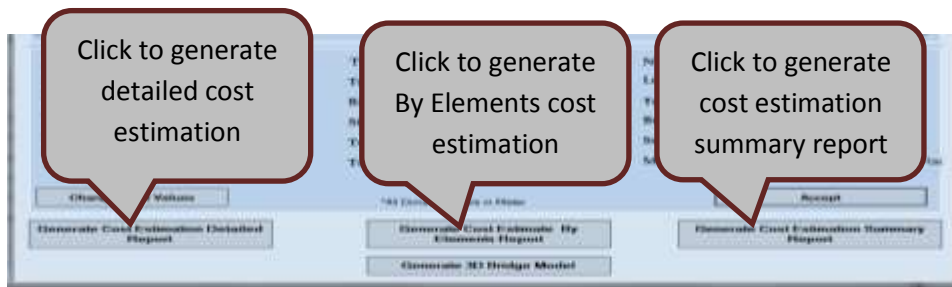


Figure 4. 40 Snapshot of the Three Buttons to Generate Cost Estimating Reports

The detailed cost estimating report contains a summary of project information. The cost estimating database is shown to the user in the view list object as shown in Figure 4.41. If any modifications are required, the user can open the Excel sheet directly by click the button View Excel Spreadsheet in the toolbar. Figure 4.42 shows snapshots of a filled detailed cost estimating report.

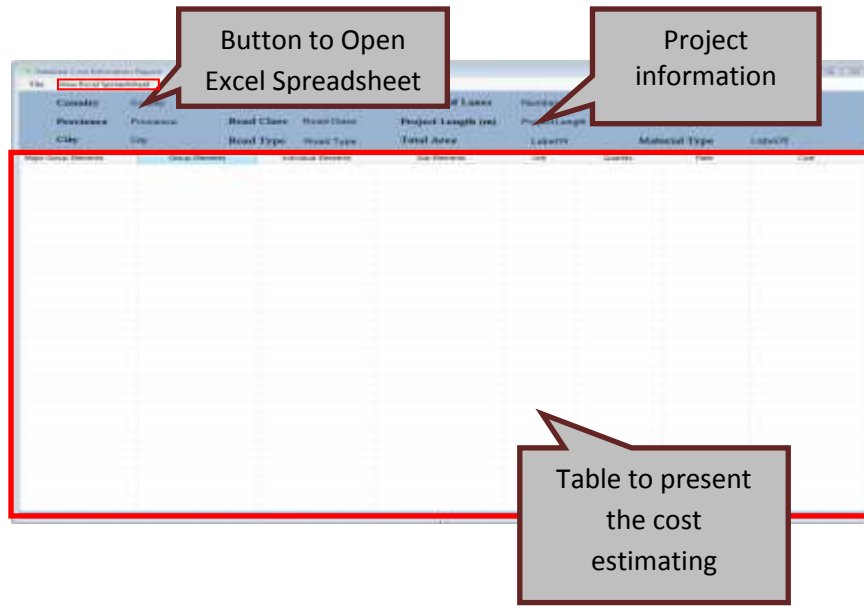


Figure 4. 41 Snapshot of the Detailed Cost Estimating Report

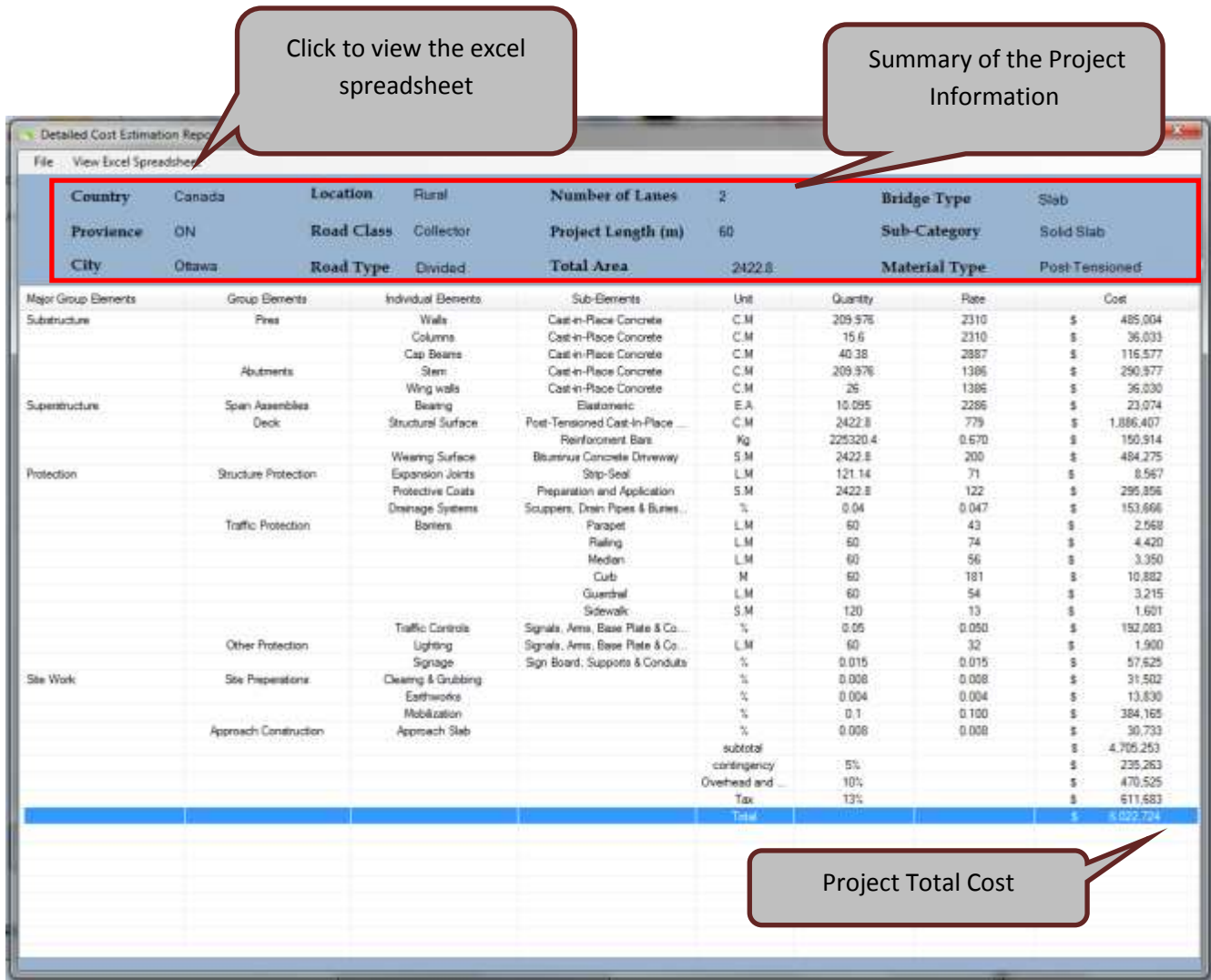


Figure 4. 42 Snapshot of the Detailed Cost Estimating Report

The same procedure was used for the By-Elements and Summary cost estimating reports. Figure 4.43 and Figure 4.44 show a snapshot for By Elements Cost Estimating Report and Summary Cost Estimating Report respectively.

If any modification is desired, the user can go back to the first form using the two buttons provided in the cost estimation module window form. The user can view a 3D visualization of the bridge by clicking the button Generate 3D Bridge Model from the cost estimation module window form as shown in Figure 4.45.

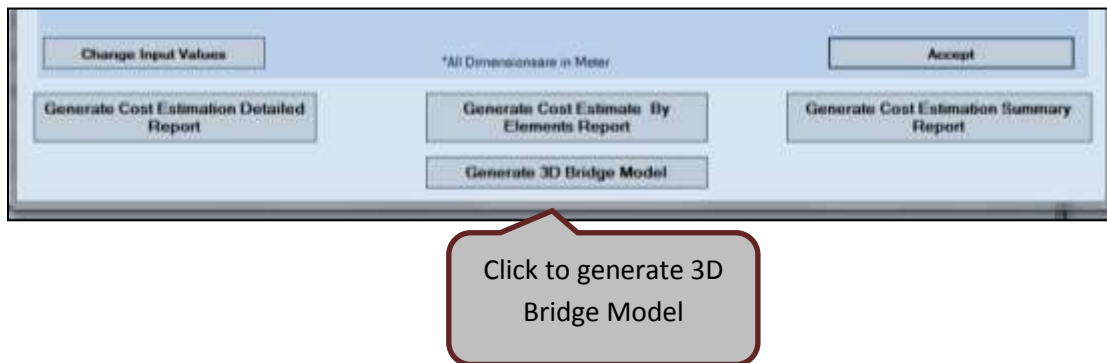


Figure 4. 45 Snapshot of Generate 3D Bridge Model Button

4.5 3D-CAD Module Implementation

The 3D-CAD module shares the same source of data as the conceptual cost estimating module. This source of data is the Excel spreadsheets that store combined information from KBS, bridge type selection, cost data and the ASTM (E2103). The first step in implementing the 3D-CAD module is to create a new form within the VB.NET interface. Figure 4.46 shows a snapshot of the 3D-CAD module form.

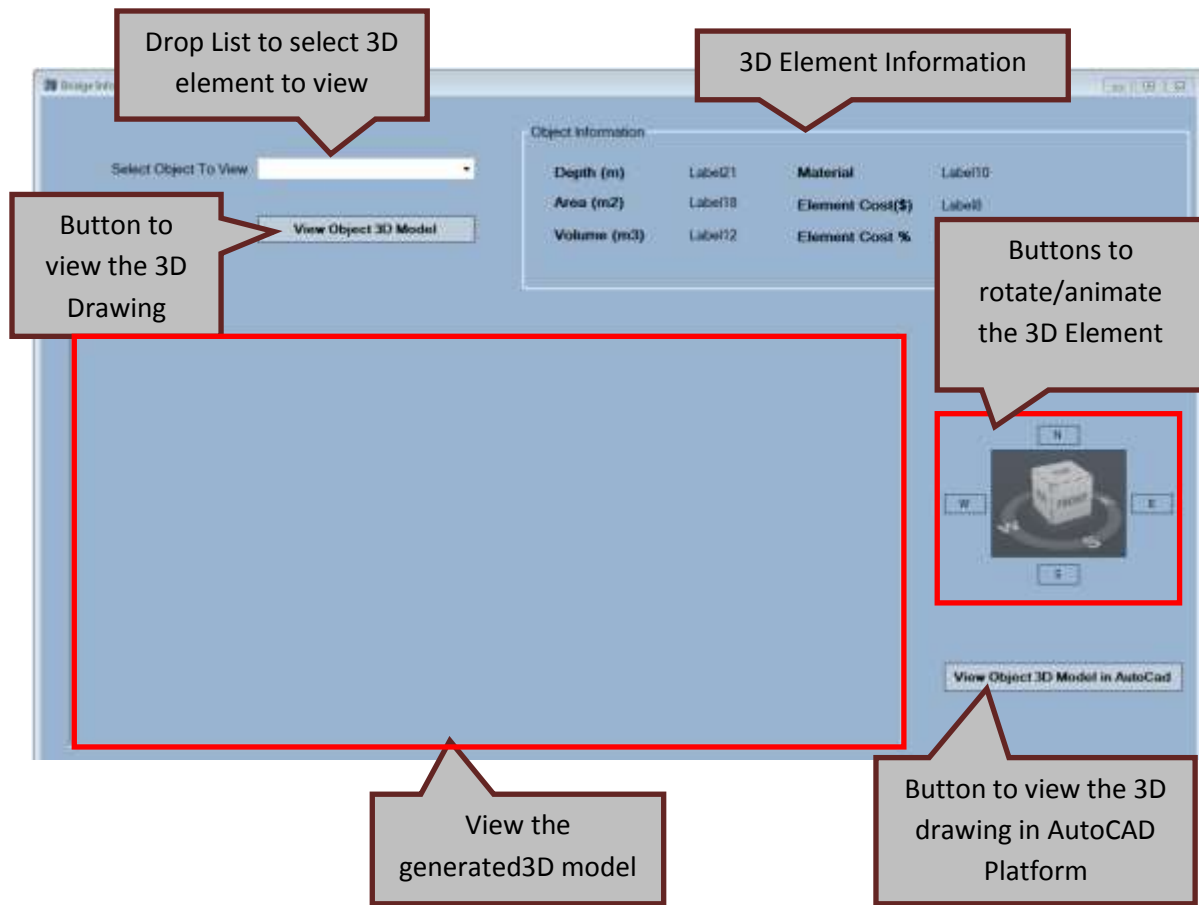


Figure 4. 46 Snapshot of the Window Form of the 3D-CAD Module

A drop list is used to provide the user to choose a bridge element to view. Figure 4.47 shows a snapshot of the drop list. However, if the user selects the option to view the whole bridge, the model will provide the user more information regarding the whole project. Figure 4.48 shows a snapshot of the form if the whole bridge is selected. Buttons are used to provide the user the capability to rotate/animate the viewed bridge element.

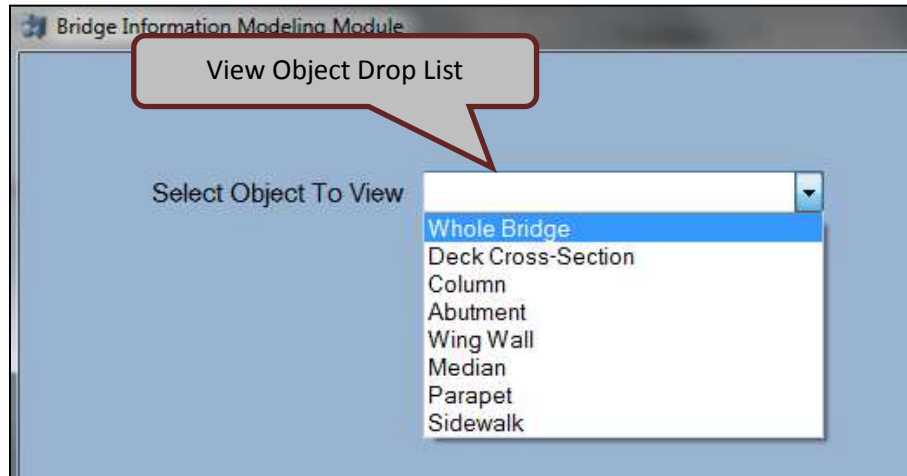


Figure 4. 47 Snapshot of the Drop List

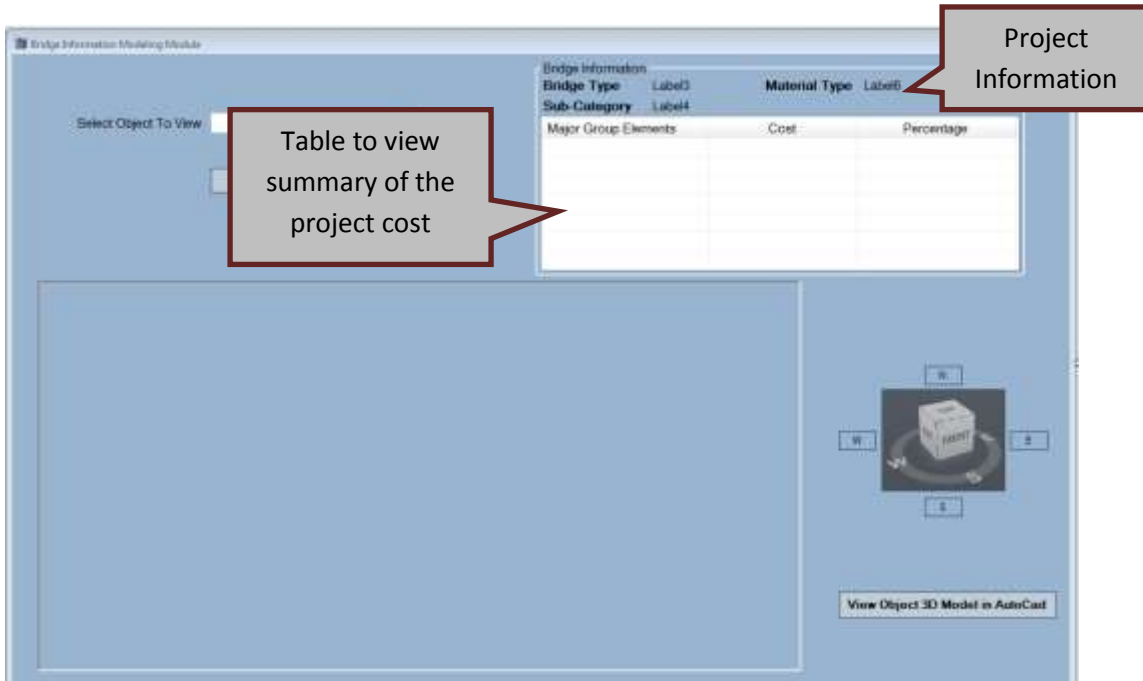


Figure 4. 48 Snapshot of the 3D-CAD Module Form with the Bridge Information

All the data and information used in creating the 3D model is obtained from the bridge Excel spreadsheet. Figure 4.49 shows a snapshot of the 3D bridge model within the developed VB.NET interface.

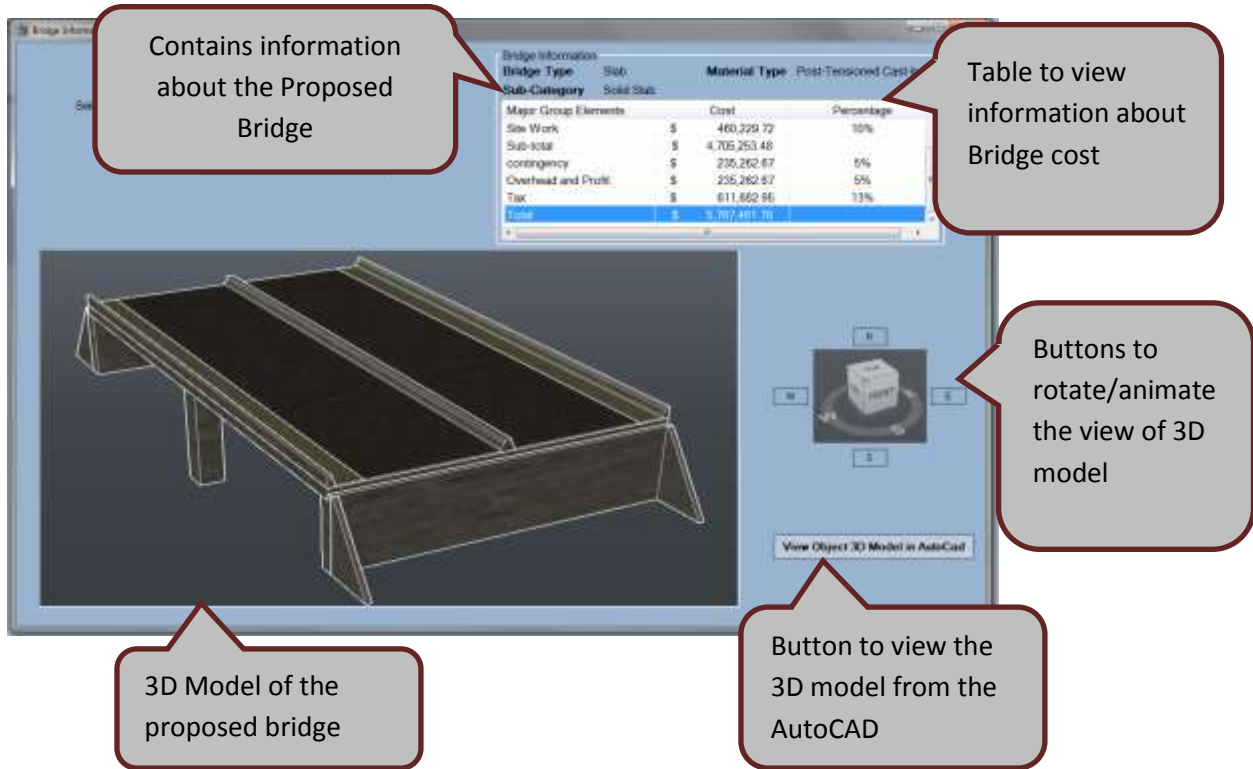


Figure 4. 49 Snapshot of Generated 3D Bridge Model Viewed in VB.NET Interface

The 3D-CAD module allows the user to view the 3D model within the AutoCAD platform generating a realistic visualization of the model. Figure 4.50 shows a snapshot of the 3D model viewed from the AutoCAD drawing file. The 3D model consists of 3D objects, which contain information and properties that can be viewed by clicking on the 3D object.

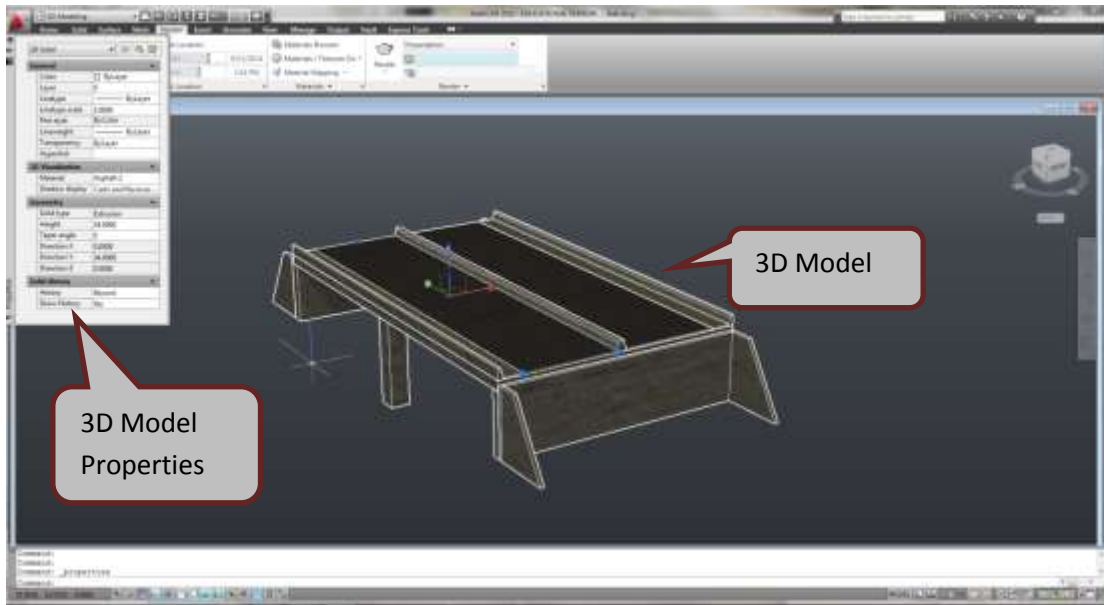


Figure 4. 50 Snapshot of the 3D Bridge Model Viewed in AutoCAD Platform

The proposed model presents all the properties of creating a rendering view of the bridge to provide a realistic view of the bridge, and to provide the light and shade effect on the 3D Bridge model. Figure 4.51 shows a snapshot of the bridge 3D rendering model.

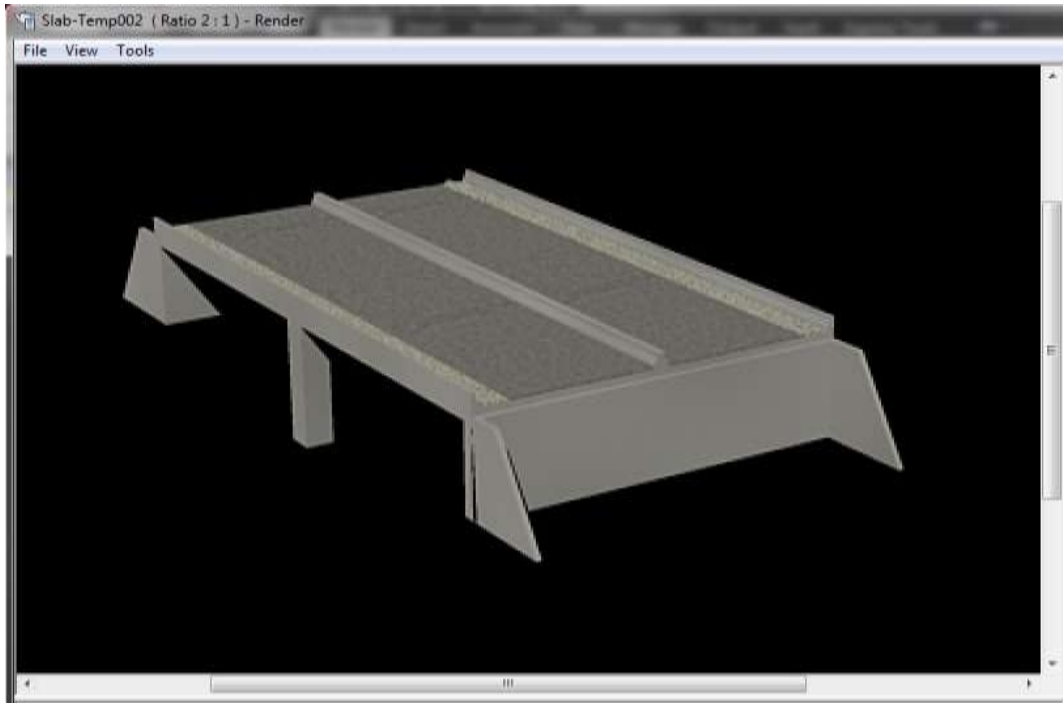


Figure 4. 51 Snapshot of the Bridge 3D Rendering Model

4.6 Summary

This chapter presented the physical development of the integrated model with the conceptual cost estimating model using Visual Basic .NET and Microsoft Excel. The process of developing the model is presented in a way that provides the user with guidance in choosing variety of options, flexibility and fast data recall and retrieval. In addition, figures and tables are used in describing all the attempted steps and processes. The development of the knowledge-based system was first presented by illustrating the development of the knowledge bases. Then the development of the conceptual cost estimation module was presented by showing the process followed in creating the Excel Spreadsheets and VB.NET interface. Finally, the development of the interface of the 3D-CAD module was presented and explained.

