RESILIENT INFRASTRUCTURE
June 1–4, 2016

OPTIMIZATION FOR BRIDGE TYPE SELECTION USING ARTIFICIAL NEURAL NETWORKS

Elie M. Otayek
Concordia University, Canada

Ahmad Jrade
University of Ottawa, Cananda

ABSTRACT

Many Researchers have attempted to establish a methodology for the selection of bridge type in a systematic manner. Knowledge based systems (KBS) and other Expert Systems (ES) have been used for this purpose but they have some limitations and restrictions. This paper proposes a methodology to implement a Decision Support System (DSS) in an artificial intelligent environment that aims to suggest a bridge type with its main components at the conceptual design phase, based on the characteristics and performance of existing and similar bridges in order to predict the performance of proposed ones that have been analyzed by decision makers with limited subjectivity. The proposed methodology is divided into three main divisions: 1) this division includes a database that will be structured to store appropriated information besides including models like Point Scale and Quality Function Deployment (QFD) systems that will serve for linguistic conversion to numbers needed for the DSS engine. This division contains as well all the mandatory criteria that have influence on the performance of proposed bridges. 2) this division is the core of the "DSS Engine" where it receives the information from the database that will be implemented in an Artificial Neural Network (ANN) module for training, testing and then predicting the performance of a new case bridge. Afterwards a decision will be made to implement the ANN's results into a Bridge Information Modeling (BrIM) environment to visualize the suggested design and to predict the potential problems. 3) In this division, a final decision will be made based on the results of the second division. In the proposed DSS, most of the factors are considered as criteria in the database; criteria that have influence on the decision are automatically considered during the analysis process and are introduced in the DSS Engine. The flexibility of the proposed methodology and particularly the database and the method of analysis will make the DSS very helpful in the area of bridge design and management. This will provide bridge engineers with an efficient tool that will minimize the subjectivity in their decisions. A case project will be considered to test the workability and capability of the proposed methodology.

Keywords: Knowledge Based Systems KBS, Bridge Information Modeling BrIM, Decision Support System DSS

1. INTRODUCTION

Lots of references mentioned that Bridge design is divided into two stages: conceptual & analytical design (Miles & Moore, 1991; Chen Wai-Fah & DuanLian, 2000; [Troitsky M.S., 2000]). The analytical design stage is very well defined where codes and formulas are widely applied, which is not the case for the conceptual design stage. Lots of studies conducted by engineering and consulting agencies have drawn different opinions that lead to diversity of final decisions (Smith & al, 1994). Based on many factors, designers (decision-makers) will choose the final perception to propose the type of bridge that should be adopted; the decision is based on their own experience and other factors that have remarkable influence on the decision taken. Generally, neither mathematical formulas nor deterministic or stochastic models are used during the decision making process; just engineering judgments and subjectivities are the core of the final decision. The lack of clarity and the need to be away from the subjectivity issues are the cause of this proposal, which main objective is to propose a methodology that could be a starting point for advanced development toward minimizing shortcomings that influence the decision on bridges during the conceptual design stage.

2. LITERATURE REVIEW

A literature review is conducted in order to highlight the components, characteristics and factors that influence major decisions related to the bridge types and their relevant components.

2.1 Bridge Elements and Components

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

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

However, in order to well define such bridge types, it is necessary to recognize the elements and components of every possible bridge. It is important to establish an inventory that will act as a "geometric" database to help decision makers in their selection process. Similar work has been conducted by Thompson and Shepared (2000) in which they proposed an inventory that will be the base for the inspection and maintenance tasks. In their report the bridge components were divided into four main groups: superstructure, substructure, decks and culverts. Those components are important to rate the bridge performance based on their performance and sustainability. Furthermore, the type of materials used in the bridge has its own and special influence. Smith and al., (1994) published the characteristics of some materials and their influence on bridges' components.

