INTEGRATED DECISION SUPPORT SYSTEM FOR BRIDGES AT CONCEPTUAL DESIGN STAGE

Elie Otayek, Ph.D. Student, oee5@hotmail.com
Ahmad Jrade, Assistant Professor, ajrade@uottawa.ca
Department of Civil Engineering, University of Ottawa, Ottawa, ON, Canada
Sabah Alkass, Professor, alkass@bcee.concordia.ca
Department of Building, Civil & Environmental Engineering, Concordia University, Montreal, QC, Canada

ABSTRACT

Subjectivity is the main factor that affects the selection process of a bridge type at the conceptual design stage. Selecting the bridge type is generally influenced by many parameters. In most cases, these parameters are evaluated and assessed by engineers based on their own experience, knowledge and judgment.

Therefore, in an attempt to provide some consistency and objectivity to the selection process, this paper proposes a methodology to develop a model that incorporates systematical procedures that can be used to avoid and limit the decision maker's subjectivity.

This methodology considers "machine technique", which is a branch of Artificial Intelligence (AI), as the core for the guideline engine of the proposed model, besides using Artificial Neural Network (ANN) modeling with its back-propagation algorithm to identify and select the utmost solution.

Comprehensive evaluation of bridge characteristics and parameters that influence the final decision is implemented and considered in the proposed model. The model is applicable for both general and specific cases of bridge design. Its simplicity, user friendly and comprehension would help designers minimize the influence of human subjectivity while taking major decisions; automatically rank all possible alternatives and consider all factors that impact the decision process. The process is automatic and will require minimal user intervention.

Keywords: ANN, bridges, conceptual design, Decision Support System (DSS), machine technique

1. INTRODUCTION

During the decision making process, many parties are invited, directly or indirectly, to share their experiences, knowledge and opinions in order to select a suitable type of bridge. It's commonly known that the main factor affecting the selection process is the design engineer preference, favoritism or inclination towards a specific type of design. To eliminate or reduce the human subjectivity in such situation, many researches, methodologies and procedures have been partially elaborated and all aimed to minimize any negative impact. This paper proposes a methodology to develop a model that depends on systematical procedures based on machine technique that can be used to avoid and limit the decision maker's subjectivity. The DSS will be based on a historical database from previous projects in order to provide the appropriate results.

2. BRIDGES HISTORY

2.1 Types and Bridge Components

Bridge revolution has been stated and exposed by many researchers; *Tang (2007)* has made his assumption which led to divide the bridges evolution into two major periods within the last four thousand years: Arch Era and Contemporary Era. These two eras incubate all type of bridges starting by the very primitive arch bridge formed by the natural stone for pedestrian, passing by the ordinary bridges with a medium span length, up to the more recent bridges 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; however, there has not been complete consent with Tang's classification. For example, sources like Wikipedia, classify the bridges within seven types: Beam Bridges, Cantilever Bridges, Arch Bridges, Suspension Bridges, Cable-Stayed Bridges, Movable Bridges and Double-Decked Bridges.

As for bridge components, Thompson and Shepared (2000) have prepared CoRe elements to serve in bridge inspection and performance evaluation and they have proposed to develop a formal dictionary to well define the appropriated elements related to a bridge project. They have classified the bridge components into four main groups: Superstructure, Substructure, decks and Culverts. Referring to FHWA 1991, table 1 summarizes bridge elements within 13 items under Deck entitle, 16 elements as superstructure and 20 elements for the substructure.

Table 1: Bridge Element. *(FHWA 1991)*

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

2.2 Decision Factors and Constraints

Decision's maker is faced by many factors and constraints during the assessment process. Other than standard factors as required by bridge capacity and field's geometric constraints, there are a lot of other factors that have a valuable and prized influence. *Meyer et al. (2001)* in an attempt to identify the main criteria taken into consideration into the process for bridge type’s selection and based on investigations