Chapter Five

Model's Validation

5.1 Introduction

This chapter tests the capability of the developed model with respect to its three modules: (1) Knowledge-Based System, (2) Conceptual Cost Estimation Module, and (3) 3D-CAD Module. Thus, the validation is specified through a comparison between the values generated by the model and the actual project. The actual project is a two-lane bridge located on Lakeshore Drive, Ontario. The actual project information is shown in Table 5.1. Figure 5.1 and Figure 5.2 show pictures for the bridge.

Table 5. 1 Lakeshore Drive Bridge Information

Project Information	
Country	Canada
Province	Ontario
City	Toronto
Area	Rural
Road Class	Collector
Road Type	Undivided
Design Speed	60 Km/h
Length	60 m
Number of Spans	Two Spans
Number of Lanes / Direction	1 Lanes
Special lanes	No Special Lanes
Underpass Object	Roadway
Underpass Road Class	Highway
Underpass Number of Lanes / Direction	2 Lanes
Underpass Road Median Width	8 m
Underpass Road Barrier	No Barrier
Column System Type	Multiple Braced Pier Column

Abutment Type	Spill-Through Abutment
----------------------	-------------------------------



Figure 5. 1 Side View of the Actual Bridge (Google Earth™)



Figure 5. 2 Actual Bridge Lanes (Google Earth™)

5.2 Knowledge-based System

To test the workability of the model, the first step is to select input variables of the KBS similar to the ones in the actual project. These input variables include: country, province, city, location, road class, road type, traffic type, design speed, and traffic volume. Figure 5.3 shows the selection of the input variables.

BrIM & Conceptual Cost Estimating

File Databases

Please select the following Parameters

Country: Canada

province: ON

City: Toronto

Location: Rural

Road Class: Collector

One Way / Two Way: Two Way

Road Type: Undivided

Design Speed (Km/hr): 60

Traffic Volume (Veh/hr): <5000 AADT

Continue

Project Length (m): 60

Number of Road Lanes: 1

Special Lane

Bikes Transit Lane Pedestrians

Continue

Click Button to Continue

Figure 5. 3 Input variables selection

Once we select all the variables we click on the "Continue" button to continue the process of selecting the input variables. The second step is to select the input variables of the underpass road information. The underpass road information input variables are road class, road type,

traffic type, number of lanes, median width and barrier type. Figure 5.4 shows the selection of underpass road information.

The screenshot shows a software window titled "BIM & Conceptual Cost Estimating". The interface is divided into several sections for data entry:

- Please select the following Parameters:** A list of dropdown menus for Country (Canada), province (ON), City (Toronto), Location (Rural), Road Class (Collector), One Way / Two Way (Two Way), Road Type (Undivided), Design Speed (Km/hr) (60), and Traffic Volume (Vely/hr) (<5000 AADT). A "Continue" button is located to the right of these fields.
- Project Length (m):** A text input field containing "60".
- Number of Road Lanes:** A text input field containing "1".
- Special Lane:** Three checkboxes for "Bikes", "Transit Lane", and "Pedestrians", all of which are currently unchecked.
- Overpass Object:** A dropdown menu set to "Road".
- Waterway Information:** A list of fields for "Is the Waterway Navigable?", "Waterway Width (m)", "Waterway Classification", "Target Vessel Category", "Target Vessel", "Target Vessel Height (m)", "Stream Velocity", "Crosswind Severity", "Traffic Type", "Aids and Visibility", "Wave Severity", and "Channel Bed Material", each with a dropdown arrow.
- Underpass Road Information:** A set of dropdown menus for "Road Class" (Freeway), "One Way / Two Way" (Two Way), "Road Type" (Divided), "No Lanes/Direction" (2), "Median Width" (8), and "Barrier Type" (No Barrier). A "Continue" button is located below these fields.

A callout bubble with a red border and a white background points to the "Continue" button in the "Underpass Road Information" section, containing the text "Click Button to Continue".

Figure 5. 4 Selection of the Underpass Road Information

After we insert all the required information, we click on the "Continue" Button to view the suggested span arrangement for the project. Figure 5.5 shows the span arrangement. We select the number of spans to be two, with a length of 30 m each. Then, we click on the button "Continue" to view the knowledge-based system outputs. Figure 5.6 shows the knowledge-based system outputs.

The screenshot shows the 'BIM & Conceptual Cost Estimating' software interface. The main window is titled 'BIM & Conceptual Cost Estimating' and has a 'File - Database' menu. The interface is divided into several sections:

- Please select the following Parameters:** This section contains dropdown menus for Country (Canada), province (ON), City (Toronto), Location (Rural), Road Class (Collector), One Way / Two Way (Two Way), Road Type (Undivided), Design Speed (Km/h) (80), and Traffic Volume (Veh/h) (>5000 AADT). There is a 'Continue' button at the bottom right of this section.
- Please Select Number of Bridge Spans:** This section has radio buttons for One Span, Two Spans, Three Spans, Four Spans, and Five Spans. A 'Continue' button is located to the right.
- Bridge Span Arrangement:** This section has input fields for Span # 1, Span # 2, Span # 3, Span # 4, and Span # 5, each followed by a 'Meter' label. A 'Continue' button is located to the right.
- Project Length (m):** Input field with value 60.
- Number of Road Lanes:** Input field with value 1.
- Special Lane:** Checkboxes for Bikes and Transit Lane.
- Parade Lane:** Checkboxes for Bikes and Transit Lane.
- Continue** button.
- Overpass Object:** Dropdown menu set to Road.
- Waterway Information:** A list of input fields including Is the Waterway Navigable?, Waterway Width (m), Waterway Classification, Target Vessel Category, Target Vessel, Target Vessel Height (m), Stream Velocity, Crosswind Severity, Traffic Type, Aids and Visibility, Wave Severity, and Channel Bed Material.
- Underpass Road Information:** This section contains dropdown menus for Road Class (Freeway), One Way / Two Way (Two Way), Road Type (Divided), and Barrier Type (No Barrier). It also has input fields for No lanes/Direction (2) and Median Width (8). A 'Continue' button is at the bottom right.

A callout box with a red border and a white background points to the 'Continue' button in the 'Bridge Span Arrangement' section. The text inside the callout box reads: "Click Button to view the Outputs".

Figure 5. 5 Selection of the Bridge Span Arrangement

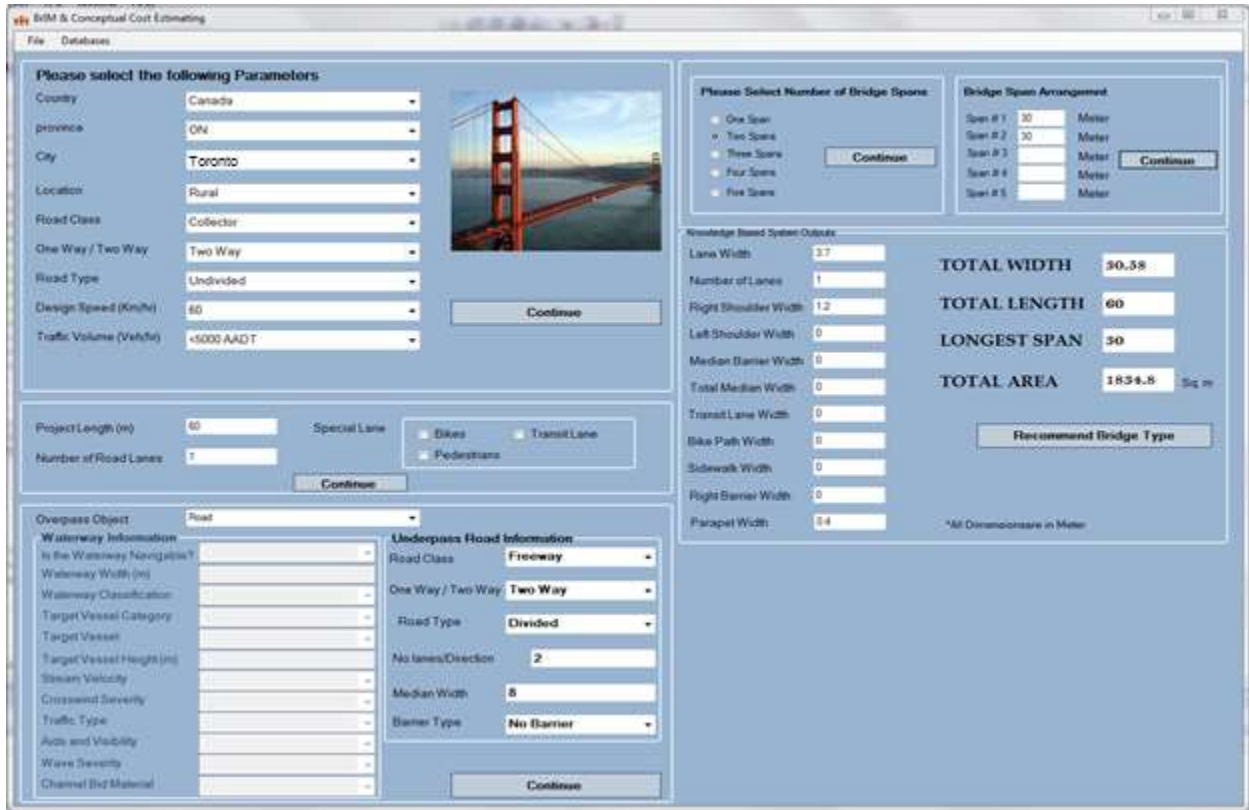


Figure 5 .6 Knowledge-Based System Outputs

In order to validate the outputs of the KBS, the values are compared with the actual bridge values. Also, the KBS outputs are compared with values obtained manually from TAC (1999) Highway Geometric Design Guidelines. Table 5.2 summarizes the comparison of the KBS outputs.

Table 5. 2 Knowledge-Based System Outputs

	KBS Outputs	Actual Project Values	TAC (1999)
Lane Width	3.7 m	3.7 m	Based on Table (2.2.2.1) lane width ranges between (3.5m – 3.7m)
Right Shoulder Width	1.2 m	1.2 m	Based on Table (2.2.10.2) Right Shoulder width is (2.7m)

Left Shoulder Width	0 m	0 m	Undivided Collector Rural Road without left shoulder
Median Barrier Width	0 m	0 m	Undivided Collector Rural Road with no median
Transit Lane Width	0 m	0 m	Undivided Collector Rural Road with no Transit Lanes
Bike Path Width	0 m	0 m	Undivided Collector Rural Road with not Bike Path
Sidewalk Width	0 m	0 m	Undivided Collector Rural Road with no Pedestrians
Right Barrier Width	0 m	0 m	Undivided Collector Rural Road with no Sidewalk and Design Speed less than (80Km/h)
Parapet Width	0.4 m Concrete Parapet	0.4 Concrete Parapet	Standard Concrete Parapet Width

As shown in Table 5.2, KBS output values are the same as the actual project and within the values and ranges of the TAC (1999) Highway Geometric Design Guidelines.

The next step is to click "Recommend Bridge Types" button to show us the recommended bridge types for our case. Figure 5.7 shows the results of the bridge types recommended for us.

Please select the following Parameters

Country: Canada
 province: ON
 City: Toronto
 Location: Rural
 Road Class: Collector
 One Way / Two Way: Two Way
 Road Type: Undivided
 Design Speed (km/h): 60
 Traffic Volume (Veh/h): <5000 AADT

Please Select Number of Bridge Spans

One Span
 Two Spans
 Three Spans
 Four Spans
 Five Spans

Bridge Span Arrangement

Span # 1: 30 Meter
 Span # 2: 30 Meter
 Span # 3: Meter
 Span # 4: Meter
 Span # 5: Meter

Knowledge Based System Outputs

Lane Width: 3.7
 Number of Lanes: 1
 Right Shoulder Width: 1.2
 Left Shoulder Width: 0
 Median Barrier Width: 0
 Total Median Width: 0
 Transited Lane Width: 0
 Bike Path Width: 0
 Sidewalk Width: 0
 Right Barrier Width: 0
 Parapet Width: 0.4

TOTAL WIDTH: 30.58
TOTAL LENGTH: 60
LONGEST SPAN: 30
TOTAL AREA: 1834.8 Sq m

Project Length (m): 60 Special Lane: Bikes Transit Lane Pedestrians
Number of Road Lanes: 1

Overpass Object: Road

Underpass Road Information

Road Class: Freeway
 One Way / Two Way: Two Way
 Road Type: Divided
 No lanes/Direction: 2
 Median Width: 8
 Barrier Type: No Barrier

Bridge Type	Status	Comment
Arch	Not Recommended	Width Coefficient is less than 80%
Beam / Girder	Recommended	
Frame	Recommended	
Slab	Recommended	
Temporary Modular	Not Recommended	Width Coefficient is less than 80%
Trestle	Not Recommended	Width Coefficient is less than 80%

Please Select Bridge Type

Bridge Type:
 Sub-Category:
 Material Type:

Recommend Bridge Type **Estimate The Cost**

Figure 5. 7 Recommended Bridge Types

As shown in Figure 5.7, only Bridge/Girder, Frame and Slab bridge types are recommended. Based on this recommendation, the next step is to select the desired bridge type. Figure 5.8 shows the selection of the bridge type. Once the bridge type is selected, we click on "Estimate the Cost" button to go to the conceptual cost estimating module.

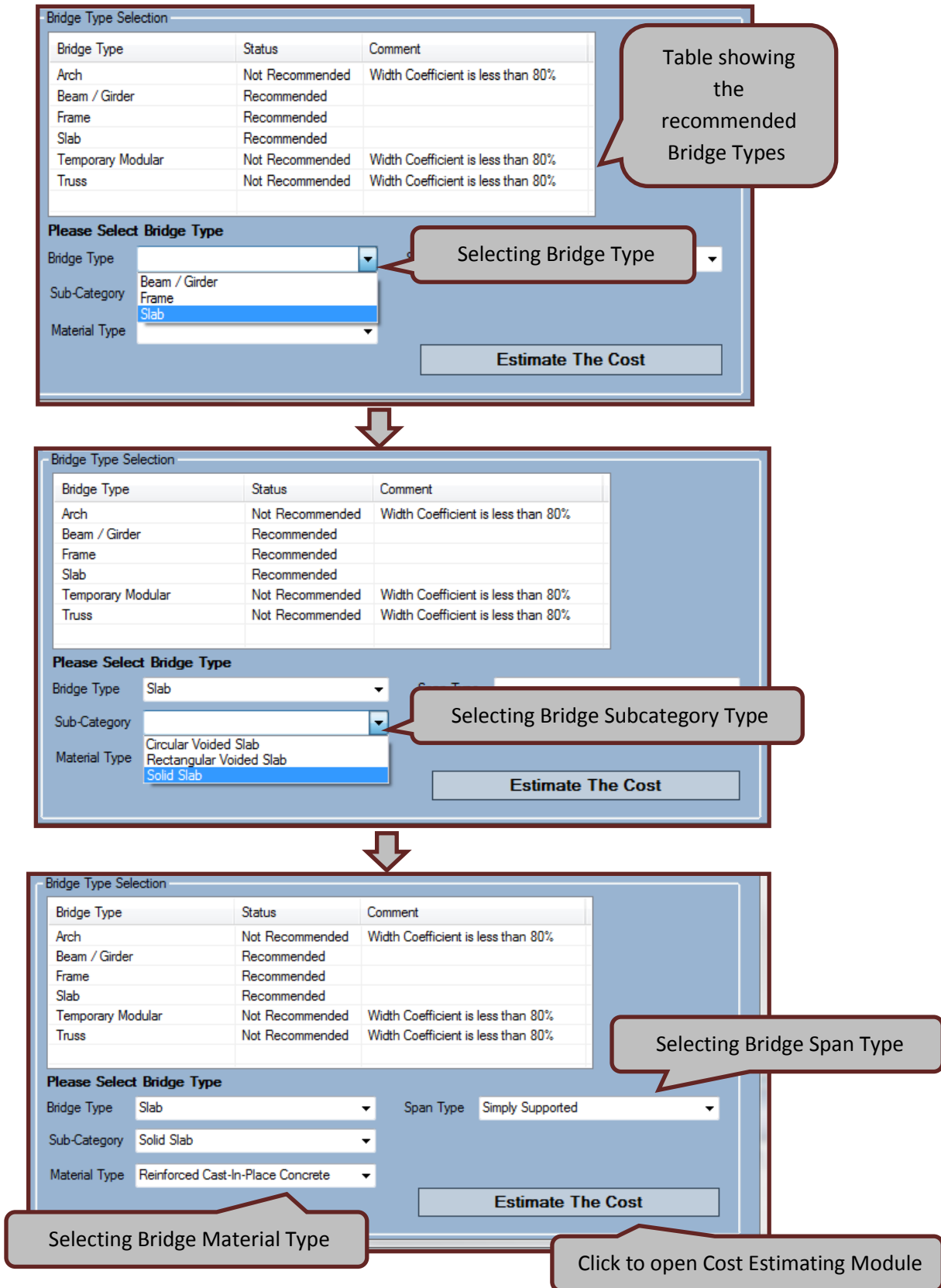


Figure 5. 8 Bridge Type Selection

5.3 Conceptual Cost Estimation Module

The next step is to select the column system type and the abutment type, as shown in Figure 5.9. After that, we should insert the percentage of profit, contingency, overhead and purchase taxes along with the project year of construction as shown in Figure 5.10.

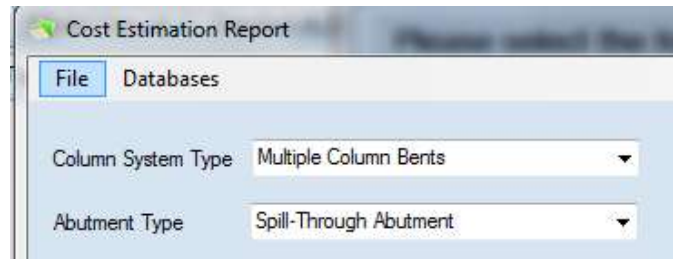


Figure 5. 9 Selecting the Column System Type and Abutment Type

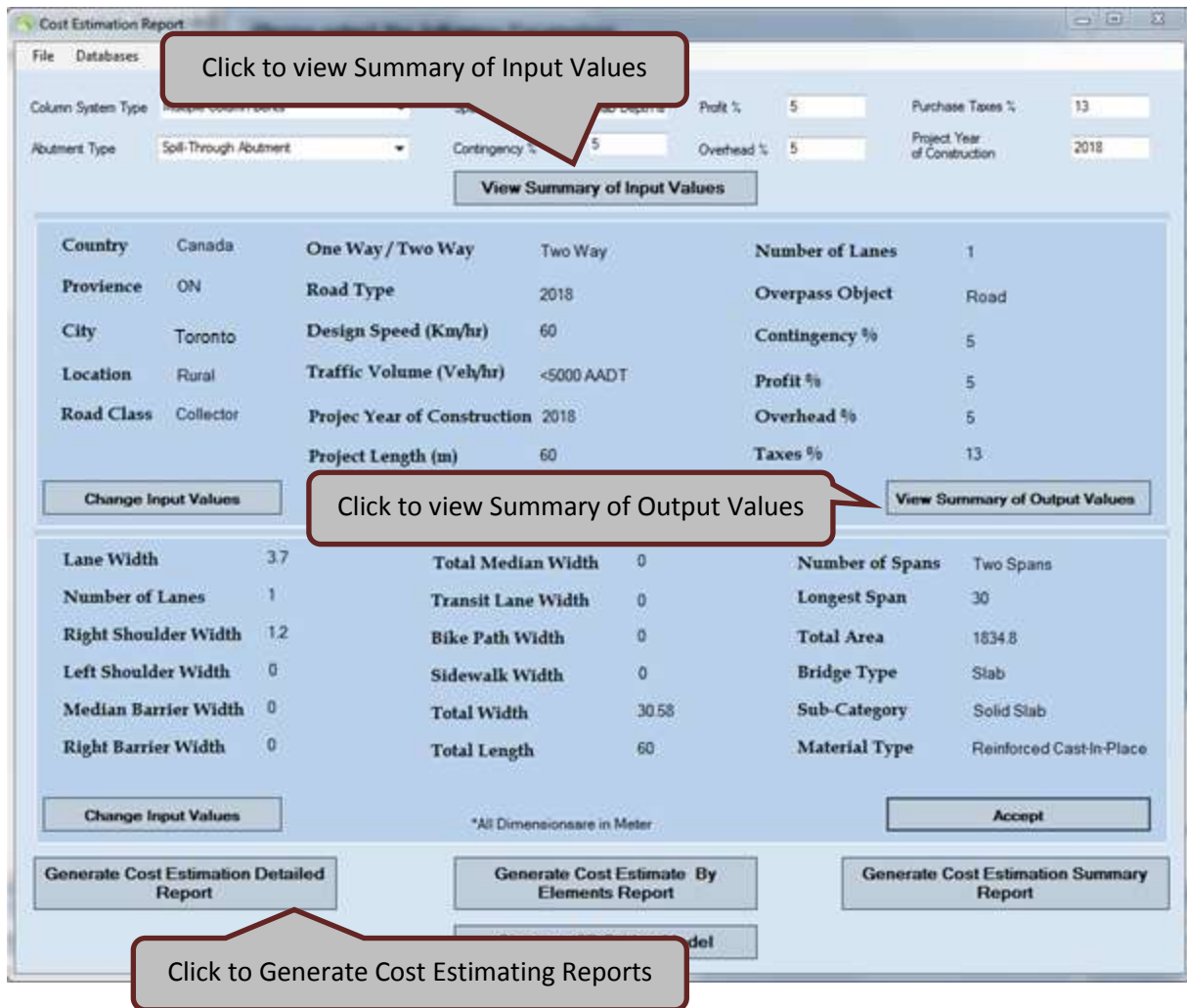


Figure 5. 10 Snapshot of the Cost Estimating Module

As shown in Figure 5.10, we can view all the input and output values before generating any cost estimating report. In case of any modification desired, we can click on "Change Input Values" button to go back to the previous form to change the variables. Since no modification is desired, we click on "Generate Cost Estimating Detailed Report" button to generate detailed cost estimating report. Figure 5.11 shows the detailed cost estimating report. Figure 5.12 and Figure 5.13 show the By-Elements cost estimating report and cost estimating summary report respectively.

Detailed Cost Estimation Report								
Country	Canada	Location	Rural	Number of Lanes	1	Bridge Type	Slab	
Province	ON	Road Class	Collector	Project Length (m)	60	Sub-Category	Solid Slab	
City	Toronto	Road Type	Undivided	Total Area	1834.8	Material Type	Reinforced Cast-In-Place Concrete	
Major Group Elements	Group Elements	Individual Elements	Sub-Elements	Unit	Quantity	Rate	Cost	
Substructure	Pier	Walk	Cast-in-Place Concrete	C.M	159.016	2395	\$ 380,775	
		Columns	Cast-in-Place Concrete	C.M	15.6	2395	\$ 37,355	
	Abutments	Cap Beams	Cast-in-Place Concrete	C.M	30.88	2993	\$ 91,524	
		Sets	Cast-in-Place Concrete	C.M	159.016	1437	\$ 228,445	
Superstructure	Span Assemblies	Wing walls	Cast-in-Place Concrete	C.M	26	1437	\$ 37,352	
		Bearing	Elastomeric	E.A	7.645	2370	\$ 18,115	
	Deck	Structural Surface	Post-Tensioned Cast-In-Place	C.M	1834.8	807	\$ 1,481,012	
			Reinforcement Bars	Kg	179636.4	0.694	\$ 116,482	
			Wearing Surface	Bituminous Concrete Driveway	S.M	1834.8	207	\$ 380,203
			Expansion Joints	Strip-Seal	L.M	91.74	73	\$ 6,726
Protection	Structure Protection	Protective Coats	Preparation and Application	S.M	1834.8	127	\$ 232,276	
		Drainage Systems	Souppets, Drain Pipes & Buses	%	0.04	0.047	\$ 121,583	
		Traffic Protection	Barriers	Fanpet	L.M	60	44	\$ 2,662
				Railing	L.M	60	76	\$ 4,582
			Median	L.M	60	58	\$ 3,473	
			Curb	M	60	188	\$ 11,282	
			Guardrail	L.M	60	95	\$ 3,333	
		Sidewalk	S.M	0	14	\$ -		
	Other Protection	Traffic Controls	Signals, Arms, Base Plate & Co...	%	0.05	0.050	\$ 151,578	
		Lighting	Signals, Arms, Base Plate & Co...	L.M	60	33	\$ 1,970	
		Signage	Sign Board, Supports & Conduits	%	0.015	0.015	\$ 45,594	
	Site Work	Site Preparations	Clearing & Grubbing	%	0.008	0.008	\$ 24,924	
Earthworks			%	0.004	0.004	\$ 10,942		
Approach Construction		Mobilization	%	0.1	0.100	\$ 303,957		
		Approach Slab	%	0.008	0.008	\$ 24,317		
				Subtotal			\$ 3,722,852	
				contingency	5%		\$ 186,143	
				Overhead and	10%		\$ 372,286	
				Tax	13%		\$ 483,972	
				Total			\$ 4,765,253	

Figure 5. 11 Detailed Cost Estimating Report

Sub-Classification Cost Estimation Report

Major Group Elements	Group Elements	Cost	Percentage
	Deck	\$ 1,979,696.59	53%
Protection	Structure Protection	\$ 360,584.31	10%
	Traffic Protection	\$ 177,310.41	5%
	Other Protection	\$ 47,563.58	1%
Site Work	Site Preparations	\$ 339,823.61	9%
	Approach Construction	\$ 24,316.54	1%
Subtotal	--	\$ 3,722,861.88	
Contingency	5%	\$ 186,143.09	
Overhead and Profit	10%	\$ 372,286.19	
Tax	13%	\$ 483,972.05	
Total	--	\$ 4,765,263.21	

Generate Cost Estimation Detailed Report

Generate Cost Estimation Summary Report

Figure 5 .12 By-Elements Cost Estimating Report

Summary Cost Estimation Report

Major Group Elements	Cost	Percentage
Substructure	\$ 775,451.51	21%
Superstructure	\$ 1,997,811.91	54%
Protection	\$ 585,458.31	16%
Site Work	\$ 364,140.15	10%
Sub-total	\$ 3,722,861.88	
contingency	\$ 186,143.09	5%
Overhead and Profit	\$ 372,286.19	10%
Tax	\$ 483,972.05	13%
Total	\$ 4,765,263.21	

Generate Cost Estimate Report By Elements

Generate Cost Estimation Detailed Report

Figure 5. 13 Summarized Cost Estimating Report

As shown in the cost estimating reports, the total cost to construct a concrete slab bridge in Toronto in 2018 is \$4,765,263.21. The cost of the actual project is not available due to privacy and confidentiality. However, the cost of the actual project is estimated using Ontario Ministry of Transportation (MTO) Parametric Estimating Guide (2011). The cost to construct a square meter of deck area between 750 m² to 2999 m² is \$2,420. The MTO Parametric Estimating Guide (2011) is illustrated in Appendix G. The actual bridge area is 1,834 m². The estimated cost for the actual bridge project in the year 2011 is \$4,438,280. One adjustment needs to be applied on the actual project cost so it will be compatible with the model's values. Therefore we need to bring the information of the actual bridge from the year 2011 to the year 2018. This adjustment will be for time. To do time adjustment, the cost of the actual project has to be brought from the year 2011 to the year 2018 using the following equation.

$$F = P(1 + i)^n \quad 5.1$$

Where,

P = Past cost of completed project at year 2011, in this case \$4,438,280.

i = Inflation rate assumed to be (3%) because it is a common and practical value in the Canadian Industry based on the MTO Parametric Cost Estimating Guide 2011.

n = Number of years among the known and the forecasted year, in this case is 7

Therefore, the estimated cost of the actual project of year 2018 = \$4,438,280 (1 + 0.03)⁷ = \$ 5,458,525

The project cost that was obtained from the model is \$4,765,236.21 based on year 2018 as illustrated in Figure 5.13, comparing this value to the actual project cost, after bringing it to the year 2018 shows a difference of \$693,288.79 in the cost. That reflects a cost 12.7% less than the actual cost, which is acceptable for conceptual estimates. This difference in the cost is due to many reasons; the most important being that the model is based on published cost value, accumulated from 20 different cities in North America, whereas, the actual project cost value is

estimated using parametric cost estimating, which reflects a higher level of accuracy. Location adjustment is applied on the collected costs from 20 different cities so they will be compatible with the actual project.