2.2 Influencing Factors and Constraints

Smith et al. (1994) listed many factors that can affect the decision on selecting bridge's materials. The analytical Hierarchy Process (AHP) has been used to rank the factors that have significant impact on the selection of bridge type. This ranking was based on data collected from over thirteen hundred (1,300) highways and bridges in USA. The collected data focused on non-structural factors that influence the bridge material decision. Out of twenty-three (23) factors, the following have been ranked as the most important ones: past performance, lifespan, maintenance requirement, resistance to natural deterioration, initial cost & life cycle cost. Choi (1993) has grouped the factors that affect the conceptual design of bridges into two sets of constraints: "Hard Constraints - HC" and "Soft Constraints - SC". This proposed methodology will consider only the Aesthetic and the Environmental factors, which influence the final decision of bridge selection.

2.3 Bridge Management System (BMS) and Bridge Information Modeling (BrIM)

The proposed methodology will be implemented within a Bridge Information Modeling environment and will be based on data retrieved from the Bridge Management System. Al-Hajj and Aouad (1999) considered that the design, construction and maintenance of bridges have to be addressed for any holistic productivity study, however the life-cycle cost of the elements should be considered early during the design phase. Abu Dabous (2008) referred to Pontis and Bridgit, which are two applications widely known and used in the USA, while there are other applications used by many agencies to manage the bridge behaviors and to predict its future performance in order to prevent any unexpected situations. Thompson and Shepard (2000) considered the CoRe (Commonly Recognized) elements for bridge inspection as the basic for data collection, performance measurement, resource allocation, and management decision support. They mentioned that prior to the CoRe elements, bridge managers used data that was based on the National Bridge Inspection Standards (NBIS), which helped them decide on how to address problems related to the limited information available about the four groups of a bridge (Superstructure, Substructure, Deck and Culverts). Nedev and Khan (2011) mentioned that most the engineers' decisions are based on past experience and standard solution, which is probably the ideal method. Those engineers claimed that the selection of the different bridge elements and associated materials is not followed in a structural format, and despite of their research and proposed methodology, they revealed some limitations like the number of alternative to be compared, span length, type of bridge, and others.. A study conducted by Dekker (2000) showed that engineers in Sweden stated that the biggest obstacle that causes problem is the lack of time. They provided different reasons for that but the final conclusion was that engineers need more time and money in order to create and to produce structures of high performance. As shown in Figure 1 it is obvious that if more time is spent during the conceptual design stage better and more appropriate solutions can be found. Niemeyer (2003) described his methodology in a graphical format where five main keys are identified: 1) need definition, 2) design requirements, 3) key parameter identification, 4) configuration and 5) evaluation. Engstrom (2002) stated that every structure has to meet a wide range of demands out of which six main areas were outlined for buildings in general, which might be also adopted for bridges. 3D modeling has been introduced by many application and tools where their use and benefits have been raised by introducing additional tools and levels of details. As 3D CAD software, Autodesk Revit has been the most known tool; Tekla structures offers a reasonable way of modeling the structural components of concrete bridges, while SolidWorks CAD has been used for terrain model around the bridge.