5.4 3D-CAD Module

In order to view the 3D-CAD module, we click on the button "Generate 3D Bridge Model" as shown in Figure 5.14. Once the 3D-CAD module is viewed, we have to select the bridge element and click on the "View Object 3D Model" button as shown in Figure 5.15.

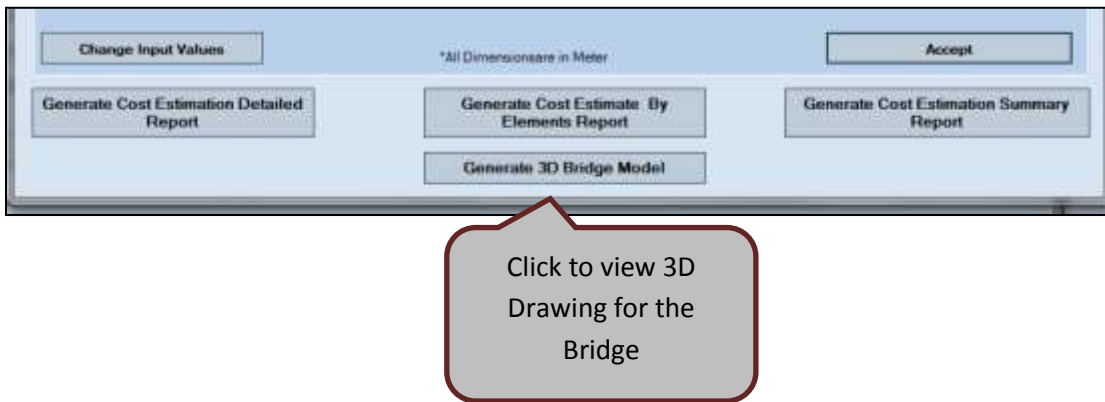


Figure 5. 14 3D-CAD Module Button

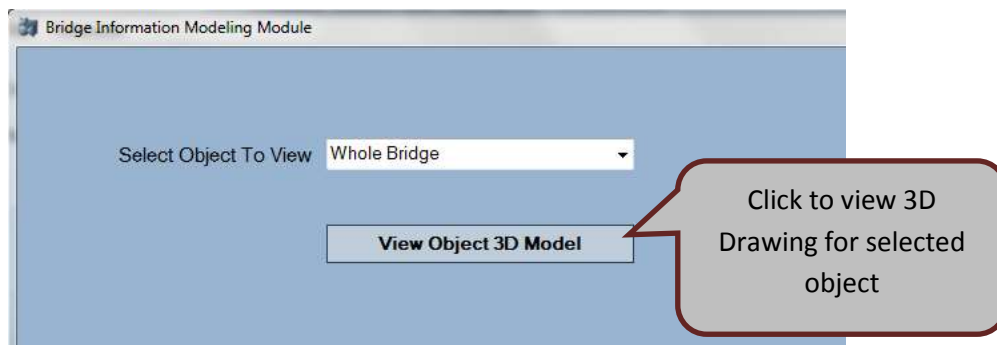


Figure 5. 15 Select Bridge Element to View

Figure 5.16 shows the 3D drawing of the whole bridge within the VB.NET platform. To view the 3D drawing at another angle we click on the buttons of orientation control as shown in Figure 5.17. To view another bridge element, we simply have to select the bridge element from the drop list. Figure 5.18, Figure 5.19 and Figure 5.20 show 3D drawings of the columns, abutments and parapet respectively.

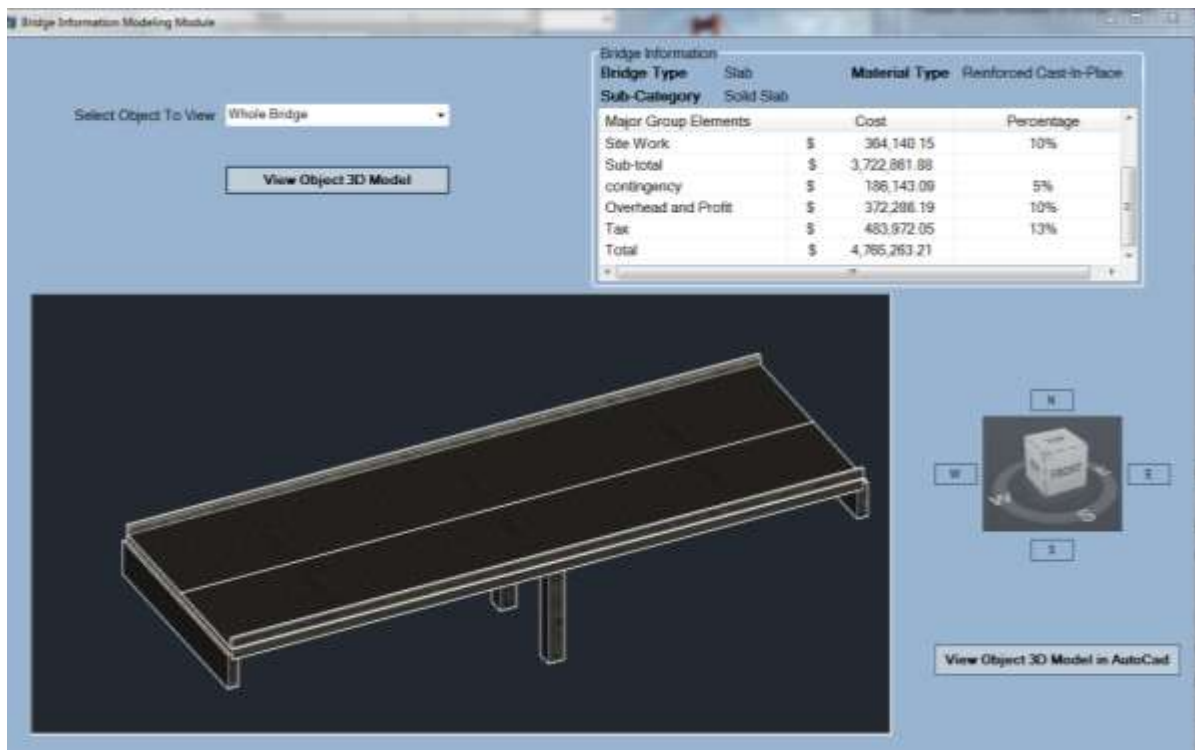


Figure 5. 16 Snapshot of the Whole Bridge 3D Drawing

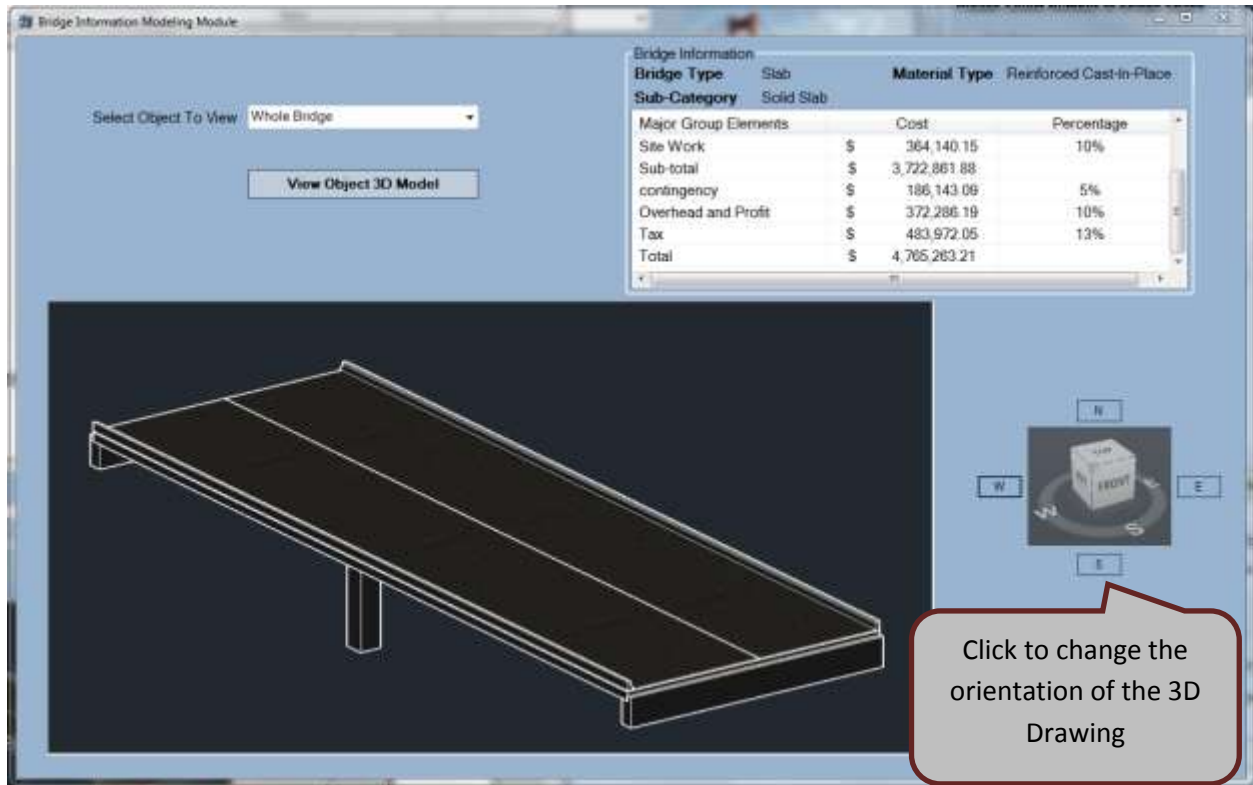


Figure 5. 17 Snapshot of the Whole Bridge 3D Drawing from Different Angle

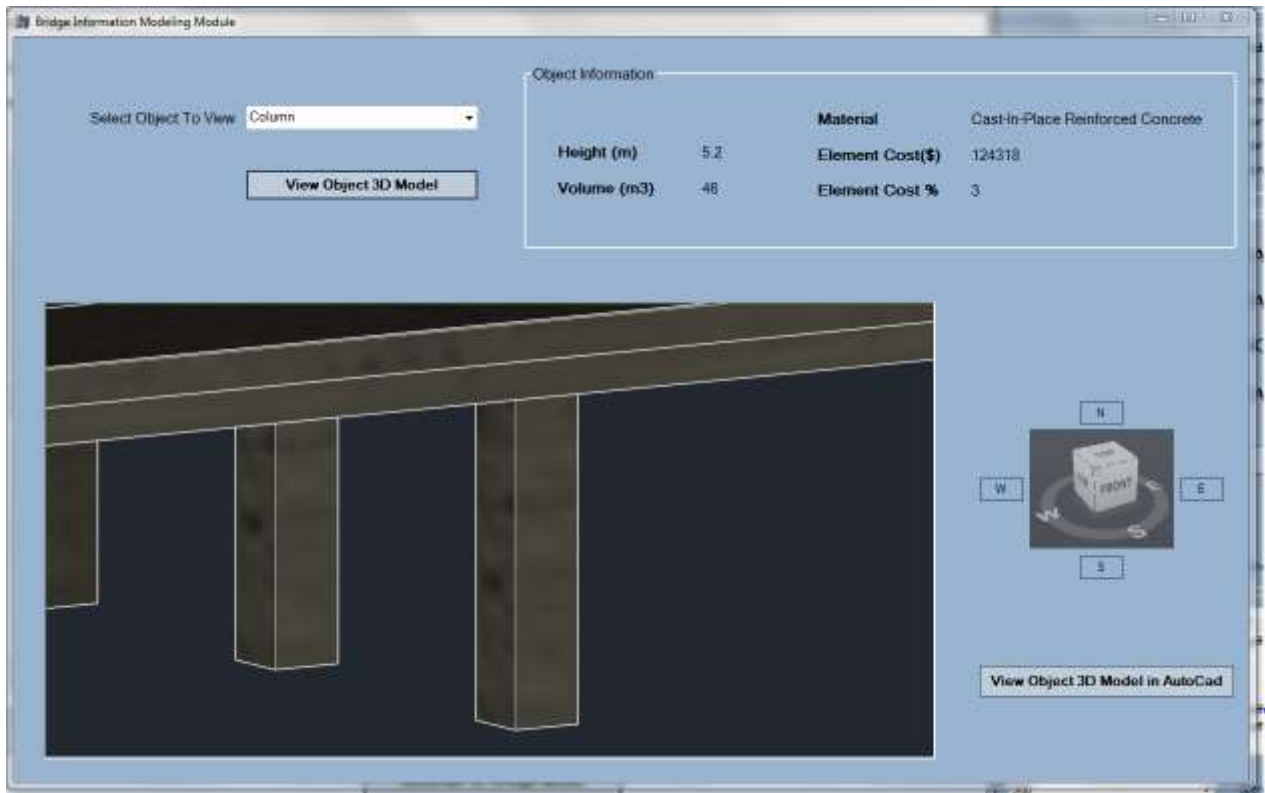


Figure 5. 18 Snapshot of the Columns 3D Drawing



Figure 5. 19 Snapshot of the Abutment 3D Drawing

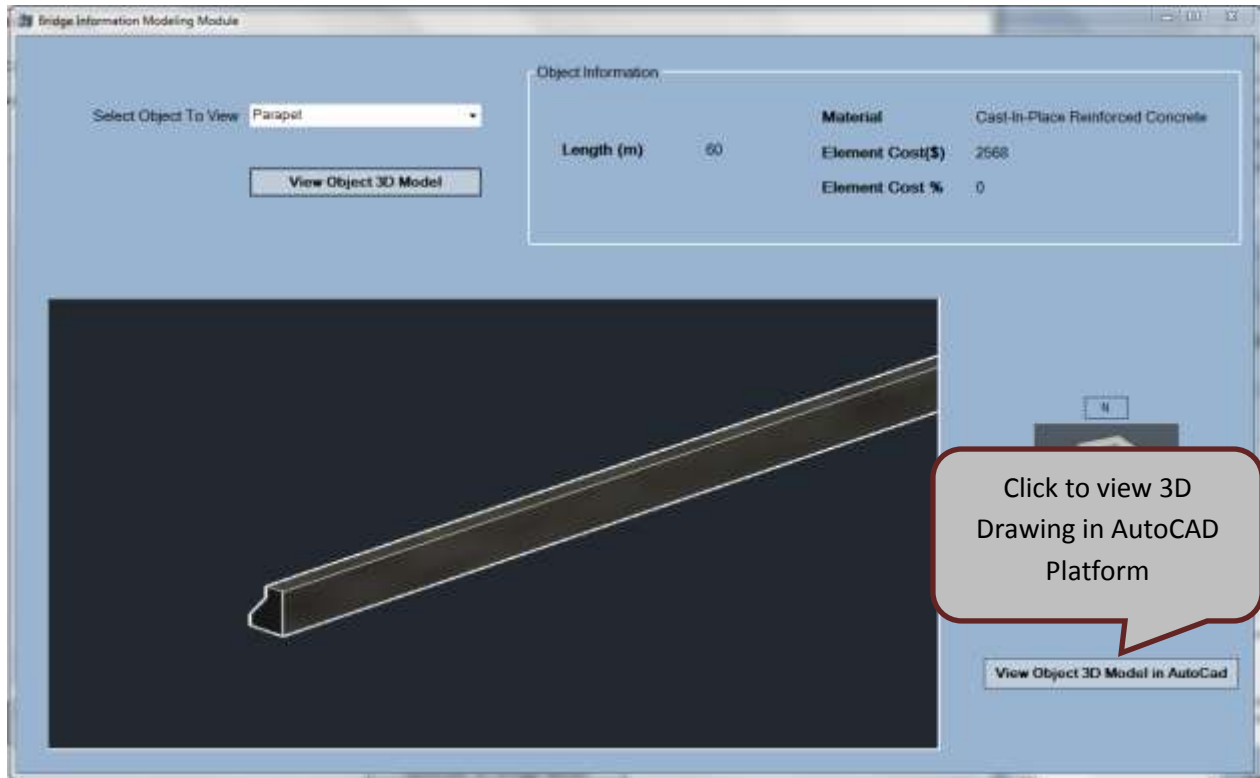


Figure 5. 20 Snapshot of the Parapet 3D Drawing

To view the 3D drawing on the AutoCAD platform, we have to click the button "View Object 3D Model in AutoCAD" as shown in Figure 5.20. Figure 5.21 shows a snapshot of viewing the 3D drawing on the AutoCAD platform. Viewing the 3D drawing within the AutoCAD platform provides the ability to view realistic 3D drawings. Figure 5.22 shows a snapshot of the rendered 3D Drawing.

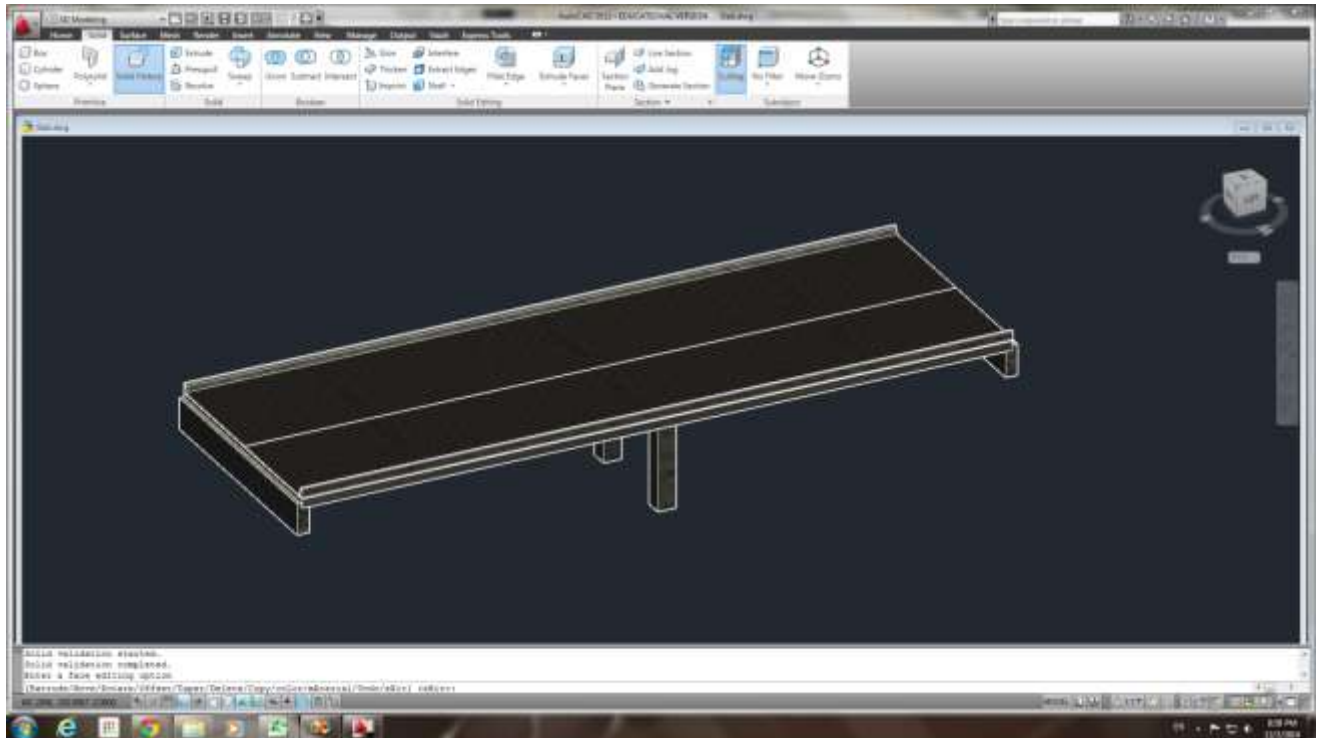


Figure 5. 21 Viewing the 3D Drawing within the AutoCAD Platform

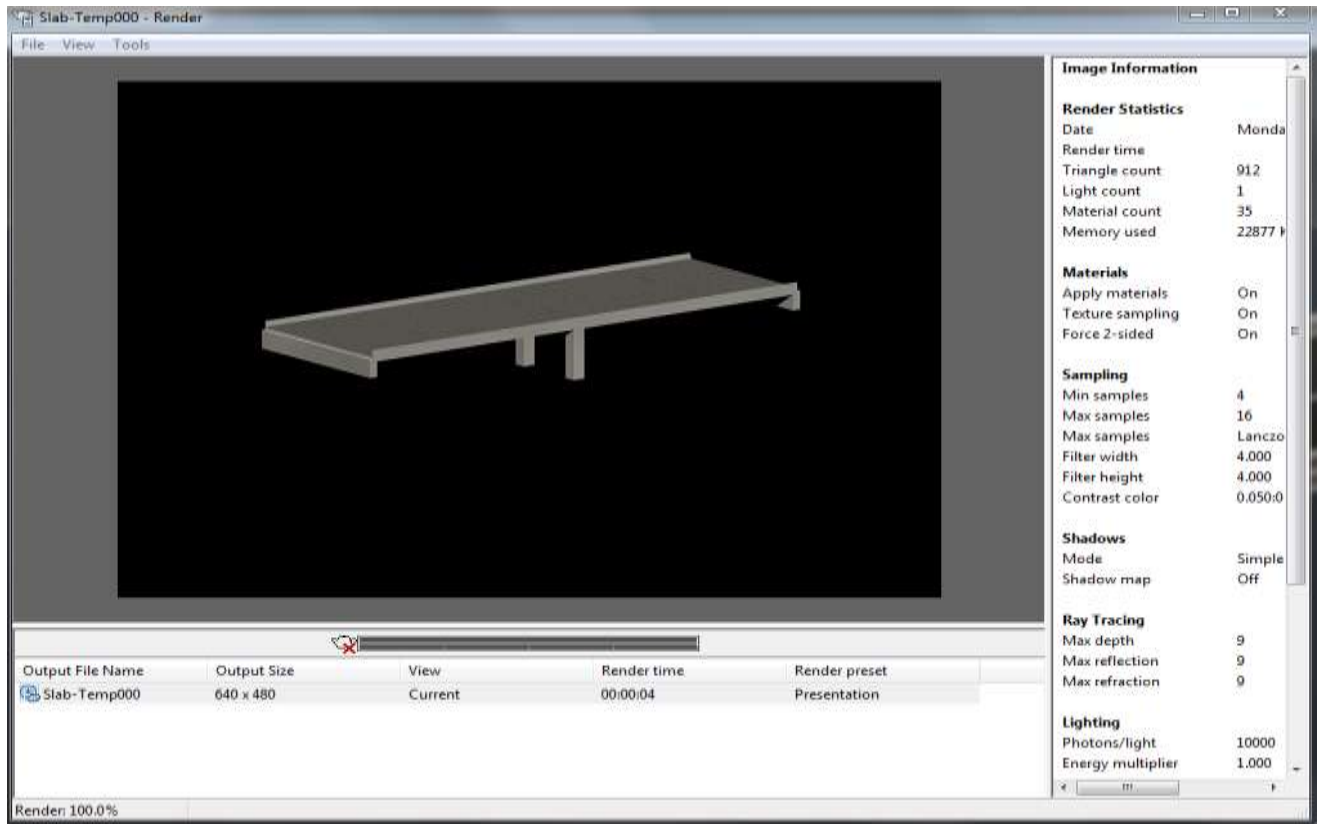


Figure 5. 22 Rendering View of the 3D Drawing

5.5 Summary

This chapter validated the performance of the model by estimating the cost and generating 3D CAD drawings of an actual project. This performance is measured by comparing the model's results with the actual project values. The actual project was a two-lane concrete slab bridge located on Lakeshore Drive, Toronto, Ontario, Canada. The comparison between the preliminary dimensions of the actual bridge and those of the model showed exactly the same values. Also, the model's preliminary dimensions were compared with the values obtained manually from TAC (1999) Highway Geometric Design Guidelines and showed matched values. Regarding the construction cost estimation, both the actual and model's construction cost showed close values with a small difference, which is acceptable because at the conceptual stage there is not enough information known about the project. The generated preliminary dimensions and the estimated

cost by the model were in the same range, which proves the feasibility and reliability of the developed model. 3D CAD drawings of the case project were viewed in VB.NET and AutoCAD platforms to provide flexibility in visualization.

Chapter Six

Conclusion and Future Recommendations

6.1 Conclusion

The concept of the Bridge Information Modeling (BrIM) has been introduced to enhance the procedure of the whole phases of bridge life-cycle starting with concept and design, through construction and operation, and ending with maintenance and rehabilitation. The absence of employing the BrIM concept at the conceptual design stage that particularly serves the owners, designers and construction managers in visualizing bridge projects in a 3D mode with according conceptual cost estimate necessitated the development of a methodology to integrate the conceptual cost estimation with the 3D CAD. The described methodology consists of three modules, and they are: a knowledge-based system module, which is used to generate preliminary dimensions and parameters depending on algorithmic and heuristic knowledge gathered from codes, guidelines and design experts; a conceptual cost estimation module, which is used to generate conceptual cost estimate based on the results of the first module; and a 3D-CAD module, which is integrated with the previous modules, where users will see the proposed bridge in 3D mode based on the results of the knowledge based module.

The developed model has the following advantages:

1. It has ability to produce a conceptual bridge design by utilizing the knowledge-based system.
2. It has user friendly interface, which provides the user guidance, flexibility and execute quick calculations.
3. It generates professional output reports in a quick and efficient way.

6.2 Research Contributions:

Research contributions include the following:

1. An integrated model has been developed in which two concepts were combined to provide a cost estimation and visualization at the conceptual design stage of bridge projects utilizing Visual Basic.NET as an interface, MS Excel for data storage and AutoCAD for 3D visualization.
2. Knowledge based system has been integrated with the proposed methodology to simulate the expertise of designers in generating conceptual bridge design along with employing the benefits of implementing the 3D visualization.

The intention of developing the model is to assist owners, designers and construction managers in preparing fast, efficient and reliable conceptual cost estimates along with 3D visualization of bridge projects. It assists the user taking go-no-go decisions by evaluating the estimated cost and the visualized bridge model that reduces the time required for the conceptual design process. It provides professional output reports and realistic visualization of the bridge aesthetics.

6.3 Research Limitation:

The developed model recommends bridge types based on existing bridges in Ontario, which might reflect reliable results in Ontario only. Also the developed model can be used for straight bridges in visualizing and cost estimating and cannot be used for skewed or curved bridges. In addition, the collected cost data used in the model is based on previously constructed bridge projects, which needs to be updated. Moreover, the programming linkage between AutoCAD platform and the Excel spreadsheets is not executed, and the process of creating 3D models is not automated.

6.4 Future Expansion:

Despite the ability of the developed model in generating conceptual cost estimation and creating 3D bridge drawings, the model can be enhanced by adding the following features:

1. Provide an automated process in creating 3D models by programming the linkage between the AutoCAD and MS Excel.
2. Utilize more information in the knowledge-based system regarding to bridge aesthetics handbooks and guidelines to provide more assistant and guidance to user.
3. Incorporate advance artificial intelligence decision support system in the bridge type selection process.
4. Develop integration with a preliminary bridge structural design models such as SAP2000.
5. Develop a conceptual scheduling model to estimate the duration of the proposed bridge projects.

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Appendix A: TAC (1999)
Tables used in the Highway
Geometric Design
Guidelines Knowledge base

TAC (1999) Highway Geometric Design Guideline

Table 1.3.4.1 Characteristics of Rural Roads

	Rural Locals	Rural Collectors	Rural Arterials	Rural Freeways
service function	traffic movement secondary consideration	traffic movement and land access of equal importance	traffic movement primary consideration	optimum mobility
land service	land access primary consideration	traffic movement and land access of equal importance	land access secondary consideration	no access
traffic volume vehicles per day (typically)	<1000 AADT	<5000 AADT	<12 000 AADT	>8000 AADT
flow characteristics	interrupted flow	interrupted flow	uninterrupted flow except at	freeflow (grade separated) major intersections
design speed (km/h)	50 - 110	60 - 110	80 - 130	100 - 130
average running speed (km/h) (free flow conditions)	50 - 90	50 - 90	60 - 100	70 - 110
vehicle type	predominantly passenger cars, light to medium trucks and occasional heavy trucks	all types, up to 30% trucks in the 3 t to 5 t range	all types, up to 20 % trucks	all types, up to 20 % heavy trucks
normal connections	locals collectors	locals collectors arterials	collectors arterials freeways	arterials freeways

Table 1.3.4.2 Characteristics of Urban Roads

	Public Lanes		Locals		Collectors		Arterials		Expressways		Freeways	
	Residential	Commercial	Residential	Industrial/Comm.	Residential	Industrial/Comm.	Minor	Major				
traffic service function	traffic movement, not a consideration	land access primary function	traffic movement secondary consideration	land access primary function	traffic movement and land access of equal importance	traffic movement and land access of equal importance	traffic movement major consideration	traffic movement primary consideration	traffic movement primary consideration	no access	optimum mobility	
land service / access	land access only function		land access primary function				some access control	right access control	no access	no access	no access	
traffic volume (weekday typical)	<500	<1000	<1000	<3000	<8000	1000 - 12 000	5000 - 20 000	10 000 - 30 000	> 50 000	> 20 000	> 20 000	
flow characteristics	interrupted flow	interrupted flow	interrupted flow	interrupted flow	interrupted flow	interrupted flow	uninterrupted flow except at signals and crosswalks	uninterrupted flow except at signals and crosswalks	uninterrupted flow except at signals	uninterrupted flow except at signals	free-flow (grade separated)	
design speed (km/h)	30 - 40	30 - 50	30 - 50	30 - 50	50 - 80	50 - 80	50 - 70	60 - 100	80 - 110	80 - 120	80 - 120	
average running speeds (km/h) (off-peak)	20 - 30	20 - 40	20 - 40	20 - 40	30 - 70	30 - 70	40 - 60	50 - 90	60 - 90	60 - 90	70 - 110	
vehicle type	passenger and service vehicles	passenger and service vehicles	passenger and service vehicles	all types	passenger and service vehicles	all types	all types	all types up to 20% trucks	all types up to 20% trucks	all types up to 20% trucks	all types up to 20% trucks	
desirable connections	public lanes, locals	public lanes, locals, collectors	public lanes, locals, collectors	public lanes, locals, collectors	locals, collectors, arterials	locals, collectors, arterials	collectors, arterials, expressways, freeways	collectors, arterials, expressways, freeways	arterials, expressways, freeways	arterials, expressways, freeways	arterials, expressways, freeways	
transit service	not permitted	generally avoided	generally avoided	generally avoided	permitted	permitted	express and local buses permitted	express and local buses permitted	express buses only	express buses only	express buses only	
accommodation of cyclists	no restrictions or special facilities	no restrictions or special facilities	no restrictions or special facilities	no restrictions or special facilities	no restrictions or special facilities	no restrictions or special facilities	lane widening or separate facilities desirable	lane widening or separate facilities desirable	prohibited	prohibited	prohibited	
accommodation of pedestrians	pedestrians permitted, no special facilities	sidewalks normally on one or both sides	sidewalks provided where required	sidewalks provided where required	sidewalks provided both sides	sidewalks provided where required	sidewalks may be provided, separation for traffic lanes preferred	sidewalks may be provided, separation for traffic lanes preferred	pedestrians prohibited	pedestrians prohibited	pedestrians prohibited	
parking (typical)	some restrictions	no restrictions or restrictions one side only	no restrictions or restrictions one side only	no restrictions or restrictions one side only	low restrictions other than peak hour	low restrictions other than peak hour	peak hour restrictions	prohibited or peak hour restrictions	prohibited	prohibited	prohibited	
min. intersection spacing (m)	as needed	60	60	60	60	60	200	400	600	600	1000 (between interchanges)	
right-of-way width (m) (typical)	6 - 10	15 - 22	15 - 22	15 - 22	20 - 24	20 - 24	20 ³ - 45 ³	20 ³ - 45 ³	> 45 ³	> 45 ³	> 60 ³	

- Notes:
1. Further information on intersection spacing is provided in Chapter 2.3, Intersections.
 2. Arterial rights of way 20 m in width applicable to retrofit conditions only.
 3. Wider rights of way are often required to accommodate other facilities such as utilities, noise mitigation installations, bikeways, and landscaping. For new streets, the immediate provision of wider rights of way may be considered to accommodate such facilities.

Table 2.2.2.1 Lane Widths for Two-Lane Rural Roadways

Design Speed (km/h)	Classification and Design Hour Volume					
	Local	Collector Design Hour Volume			Arterial Design Hour Volume	
		<250	250-450	>450	<450	>450
30, 40	3.0 - 3.7					
50	3.0 - 3.7	3.3 - 3.7	3.3 - 3.7	3.5 - 3.7		
60	3.0 - 3.7	3.3 - 3.7	3.3 - 3.7	3.5 - 3.7		
70	3.0 - 3.7	3.5 - 3.7	3.5 - 3.7	3.7		
80	3.0 - 3.7	3.5 - 3.7	3.5 - 3.7	3.7	3.5 - 3.7	3.7
90	3.3 - 3.7	3.5 - 3.7	3.5 - 3.7	3.7	3.5 - 3.7	3.7
100	3.3 - 3.7	3.5 - 3.7	3.5 - 3.7	3.7	3.5 - 3.7	3.7
110					3.7	3.7
120					3.7	3.7
130					3.7	3.7

Table 2.2.2.2 Lane Widths for Multilane Rural Roadways

Design Speed	Lane Width (m)
less than 100 km/h	3.5 - 3.7
100 km/h and greater	3.7

**Table 2.2.2.3 Through Lane Widths
for Urban Roadways**

Through Lane	Lane Width (m)
i) Freeway and expressway	3.7
ii) Major arterial	3.7
iii) Minor arterial (60 km/h design speed)	3.5 - 3.7
iv) Collector - residential	3.5 - 3.7
- industrial/ commercial	3.7
v) Local - residential	3.0 - 3.7
- industrial/ commercial	3.5 - 3.7

Table 2.2.10.1 Horizontal Clearance at Bridges on Local and Collector Urban Roads

Design Speed (km/h)	Short Overpass (<50 m)				Long Overpass (>50 m)				
	Left	Right *		Left	Right *		Left	Right *	
		Sidewalk	Sidewalk		Sidewalk	Sidewalk		Sidewalk	Sidewalk
Undivided Local	30	1.0	0.5	1.0	1.0	0.5	1.2	1.0	1.0
	40	1.0	0.5	1.0	1.0	0.5	1.2	1.0	1.0
	50	1.0	0.5	1.0	1.0	0.5	1.2	1.0	1.0
Undivided Collector	50	1.0	0.5	1.0	1.0	0.5	1.6	1.0	1.0
	60	1.0	0.5	1.0	1.0	0.5	1.6	1.0	1.0
	70	1.2	1.0	1.5	1.5	1.0	2.0	1.0	1.0
	80	1.2	1.0	1.5	1.5	1.0	2.5	1.0	1.0
Divided Collector	50	1.2	0.5	1.0	1.0	0.5	1.6	1.4	1.0
	60	1.2	0.5	1.0	1.0	0.5	1.6	1.4	1.0
	70	1.5	1.0	1.0	1.5	1.0	2.0	1.4	1.0
	80	1.5	1.0	1.0	1.5	1.0	2.0	1.5	1.0

- Notes: 1. * If a barrier is to be placed between the sidewalk and roadway, then clearance should be the same as when there are no sidewalks.
 2. For short overpasses (<50 m) shoulder widths should be carried across bridge.
 3. All clearances should meet requirements for sight distance.

TAC (1999) Highway Geometric Design Guideline

Table 2.2.10.2 Horizontal Clearance at Bridges on Rural Roads

	Design Speed (km/h)	Short Overpass (<50 m)		Long Overpass (>50 m)			
		Right	Left		Right	Left	
			No Sidewalk	Sidewalk		No Sidewalk	Sidewalk
Undivided Local	50		1.2	0.5		1.0	1.0
	60		1.2	0.5		1.0	1.0
	70		1.2	0.5		1.0	1.0
	80		1.2	0.5		1.2	1.0
	90		1.2	0.5		1.2	
	100		1.2	0.5		1.4	
Undivided Collector	60		1.5	1.0		1.2	1.0
	70		1.5	1.2		1.2	1.0
	80		2.0	1.2		1.0	1.0
	90		2.0	1.5		1.2	
	100		2.5	1.5		1.4	
Divided Collector	70	1.2	1.5	1.2	1.0	1.2	1.0
	80	1.2	2.0	1.2	1.0	1.2	1.0
	90	1.2	2.0	1.5	1.0	1.2	
	100	1.2	2.5	1.5	1.0	1.4	
Undivided Arterial	80		2.5	1.5		1.5	
	90		2.7	1.5		1.5	
	100		3.0	2.0		1.6	
	110		3.0	2.5		1.7	
	120		3.0	2.5		1.8	
	130		3.0	2.5		1.8	
Divided Arterial	80	1.5	2.5		1.0	1.5	
	90	1.5	2.7		1.0	1.5	
	100	2.0	3.0		1.0	1.6	
	110	2.0	3.0		1.0	1.7	
	120	2.0	3.0		1.0	1.8	
	130	2.0	3.0		1.0	1.8	
Freeway	100	2.5	3.0		1.5	2.0	
	110	2.5	3.0		1.5	2.0	
	120	2.5	3.0		1.5	2.0	
	130	2.5	3.0		1.5	2.0	

Figure 2.2.10.3 Horizontal Clearance on Bridges on Urban Arterial Roads (Overpass)

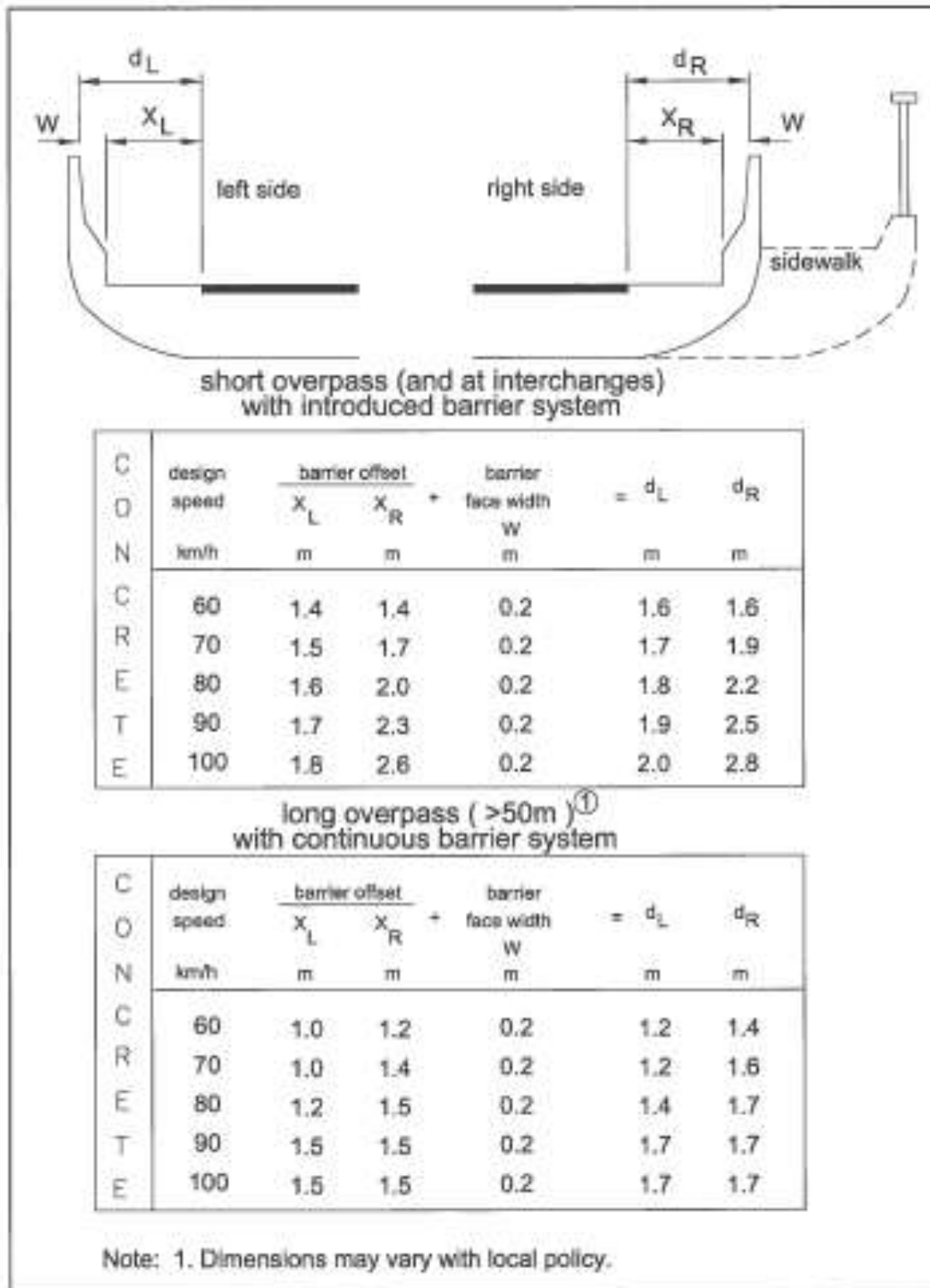
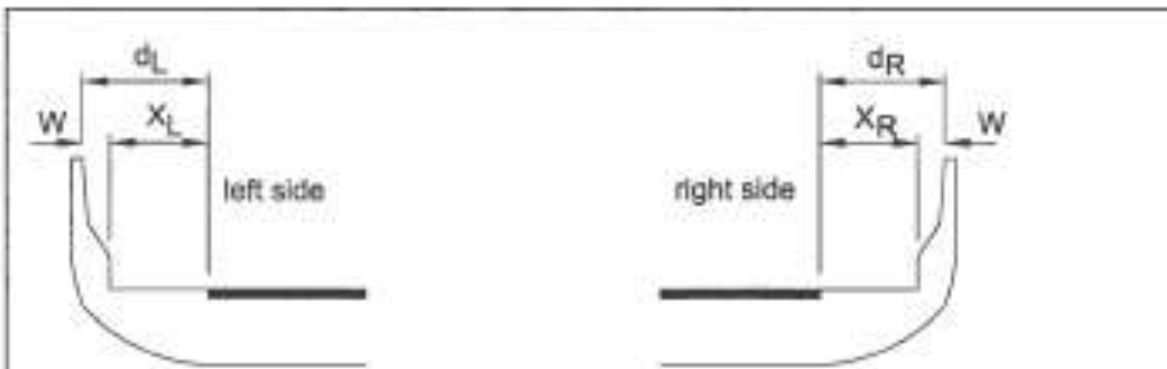


Figure 2.2.10.4 Horizontal Clearance on Bridges on Urban Freeways (Overpass)



short overpass (and at interchanges) with introduced barrier system

C O N C R E T E	design speed km/h	barrier offset ^①				+ barrier face width W m	= d _L		d _R	
		X _L		X _R			4-lane	6+ lane	4-lane	6+ lane
		4-lane m	6+ lane m	4-lane m	6+ lane m		m	m	m	m
80		2.5		3.0		0.2	2.7		3.2	
90		2.5		3.0		0.2	2.7		3.2	
100		2.5	3.0	3.0	3.0	0.2	2.7	3.2	3.2	
110		2.5	3.0	3.0	3.0	0.2	2.7	3.2	3.2	
120		2.5	3.0	3.0	3.0	0.2	2.7	3.2	3.2	

Note: 1. For X_L (6+ lane), the cross-section elements on structures should match those of the approach, i.e. left shoulder on multi-lane = 3.0 m.

long overpass (>50 m)^② with continuous barrier system

C O N C R E T E	design speed km/h	barrier offset ^③				+ barrier face width W m	= d _L		d _R	
		X _L		X _R			4-lane	6+ lane	4-lane	6+ lane
		4-lane m	6+ lane m	4-lane m	6+ lane m		m	m	m	m
80		1.5		1.5		0.2	1.7		1.7	
90		1.5		1.5		0.2	1.7		1.7	
100		1.5	2.0	1.5	2.0	0.2	1.7	2.2	1.7	
110		1.5	2.0	1.5	2.0	0.2	1.7	2.2	1.7	
120		1.5	2.0	1.5	2.0	0.2	1.7	2.2	1.7	

Notes: 2. Dimensions may vary with local policy.

3. X_L and X_R: (6+ lane) 2.0 m is minimum width disabled vehicle provision, a requirement on both sides of high speed multi-lane facilities.

TAC (1999) Highway Geometric Design Guideline

Table 3.4.6.1 Bike Path Lane Width

Classification	Lane Width (m) Design Domain
two-way, exclusive	2.5 – 3.5
two-way, shared with pedestrians	3.0 – 4.0
one-way, exclusive	1.5 – 2.0
one-way, shared with pedestrians	2.0 – 3.0

Note: A horizontal clearance of 600 mm is maintained between a bikeway and a lateral obstruction. Curbing, in excess of 150 mm in height, is regarded as a lateral obstruction.

Table 3.4.6.2 Bike Lane and Shared Street Lane Width

Classification	Lane Width (m) Design Domain
bike lane, one-way exclusive ^c	1.5 ^a – 2.0 ^a
bike route and shared roadway right lane (arterial)	
- AADT ^a 0-1000	standard roadway lane – 4.0
- AADT ^a 1000-3000	standard roadway lane – 4.3
- AADT ^a 3000-6000	4.0 – 4.5
- AADT ^a >6000	4.3 – 4.8

Notes: a. Add 0.5 m if AADT^b exceeds 6000 or if trucks exceed 10%, add an additional 0.5 m if roadway speed is 100 km/h or greater.

b. AADT is the volume of traffic in the shared lane.

c. Applies to shoulder bikeways as well.