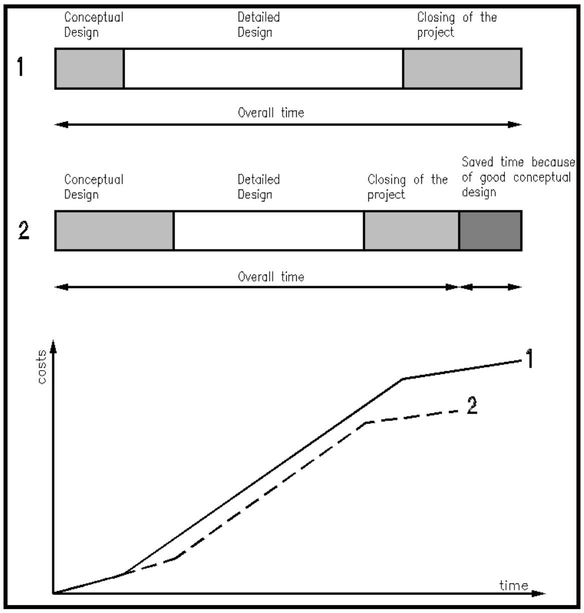

Figure 1: Effect of time spent on conceptual design *(Dekker, 2000)*

2.4 Existing Methods

Over the time, the construction industry used different methods based on artificial intelligence and human reasoning processes. In recent years, there has been an increased interest among researchers to explore the feasibility of applying artificial intelligence (AI) paradigms in order to improve the efficiency, safety, and environmental-compatibility of transportation systems (Sadek et al., 2003). AI has been used to solve difficult problems that couldn't be solved by using classical mathematical methods. Quality Function Deployment (QFD), Knowledge-based Systems (KBS), Case-based reasoning (CBR), Expert System (ES), Fuzzy Systems (FS), Artificial Neural Network (ANN), Genetic Algorithm (GA), and other Learning Machine systems (LM) are among the models that have been used while making decisions related to design in the transportation field. The Gradient Descent methods as well as the Regression Analysis methods are widely used to define some of the functions employed by these models. Otayek et al. (2012 and 2013) considered that researchers have mentioned and introduced these models by highlighting their ability, their functionality and effectiveness, which have been abridged.

3. PROPOSED METHODOLOGY

The proposed methodology is routed on incorporating the minimum necessary factors and restrictions that are needed into any model. Bridge parameters and characteristics are listed in a standard form in order to introduce the bridge identity by these values, which are stored into set of tables that contain the necessary information required to identify the bridge behavior and performance.

3.1 Models and Methods

Problems related to structural design are often unpleasant tasks that need a wide range of experience, good engineering judgment and high level of subjectivity. The Rule-Based Expert System (RBES) approach has the capability to incorporate some of the above-mentioned requirements while other similar approaches are needed to establish some platform for a right decision. Therefore, a Decision Support System (DSS) is proposed in this paper where all the required platform are considered while its development will be based on the following four steps: (a) establishing an accurate library of bridge types and their components, (b) structuring the necessary database that stores appropriate information collected from previous projects, (c) defining the model's engine that will treat the information and that will provide a convenient solution in the form of output, and (d) using the BrIM concept and tools to provide a 3D visualization of the generated outputs. The most important and expected difficult part of the proposed system is to define and convert some aspects, information and situations into numerical values, such as the soil behavior that an engineer has to evaluate and to consider during his final decision. The performance of a proposed bridge is predicted and evaluated depending on the rate that the following factors will get: Aesthetic, LCC, Environment and public satisfaction/capacity and services. This will be based on existing bridges that have the same conditions as the proposed one. The proposed methodology will generate three different outputs that should be analyzed in order to decide if the values are relevant and acceptable or not. These values are: Total Cost $/m^2 (TC); Environmental Impact Rate (EIR), which varies from 1 (Friendly to the environment) to 9 (Very aggressive to the environment); and the Aesthetic Impact Rate (AIR), which varies from 1 (considered as very well fitted into its surround) to 9 (Considered as damaging the surround aspect).

3.2 Decision Support System (DSS) Framework

The main components of the DSS include a database module that contains the bridge types with their components (related to their geometric parameters) and the bridges' parameters that influence their performances (such as the overpass area, soil behavior, bridge capacity, number of lanes, number of spans, total length, etc…), a DSS engine that includes the input and output parameters, and a BrIM module to visualize and then verify the accuracy and suitability of the selection made by decision makers based on the output values provided by the DSS Engine. Thus, the framework of DSS is shown in Figure 2.

3.3 DATABASE: Components and Included Information

A database is a collection of information that is organized so that it can be easily accessed, managed, and updated. In computing, databases are classified according to their organizational approach. The most prevalent approach is the relational database, a tabular database in which data is defined so that it can be reorganized and accessed in a number of different ways. Thus, the type of information with their characteristics and relationships that will be stored in the database should be well defined. Therefore, Figure 3 describes the information that should be included in a well-structured database that will provide the proper values for the DSS engine. Furthermore, as shown in Figure 3, all criteria are grouped under 5 categories: (1) Administrative Info, (2) Geometric and Structure Info, (3) Restricted Variables, (4) Unrestricted Variables, and (5) Soft Factors.