**Appendix B: NWPD Tables
Used in the Navigational
Waterways Clearances
Guidelines Knowledge
base**

Table 3-1 Classes of Waterways in Canada

Waterway Category	Examples	General Types of "Target Vessels"
Small rivers/streams and lakes with limited access	"Cottage Country" lakes and interconnecting streams, tributaries to large rivers	Canoes and kayaks, small pleasure vessels (outboards)
Large rivers and lakes with good access	Lake Simcoe, Ottawa River, Upper Fraser River	Recreational, dredging barge, small to medium cargo vessels
"Controlled Waterways"	St. Lawrence River, Welland Canal, St. Clair River, Trent-Severn Waterway, Rideau Canal, Lower Fraser River, Red River	Dependent on waterway: Rideau/Trent-Severn – Small/Med Pleasure Vessels St. Lawrence/Fraser – Large Vessels
Great Lakes	Lakes Superior, Huron, Michigan, Erie and Ontario, Georgian Bay, Lake St. Clair	Lake Freighters ("Lakers")
Harbours	Halifax, Toronto, Montreal, Vancouver, local fishing harbours, marinas, etc.	Determined by harbour purpose (e.g. fishing, bulk carriers, some large vessels, etc.), but generally medium to large cargo and commercial vessels.
Coastal	Gulf of St. Lawrence, close to shorelines in marine waters	Large vessels
Ocean/Marine	Pacific/Atlantic/Arctic	Largest commercial and cargo vessels (ULCC)

Table 2-1 General characteristics of Small Recreational Vessels

Vessel Type	Length	Beam	Draft/Keel	Height	Manoeuvrability	Speed	Common Names
Canoe	3.5-4.9 m	0.6-0.9 m	0.15 m	1.5 m (incl. passenger)	Good	Slow	Canoe
Kayak	4.9-5.8 m	0.6-0.8 m	0.15 m	1.5 m (incl. passenger)	Excellent	Medium	Kayak

NWPD (2006) Navigational Waterways Clearances Guideline

Table 2-2 General characteristics of Recreational and Small to Medium Commercial and Cargo Vessels

Vessel Type	Length	Beam	Draft/Keel	Height	Manoeuvrability	Speed	Common Names
Powered Inflatable Vessel	3-4.6 m	1.5-2.1 m	< 0.6 m	Dependent on Equipment and Passengers	Excellent	Fast	Zodiac
Small/Medium Sail Vessel	4.6-12.2 m	1.5-4.3 m	0.9-2.4 m	Approximately 1.25 times Length	Excellent	Fast	Dinghy, Cruiser, Day Sailer, Yacht
Large Sail Vessel	12.2-24.4 m	4.1-9.1 m	1.8-4.9 m	Approximately 1.25 times Length	Good	Fast	Sloop, Yacht
Small/Medium Powered Pleasure Vessel	4.6-12.2 m	1.5-4.3 m	0.5-1.1 m	Varies Widely	Excellent	Fast	Sport Cruiser
Large Powered Pleasure Vessel	12.2-24.4 m	4.3-6.1 m	1.2-1.8 m	Varies Widely	Good	Fast	Sport Yacht
Harbour Tug	4-13 m	2.5-4.5 m	1-2.5 m	Varies	Excellent	Slow	Tug

Table 2-3 General characteristics of Large Vessels

Vessel Type	Length	Beam	Draft/Keel	Height	Manoeuvrability	Speed	Common Names
Lake Freighter	183-215 m	23.8 m	7.9 m	35.5 m max	Good	Medium	Lakers
Container Transport (Panamax)	295 m	32.3 m	12 m	57.9 m	Good	Medium	
VLCC/ULCC	305-380 m	59-68 m	20-24.5 m	Unknown	Good	Medium	Tanker
Cruise Ships (Queen Mary 2)	345 m	45 m	10 m	72 m	Good	Medium	

Table 4-1 Stream Velocity Ranges and Applicable Velocity Factors (VF)

Velocity Ranges	Relative Velocity Increase (%)	Velocity Factor (VF)
0.0 – 2.7 m/s	0	VF = 1.0
2.7 – 3.0 m/s	0 – 10	VF = 1.1
3.0 – 3.2 m/s	10 – 20	VF = 1.2
3.2 – 3.5 m/s	20 – 30	VF = 1.3
3.5 – 3.8 m/s	30 – 40	VF = 1.4
3.8 – 4.1 m/s	40 – 50	VF = 1.5
4.1 – 4.3 m/s	50 – 60	VF = 1.6
4.3 – 4.7 m/s	60 – 75	VF = 1.7
> 4.7 m/s	> 75	VF = 1.8

Table 4-2 Structure Lengths and Corresponding Equivalent Areas and Length Factors (LF)

Structure Length (m)	Equivalent Area (m ²)	Length Factor (LF)
20 or less	4.5	LF = 1.00
25	6.1	LF = 1.17
30	8.0	LF = 1.33
35	10.1	LF = 1.50
40	12.5	LF = 1.67
45	15.1	LF = 1.83
50	18.0	LF = 2.00
55	21.1	LF = 2.17
60	24.5	LF = 2.33
65	28.1	LF = 2.50
70	32.0	LF = 2.67
75	36.1	LF = 2.83
80	40.5	LF = 3.00
85	45.1	LF = 3.17
90	50.0	LF = 3.33
95	55.1	LF = 3.50
100	60.5	LF = 3.67

NWPD (2006) Navigational Waterways Clearances Guideline

Table 5-1 Recreational and Small Commercial Vessel Manoeuvring Lane Width Requirement

Target Vessel Manoeuvrability	Sample Vessels	Manoeuvring Lane Width (MLW)
Excellent	Small/medium pleasure vessels, tugboats	1.3 B
Good	Fishing vessels, large pleasure vessels, passenger ferries	1.5 B
Poor	Barges, tug and tows	1.8 B

Table 5-2 Bank and Structure Clearance for Recreational and Small to Medium Commercial and Cargo Vessels

Target Vessel Manoeuvrability	Bank and Structure Clearance (BSC)
Excellent	0.5 B
Good	1.0 B
Poor	1.5 B

Table 5-4 Horizontal Clearance Safety Buffer due to Crosswinds

Severity of Crosswinds (AHC1)	Additional Horizontal Clearance
Low (< 15 knots)	0 B
Moderate (15 - 33 knots)	0.5 B
Severe (> 33 knots)	1.0 B

Table 5-5 Horizontal Clearance Safety Buffer due to Navigational Aids and Visibility

Navigational Aids / Visibility (AHC2)	Additional Horizontal Clearance
Aids / Good Visibility	0 B
No Aids / Good Visibility	0.5 B
Aids / Poor Visibility	0.75 B
No Aids / Poor Visibility	1.0 B

Table 5-7 Depth Clearance due to Wave Effects

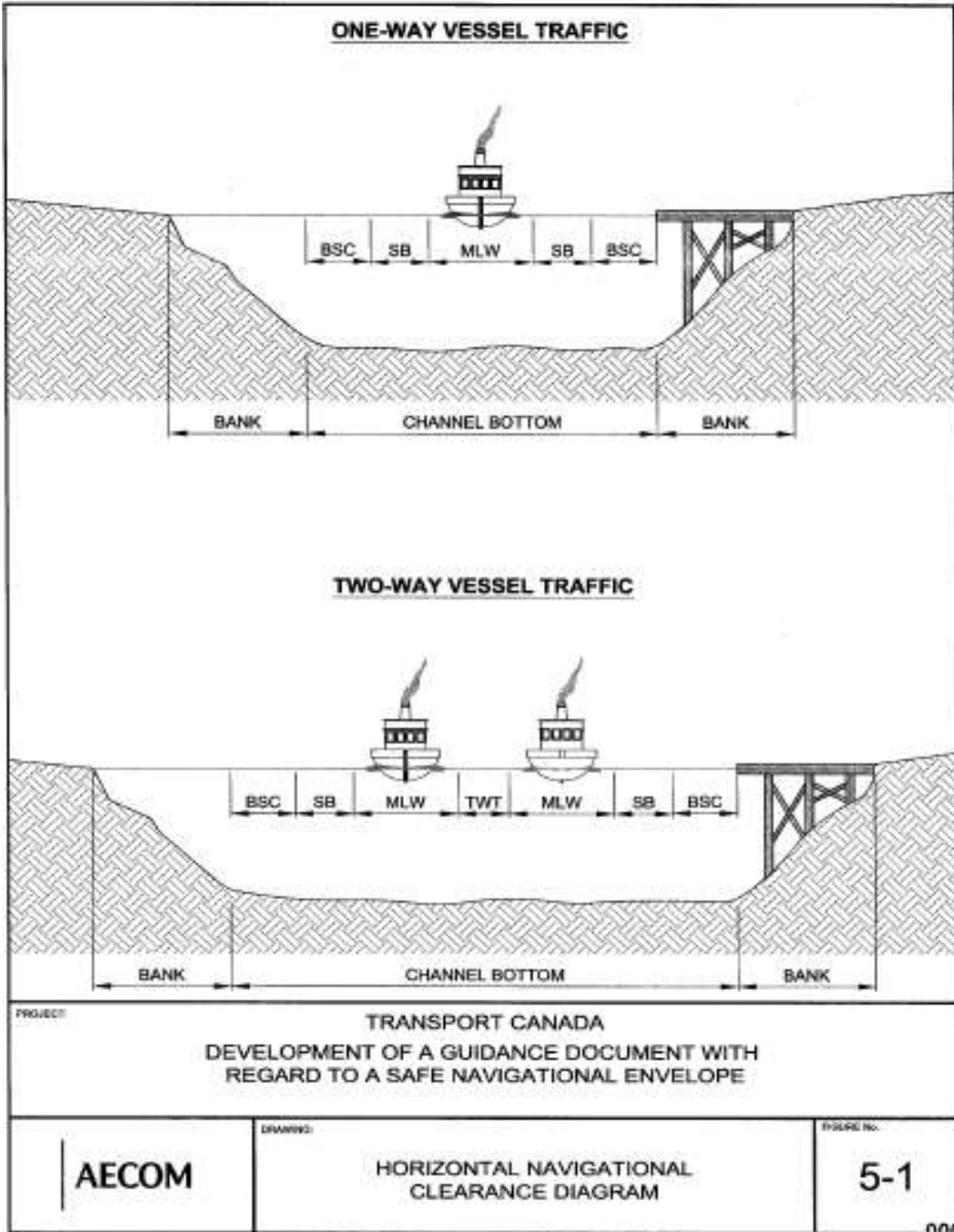
Wave Severity	Additional Height Clearance
None	0.1 D
Low	0.15 D
Moderate	0.3 D
High	0.5 D

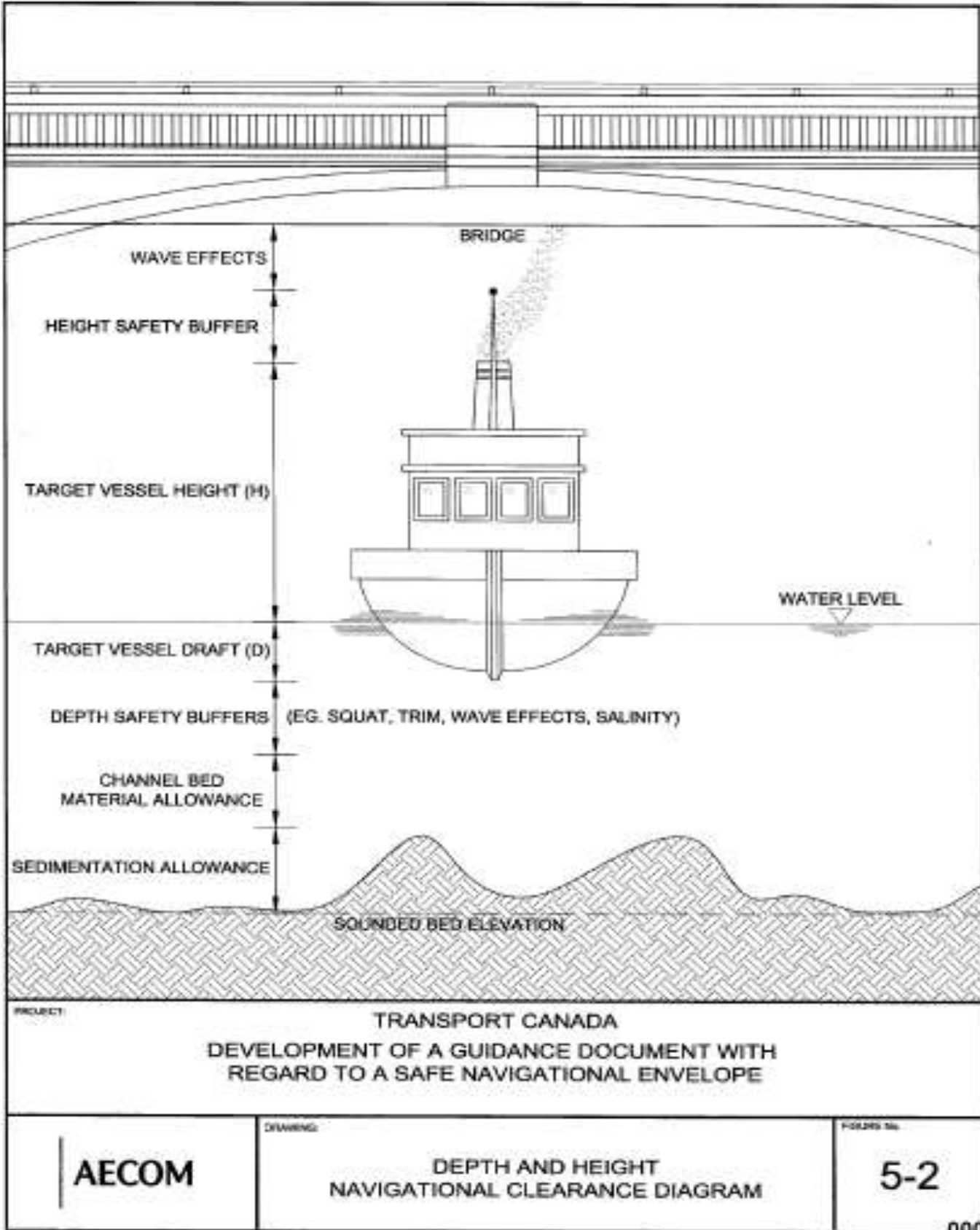
Table 5-8 Depth Clearance Safety Buffer due to Channel Bed Material

Bottom Material	Required Depth Clearance
Soft	0.25 m
Medium (Sand)	0.60 m
Hard Bottom (Rock)	0.90 m

Table 5-9 Height Clearance due to Wave Effects

Wave Severity	Additional Height Clearance (WE)
None	0.1 D
Low	0.15 D
Moderate	0.3 D
High	0.5 D





**Appendix C: Sample of
the Bridge Database
Acquired from MTO**

ID	STRUCTURE	SUBCATEGORY 1	TYPE 1	MATERIAL 1	REGION	HWY	VEAR	LATITUDE	LONGITUDE	SPAR DETAILS	Total Length	Spans #	DECK LENGTH	WIDTH	TOTAL
1-121	Highway 24 Underpass @ Highway 403	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	403	1945	43.167214	-80.275446	Total=64 (1)=12;(2)=19;(3)=21;(4)=12	64	4	64.9	25.4	
1-143	WEST STREET UNDERPASS	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	403	1943	43.164479	-80.251018	Total=80.4 (1)=12;(2)=18;(3)=18;(4)=12;2	80.4	4	61	18.39	
1-144	NORTH PARK STREET UNDERPASS	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	403	1942	43.162913	-80.263791	Total=80 (1)=12;(2)=18;(3)=18;(4)=12	80	4	60.8	18.4	
1-185	QUINCY CREEK WHITMAN BRIDGE	Beam/Girder	T Beam (Box Type)	Reinforced Cast-In-Place Concrete	West	24	1959	43.137458	-80.367236	Total=34 (1)=8;(2)=18;(3)=8	34	3	33.5	10.16	
1-129	BONIT COUNTY RD. #27 OVERPASS	Slab	Slab	Pack-Tensored Cast-In-Place Concrete	West	403	1975	43.167031	-80.33827	Total=80.6 (1)=20;(2)=30;3	80.6	2	61	17.09	
1-141/1	HWY. #2 OVERPASS, EBL	Beam/Girder	Plate Girder	Steel	West	403	1945	43.170204	-80.296571	Total=92 (1)=20;(2)=26;(3)=24;(4)=20	92	4	93.4	15.46	
1-141/2	HWY. #2 OVERPASS, WBL	Beam/Girder	Plate Girder	Steel	West	403	1944	43.170291	-80.300157	Total=92 (1)=20;(2)=26;(3)=24;(4)=20	92	4	93.4	15.45	
1-142	EWING DRIVE UNDERPASS	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	403	1945	43.169121	-80.291853	Total=62 (1)=12;(2)=19;(3)=19;(4)=12	62	4	63.3	12.3	
1-143	TOLLGATE ROAD UNDERPASS	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	403	1945	43.167093	-80.279811	Total=78 (1)=15;(2)=24;(3)=24;(4)=15	78	4	78.1	12.3	
1-144	PARK ROAD UNDERPASS	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	403	1944	43.162668	-80.243533	Total=64 (1)=12;(2)=19;(3)=20;(4)=12	64	4	63.9	20.21	
1-145/1	C.N.R. OVERHEAD EBL	Beam/Girder	Plate Girder	Steel	West	403	1943	43.166097	-80.292594	Total=69 (1)=20;(2)=27;(3)=21	69	3	70.4	11.76	
1-145/2	C.N.R. OVERHEAD WBL	Beam/Girder	Plate Girder	Steel	West	403	1943	43.167039	-80.292594	Total=69 (1)=20;(2)=27;(3)=21	69	3	70.4	11.76	
1-147/1	GRAND RIVER BRIDGE EBL	Beam/Girder	Plate Girder	Steel	West	403	1976	43.166091	-80.351164	Total=223.4 (1)=46;(2)=63;(3)=63;(4)=48;7	223.4	4	223.1	11.28	
1-147/2	GRAND RIVER BRIDGE WBL	Beam/Girder	Plate Girder	Steel	West	403	1976	43.166099	-80.351291	Total=224 (1)=46;(2)=63;(3)=63;(4)=48	224	4	223.1	11.28	
1-148/1	HORNBY CREEK BRIDGE EBL	Beam/Girder	CFRC Girder	Prestressed Precast Concrete	West	403	1983	43.133119	-80.521848	Total=48 (1)=12;(2)=22;(3)=13	48	3	48.5	11.9	
1-148/2	HORNBY CREEK BRIDGE WBL	Beam/Girder	CFRC Girder	Prestressed Precast Concrete	West	403	1983	43.133388	-80.521446	Total=48 (1)=12;(2)=22;(3)=13	48	3	48.5	11.9	
1-149	TOWNSHIP ROAD UNDERPASS	Slab	Circular Voided Slab	Pack-Tensored Cast-In-Place Concrete	West	400	1981	43.13622	-80.559899	Total=60 (1)=30;(2)=30	60	2	60.9	9.4	
1-150	COUNTY ROAD 130/22 UNDERPASS	Slab	Circular Voided Slab	Pack-Tensored Cast-In-Place Concrete	West	400	1983	43.132094	-80.600073	Total=60 (1)=30;(2)=30	60	2	60	9.4	
1-151	MAPLE ROAD UNDERPASS	Slab	Circular Voided Slab	Pack-Tensored Cast-In-Place Concrete	West	403	1982	43.14492	-80.446253	Total=81 (1)=30;(2)=30;5	81	2	81	8.4	
1-154	WEST HOBES ROAD UNDERPASS	Slab	Slab	Pack-Tensored Cast-In-Place Concrete	West	400	1975	43.161551	-80.376911	Total=68 (1)=34;(2)=34	68	2	68.2	18.34	
1-155	COUNTY ROAD 16 UNDERPASS	Slab	Circular Voided Slab	Pack-Tensored Cast-In-Place Concrete	West	403	1982	43.132748	-80.422996	Total=67 (1)=33;(2)=33;3	67	2	67	9.9	
1-156	COUNTY RD 25 INTERCHANGE UPASS	Slab	Circular Voided Slab	Pack-Tensored Cast-In-Place Concrete	West	403	1982	43.134696	-80.512841	Total=69 (1)=34;(2)=34;5	69	2	69	17.4	
1-180	BERSEVILLE ROAD UNDERPASS	Slab	Circular Voided Slab	Pack-Tensored Cast-In-Place Concrete	West	400	1981	43.171373	-80.179086	Total=64 (1)=32;(2)=32	64	2	64	10.46	
1-192/1	FURCHLOD CREEK BRIDGE EBL	Beam/Girder	CFRC Girder	Prestressed Precast Concrete	West	403	1996	43.168097	-80.185444	Total=81.1 (1)=26;(2)=27;(3)=28;9	81.1	3	82	11.96	
1-192/2	FURCHLOD CREEK BRIDGE WBL	Beam/Girder	CFRC Girder	Prestressed Precast Concrete	West	403	1996	43.168313	-80.185433	Total=81.1 (1)=26;(2)=27;(3)=28;9	81.1	3	82	11.96	
1-193	JOHNSON ROAD UNDERPASS @ 403	Slab	Circular Voided Slab	Pack-Tensored Cast-In-Place Concrete	West	403	1981	43.16865	-80.190146	Total=56 (1)=28;(2)=28	56	2	56	9.46	
1-194/1	GARDEN AVE. UNDERPASS EBL	Slab	Circular Voided Slab	Pack-Tensored Cast-In-Place Concrete	West	403	1980	43.167017	-80.212329	Total=68 (1)=34;(2)=34	68	2	68	9.48	
1-194/2	GARDEN AVE. UNDERPASS WBL	Slab	Circular Voided Slab	Pack-Tensored Cast-In-Place Concrete	West	403	1980	43.167063	-80.212346	Total=68 (1)=34;(2)=34	68	2	68	10.88	
2-4	STOKES RIVER BRIDGE	Frame	Rigid Frame, Slab	Reinforced Cast-In-Place Concrete	West	6	1936	45.070739	-81.33579	Total=16 (1)=16	16	1	19	10.4	
2-30	SAUBLE RIVER BRIDGE, WEST OF ALLENFORD	Beam/Girder	Plate Girder	Steel	West	21	1942	44.332494	-81.196394	Total=32 (1)=32	32	1	31.1	11.06	
2-102	MCLEARY YOUNG BRIDGE	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	21	1967	44.161174	-81.625418	Total=25.6 (1)=25.6	25.6	1	28.2	9.74	

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
ID	STRUCTURE	SUBCATEGORY 1	TYPE 1	MATERIAL 1	REGION	IRY NAME	YEAR	LATITUDE	LONGITUDE	SPALI DETAILS	Total Length	Spalls #	INCK LENGTH	WIDTH TOTAL
32	MCLEAM YOUNG BRIDGE (PHEMETANGORE RIVER)	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	21	1957	44.101174	-81.024432	Total=25.6 (1)=25.6;	25.6	1	28.2	9.76
33	COAK'S CREEK BRIDGE	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	21	1970	44.055823	-81.707809	Total=17.2 (1)=17.2;	17.2	1	19.3	11.77
34	SOUTH PINE RIVER BRIDGE	Frame	Rigid Frame, Slab	Reinforced Cast-In-Place Concrete	West	21	1957	44.090305	-81.693404	Total=18.5 (1)=18.5;	18.5	1	20.5	12.2
35	CENTRAL PINE RIVER BRIDGE	Frame	Rigid Frame, Slab	Reinforced Cast-In-Place Concrete	West	21	1968	44.098277	-81.674205	Total=16.5 (1)=16.5;	16.5	1	18.4	11.94
36	ROYAL OAK CREEK BRIDGE	Frame	Rigid Frame, Slab	Reinforced Cast-In-Place Concrete	West	21	1991	44.112722	-81.643111	Total=12.2 (1)=12.2;	12.2	1	13.5	11.53
37	PHEMETANGORE RIVER BRIDGE	Frame	Rigid Frame, Slab	Reinforced Cast-In-Place Concrete	West	9	1992	44.138894	-81.502777	Total=7.6 (1)=7.6;	7.6	1	8.8	12.76
38	TEESWATER RIVER BRIDGE	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	9	1969	44.088997	-81.311956	Total=43.3 (1)=43.3;	43.3	3	44.3	12.2
39	CHEBROOK CREEK BRIDGE (RIVERGALE)	Frame	Rigid Frame, Slab	Reinforced Cast-In-Place Concrete	West	9	1986	44.090388	-81.327004	Total=9 (1)=9;	9	1	10	11.96
40	GREENOCK CREEK BRIDGE	Beam/Girder	ASHTO Girder	Prestressed Precast Concrete	West	9	1971	44.096338	-81.284448	Total=17.7 (1)=17.7;	17.7	1	18.2	12.17
41	OTTER CREEK (SOUTH) BRIDGE	Frame	Rigid Frame, Slab	Reinforced Cast-In-Place Concrete	West	9	1962	44.066001	-81.148187	Total=10.7 (1)=10.7;	10.7	1	12	11.4
42	OTTER CREEK (NORTH) BRIDGE	Frame	Rigid Frame, Slab	Reinforced Cast-In-Place Concrete	West	9	1962	44.068889	-81.141611	Total=12.8 (1)=12.8;	12.8	1	16.8	11.30
43	NORTH PRETIENCARE RIVER BRIDGE	Beam/Girder	CPCL Girder	Prestressed Precast Concrete	West	21	1988	44.178327	-81.011138	Total=68.8 (1)=68.8;	68.8	3	69.3	11.8
44	MISSISSIPPI RIVER BRIDGE	Truss	Through Truss	Steel	Eastern	17	1954	45.38725	-78.254861	Total=100 (1)=100;	100	3	101.7	10.97
45	RICHMOND ROAD UNDERPASS (WBL)	Beam/Girder	Plate I Girder	Steel	Eastern	417	1968	45.345388	-75.882753	Total=70 (1)=35(2)=35;	70	2	72.2	16.5
46	RICHMOND ROAD UNDERPASS (WBL)	Beam/Girder	Plate I Girder	Steel	Eastern	417	1968	45.345388	-75.882753	Total=70 (1)=35(2)=35;	70	2	72.2	16.5
47	PREMETANGORE AVENUE/O.Q.W. UNDERPASS (WBL)	Beam/Girder	Plate I Girder	Steel	Eastern	417	1968	45.345388	-75.882753	Total=64 (1)=32(2)=32;	64	2	64	24.07
48	WOODBOROFT AVENUE/O.Q.W. UNDERPASS (WBL)	Beam/Girder	Plate I Girder	Steel	Eastern	417	1968	45.345388	-75.882753	Total=64 (1)=32(2)=32;	64	2	64	24.07
49	MANTLAND AVENUE/O.Q.W. UNDERPASS (WBL)	Beam/Girder	Rollled I Beam	Steel	Eastern	417	1959	45.370408	-75.754594	Total=70 (1)=35(2)=35;	70	2	70.6	18.7
50	CLYDE AVENUE OPS (EBL)	Beam/Girder	Rollled I Beam	Steel	Eastern	417	1959	45.370408	-75.754594	Total=22 (1)=22;	22	1	22	18
51	CLYDE AVENUE UNDERPASS (WBL)	Beam/Girder	Rollled I Beam	Steel	Eastern	417	1959	45.370408	-75.754594	Total=22 (1)=22;	22	1	22.4	16
52	CARLING AVENUE UNDERPASS (EBL)	Beam/Girder	Rollled I Beam	Steel	Eastern	417	1959	45.381394	-75.742903	Total=20 (1)=20;	20	1	19.1	22
53	CARLING AVENUE UNDERPASS (WBL)	Beam/Girder	Rollled I Beam	Steel	Eastern	417	1959	45.381394	-75.742903	Total=20 (1)=20;	20	1	19.1	16
54	KIRKWOOD AVENUE OVERPASS (EBL)	Beam/Girder	Rollled I Beam	Steel	Eastern	417	1959	45.388853	-75.739818	Total=25 (1)=25;	25	1	25.4	13.84
55	KIRKWOOD AVENUE OVERPASS (WBL)	Beam/Girder	Rollled I Beam	Steel	Eastern	417	1959	45.388853	-75.739818	Total=25 (1)=25;	25	1	24.7	16
56	CARLING AVENUE/O.Q.W. UNDERPASS (EBL)	Beam/Girder	Rollled I Beam	Steel	Eastern	417	1959	45.388853	-75.739818	Total=18 (1)=18;	18	1	22.1	19.1
57	CARLING AVENUE/O.Q.W. UNDERPASS (WBL)	Beam/Girder	Plate I Girder	Steel	Eastern	417	1961	45.385384	-75.730364	Total=18 (1)=18;	18	1	19.1	16
58	MERRIVALE ROAD OVERPASS (EBL)	Frame	Rigid Frame, Slab	Reinforced Cast-In-Place Concrete	Eastern	417	1960	45.388923	-75.734450	Total=14 (1)=14;	14	1	16	18.1
59	MERRIVALE ROAD OVERPASS (WBL)	Frame	Rigid Frame, Slab	Reinforced Cast-In-Place Concrete	Eastern	417	1961	45.388997	-75.734460	Total=14 (1)=14;	14	1	16	18.1
60	ISLAND PARK DRIVE DPASS (EBL)	Beam/Girder	Rollled I Beam	Steel	Eastern	417	1961	45.390136	-75.733707	Total=25 (1)=25;	25	1	25.2	18.1
61	ISLAND PARK DRIVE DPASS (WBL)	Beam/Girder	Rollled I Beam	Steel	Eastern	417	1961	45.390044	-75.733892	Total=25 (1)=25;	25	1	25.2	18.1

**Appendix D:
Structural Code
Knowledge Base**

**APPENDIX D1:
AASHTO LRFD Bridge Design
Specifications (2007)**

AASHTO LRFD Bridge Design Specifications (2007)

Table 2.5.2.6.3-1 Traditional Minimum Depths for Constant Depth Superstructures.