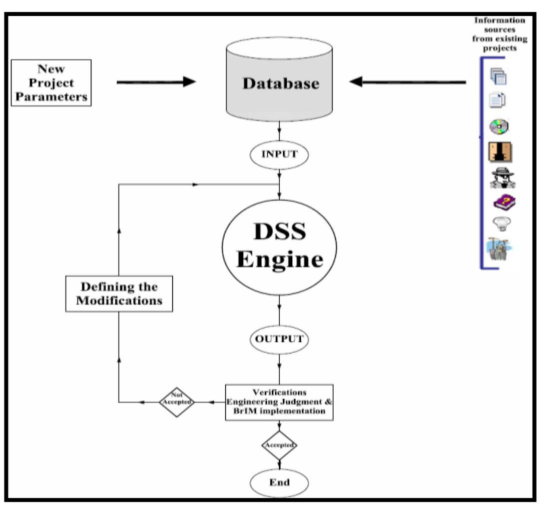

Figure 2: DSS Framework

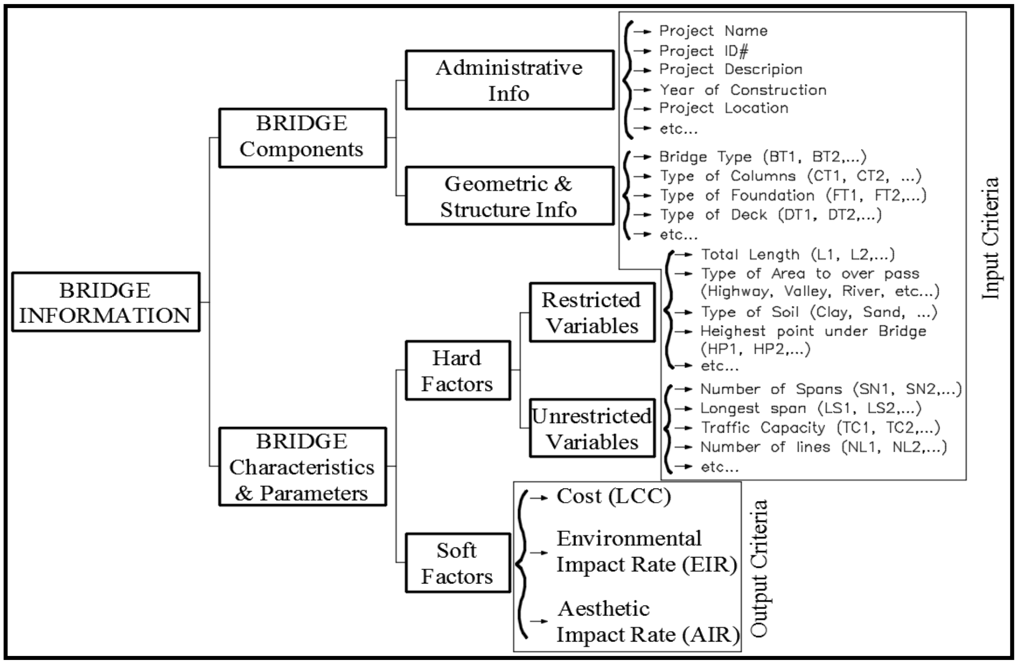

Figure 3: Bridge Information Criteria

The linguistic factors will be converted into numerical values by using two methods: the Point Scale method and the Quality Function Deployment (QFD) method. For instance, for the four linguistic bridge types, a 4-points scale is assigned as shown in Figure 4. According to this scale, a value of “1” is assigned to the Girder bridges, a value of “2” to the Arch bridges, a value of “3” to the Suspension bridges, and a value of “4” to the Cable-Stayed bridges. A library of photos is established in order to clarify the point scale assigned to a specific bridge.