Superstructure		Minimum Depth (Including Deck)	
		When variable depth members are used, values may be adjusted to account for changes in relative stiffness of positive and negative moment sections	
Material	Type	Simple Spans	Continuous Spans
Reinforced Concrete	Slabs with main reinforcement parallel to traffic	$\frac{1.2(S + 3000)}{30}$	$\frac{S + 3000}{30} \geq 165 \text{ mm}$
	T-Beams	$0.070L$	$0.065L$
	Box Beams	$0.060L$	$0.055L$
	Pedestrian Structure Beams	$0.035L$	$0.033L$
Prestressed Concrete	Slabs	$0.030L \geq 165 \text{ mm}$	$0.027L \geq 165 \text{ mm}$
	CIP Box Beams	$0.045L$	$0.040L$
	Precast I-Beams	$0.045L$	$0.040L$
	Pedestrian Structure Beams	$0.033L$	$0.030L$
	Adjacent Box Beams	$0.030L$	$0.025L$
Steel	Overall Depth of Composite I-Beam	$0.040L$	$0.032L$
	Depth of I-Beam Portion of Composite I-Beam	$0.033L$	$0.027L$
	Trusses	$0.100L$	$0.100L$

**APPENDIX D2:
Sample of the Information Gathered
from Design Experts**

❖ **SUPERSTRUCTURE:**

- **Deck:**

- *Add 100-200 cm to the depth gained from AASHTO LRFD Span-Depth Ratio Table.*
- *Cast-in-Place Concrete Reinforcement Bars weight is found using ratio of 100 Kg of Steel Bars per 1 m³ of Concrete.*
- *Use Wearing Surface depth of 25 cm for urban areas and 30 cm for rural areas. Protection coats of 10 cm depth at urban areas and 15 cm at rural areas.*
- *Use expansion joint at the connection point between approach slab and bridge span. Also, use expansion joint at each support if the bridge is simply supported. Expansion joint width is the same of bridge deck width.*
- *Use bridge Diaphragm if using Beam-Girder bridge type. If the bridge width is more than 15m, use diaphragm width of 1m. Use width of 0.75 if less than 15m. Diaphragm spacing is 5m if the span is 40m and less. Use 3m spacing if the span is more than 40m.*

- **Traffic Protection:**

- *Curb height of 10 cm at rural areas and 15 cm at the urban areas.*
- *Use one Lightning per 10m bridge length at the urban areas and one lightning per 15m bridge length at rural areas.*
- *Use one traffic per 25m bridge length at urban areas and one traffic signage per 35m bridge length at rural areas.*
- *Use parapet width of 0.40m.*
- *Use lane width of 3.7 if the area is rural and 3.6 if the area is urban.*
- *Use protection barrier if the design speed is more than 80 Km/h and there is a sidewalk.*

❖ **SUBSTRUCTURE:**

• **Piers:**

- *If using Wall column, use width of 1m of Cast-in-Place Concrete if the span is less or equal of 30m. Add 0.20m of width for each 20m.*
- *If using rectangular columns, use width of 1m of Cast-in-Place Concrete if the span is less or equal of 30m. Add 0.50m of width for each 20m. The spacing between the columns should not be bigger than 7m.*
- *If using Bent-Column System, use bent width same as the column width. Use bent depth of 1m of Cast-in-Place Concrete if the span is less or equal of 30m. Add 0.50m of width for each 20m.*
- *Use number of Bearings equal to the number of the columns.*
- *If using Hammer column, use top flange height of 1m if the span is less than 20m and the width is less than 15m. Add 0.25m for each 5m bridge span and width. Column width of 1m of Cast-in-Place Concrete if the span is less or equal of 30m. Add 0.50m of width for each 20m. The spacing between the columns should not be bigger than 7m.*

• **Abutments:**

- *If using Spill-Through Abutment type, use total height of 5m and depth of 2.5m. Add 5% cost to the earthwork total cost for the compaction of the embankment. Use depth of the abutment chair of 0.5m and abutment width equals to the bridge width. Add number of bridge bearing equal to the number of the bridge piers.*
- *If using Heavy Abutment, use total height equals to the bridge height. Add 2.5m to the height for the foundation. Use Abutment Depth of 1.0m at the top and 2.0 at the bottom if the total height is less than 8m. Use Wing wall width of 1.0m if the total height is less than 8.0m. Add width of 0.20m for each 1m of height.*
- *Use MSE Wall if the length of the bridge approach is more than 20m and bridge height more than 10m. Add 5% cost to the earthwork total cost for the compaction work of the MSE Wall.*

**Appendix E: Sample
of the Collected Cost
Data**

**APPENDIX E1:
Unit Costs for
Standard Bid Items Alberta
Department of Transportation**

AVERAGE UNIT PRICES FOR STANDARD BID ITEMS
(Based Upon 3 Low Bids thru December 2013)

SECTION 203 - REMOVAL OF OBSTRUCTIONS

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICT S</u>
203-020A	Removal of Single Span Bridges	SF	\$12
203-020A	Removal of Multi-span Bridges	SF	\$16
203-020A	Removal of Truss Bridges	SF	\$19
203-035A	Removal of Culverts	SF	\$22

NOTE: Use square foot cost for estimating purposes but show as cost per EACH on the Cost Estimate.

SECTION 205 - EXCAVATION & EMBANKMENT

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
205-040A	Granular Borrow	CY	\$15

SECTION 210 - STR. EXC. & COMP. BACKFILL

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
210-005A	Structure Excavation Sch. No. 1	CY	\$14
210-015A	Compacting Backfill	CY	\$11

NOTE: Multiply Str. Exc. unit cost by 2.0 if underwater excavation involved, and by 3.0 if rock excavation involved.

SECTION 301 – GRANULAR SUBBASE

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
301-010A	Granular Subbase	CY	\$20

SECTION 502 - CONCRETE

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
502-005A	Concrete Class 15	CY	\$240
502-025A	Concrete Class 40A	CY	\$600
502-140A	Concrete Class 40A Sch. No. 1	CY	\$430
502-250A	Concrete Class 40A Sch. No. 2	CY	\$550
502-345A	Seal Concrete	CY	\$260
502-400A	AASHTO Type 2 Girder	FT	\$185
502-400A	AASHTO Type 3 Girder	FT	\$195
502-400A	AASHTO Type 4 Girder	FT	\$210
502-415A	Bulb Tee Girders	LF/in ² of area	\$0.37
502-415A	WF Girders	LF/in ² of area	\$0.40
502-430A	Concrete Parapet-32" high	FT	\$95
502-430A	Concrete Parapet-42" high	FT	\$115
502-431A	Concrete Parapet, Decorative	FT	\$200
502-435A	Approach Slab	SY	\$196
502-445A	Voided Slabs	LF/in ² of area	\$0.35
502-470A	Prestr. T-beam & Deck Tee	LF/in ² of area	\$0.45
502-500A	Prestr. Box Beam	LF/in ² of area	\$0.43

NOTE : Reduce deck concrete costs by \$50/CY when girder type makes slab forms unnecessary.
Use LF/in² of girder cross-section area for estimating, but show as FT on Cost Estimate.
For Voided Slabs, use the net cross-section area.

AVERAGE UNIT PRICES FOR STANDARD BID ITEMS
(Based Upon 3 Low Bids thru December 2013)

SECTION 503 - METAL REINFORCEMENT

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
503-005A	Metal Reinforcement	LB	\$1.05
503-010A	Metal Reinforcement Sch. No. 1	LB	\$0.90
503-015A	Metal Reinforcement Sch. No. 2	LB	\$0.85
503-020A	Epoxy Coated Metal Reinforcement	LB	\$0.90
S501-30A	#4 GFRP	FT	\$2.00

SECTION 504 - STRUCTURAL METALS

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
504-005A	Steel Bridge	LB	\$2.20
504-015A	Structural Steel	LB	\$3.50
504-030A	2 Tube Curb Mount Rail	FT	\$125
504-035A	Pedestrian/Bicycle Rail	FT	\$130
504-040A	Combination Pedestrian/Bicycle & Traffic Rail	FT	\$160
504-040A	Combination Rail w/Ped Screen	FT	\$310

NOTE: Steel Bridge - Use Cost/lb for estimating purposes but show as lump sum on the Cost Estimate. Reduce costs by \$0.10/lb for rolled girders. Increase costs by \$0.05/lb for haunched girders. Increase costs by \$0.10/lb for curved girders.

SECTION 505 - PILING

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
505-030A	Provide & Drive HP 12X74 Piling	FT	\$65
505-045A	Provide & Drive HP 14X117 Piling	FT	\$80
505-100A	Provide & Drive Shell Piling, 12" Diam	FT	\$60
505-110A	Provide & Drive Shell Piling, 16" Diam	FT	\$100
505-185A	Provide & Drive Test Pile HP 12X74	FT	\$75
505-197A	Provide & Drive Test Pile HP 14X117	FT	\$90
505-150A	Provide & Drive Test Pile 12" Diam	FT	\$60
505-160A	Provide & Drive Test Pile 16" Diam	FT	\$110
505-205A	Provide & Install 12" ϕ Shell Pile Shoes or Tips	EA	\$175
505-205A	Provide & Install 16" ϕ Shell Pile Shoes or Tips	EA	\$200
505-205A	Provide & Install HP 12x74 Pile Shoes or Tips	EA	\$120
505-205A	Provide & Install HP 14x117 Pile Shoes or Tips	EA	\$165

SECTION 506 - PRESTRESSING CONCRETE

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
506-005A	Prestressing Cast-In-Place Concrete	LB	\$2.50

NOTE: Use Cost/lb for estimating purposes but show as lump sum on the Cost Estimate.

SECTION 510 - CONCRETE OVERLAY

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
510-005A	Concrete Overlay	CY	\$760

SECTION 511 - CONCRETE WATERPROOFING SYSTEM

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
511-005A	Conc Waterproofing System, Type A or D	SY	\$20
511-005A	Conc Waterproofing System, Type C	SY	\$7
S501-51A	Spray-Applied Waterproofing membrane	SF	\$5

AVERAGE UNIT PRICES FOR STANDARD BID ITEMS
(Based Upon 3 Low Bids thru December 2013)

SECTION 623 - CONCRETE SLOPE PAVING

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
623-005A	Concrete Slope Paving	SY	\$85

SECTION 624 - RIPRAP

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
624-005A	Loose Riprap	CY	\$55

SECTION 632 - REMOVAL OF BRIDGE DECK CONCRETE

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
632-005A	Concrete Bridge Deck Removal Class A	SY	\$60
632-010A	Concrete Bridge Deck Removal Class B	SY	\$30

SECTION 640 – CONSTRUCTION GEOTEXTILES

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
640-010A	Riprap/Erosion Control Geotextile	SY	\$2.80
640-015A	Subgrade Separation Geotextile	SY	\$1.80

SECTION 629 - MOBILIZATION

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
Z629-05A	Mobilization	LS	

NOTE : Use 10% of total of all other bid items for small projects and 7.5% for large projects for estimating purposes but show as lump sum on Cost Estimate.

AVERAGE UNIT PRICES FOR SPECIAL PROVISION BID ITEMS
(Based Upon 3 Low Bids thru December 2013)

EXPANSION JOINTS

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-06A	Compression Seal Joints w/armor angles	LF/inch	\$40
S501-06A	Compression Seal only ≤2"	LF/inch	\$16
S501-06A	Compression Seal only >2"	LF/inch	\$18
S501-06A	4" Strip Seal Joints & Extrusions	LF	\$190
S501-06A	Modular Joints	LF/inch	\$110
S501-05A	Asphaltic Plug Joints	CF	\$370
S501-06A	Silicone Sealant	FT	\$20
S501-06A	W or J Series Joint (Jeene)	LF/inch	\$26
S501-40A	Elastomeric Concrete Header	CY	\$9,400
S501-30A	Removal of Armored Joints	FT	\$27

NOTE: Use LF/inch for estimating, but show as FT on Cost Estimate. For compression seals, use uncompressed width for size to determine cost. For strip seals & modular joints, use total movement range for size to determine cost.

SURFACE TREATMENT

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-60A	Textured Concrete Surface	SY	\$28
S501-51A	Anti-Graffiti Coating	SF	\$1.60

PRE-DRILLING FOR PILES

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S505-05A	Predrilling For Piling in Soil	LF/inch of diam	\$2.75
S505-05A	Predrilling For Piling in Rock	LF/inch of diam	\$7.00

NOTE: Use LF/inch of diameter for estimating, but show as FT on Cost Estimate.

CASING FOR INTEGRAL ABUTMENTS

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-30A	Pile Casing – 24" diameter	FT	\$35
S501-30A	Pile Casing – 30" diameter	FT	\$45

DEWATER FOUNDATION

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S500-11A	Cofferdam	SF	\$48
S500-11A	Other	LS	\$10,000

NOTE: Use Cost/sf of cofferdam form area for estimating purposes but show as lump sum on the Cost Estimate. Cofferdam form area is equal to the perimeter of the seal concrete times the difference in elevation of the bottom of the seal concrete and the cofferdam vent elevation.

RAIL RETROFIT

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-30A	Std Drawing G-2-F Type 1	FT	\$105
S501-30A	Std Drawing G-2-F Type 2	FT	\$110
S501-30A	Std Drawing G-2-F Type 4	FT	\$95
S501-30A	Delaware Thrie Beam	FT	\$98
S501-20A	Remove End Block	EA	\$1000

AVERAGE UNIT PRICES FOR SPECIAL PROVISION BID ITEMS

(Based Upon 3 Low Bids thru December 2013)

RETAINING WALL

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-17A	MSE Wall	SF	\$45
S501-18A	Coping	FT	\$102
S501-15A	Reinforced Segmental Block Wall	SF	\$46
S501-15A	Welded Wire Wall	SF	\$32
S501-15A	Welded Wire Wall w/Concrete facing	SF	\$78
S501-51A	Soil Nail Wall	SF	\$70
S501-51A	Soldier Pile Wall	SF	\$85

TEMPORARY SHORING

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-90A	Bridge	LS	\$37,000
S501-90A	Culvert	LS	\$12,000

PATCH & REPAIR CONCRETE SURFACE

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-51A	Substructure	SF	\$100
S501-51A	Deck	SF	\$80

CRACK REPAIR

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-30A	Preparation	FT	\$55
S501-50A	Injection	GAL	\$700

Note: Gallons = in³ of crack/231**REMOVE ASPHALT OVERLAY**

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-35A	Remove Asphalt Overlay	SY	\$6

PAINT STRUCTURAL STEEL

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-70A	At Expansion Joints in Field	SF of girder painted area	\$34
S501-30A	Picket Fence Rail in Field	FT	\$220

UTILITY CONDUITS

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-30A	Complete across bridge	FT/conduit	\$13
S501-30A	At Abutments with diaph sleeves & deck inserts	FT/conduit	\$9

DECK CRACK SEALER

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-35A	Preparation	SY	\$2.50
S501-50A	Sealer	GAL	\$56

AVERAGE UNIT PRICES FOR SPECIAL PROVISION BID ITEMS
(Based Upon 3 Low Bids thru December 2013)

DECK OVERLAYS

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-35A	Polyester Concrete Overlay	SY	\$125
S501-51A	Epoxy Overlay	SF	\$3.80

BEARINGS

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-55A	Plain elastomeric pads	in ³ of pad	\$0.80
S501-55A	Laminated elastomeric pads	in ³ of pad	\$1.00
S501-55A	Stainless Steel/PTFE	Kip	\$36

NOTE: Use Cost/ in³ of pad for estimating purposes but show as EACH on the Cost Estimate.
Use Cost/ kip for estimating purposes but show as EACH on the Cost Estimate.

DYNAMIC PILE TESTING

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
S501-20A	Dynamic Pile Testing	EA	\$2800
S501-20B	CAPWAP Analysis	EA	\$300

DRILLED SHAFT

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
	Drilled Shaft	LF/ft ² of area	\$60

NOTE: Use cross-sectional area of drilled shaft. Cost should be used for preliminary estimating only.
Final drilled shaft cost is based on multiple bid items.

PC/PS DECK PANEL

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
	Precast Deck Panel	SF	\$60

NOTE: Use plan area of deck panels.
Cost includes panel and prestressing and should be used for preliminary estimating only.

PC ABUTMENT PILE CAP

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
	Precast Abutment Pile Cap	CY	\$1200

NOTE: Cost includes concrete and reinforcement and should be used for preliminary estimating only.

PC CANTILEVER WING WALLS

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
	Precast Cantilever Wing Walls	CY	\$1200

NOTE: Cost includes concrete and reinforcement and should be used for preliminary estimating only.

AVERAGE UNIT PRICES FOR SPECIAL PROVISION BID ITEMS

(Based Upon 3 Low Bids thru December 2013)

PC PIER CAP

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
	Precast Pier Cap	CY	\$2500

NOTE: Cost includes concrete and reinforcement and should be used for preliminary estimating only.

PC PIER COLUMN

<u>ITEM NO.</u>	<u>ITEM</u>	<u>UNIT</u>	<u>ALL DISTRICTS</u>
	Precast Pier Column	CY	\$2000

NOTE: Cost includes concrete and reinforcement and should be used for preliminary estimating only.

**APPENDIX E2:
Cost Estimating Guidelines
Connecticut Department of
Transportation 2013**

Connecticut DOT
2013 Cost Estimating Guidelines
Attachment 3, General Price Ranges of Common Items

Item No.	Item Description	Units	Unit Price Range	
0101117	CONTROLLED MATERIALS HANDLING	c.y.	5.00	20.00
0101168	RSAWSA EQUIPMENT OPERATOR	hour	65.00	75.00
0104057	POLE FOUNDATIONS, TYPE A	ea.	675.00	850.00
0202000	EARTH EXCAVATION	c.y.	8.00	15.00
0202100	ROCK EXCAVATION	c.y.	30.00	60.00
0202315	DISPOSAL OF CONTROLLED MATERIALS	ton	40.00	55.00
0202502	REMOVAL OF CONCRETE PAVEMENT	s.y.	8.00	14.00
0203000	STRUCTURE EXCAVATION EARTH (COMPLETE)	c.y.	18.00	40.00
0203100	STRUCTURE EXCAVATION ROCK (COMPLETE)	c.y.	75.00	100.00
0204001	COFFERDAM AND DEWATERING	l.f.	90.00	140.00
0207000	BORROW	c.y.	4.00	12.00
0207150	LIGHTWEIGHT FILL	c.y.	50.00	75.00
0209001	FORMATION OF SUBGRADE	s.y.	2.00	4.00
0212000	SUBBASE	c.y.	25.00	40.00
0213100	GRANULAR FILL	c.y.	25.00	35.00
0216000	PERVIOUS STRUCTURE BACKFILL	c.y.	35.00	50.00
0216009	EXPANDED POLYSTYRENE FILL	c.y.	85.00	125.00
0219001	SEDIMENTATION CONTROL SYSTEM	l.f.	3.00	4.00
0304002	PROCESSED AGGREGATE BASE	c.y.	30.00	45.00
0401159	DIAMOND GRINDING	s.y.	3.50	4.50
0406165	WMA S0.5	ton	65.00	85.00
0406170	HMA S1	ton	80.00	115.00
0406171	HMA S0.5	ton	70.00	120.00
0406173	HMA S0.25	ton	80.00	125.00
0406236	MATERIAL FOR TACK COAT	gal.	4.00	8.00
0406267	MILLING OF HMA (0" TO 4")	s.y.	3.00	8.00
0406285	FINE MILLING OF H.M.A. (0" - 4")	s.y.	2.00	15.00
0507001	TYPE "C" CATCH BASIN	ea.	2,200.00	2,600.00
0507201	TYPE "C-L" CATCH BASIN	ea.	2,200.00	2,800.00
0520036	ASPHALTIC PLUG EXPANSION JOINT SYSTEM	c.f.	200.00	400.00
0601000	CLASS "A" CONCRETE	c.y.	500.00	800.00
0601070	CLASS "S" CONCRETE	c.y.	9,500.00	10,500.00
0601201	CLASS "F" CONCRETE	c.y.	800.00	1,200.00
0601318	PARTIAL DEPTH PATCH	c.f.	150.00	250.00
0601604	ASPHALTIC PLUG EXPANSION JOINT SYSTEM	l.f.	115.00	140.00
0602000	DEFORMED STEEL BARS	lb.	1.00	2.00
0602006	DEFORMED STEEL BARS - EPOXY COATED	lb.	1.40	2.20
0603142	FIELD TOUCH-UP PAINTING	s.f.	40.00	100.00
0603858	REHABILITATION OF EXISTING STRUCTURAL STEEL	cwt.	2,500.00	4,000.00

Connecticut DOT
2013 Cost Estimating Guidelines
Attachment 3, General Price Ranges of Common Items

Item No.	Item Description	Units	Unit Price Range	
0651012	15" R.C. PIPE	l.f.	40.00	60.00
0651013	18" R.C. PIPE	l.f.	50.00	70.00
0651015	24" R.C. PIPE	l.f.	55.00	75.00
0651017	30" R.C. PIPE	l.f.	60.00	80.00
0702101	FURNISHING STEEL PILES	lb.	0.50	0.65
0702111	DRIVING STEEL PILES	l.f.	12.00	24.00
0707001	MEMBRANE WATERPROOFING (WOVEN GLASS FABRIC)	s.y.	23.00	40.00
0714050	TEMPORARY EARTH RETAINING SYSTEM	s.f.	8.00	30.00
0728020	STONE BALLAST	ton	30.00	50.00
0811001	CONCRETE CURBING	l.f.	20.00	35.00
0813001	5" GRANITE STONE CURBING	l.f.	25.00	30.00
0813031	6" GRANITE STONE CURBING	l.f.	40.00	60.00
0815001	BITUMINOUS CONCRETE LIP CURBING	l.f.	4.00	7.00
0822001	TEMPORARY PRECAST CONCRETE BARRIER CURB	l.f.	20.00	50.00
0822002	RELOCATED TEMPORARY PRECAST CONCRETE BAR	l.f.	8.00	15.00
0910170	METAL BEAM RAIL (TYPE R-B 350)	l.f.	20.00	25.00
0910194	METAL BEAM RAIL (TYPE R-B 350 10GA)	l.f.	20.00	23.00
0916126	NOISE BARRIER WALL	s.f.	40.00	50.00
0921001	CONCRETE SIDEWALK	s.f.	8.00	12.00
0922500	BITUMINOUS CONCRETE DRIVEWAY (COMMERCIAL)	s.y.	35.00	50.00
0922501	BITUMINOUS CONCRETE DRIVEWAY	s.y.	30.00	40.00
0939001	SWEEPING FOR DUST CONTROL	hr.	10.00	25.00
0944000	FURNISHING AND PLACING TOPSOIL	s.y.	5.00	10.00
0969060	CONSTRUCTION FIELD OFFICE, SMALL	month	1,800.00	3,200.00
0969062	CONSTRUCTION FIELD OFFICE, MEDIUM	month	1,800.00	3,500.00
0969064	CONSTRUCTION FIELD OFFICE, LARGE	month	2,100.00	4,000.00
0970007	TRAFFICPERSON (UNIFORMED FLAGGER)	hr.	30.00	60.00
0974001	REMOVAL OF EXISTING MASONRY	c.y.	150.00	600.00
0978002	TRAFFIC DRUM	ea.	60.00	80.00
1001001	TRENCHING AND BACKFILLING	l.f.	10.00	15.00
1008115	2" RIGID METAL CONDUIT IN TRENCH	l.f.	8.00	12.00
1008720	4" RIGID METAL MULTI DUCT CONDUIT - UNDER ROADWAY	l.f.	50.00	70.00
1111451	LOOP DETECTOR SAW CUT	l.f.	10.00	15.00
1131002	REMOTE CONTROL CHANGEABLE MESSAGE SIGN	day	30.00	50.00
1806200	FURNISHING AND USE OF PORTABLE IMPACT ATTENUATION	hr.	35.00	55.00

**APPENDIX E3:
LRFD Bridge Development
Report – Cost Estimation 2002**

Step One:

Utilizing the cost provided herein, develop the cost estimate for each bridge type under consideration.

11.2.1 Substructure

A. Prestressed Concrete Piling; cost per linear foot (furnished and installed)

**Size of Piling	Driven Plumb or 1" Batter	Driven Battered
18 in	\$38	\$47
24 in	\$53	\$67
30 in	\$63*	\$80

*When heavy mild steel reinforcing is used in the pile head, add \$250.

** When silica fume is used, add \$6.0 per LF to the piling cost.

B. Steel Piling; cost per linear foot (furnished and installed)

14" x 73 H Section	\$35
14" x 89 H Section	\$38
20" Pipe Pile.....	\$84
24" Pipe Pile.....	\$90
30" Pipe Pile.....	\$152

C. Drilled Shaft; cost per linear foot

1.) On Land with casing salvaged. (Total in-place cost)

3 ft	\$239
4 ft	\$277
5 ft	\$340
6 ft	\$441
7 ft	\$542

2.) In water with casing salvaged. (Total in-place cost)

3 ft	\$277
4 ft	\$302
5 ft	\$353
6 ft	\$479
7 ft	\$605
8 ft	\$806

3.) In water with permanent casing. (Total in-place cost)

3 ft	\$428
4 ft	\$466
5 ft	\$554
6 ft	\$643
7 ft	\$781
8 ft	\$970
9 ft	\$1184

D. Sheet Piling Walls

1.) Prestressed concrete; cost per linear foot.	
10" x 30"	\$71
12" x 30"	\$86
2.) Steel; cost per square foot	
Permanent Cantilever Wall	\$20
Temporary Cantilever Wall	\$6

E. Cofferdam Footing (cofferdam and seal concrete)

Prorate the cost provided herein based on area and depth of water. A cofferdam footing having the following attributes will cost \$328,000.

Area; 63 ft x 37.25 ft. Depth of seal; 5 ft. Depth of water over the footing; 16 ft.