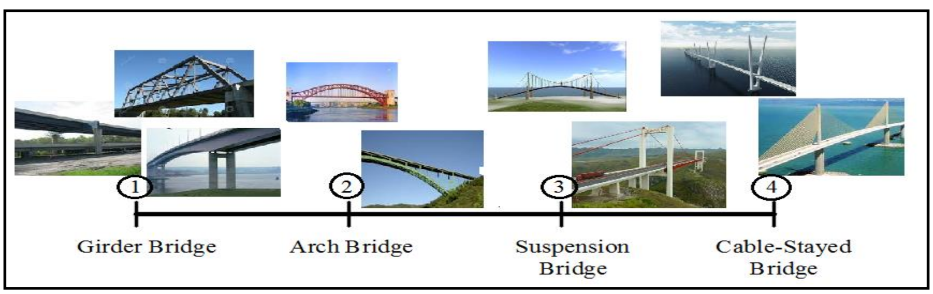

Figure 4: A 4-point scale for bridge types

3.4 DSS Engine

The main component of the DSS engine is the Artificial Neural Network (ANN) frame, as illustrated in Figure 5, which will retrieve the input data from the database structure and will provide a new data about the proposed Bridge type that will be constructed. The correlation between the number of existing cases to be used and the number of hidden layers, neurons and the activation function are studied, evaluated and defined in order to accurately structure the proposed ANN.

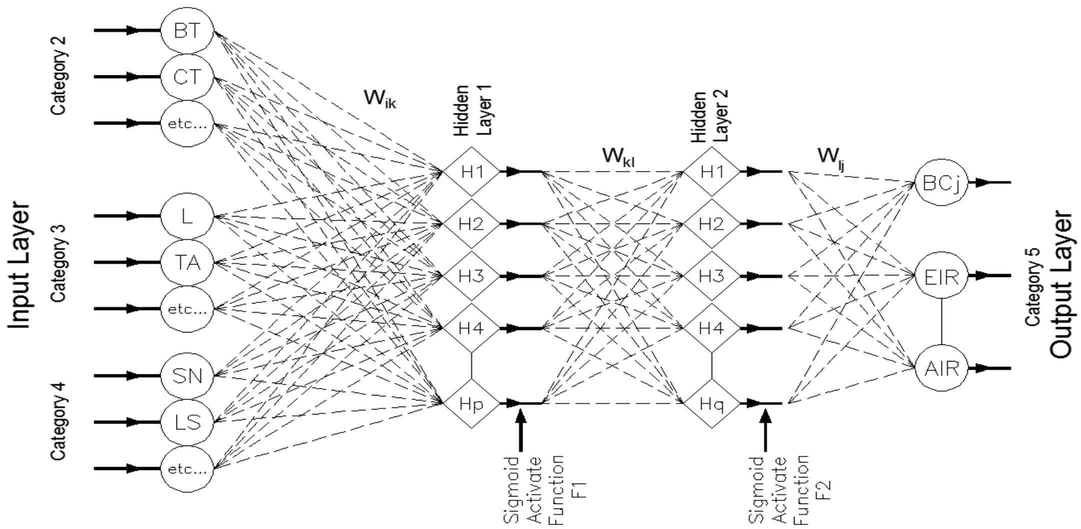

Figure 5: ANN Framework

3.5 Bridge Information management (BrIM) Tools

Lots of tools are used to apply the BrIM concept. Some of them focus on the geometric part, which covers the architecture elements, while others focus on the structural parts, which look at the structural elements and their capacity to resist the acting loads, however they are all used by the construction industry in order to control and mitigate the engineer's tasks. In this proposed methodology, these tools will receive the results from the DSS engine and will transform them into a real word environment. Decision makers (engineers) will verify all the bridge aspects that have already been extracted from the input and output data of the DSS engine, then they will verify and visualize the project's design via a 3D model; afterwards a decision will be taken concerning the extracted results, which will either be acceptable, or be rejected or modified and in those two cases launching another iteration will be required. For this purpose, different types of software will be used (i.e. Tekla structure/ Bridge CSI for the structure analysis, and Autodesk Civil 3D-CAD and Design and Revit) for verifications and visualizations in a 3D environment.