F. Substructure Concrete; cost per cubic yard.

Concrete	\$550
Mass concrete	\$315
Seal concrete.....	\$344
Shell fill	\$5
Admixtures	
For calcium nitrite, add \$32 per cubic yard. (@4.5 gal per cubic yard).	
For silica fume, add \$25 per cubic yard. (@60 lbs. per cubic yard.)	

G. Reinforcing Steel; cost per pound.....\$0.46

11.2.2 Superstructure

A. Bearing Material

1.) Neoprene Bearing Pads; Cost per Cubic Foot	\$500
2.) Multirotational Bearings, Cost per Each	
Capacity in Kips.....	Cost
1-251	\$3,465
251-500	\$3,780
501-750	\$4,410
751-1000	\$5,040
1001-1250	\$5,670
1251-1500	\$6,300
1501-1750	\$6,930
1751-2000	\$7,875
>2000	\$10,080

B. Bridge Girders

- 1.) Structural Steel; cost per pound (includes coating costs).
- | | |
|-----------------------------------|--------|
| Rolled wide flange sections | \$0.90 |
| Plate girders; straight | \$1.04 |
| Plate girders; curved | \$1.21 |
| Box girders; straight | \$1.32 |
| Box girders; curved | \$1.54 |
- When uncoated weathering steel is used, reduce the price by \$0.04 per pound. Inorganic zinc coating systems have an expected life cycle of 20 years.

- 2.) Prestressed Concrete Girders; cost per linear foot.
- | | |
|------------------------------------|--------|
| AASHTO Type II..... | \$80 |
| AASHTO Type III..... | \$86 |
| AASHTO Type IV | \$100 |
| AASHTO Type V | \$120 |
| AASHTO Type VI | \$130 |
| FI Bulb Tee; 54"..... | \$90 |
| FI Bulb Tee; 63"..... | \$98 |
| FI Bulb Tee; 72"..... | \$120 |
| FI Bulb Tee (M); 78" | \$135 |
| 78" Haunched units (CJ to CJ)..... | \$380 |
| FI Double Tee; 18"..... | \$185 |
| FI Double Tee; 24"..... | \$200 |
| FI Double Tee; 30"..... | \$270 |
| FI Inverted Tee; 16" | \$50* |
| FI Inverted Tee; 20" | \$56* |
| FI Inverted Tee; 24" | \$62* |
| FI Inverted Tee; 16" | \$50* |
| FI Tub (U-Beam); 48" | \$300* |
| FI Tub (U-Beam); 54" | \$330* |
| FI Tub (U-Beam); 63" | \$370* |
| FI Tub (U-Beam); 72" | \$400* |
| Solid Flat Slab (36'x15")..... | \$110 |
| Solid Flat Slab (36'x18")..... | \$125 |

* Price is based on ability to furnish products without any conversions of casting beds and without purchasing of forms. If these conditions do not exist, add the following costs:

Inverted Tee - \$202,000
FI Tub - \$403,000

- 3.) Cast-in-Place Superstructure Concrete; cost per cubic yard.
- | | |
|------------------------------------|-------|
| Box Girder Concrete; straight..... | \$650 |
| Box Girder Concrete; curved..... | \$675 |
| Deck Concrete | \$425 |

4.) Concrete for Pre-cast Segmental Box Girders; cantilever construction; price per cubic yard. For deck area between 300,000 SF and 500,000 SF, interpolate between the stated costs per cubic yard.	
<=300,000 SF	\$693
>300,000 SF and <=500,000 SF	interpolate
>500,000 SF	\$567
5.) Reinforcing Steel; cost per pound	\$0.46
6.) Post-tensioning Steel; cost per pound.	
Strand; longitudinal.....	\$1.53
Strand; transverse	\$1.82
Bars.....	\$3.90
7.) Railings and Barriers, cost per linear foot.	
Traffic Barrier	\$44
Pedestrian Railing	\$57
Bicycle Railing.....	\$69*
*For metal railing add \$38 per linear foot.	
8.) Expansion joints; cost per linear foot.	
Strip seal	\$106
Finger joint <6"	\$315
Finger joint >6"	\$473
Modular 6"	\$500
Modular 8"	\$700
Modular 12"	\$900
 C. Retaining Walls	
1.) MSE Walls; Cost per square foot	
Permanent.....	\$23
Temporary.....	\$8
 D. Noise Wall; Cost per square foot	\$18
 E. Detour Bridge; Cost per square foot	\$10*
*Using FDOT supplied components. The cost is for the bridge proper and does not include approach work, surfacing, or guardrail.	

11.2.3 Design Aid for Determination of Reinforcing Steel

In the absence of better information, use the following quantities of reinforcing steel per cubic yard of concrete.

Pile abutments	135
Pile Bents	145
Single Column Piers; Tall (>25 ft).....	210
Single Column Piers; Short (<25 ft).....	150
Multiple Column Piers; Tall (>25 ft)	215
Multiple Column Piers; Short (<25 ft)	195

Bascule Piers	110
Deck Slabs; Standard	205
Deck Slabs; Isotropic	125
Concrete Box Girders; Pier Segment	225
Concrete Box Girders; Typical Segment	165
Concrete Box Girders; Flat Slabs (30 ft x 15" deep).....	220

Step Two:

After developing the total cost estimate utilizing the unit cost, modify the cost to account for site condition variables. If appropriate, the cost will be modified by the following variables:

1. For rural construction decrease construction cost by 6 percent.
2. For urban construction (Broward, Dade, Duval, Hillsborough, Orange, Palm Beach and Pinellas counties), increase construction cost by 6 percent.
3. For construction over water increase construction cost by 3 percent.
4. For phased construction (over traffic or construction requiring multiple phases to complete the entire cross section of the bridge), add a 20 percent premium to the affected units of the structure.

Step Three:

The final step is a comparison of the cost estimate with historic bridge cost per square foot data. These total cost numbers are calculated exclusively for the bridge cost as defined in the General Section of this chapter. Price computed by Steps 1 and 2 should be generally within the range of cost of as supplied herein. If the cost falls outside the provided range, good justification must be provided.

Bridge Superstructure Type	Total Cost per Square Foot
Reinforced Concrete Flat Slab; Simple Span	\$50-65*
Reinforced Concrete Flat Slab; Continuous Span	\$60-80*
Steel Deck/Girder; Simple Span.....	\$62-75*
Steel Deck/Girder; Continuous Span	\$70-90*
Prestressed Concrete Deck/Girder; Simple Span	\$50-70*
Prestressed Concrete Deck/Girder; Continuous Span	\$65-110*
Post-tensioned, cast-in-place Concrete Box Girder	
Cast on scaffolding; span length <=240 ft.....	\$75-110
Steel Box Deck/Girder	
Span range from 150 ft to 280 ft	\$76-120
For curvature add a 15 percent premium	
Segmental Concrete Box Girders	
Span range from 150 ft to 280 ft	\$80-110
Movable Bridges; bascule spans & piers.....	\$900-1500
Demolition of existing bridges	
Typical	\$9-15
Bascule spans & piers	\$63

* Increase the cost by twenty percent for phased construction.

**APPENDIX E4:
South Burlington Preliminary
Cost of Bridges 2008**

Construction Cost Estimate - Alternative A - Modified Diamond Interchange

<u>Section 1 : Earthwork</u>	<u>Units</u>	<u>Quantity</u>	<u>Unit Price</u>	<u>Item Total</u>
Clearing and Grubbing	HA	8	10,600	\$ 84,800
Common Excavation	CM	21100	9	\$ 189,900
Excavation of Surfaces and Pavement	CM	1200	15	\$ 18,000
Solid Rock Excavation	CM	12700	17	\$ 215,900
Import Borrow / Place Embankment	CM	8400	22	\$ 184,800
Section 1 Subtotal =				\$ 693,400

<u>Section 2 : Roadway Items</u>	<u>Units</u>	<u>Quantity</u>	<u>Unit Price</u>	<u>Item Total</u>
Asphalt Concrete	MTON	3000	108	\$ 324,000
Base of Crushed Gravel (Fine Graded)	CM	28600	40	\$ 1,144,000
Subbase of Dense Graded Sand	CM	33700	22	\$ 741,400
Cast-in-Place Cement Concrete Curb, Type B	M	900	96	\$ 86,400
Portland Cement Concrete Sidewalk, 5 inch	SM	2900	76	\$ 220,400
Removal of Existing Guardrail	M	300	8	\$ 2,400
Guardrail	M	300	54	\$ 16,200
Chain Link Fence	M	710	70	\$ 49,700
Utility Relocation	LS	1	64,700	\$ 64,700
Miscellaneous Roadway Items	LS	1	265,000	\$ 265,000
Section 2 Subtotal =				\$ 2,914,200

<u>Section 3 : Drainage Items</u>	<u>Units</u>	<u>Quantity</u>	<u>Unit Price</u>	<u>Item Total</u>
Drainage Items	LS	1	1,020,000	\$ 1,020,000
Section 3 Subtotal =				\$ 1,020,000

<u>Section 4 : Environmental Items</u>	<u>Units</u>	<u>Quantity</u>	<u>Unit Price</u>	<u>Item Total</u>
Erosion and Sediment Control Plan	LS	1	5,000	\$ 5,000
Monitoring Erosion and Sediment Control Plan	HR	1000	44	\$ 44,000
Maintenance of Erosion and Sediment Control Plan	LS	1	407,200	\$ 407,200
Environmental Mitigation	LS	1	100,000	\$ 100,000
Wetland Restoration	LS	1	100,000	\$ 100,000
Section 4 Subtotal =				\$ 656,200

<u>Section 5 : Signage, Striping, Signals, and Lighting</u>	<u>Units</u>	<u>Quantity</u>	<u>Unit Price</u>	<u>Item Total</u>
Traffic Signs	LS	1	145,800	\$ 145,800
Removing Signs	LS	1	21,900	\$ 21,900
Striping	LS	1	29,200	\$ 29,200
Traffic Signals	EA	3	214,000	\$ 642,000
Lighting	LS	1	291,500	\$ 291,500
Section 5 Subtotal =				\$ 1,130,400

<u>Section 6 : Landscaping</u>	<u>Units</u>	<u>Quantity</u>	<u>Unit Price</u>	<u>Item Total</u>
Landscaping	LS	1	145,800	\$ 145,800
Section 6 Subtotal =				\$ 145,800

<u>Section 7 : Traffic Control</u>	<u>Units</u>	<u>Quantity</u>	<u>Unit Price</u>	<u>Item Total</u>
Interstate Crossover	LS	1	500,000	\$ 500,000
Uniformed Traffic Officers	LS	1	250,000	\$ 250,000
Flaggers	HR	1700	21	\$ 35,700
Maintenance of Traffic	LS	1	70,900	\$ 70,900
Portable Changeable Message Sign	LS	1	254,000	\$ 254,000
Section 7 Subtotal =				\$ 1,110,600

<u>Section 8 : Construction Operations</u>	<u>Units</u>	<u>Quantity</u>	<u>Unit Price</u>	<u>Item Total</u>
Field Office - Engineers	MON	15	2,000	\$ 30,000
Testing Equipment - Bituminous	LS	1	64,800	\$ 64,800
Mobilization/Demobilization	LS	1	728,600	\$ 728,600
Section 8 Subtotal =				\$ 823,400

<u>Section 9 : Structures</u>	<u>Units</u>	<u>Quantity</u>	<u>Unit Price</u>	<u>Item Total</u>
Removal of Existing Structure	LS	1	600,000	\$ 600,000
New Bridge Structure & Piers	SM	2100	4,000	\$ 8,400,000
Retaining Walls	SM	0	800	\$ -
Architectural Treatments	LS	1	840,000	\$ 840,000
Section 9 Subtotal =				\$ 9,840,000

Estimated Construction Costs	\$ 18,334,000
Contingency (15%)	\$ 2,750,100
Preliminary Engineering (20%)	\$ 3,666,800
Project Management (10%)	\$ 1,833,400
ROW Costs (estimated)	\$ -
Construction Engineering (15%)	\$ 2,750,100
TOTAL PROJECT COSTS	\$ 29,334,400

Construction Cost Estimate - Alternative B - Modified Single Point Urban Interchange

Section 1 : Earthwork

	Units	Quantity	Unit Price	Item Total
Clearing and Grubbing	HA	9	10,600	\$ 95,400
Common Excavation	CM	13500	9	\$ 121,500
Excavation of Surfaces and Pavement	CM	1200	15	\$ 18,000
Solid Rock Excavation	CM	8100	17	\$ 137,700
Import Borrow / Place Embankment	CM	44900	22	\$ 987,800
Section 1 Subtotal =				\$ 1,360,400

Section 2 : Roadway Items

	Units	Quantity	Unit Price	Item Total
Asphalt Concrete	MTON	2900	108	\$ 313,200
Base of Crushed Gravel (Fine Graded)	CM	28500	40	\$ 1,140,000
Subbase of Dense Graded Sand	CM	33300	22	\$ 732,600
Cast-in-Place Cement Concrete Curb, Type B	M	940	96	\$ 90,240
Portland Cement Concrete Sidewalk, 5 inch	SM	3500	76	\$ 266,000
Removal of Existing Guardrail	M	300	8	\$ 2,400
Guardrail	M	300	54	\$ 16,200
Chain Link Fence	M	670	70	\$ 46,900
Utility Relocation	LS	1	65,200	\$ 65,200
Miscellaneous Roadway Items	LS	1	267,300	\$ 267,300
Section 2 Subtotal =				\$ 2,940,040

Section 3 : Drainage Items

	Units	Quantity	Unit Price	Item Total
Drainage Items	LS	1	1,029,100	\$ 1,029,100
Section 3 Subtotal =				\$ 1,029,100

Section 4 : Environmental Items

	Units	Quantity	Unit Price	Item Total
Erosion and Sediment Control Plan	LS	1	5,000	\$ 5,000
Monitoring Erosion and Sediment Control Plan	HR	1000	44	\$ 44,000
Maintenance of Erosion and Sediment Control Plan	LS	1	458,000	\$ 458,000
Environmental Mitigation	LS	1	100,000	\$ 100,000
Wetland Restoration	LS	1	100,000	\$ 100,000
Section 4 Subtotal =				\$ 707,000

Section 5 : Signage, Striping, Signals, and Lighting

	Units	Quantity	Unit Price	Item Total
Traffic Signs	LS	1	294,100	\$ 294,100
Removing Signs	LS	1	21,900	\$ 21,900
Striping	LS	1	58,900	\$ 58,900
Traffic Signals	EA	3	214,000	\$ 642,000
Lighting	LS	1	294,100	\$ 294,100
Section 5 Subtotal =				\$ 1,311,000

Section 6 : Landscaping

	Units	Quantity	Unit Price	Item Total
Landscaping	LS	1	294,100	\$ 294,100
Section 6 Subtotal =				\$ 294,100

Section 7 : Traffic Control

	Units	Quantity	Unit Price	Item Total
Interstate Crossover	LS	1	500,000	\$ 500,000
Uniformed Traffic Officers	LS	1	250,000	\$ 250,000
Flaggers	HR	1700	21	\$ 35,700
Maintenance of Traffic	LS	1	70,900	\$ 70,900
Portable Changeable Message Sign	LS	1	254,000	\$ 254,000
Section 7 Subtotal =				\$ 1,110,600

Section 8 : Construction Operations

	Units	Quantity	Unit Price	Item Total
Field Office - Engineers	MON	15	2,000	\$ 30,000
Testing Equipment - Bituminous	LS	1	62,700	\$ 62,700
Mobilization/Demobilization	LS	1	735,100	\$ 735,100
Section 8 Subtotal =				\$ 827,800

Section 9 : Structures

	Units	Quantity	Unit Price	Item Total
Removal of Existing Structure	LS	1	600,000	\$ 600,000
New Bridge Structure & Piers	SM	3700	4,000	\$ 14,800,000
Retaining Walls	SM	800	800	\$ 640,000
Architectural Treatments	LS	1	1,544,000	\$ 1,544,000
Section 9 Subtotal =				\$ 17,584,000

Estimated Construction Costs	\$ 27,164,040
Contingency (15%)	\$ 4,074,606
Preliminary Engineering (20%)	\$ 5,432,808
Project Management (10%)	\$ 2,716,404
ROW Costs (estimated)	\$ -
Construction Engineering (15%)	\$ 4,074,606
TOTAL PROJECT COSTS	\$ 43,462,464

**APPENDIX E5:
Washington State Department of
Transportation – Bridge Design
Manual 2011**

Structural Estimating Aids Construction Costs

Appendix 12.3-A1

UNIT COSTS

	UNIT	LOW	AVERAGE	HIGH $\Delta\Delta$
Prestressed Concrete Girders				
— Span 50 - 175 FT.				
Water Crossing w/piling	SF	\$150.00	\$175.00	\$200.00
Water Crossing w/spread footings	SF	\$140.00	\$165.00	\$190.00
Dry Crossing w/piling	SF	\$120.00	\$155.00	\$180.00
Dry Crossing w/spread footings	SF	\$110.00	\$145.00	\$160.00
Reinforced Concrete And Post-Tensioned Concrete Box Girder — Span 50 - 200 FT.				
Water Crossing w/piling	SF	\$200.00	\$250.00	\$300.00
Water Crossing w/spread footings	SF	\$175.00	\$225.00	\$275.00
Dry Crossing w/piling	SF	\$160.00	\$200.00	\$250.00
Dry Crossing w/spread footings	SF	\$150.00	\$190.00	\$230.00
Reinforced Concrete Flat Slab	SF	\$130.00	\$155.00	\$180.00
— Span 20 - 60 FT.				
Prestressed Concrete Slabs	SF	\$110.00	\$130.00	\$150.00
— Span 13 - 69 FT.				
Prestressed Concrete Decked Bulb -Tee Girder	SF	\$130.00	\$155.00	\$180.00
— Span 40 - 115 FT.				
Steel Girder — Span 60 - 400 FT.	SF	\$150.00	\$200.00	\$250.00
Steel Box Girder — Span 300 - 700 FT.	SF		\$250.00	
Steel Truss — Span 300 - 700 FT.	SF		\$275.00	
Steel Arch — Span 30 - 400 FT.	SF		* \$300.00	
Bridge Approach Slab	SY		\$250.00	
Concrete Bridge Removal	SF	\$20.00	\$35.00	\$50.00
Widening Existing Concrete Bridges (Including Removal)	SF	\$175.00	\$200.00	\$300.00
Railroad Undercrossing — Single Track	LF	* \$9,000.00 (Steel Underdeck Girder)		
		* \$11,000.00 (Steel Thru-Girder)		
Railroad Undercrossing — Double Track	LF	* \$14,000.00		
Pedestrian Bridge — Reinforced Concrete	SF	\$200.00	\$300.00	\$600.00
Reinforced Concrete Rigid Frame (Tunnel)	SF		* \$100.00	
Replace Existing Curbs & Barrier With Safety Shape Traffic Barrier (Including Removal)	LF	\$150.00	\$200.00	\$250.00
Reinforced Concrete Retaining Wall (Exposed Area)	SF	\$55.00	\$75.00	\$90.00
SE Wall — Welded Wire	SF	\$20.00	\$30.00	\$40.00
SE Wall — Precast Conc. Panels or Conc. Block	SF	\$30.00	\$40.00	\$50.00
SE Wall — CIP Conc. Fascia Panels (Special Design)	SF	\$40.00	\$50.00	\$60.00

UNIT COSTS

	UNIT	LOW	AVERAGE	HIGH $\Delta\Delta$
Permanent Geosynthetic Wall w/ Shotcrete Facing	SF	\$20.00	\$35.00	\$50.00
Permanent Geosynthetic Wall w/ Concrete Fascia Panel	SF	\$30.00	\$45.00	\$60.00
Soil Nail Wall	SF	\$80.00	\$100.00	\$130.00
Shotcrete Facing	SF	\$20.00	\$30.00	\$40.00
Concrete Fascia Panel	SF	\$30.00	\$40.00	\$50.00
Soldier Pile Wall (Exposed Area)	SF	\$100.00	\$120.00	\$130.00
Soldier Pile Tieback Wall (Exposed Area)	SF	\$140.00	\$160.00	\$200.00
Concrete Crib Wall Concrete Headers	SF	\$40.00	\$50.00	\$60.00

*Based on limited cost data. Check with the Bridge PS&E Engineer.

Bridge areas are computed as follows:

Typical Bridges: Width x Length

Width: Total width of Deck, including portion under the barrier.

Length: Distance between back of pavement seats, or for a Bridge having Wingwalls, 3'-0" behind the top of the embankment slope; typically end of Wingwalls to end of Wingwalls, reference Standard Plans H9.

Special Cases:

Widenings - Actual area of new construction.

Tunnel - Outside dimension from top of footing to top of footing over the tunnel roof, i.e., including walls and top width.

$\Delta\Delta$ For small jobs (less than \$100,000), use the high end of the cost range as a starting point.

Before using these structure unit costs for any official WSDOT project cost estimate, contact the Bridge and Structures Office at (360) 705-7201 to discuss the specific project criteria and constructability related risks, so an appropriate structures construction cost can be provided.

(Note: Unit structure costs include mobilization but do not include sales tax, engineering, or contingency)

SUBSTRUCTURE

BID ITEMS	UNIT	UNIT COST		
		LOW	HIGH ΔΔ	
Structure Excavation Class A Incl. Haul				
Earth	CY	\$12.00	—	\$30.00
Rock	CY	\$100.00	—	\$220.00
Inside Cofferdam — Earth	CY	\$22.00	—	\$33.00
— Rock	CY	\$110.00	—	\$190.00
Shoring Extra Excavation Class A				
Dry — Depth under 6'	SF	\$3.00	—	\$8.00
Dry — 6' - 10'	SF	\$7.00	—	\$11.00
Dry — 10' - 20'	SF	\$11.00	—	\$22.00
Cofferdam	SF	\$30.00	—	\$40.00
Preboring For Standard Piles Furnishing & Driving Test Piles	LF	\$35.00	—	\$60.00
Concrete	EACH	\$5,000.00	—	\$10,000.00
Steel	EACH	\$4,000.00	—	\$8,000.00
Timber	EACH	\$2,000.00	—	\$3,000.00
Furnishing Piling				
Conc. _____ Dia.	LF	\$35.00	—	\$45.00
Steel — TYP HP 12x53	LF	\$30.00	—	\$35.00
Timber — Creosote Treated	LF	\$10.00	—	\$12.00
Timber — Untreated	LF	\$8.00	—	\$10.00
** Pile Tip				
CIP Concrete (Steel Casing — Short Tip)	EACH	\$200.00	—	\$250.00
CIP Concrete (Steel Casing — 10 Stinger)	EACH	\$4,500.00	—	\$5,500.00
Steel (H-Pile)	EACH	\$120.00	—	\$220.00
Timber (Arrow Tip)	EACH	\$25.00	—	\$45.00
Driving Piles (40' - 70' Lengths)				
Concrete _____ Dia.	EACH	\$500.00	—	\$1,000.00
Steel	EACH	\$350.00	—	\$800.00
Timber	EACH	\$225.00	—	\$450.00

SUBSTRUCTURE

BID ITEMS	UNIT	UNIT COST		
		LOW		HIGH $\Delta\Delta$
Shafts				
Soil Excavation For Shaft Including Haul	CY	\$300.00	—	\$600.00
Rock Excavation For Shaft Including Haul	CY	\$600.00	—	\$800.00
Furnishing & Placing Temp. Casing For Shaft	LF	\$125.00	—	\$350.00
Furnishing Permanent Casing For Shaft	LF	\$150.00	—	\$600.00
Placing Permanent Casing For Shaft	EACH	\$2,000.00	—	\$3,000.00
Casing Shoring	LF	\$150.00	—	\$350.00
Shoring or Extra Excavation CL.A — Shaft	EST	\$10,000.00	—	\$25,000.00
Conc. Class 4000P For Shaft	CY	\$250.00	—	\$350.00
St. Reinf. Bar For Shaft	LBS	\$1.00	—	\$1.50
CSL Access Tubes	LF	\$10.00	—	\$15.00
Removing Shaft Obstructions	EST	10% of all of above shaft _____		
St. Reinf. Bar For Bridge	LBS	\$1.00	—	\$1.30
Epoxy-Coated St. Reinf. Bar For Bridge	LBS	\$1.20	—	\$1.70
Conc. Class 4000W	CY	\$250.00	—	\$400.00
Conc. Class 4000P	CY	\$250.00	—	\$400.00
Conc. Class 4000 (Footings)	CY	\$400.00	—	\$600.00
Conc. Class 4000 (Abut. & Ret. Walls)	CY	\$450.00	—	\$650.00
Conc. Class 5000	CY	\$550.00	—	\$750.00
Lean Concrete	CY	\$200.00	—	\$250.00
Conc. Class 4000P (CIP Piling)	CY	\$200.00	—	\$250.00

$\Delta\Delta$ For small jobs (less than \$100,000), use the high end of the cost range as a starting point.