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

As described earlier, the DSS is based on many criteria (category 2, 3 and 4) that affect the results (criteria from category 5). In order to verify the influence of each input criteria on the results, a Sensitivity Analysis (SA) will be performed to understand the relationships between the input and output criteria. Also, the importance of the SA is that it will provide a general idea about the uncertainty in the DSS output that can be apportioned to different sources of uncertainty in its inputs, and accordingly it will identify the DSS inputs that cause significant uncertainty in the output in order to reduce its level.
On the other hand, the level of realistic (LR) will be evaluated for every output value provided by the DSS engine. This aims at quantifying how much the results are realistic. This procedure will be based on a comparative process between the ratio of the estimated over the actual values of a specified criteria (from category 5) of an existing case with the ratio of the estimated value over the value given by the DSS engine for that specific criteria. By this comparison, designers will have a tool to judge how much the output values have a sense.

4. CASE PROJECT

To validate the proposed methodology a real case project is used to test its workability and dependency. In the actual case project, data from 15 existing bridges located in different regions of Lebanon will be considered into the validation.

4.1 Database frame works and contents

The collected information related to the selected existing bridges is stored into tables 1 through 3 based on the appropriate factors for every criteria. Table 1 stores the parameters and factors to be considered based on the information related to the considered bridges. Table 2 contains the values to be considered for the factors that need Linguistic/Numerical conversion based on a Point-Scale of 1 to 9. Table 3 covers the values of the assigned parameters, which are arranged and evaluated especially those that need a linguistic/Numerical Conversion. The last column of Table 4 (Categories 1 through 4) covers the values related to the new bridge that will be entered into the DSS engine and then the output values of the criteria of category 5 is retrieved for analysis and accordingly a decision could be made to be implemented into the BrIM tools. The parameters Di, BTi and Li are defined and stored within separate tables by providing additional information concerning the project description, bridge name and its location respectively. These parameters (category 1) are considered to evaluate (if necessary) some values of the factors that are included into categories 2, 3, 4 and 5. For instance, the year of construction and location are considered to influence the Total Cost that needs to be adjusted.

4.2 Running the DSS Engine

Based on the data shown in tables 1, 2, and 3, the Neural network paradigm will run; based on the input data shown in Table 4 for categories 1, 2, 3 and 4, an output has been provided and shown in the last three rows of Table 4 (category 5). As mentioned in the methodology section, the factors are divided into 4 categories as input and one category as output as given by the ANN tool. Many possible values of the factors (categories2, 3 and 4) are proposed in order to discover how these values affect the result. The values represented in Table 4 represent the selected case by the decision-maker.

Table 1: Categories and Factors

Category 1	Category 2	Category 3	Category 4	Category 5
Project Name	Bridge Type	Total Length	Number of Span	Total Cost
Project Description	Column Type	Total Area	Longest Span	Environmental Impact Rate EIR
Year of Construction	Deck Type	Type of Area to Over Pass	Trafic Capacity	Aesthetic Impact Rate AIR
Project Location	Structure Type	Heighest Point under Bridge	Number of Lines	
	Foundation Type			

Table 2: Point-Scale assigned to Factors

Bridge Type	
Girder Bridge	1
Arch Bridge	2

Upperstructure Type (Material)	
Wood	1
Wood/Steel	3
Steel	5
Steel/Concrete	7
Concrete	9

Upperstructure Type (Structural Elements)	
W/O Main Girders	1
Just Girders	5
Girders and Secondary Beams	9

Vertical Element Type	
Individual Concrete Columns	1
Individual Steel Columns	2
Individual Steel/Concrete Columns	3
Multi Concrete Columns	5
Multi Steel Columns	6
Multi Steel/Concrete Columns	7
Concrete Wall	9

Foundation Type	
Shallow	1
Deep	9

Type of Over Pass	
Highway	1
Vale	5
Water Stream	9

4.3 Results and Analysis

The new case that has been studied is a bridge to overpass a highway with a length of 40 meters. The restricted factors are as follow: the Total Length is 40m and the Needed Traffic Capacity (semi-restricted) is 5,000 vehicles/day (possibility to be modified within a ±20 % interval). Other restrictions are defined by the different possible locations of the vertical elements due to the existing highway that needs to be overpassed and the soil type that will not be necessary to be considered as a deep foundation type. For the other factors, a sensitivit analysis has been conducted where the following ranges of results are received:

Bridge Type (1 or 2): Total Cost [1,229 – 2,259]; EIR [2.9 - 7.8]; AIR [4.6 - 8.6]

Vertical Element Type [1 - 9]: Total Cost [1,000 – 2,459]; EIR [3.1 - 10.9]; AIR [5.2 - 7.9]

After selecting the appropriate values for the factors and with the related output results, BrIM tools (e.i. Autodesk Civil 3D and CSI Bridge) have been used to create a 3D model of the new bridge where a visual inspection is made to preliminary verify the structure stability of the bridge. On the other side, a level of realistic has been verified by comparing the actual cost given by the DSS with the estimated cost provided by the BrIM tools used for this purpose. The ratio of the given actual total cost over the estimated cost is: 1.62, this value falls within the range of 0.9 and 2.1, which represents the same ratio of the existing project cases used in the model.

Table 3: Database Summary

	Parameteres/Factors List	Bridge 1	Bridge 2	Bridge 3	Bridge 4	Bridge 5	Bridge 6	Bridge 7	Bridge 8	Bridge 9	Bridge 10	Bridge 11	Bridge 12	Bridge 13	Bridge 14	Bridge 15
Category 1	Project Name	BT1	BT2	BT3	BT4	BT5	BT6	BT7	BT8	BT9	BT10	BT11	BT12	BT13	BT14	BT15
	Project Description	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
	Year of Construction	1958	1962	2000	1978	1995	1996	1970	1970	1980	1972	1960	1960	1999	1960	1965
	Project Location	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Category 2	Bridge Type	1	1	2	1	1	1	1	2	1	1	1	1	2	1	1
	Vertical Element Type	5	6	9	2	2	3	7	5	9	1	1	2	5	2	1
	Uperstructure Type (Material)	9	5	7	7	5	7	9	9	7	5	7	9	5	7	9
	Upperstructure Type (Structural Elements)	5	1	1	5	5	9	9	5	5	5	1	1	5	1	1
	Foundation Type	1	1	1	1	1	2	2	2	1	1	1	1	1	1	2
Category 3	Total Length - (m.)	14	20	100	16	16	20	20	80	50	40	20	30	70	20	30
	Total Area - (Sq.m.)	140	300	1,400	120	125	300	270	1,500	350	300	320	430	1,000	150	350
	Type of Area to Over Pass	1	1	1	5	5	9	9	9	5	5	1	1	5	1	9
	Heighest Point under Bridge - (m.)	5	6	6	20	15	20	15	16	10	15	6	6	20	5	15
Category 4	Number of Span	2	2	2	2	2	1	1	1	2	4	2	3	1	2	3
	Longest Span - (m.)	7	10	50	8	8	20	20	80	25	20	10	10	70	10	20
	Trafic Capacity - (V/d)	8,000	15,000	12,000	5,000	4,000	12,000	10,000	20,000	4,500	3,500	14,500	13,500	9,500	3,000	2,500
	Number of Lines	2	4	4	2	2	4	4	6	2	2	4	4	4	2	2
Category 5	Actual Total Cost - ($/m^2)	1,500	1,300	1,850	1,100	1,200	1,000	1,500	2,100	1,000	1,250	1,150	1,600	2,000	1,500	1,200
	Environmental Impact Rate EIR	5	4	5	6	9	4	5	5	6	4	3	7	8	3	3
	Aesthetic Impact Rate AIR	5	3	7	6	5	5	3	4	6	5	7	7	5	6	2

V/d : Vehicules per day; BT: Bridge Type; D: Project Description; L: Project Location; N: New