** Pile ultimate capacity will affect these prices. Check with Bridge PS&E Engineer if unsure.

Appendix 12.3-A3

Structural Estimating Aids Construction Costs

SUPERSTRUCTURE

BID ITEMS	UNIT	UNIT COST	
		LOW	HIGH ΔΔ
Elastomeric Bearing Pads			
Girder Seat	EACH	\$150.00	\$200.00
Girder Stop	EACH	\$100.00	\$150.00
Bearings - Spherical and Disc (In place with plates)	KIP	\$15.00	\$18.00
Fabric Pad Bearing (In place, including all plates, TFE, etc.)	EACH	\$2,000.00	\$3,000.00
Prestressed Concrete I Girder			
W42G (Series 6)	LF	\$200.00	
W50G (Series 8)	LF	\$225.00	
W58G (Series 10)	LF	\$245.00	
W74G (Series 14)	LF	\$265.00	
Wide Flange Prestressed Concrete Girder			
WF42G	LF	\$250.00	
WF50G	LF	\$275.00	
WF58G	LF	\$300.00	
WF74G	LF	\$325.00	
W83G	LF	\$350.00	
W95G	LF	\$400.00	
Spliced Prestressed Concrete I Girder			
WF74PTG	LF	\$250.00	
W83PTG	LF	\$275.00	
W95PTG	LF	\$300.00	
Bulb Tee Girder			
WBT32G	LF	\$250.00	
WBT38G	LF	\$275.00	
WBT62G	LF	\$300.00	
Trapezoidal Tub Girder			
U54G4	LF	\$500.00	
U54G5	LF	\$510.00	
U54G6	LF	\$520.00	
U66G4	LF	\$530.00	
U66G5	LF	\$540.00	
U66G6	LF	\$560.00	
U78G4	LF	\$570.00	
U78G5	LF	\$580.00	
U78G6	LF	\$600.00	
Wide Flange Trapezoidal Tub Girder			
UF60G4	LF	\$520.00	
UF60G5	LF	\$530.00	
UF60G6	LF	\$540.00	
UF72G4	LF	\$550.00	
UF72G5	LF	\$560.00	
UF72G6	LF	\$570.00	
UF84G4	LF	\$580.00	
UF84G5	LF	\$590.00	
UF84G6	LF	\$600.00	

SUPERSTRUCTURE

BID ITEMS	UNIT	UNIT COST	
		LOW	HIGH $\Delta\Delta$
Structural Carbon Steel (Steel girder, when large amount of steel is involved)	LBS	\$1.00	\$1.50
Structural Low Alloy Steel (Steel girder, when large amount of steel is involved)	LBS	\$1.25	\$1.75
Structural Steel (Sign supports, when small amounts of steel is involved)	LBS	\$4.00	\$6.00
Timber & Lumber	MBM	\$2,000.00	\$2,800.00
Creosote Treated	MBM	\$2,250.00	\$3,000.00
Salts Treated	MBM	\$1,500.00	\$2,000.00
Untreated	MBM	\$1,750.00	\$2,250.00
Lagging (in place) Untreated	MBM	\$2,550.00	\$3,500.00
Expansion Joint Modification	LF	\$400.00	\$600.00
Expansion Joint System			
Compression Seal	LF	\$80.00	\$100.00
Modular (Approx. \$100 per inch of movement)	LF	\$1,500.00	\$3,500.00
Strip Seal	LF	\$250.00	\$500.00
Rapid Cure Silicone	LF	\$70.00	\$100.00
Bridge Drains	EACH	\$400.00	\$600.00
Bridge Grate Inlets	EACH	\$1,500.00	\$2,000.00
Conc. Class 5000	CY	\$700.00	\$850.00
Conc. Class 5000 (Segmental Constr.)	CY	\$850.00	\$1,000.00
Conc. Class 4000D (Deck Only)	CY	\$700.00	\$800.00
Conc. Class 4000	CY	\$650.00	\$750.00
Conc. Class EA (Exposed Aggregate)	CY	\$500.00	\$600.00
Conc. Class 4000 LS (Low Shrinkage)	CY	\$400.00	\$550.00
Conc. Class 5000 LS	CY	\$500.00	\$600.00
St. Reinf. Bar	LBS	\$1.00	\$1.50
Epoxy-Coated St. Reinf. Bar	LBS	\$1.25	\$1.75
Post-tensioning Prestressing Steel (Includes Anchorages)	LBS	\$6.00	\$8.00
Traffic Barrier	LF	\$90.00	\$120.00
Bridge Railing Type BP & BP-S	LF	\$60.00	\$85.00
Bridge Railing Type Thrie Beam	LF	\$60.00	\$85.00
Modified Conc. Overlay	CF	\$40.00	\$80.00
Furnishing and Curing Modified Conc. Overlay	SY	\$60.00	\$100.00
Scarifying Conc. Overlay	SY	\$15.00	\$20.00
Polymer Concrete	SY	\$90.00	\$150.00
Polyester Concrete	CF	\$140.00	\$250.00

$\Delta\Delta$ For small jobs (less than \$100,000), use the high end of the cost range as a starting point.

MISCELLANEOUS

BID ITEMS	UNIT	UNIT COST	
		LOW	HIGH ΔΔ
Conduit Pipe 2" Diameter	LF	\$10.00	\$15.00
Sign Support (Brackets, Mono, or Truss Sign Bridges)	LBS	\$5.00	\$7.00
Concrete Surface Finishes			
Fractured Fin Finish	SY	\$20.00	\$30.00
Exposed Aggregate Finish (Requires the use of concrete Class EA)	SY	\$20.00	\$25.00
Pigmented Sealer	SY	\$7.00	\$10.00
Painting Existing Steel Bridges (Lead Base)	TON (Steel)	\$650.00	\$900.00
Painting New Steel Bridges	LBS (Steel)	\$0.12	\$0.15
Mobilization	Sum of Items		10%
Masonry Drilling Δ			
Holes up to 1'-0" in depth			
1" Diameter	EACH	\$30.00	
1 ½" Diameter	EACH	\$35.00	
2" Diameter	EACH	\$40.00	
2 ½" Diameter	EACH	\$42.00	
3" Diameter	EACH	\$44.00	
3 ½" Diameter	EACH	\$46.00	
4" Diameter	EACH	\$52.00	
5" Diameter	EACH	\$54.00	
6" Diameter	EACH	\$70.00	
7" Diameter	EACH	\$90.00	
Δ For holes greater than 1'-0" in depth and up to 20'-0" in depth, use 1.5 x above prices. If drilling through steel reinforcing, add \$16.00 per lineal inch of steel drilled.			
Removal of Rails and Curbs	LF	\$90.00	\$140.00
Removal of Rails, Curbs, and Slab	SF	\$30.00	\$60.00
Further Deck Preparation	CF	\$120.00	\$175.00
Bridge Deck Repair	CF	\$120.00	\$180.00
Removing HMA from bridge deck	SY	\$8.50	\$13.50
Plugging Existing Bridge Drain	EACH	\$350.00	

ΔΔ For small jobs (less than \$100,000), use the high end of the cost range as a starting point.

**Appendix F:
Code of the Developed
Model**

```

C:\Users\Bashar\Desktop\Model Programming\Last ... \VB 1 Test\WindowsApplication1\FirstForm.vb
465 Private Sub cmbLocation_SelectedIndexChanged(ByVal sender As System.Object, ByVal e As System.
EventArgs) Handles cmbLocation.SelectedIndexChanged
466 If cmbLocation.SelectedItem = "Urban" Then
467 cmbRdClass.Items.Clear()
468 cmbRdClass.Items.Add("Local")
469 cmbRdClass.Items.Add("Collector")
470 cmbRdClass.Items.Add("Arterial")
471 cmbRdClass.Items.Add("Expressway")
472 cmbRdClass.Items.Add("Freeway")
473 ElseIf cmbLocation.SelectedItem = "Rural" Then
474 cmbRdClass.Items.Clear()
475 cmbRdClass.Items.Add("Local")
476 cmbRdClass.Items.Add("Collector")
477 cmbRdClass.Items.Add("Arterial")
478 cmbRdClass.Items.Add("Freeway")
479 End If
480
481 If cmbLocation.SelectedItem = "Urban" Then
482 cmbUnderPassClass.Items.Clear()
483 cmbUnderPassClass.Items.Add("Local")
484 cmbUnderPassClass.Items.Add("Collector")
485 cmbUnderPassClass.Items.Add("Arterial")
486 cmbUnderPassClass.Items.Add("Expressway")
487 cmbUnderPassClass.Items.Add("Freeway")
488 ElseIf cmbLocation.SelectedItem = "Rural" Then
489 cmbUnderPassClass.Items.Clear()
490 cmbUnderPassClass.Items.Add("Local")
491 cmbUnderPassClass.Items.Add("Collector")
492 cmbUnderPassClass.Items.Add("Arterial")
493 cmbUnderPassClass.Items.Add("Freeway")
494 End If
495
496 End Sub
497 Private Sub cmbRdClass_SelectedIndexChanged(ByVal sender As System.Object, ByVal e As System.
EventArgs) Handles cmbRdClass.SelectedIndexChanged
498
499 'Lane Width if Road location is Urban
500 If cmbLocation.SelectedItem = "Urban" And cmbRdClass.SelectedItem = "Local" Then
501 LaneWidth = 3.6
502
503 cmbDesignSpeed.Items.Clear()
504 cmbTrafficVolume.Items.Clear()
505
506 cmbDesignSpeed.Items.Add("50")
507 cmbTrafficVolume.Items.Add("<1000 AADT")
508 cmbTrafficVolume.Items.Add("1000-3000 AADT")
509 cmbTrafficVolume.Items.Add("Other")
510
511
512 ElseIf cmbLocation.SelectedItem = "Urban" And cmbRdClass.SelectedItem = "Collector" Then
513 LaneWidth = 3.6
514
515 cmbDesignSpeed.Items.Clear()
516 cmbTrafficVolume.Items.Clear()
517
518 cmbDesignSpeed.Items.Add("50")
519 cmbDesignSpeed.Items.Add("60")
520 cmbDesignSpeed.Items.Add("70")
521 cmbDesignSpeed.Items.Add("80")
522 cmbTrafficVolume.Items.Add("<8000 AADT")
523 cmbTrafficVolume.Items.Add("1000 - 12000 AADT")
524 cmbTrafficVolume.Items.Add("Other")
525
526 ElseIf cmbLocation.SelectedItem = "Urban" And cmbRdClass.SelectedItem = "Arterial" Then

```

```

527 LaneWidth = 3.7
528
529 cmbDesignSpeed.Items.Clear()
530 cmbTrafficVolume.Items.Clear()
531
532 cmbDesignSpeed.Items.Add("50")
533 cmbDesignSpeed.Items.Add("60")
534 cmbDesignSpeed.Items.Add("70")
535 cmbDesignSpeed.Items.Add("80")
536 cmbDesignSpeed.Items.Add("90")
537 cmbDesignSpeed.Items.Add("100")
538 cmbTrafficVolume.Items.Add("5000 - 20000 AADT")
539 cmbTrafficVolume.Items.Add("10000 - 30000 AADT")
540 cmbTrafficVolume.Items.Add("Other")
541
542 ElseIf cmbLocation.SelectedItem = "Urban" And cmbRdClass.SelectedItem = "Expressway" Then
543 LaneWidth = 3.7
544
545 cmbDesignSpeed.Items.Clear()
546 cmbTrafficVolume.Items.Clear()
547
548 cmbDesignSpeed.Items.Add("80")
549 cmbDesignSpeed.Items.Add("90")
550 cmbDesignSpeed.Items.Add("100")
551 cmbTrafficVolume.Items.Add(">10000 AADT")
552 cmbTrafficVolume.Items.Add("Other")
553
554 ElseIf cmbLocation.SelectedItem = "Urban" And cmbRdClass.SelectedItem = "Freeway" Then
555 LaneWidth = 3.7
556
557 cmbDesignSpeed.Items.Clear()
558 cmbTrafficVolume.Items.Clear()
559
560 cmbDesignSpeed.Items.Add("80")
561 cmbDesignSpeed.Items.Add("90")
562 cmbDesignSpeed.Items.Add("100")
563 cmbDesignSpeed.Items.Add("120")
564 cmbTrafficVolume.Items.Add(">20000 AADT")
565 cmbTrafficVolume.Items.Add("Other")
566 End If
567
568 'Lane Width if Road location is Rural
569 If cmbLocation.SelectedItem = "Rural" And cmbRdClass.SelectedItem = "Local" Then
570 LaneWidth = 3.7
571
572 cmbDesignSpeed.Items.Clear()
573 cmbTrafficVolume.Items.Clear()
574
575 cmbDesignSpeed.Items.Add("50")
576 cmbDesignSpeed.Items.Add("60")
577 cmbDesignSpeed.Items.Add("70")
578 cmbDesignSpeed.Items.Add("80")
579 cmbDesignSpeed.Items.Add("90")
580 cmbDesignSpeed.Items.Add("100")
581 cmbDesignSpeed.Items.Add("110")
582 cmbTrafficVolume.Items.Add("<1000 AADT")
583 cmbTrafficVolume.Items.Add("Other")
584
585 ElseIf cmbLocation.SelectedItem = "Rural" And cmbRdClass.SelectedItem = "Collector" Then
586 LaneWidth = 3.7
587
588 cmbDesignSpeed.Items.Clear()
589 cmbTrafficVolume.Items.Clear()
590
591 cmbDesignSpeed.Items.Add("60")

```

```

592 cmbDesignSpeed.Items.Add("70")
593 cmbDesignSpeed.Items.Add("80")
594 cmbDesignSpeed.Items.Add("90")
595 cmbDesignSpeed.Items.Add("100")
596 cmbDesignSpeed.Items.Add("110")
597 cmbTrafficVolume.Items.Add("<5000 AADT")
598 cmbTrafficVolume.Items.Add("Other")
599
600 ElseIf cmbLocation.SelectedItem = "Rural" And cmbRdClass.SelectedItem = "Arterial" Then
601 LaneWidth = 3.7
602
603 cmbDesignSpeed.Items.Clear()
604 cmbTrafficVolume.Items.Clear()
605
606 cmbDesignSpeed.Items.Add("80")
607 cmbDesignSpeed.Items.Add("90")
608 cmbDesignSpeed.Items.Add("100")
609 cmbDesignSpeed.Items.Add("110")
610 cmbDesignSpeed.Items.Add("120")
611 cmbDesignSpeed.Items.Add("130")
612 cmbTrafficVolume.Items.Add("<12000 AADT")
613 cmbTrafficVolume.Items.Add("Other")
614
615 ElseIf cmbLocation.SelectedItem = "Rural" And cmbRdClass.SelectedItem = "Freeway" Then
616 LaneWidth = 3.7
617
618 cmbDesignSpeed.Items.Clear()
619 cmbTrafficVolume.Items.Clear()
620
621 cmbDesignSpeed.Items.Add("100")
622 cmbDesignSpeed.Items.Add("110")
623 cmbDesignSpeed.Items.Add("120")
624 cmbDesignSpeed.Items.Add("130")
625 cmbTrafficVolume.Items.Add(">8000 AADT")
626 cmbTrafficVolume.Items.Add("Other")
627 End If
628
629 txtLaneWidthOut.Text = LaneWidth
630
631 End Sub
632 Private Sub txtAADT_TextChanged(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles txtAADT.TextChanged
633 AADT = txtAADT.Text
634 End Sub
635 Private Sub cmbTrafficVolume_SelectedIndexChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles cmbTrafficVolume.SelectedIndexChanged
636 If cmbTrafficVolume.SelectedItem = "Other" Then
637 lebAADT.Visible = True
638 txtAADT.Visible = True
639 Else
640 lebAADT.Visible = False
641 txtAADT.Visible = False
642 End If
643 End Sub
644 Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button1.Click
645 GroupBox2.Visible = True
646 End Sub
647 Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button2.Click
648
649 'RIGHT SHOULDER WIDTH
650 'Rural Roads TABLE (2.2.10.2)
651 If cmbLocation.SelectedItem = "Rural" Then
652 If cmbRdType.SelectedItem = "Undivided" AndAlso cmbRdClass.SelectedItem = "Local" Then

```

```

660 If txtProjLength.Text <= 50 Then
661 If ckbPedestrians.Checked = True Then
662 RightShoulderWidth = 0.5
663 ElseIf ckbPedestrians.Checked = False Then
664 RightShoulderWidth = 1.2
665 End If
666 ElseIf txtProjLength.Text > 50 Then
667 If ckbPedestrians.Checked = True AndAlso cmbDesignSpeed.SelectedItem <= 80 Then
668 RightShoulderWidth = 1.0
669 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem <= 70
Then
670 RightShoulderWidth = 1.0
671 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = (80
Or 90) Then
672 RightShoulderWidth = 1.2
673 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = 100
Then
674 RightShoulderWidth = 1.4
675 End If
676 End If
677 End If
678
679 If cmbRdType.SelectedItem = "Undivided" AndAlso cmbRdClass.SelectedItem = "Collector"
Then
680 If txtProjLength.Text <= 50 Then
681 If ckbPedestrians.Checked = True AndAlso cmbDesignSpeed.SelectedItem <= 60 Then
682 RightShoulderWidth = 1.0
683 ElseIf ckbPedestrians.Checked = True AndAlso cmbDesignSpeed.SelectedItem = (70
Or 80) Then
684 RightShoulderWidth = 1.2
685 ElseIf ckbPedestrians.Checked = True AndAlso cmbDesignSpeed.SelectedItem = (90
Or 100) Then
686 RightShoulderWidth = 1.5
687 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem <= 70
Then
688 RightShoulderWidth = 1.5
689 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = (80
Or 90) Then
690 RightShoulderWidth = 2.0
691 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = 100
Then
692 RightShoulderWidth = 2.5
693 End If
694 ElseIf txtProjLength.Text > 50 Then
695 If ckbPedestrians.Checked = True Then
696 RightShoulderWidth = 1.0
697 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem <= 70
Then
698 RightShoulderWidth = 1.2
699 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = (80)
Then
700 RightShoulderWidth = 1.0
701 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = 90
Then
702 RightShoulderWidth = 1.2
703 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = 100
C:\Users\Bashar\Desktop\Model Programming\Last ... \VB 1 Test\WindowsApplication1\FirstForm.vb 12
Then
704 RightShoulderWidth = 1.4
705 End If
706 End If
707 End If
708
709 If cmbRdType.SelectedItem = "Undivided" AndAlso cmbRdClass.SelectedItem = "Arterial"
Then

```

```

710 If txtProjLength.Text <= 50 Then
711 If ckbPedestrians.Checked = True AndAlso cmbDesignSpeed.SelectedItem <= 90 Then
712 RightShoulderWidth = 1.5
713 ElseIf ckbPedestrians.Checked = True AndAlso cmbDesignSpeed.SelectedItem = 100
Then
714 RightShoulderWidth = 2.0
715 ElseIf ckbPedestrians.Checked = True AndAlso cmbDesignSpeed.SelectedItem >= (130
Or 120 Or 110) Then
716 RightShoulderWidth = 2.5
717 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem <= 80
Then
718 RightShoulderWidth = 2.5
719 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = (90)
Then
720 RightShoulderWidth = 2.7
721 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem >=
(100 Or 110 Or 120 Or 130) Then
722 RightShoulderWidth = 3.0
723 End If
724 ElseIf txtProjLength.Text > 50 Then
725 If ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem <= 90 Then
726 RightShoulderWidth = 1.5
727 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = 100
Then
728 RightShoulderWidth = 1.6
729 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = 110
Then
730 RightShoulderWidth = 1.7
731 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = (120
Or 130) Then
732 RightShoulderWidth = 1.8
733 End If
734 End If
735 End If
736
737 If (cmbRdType.SelectedItem = "Divided" Or cmbNumWay.SelectedItem = "One Way") AndAlso
cmbRdClass.SelectedItem = "Collector" Then
738 If txtProjLength.Text <= 50 Then
739 LeftShoulderWidth = 1.2
740 If ckbPedestrians.Checked = True AndAlso cmbDesignSpeed.SelectedItem <= 80 Then
741 RightShoulderWidth = 1.2
742 ElseIf ckbPedestrians.Checked = True AndAlso cmbDesignSpeed.SelectedItem = (90
Or 100) Then
743 RightShoulderWidth = 1.5
744 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem <= 70
Then
745 RightShoulderWidth = 1.5
746 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = (80
Or 90) Then
747 RightShoulderWidth = 2.0
748 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = 100
Then
749 RightShoulderWidth = 2.5
750 End If
751 ElseIf txtProjLength.Text > 50 Then
752 LeftShoulderWidth = 1.0
753 If ckbPedestrians.Checked = True Then
754 RightShoulderWidth = 1.0
C:\Users\Bashar\Desktop\Model Programming\Last ... \VB 1 Test\WindowsApplication1\FirstForm.vb 13
755 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem <= 90
Then
756 RightShoulderWidth = 1.2
757 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = 100
Then
758 RightShoulderWidth = 1.4

```

```

759 End If
760 End If
761 End If
762
763 If (cmbRdType.SelectedItem = "Divided" Or cmbNumWay.SelectedItem = "One Way") AndAlso
cmbRdClass.SelectedItem = "Arterial" Then
764 If txtProjLength.Text <= 50 Then
765 If cmbDesignSpeed.SelectedItem <= 90 Then
766 LeftShoulderWidth = 1.5
767 Else
768 LeftShoulderWidth = 2.0
769 End If
770 If ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem <= 80 Then
771 RightShoulderWidth = 2.5
772 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = (90)
Then
773 RightShoulderWidth = 2.7
774 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem >=
(100 Or 110 Or 120 Or 130) Then
775 RightShoulderWidth = 3.0
776 End If
777 ElseIf txtProjLength.Text > 50 Then
778 LeftShoulderWidth = 1.0
779 If ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem <= 90 Then
780 RightShoulderWidth = 1.5
781 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = 100
Then
782 RightShoulderWidth = 1.6
783 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem = 110
Then
784 RightShoulderWidth = 1.7
785 ElseIf ckbPedestrians.Checked = False AndAlso cmbDesignSpeed.SelectedItem >= 120
Then
786 RightShoulderWidth = 1.8
787 End If
788 End If
789 End If
790
791 If cmbRdClass.SelectedItem = "Freeway" Then
792 If txtProjLength.Text <= 50 Then
793 LeftShoulderWidth = 2.5
794 RightShoulderWidth = 3.0
795 End If
796 If txtProjLength.Text > 50 Then
797 LeftShoulderWidth = 1.5
798 RightShoulderWidth = 2.0
799 End If
800 End If
801 End If ' END OF RURAL SHOULDER WIDTH

```

**Appendix G:
Ministry of Transportation
Parametric Estimating
Guide 2011**

Parametric Estimating Guide



Ministry of Transportation Ontario

Highway Construction Costs
Contract Management Office 198
Estimating Section

2011

2011 Parametric Estimating Guide:

Prepared by: Kai Statulevicius

Edited by: Paul Sosney
Kathy Wood

Technical Expertise Provided by:

MTO Contract Management Office Estimating Section

Arlene Alerta
Chris Garratt
John Lee
Ed Marcon
Jeff Mitchell
Chris Smith

2011

SECTION 4 – NEW STRUCTURES



NEW STRUCTURES – ALL TYPES & MATERIALS

- Costs are based on square metre of deck area. Deck is defined as area of finished deck surface with length measured between abutment joints and width measured from the outside extremities of deck (including any cantilevered sections).

Table 10 - New Structures (All Types & Materials)

Deck Area (m ²)	Avg. Cost Per m ²	Cost Range
1 – 249	\$4,860	N/A
250 – 499	\$4,280	N/A
500 – 749	\$2,640	N/A
750 – 2,999	\$2,420	N/A
3,000 – 3,999	\$2,300	N/A
4,000 – 4,999	\$1,760	N/A
5,000 – 7,499	\$1,240	N/A

- **Costs include:** structure excavation, dewatering, piling, footings, abutments, piers, formwork, falsework, access to structure, reinforcing steel, deck, beams, parapet wall, joints, waterproofing.
- **Costs do not include** paving, embedded or other electrical work, or traffic control.
- See Example 2 in Appendix V for the intended usage of these costs.

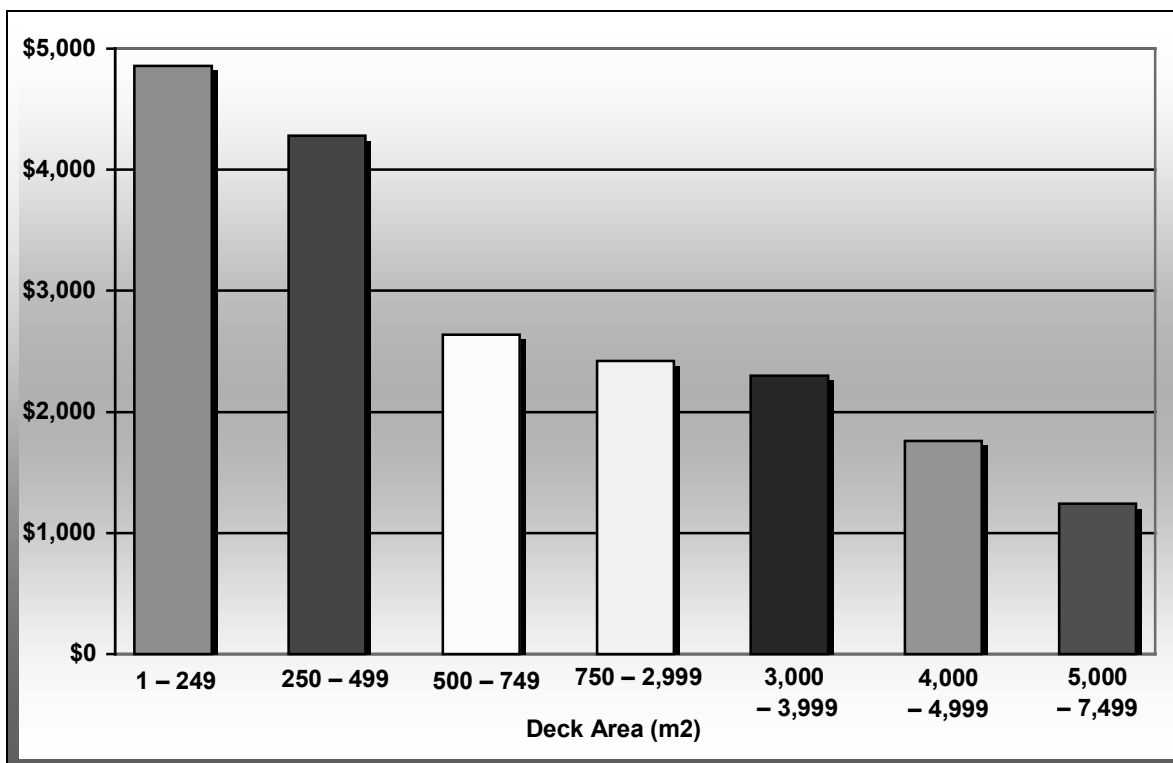


Figure 8 - New Structures (All Types & Materials)