Table 4: Results

	Parameteres/Factors List	New Bridge
Category 1	Project Name	NBT
	Project Description	ND
	Year of Construction	2017
	Project Location	NL
Category 2	Bridge Type	1
	Vertical Element Type	5
	Uperstructure Type (Material)	9
	Upperstructure Type (Structural Elements)	9
	Foundation Type	1
Category 3	Total Length - (m.)	40
	Total Area - (Sq.m.)	350
	Type of Area to Over Pass	9
	Heighest Point under Bridge - (m.)	7
Category 4	Number of Span	3
	Longest Span - (m.)	20
	Trafic Capacity - (V/d)	2,500
	Number of Lines	2
Category 5	Actual Total Cost - ($/m^2)	1,356
	Environmental Impact Rate EIR	4.52
	Aesthetic Impact Rate AIR	5.38

5. SUMMARY AND CONCLUSION

Based on a number of the existing projects, the implementation of the proposed DSS led to predict the performance (Total Cost, EIR, AIR) of the construction parameters and characteristics of a future bridge. The case project used in this paper is to show the functionality, flow of data and capacity of the proposed methodology. Additional parameters and factors must be added for the different categories and additional methods could be used to convert the linguistic information to numerical values accurately and efficiently, also the range of the sensitivity analysis could be widened by considering the correlation that could exist between the different factors, which makes the results more realistic and accurate. This is an ongoing research where its future works will be based on enhancing the methodology by introducing additional methods and models for risk analysis. Furthermore, additional investigation on the ANN application under its different paradigms and structures will be done in an attempt to get dependable and accurate results.

REFERENCES

Abu Dabous Saleh, August 2008 “A Decision Support Methodology for Rehabilitation management of Concrete Bridges”, Presented in Partial Fulfillment of the requirements for the degree of Doctor of Philosophy, Building Civil and Environmental Engineering, Concordia University, Montreal. (Thesis)

Al-Hajj A. and Aoud G., 1999, “The development of an integrated life cycle costing. Model using object oriented and vr technologies. An integrated life cycle costing model”; Institute for Research in Construction, Ottawa ON, K1A 0R6, Canada, p.p. 2901-2908

Chen Wai-Fah and DuanLian, 2000, “Bridge Engineering HandBook”; Library of CongressCataloging-in-publication Data, by CRC press LLC, ISBN: 0-8493-7434-0.

Choi C. K. and Choi I. H., 1993, “An Expert System for Selecting Types of Bridges”; Computers & Structures **Vol. 48**, No.2, p.p. 183-192.

Dekker K., 2000, “Conceptual Design of Concrete Structures”; Master’s Thesis, Department of Structural Engineering, Chalmers University of Technology, Publication no. 00:4, Geoteborg, Sweden.

Engstrom Bjorn, 2002 “SS-intuitive phase_10.pdf”; Structural systems course, Chalmers University of Technology.

Miles J.C., Moore C.J., 1991, “An Expert System for the Conceptual Design of Bridges”; Computer & Structures, **Vol. 40**, No1, p.p. 101-105.

Nedev Georgi and Khan Umair, 2011, “Guidelines for conceptual design of short-span bridges”; Master’s Thesis Seminar, Charlmers University of Technology.

Niemeyer S., 2003 “Conceptual Design in building industry”; Master’s Thesis, Department of Structural Engineering, Chalmers University of Technology, Publication no. 03:6, Geoteborg, Sweden.

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

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

Smith Robert, Bush Robert J. and Schmoldt Daniel L., 1994, “A Hierarchical Model and Analysis of Factors Affecting the Adoption of Timber as a Bridge Material”; Wood and Fiber Science, **Vol. 23**, Issue 3, p.p. 225-238.

Sadek, A. W., G. Spring, and B. L. Smith, 2003, “Toward More Effective Transportation Applications of Computational Intelligence Paradigms”. In Transportation Research Record: Journal of the Transportation

Research Board, No. 1836, Transportation Research Board of the National Academies, Washington, D.C. pp. 57–63.

Tang Man-Chung, 2007, “Evolution of Bridge Technology”; IABSE Symposium, Weimar 2007

Thompson Paul D. and Shepard Richard W., 2000, “AASHTO Commonly-Recognized Bridge Elements”; National Workshop on commonly recognized measures for maintenance.

Troitsky M. S., 2000, “Bridge Engineering Handbook – *Ch1-Conceptual Bridge Design*”; CRC Press LLC