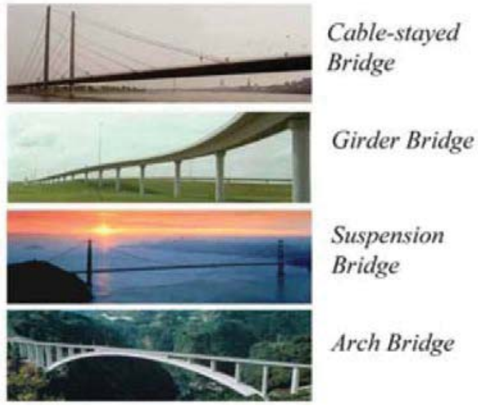


Figure 1: Four Types of Bridges - *(Tang 2007)*

conducted with different communities came out with the following findings; the mentioned criteria for decision were: public preference, local labor and materials, theme - showcase region, appearance, total cost factors, compatibility with the approach materials, maintenance of traffic and construction disruption. While *Smith et al. (1995)* has stated many factors based on a statistical process giving each of them a weighted value according to their importance to the final decision. These factors are discussed and shortened by *Smith et al. (1995)* to the following six most important ones, from an engineering perspective: past performance, lifespan, maintenance requirement, resistance to natural deterioration, initial cost and lifecycle cost. Some papers and researches have divided the factors into two types: controlled factors and un-controlled factors. The controlled factors include: Benefit/cost factor, aesthetics, environment effects, safety, etc… those factors are classified as controlled due to the possibility to be defined by decision makers who accordingly modify the design decisions to meet the required values. Differing from the controlled factors, uncontrolled factors such as site constraints, required traffic capacity, constructability complexity, etc… are fixed and the designer has no influence to modify any of them as these are typically related to the project characteristics (geometric and others).

2.3 Methods and Models

Many attempts have been conducted to model the selection of bridge's components at conceptual design phase and during renovation and replacing the existing deteriorated elements. Some of their advantages , disadvantages and limitation compared to other models make those models restrained by some limitations. (the successful is subjected by some disadvantages, as limitation of span and type of highway bridges et...)

Srinivas & Ramanjaneyulu (2007) have developed an integrated approach by using Artificial Neural Network (ANN) with Genetic Algorithm (GA) in order to optimize the replacement cost for a deteriorated concrete deck; "GA is a powerful tool in getting the optimum design solution for a given type of bridge deck, analysis of the deck superstructure needs to be carried out for evaluation of the constraints and fitness function at each stage of <u>generation of population</u> in the GA". *Srinivas & Ramanjaneyulu* have identified many parameters and components to be considered by the optimization process. Span length, carriage-way width, total depth and others are considered as input parameters and have influence on the final decision. As such, the output parameters were the stresses generated into the structural deck elements which were applied and introduced into the ANN. *Dogan et al. (2006)* has conducted a comparative study between three optimization techniques, namely feature counting, gradient descent, and genetic algorithms in generating attributes weights and based on 29 previous cases. Some limitation was mentioned due to the restricted number of cases. *Yao et al. (2011)* have used the Case-Based Reasoning model (CBR) which is a highly effective technique for problem solving and learning in the AI domain by storing and retrieving results of previous cases; Yang's paper mentions that if the appropriate features are not defined properly, the retrieved cases may lead to wrong solution. This is considered as a major issue in such an application to represent a construction project features; the authors referred to the drawback of CBR by the blindly using retrieved cases which need introducing some other techniques as mentioned by *Yao et al. (2011)*. Numerous attributes have been considered and evaluated by M*alekly et al. (2010)* to select a suitable superstructure of a small to medium-span Highway Bridge; they have faced the problems of subjectivity and ambiguous data. A novel integrated optimization-based methodology (Malekly et al., 2010) is proposed by employing Quality Function Deployment (QFD) technique to translate the project requirements into design requirements and Technique for Order Performance by similarity to Ideal Solution (TOPSIS) to select the best solution as an alternative. The proposal is divided into two phases as shown by Figure 2. Introducing fuzzy sets into an ANN technique aims to express the ambiguity and the uncertainty in order to recover or minimize the subjectivity (*Yao et al., 2011)*. Even with this multi-techniques integration (Malekly et al., 2010; Yao et al., 2011), there are still many problems that need to be addressed and resolved.

Many other models are available to mitigate the negative influences of the human subjectivity and to make the decision more standardized and computerized based on the historical information and database from previous cases.

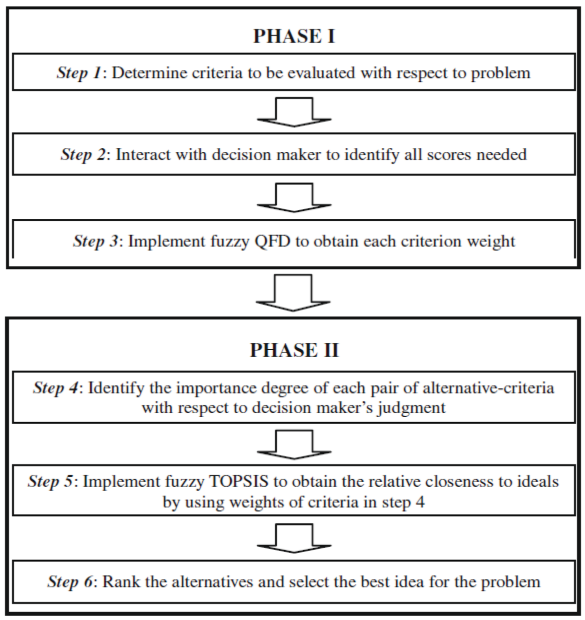
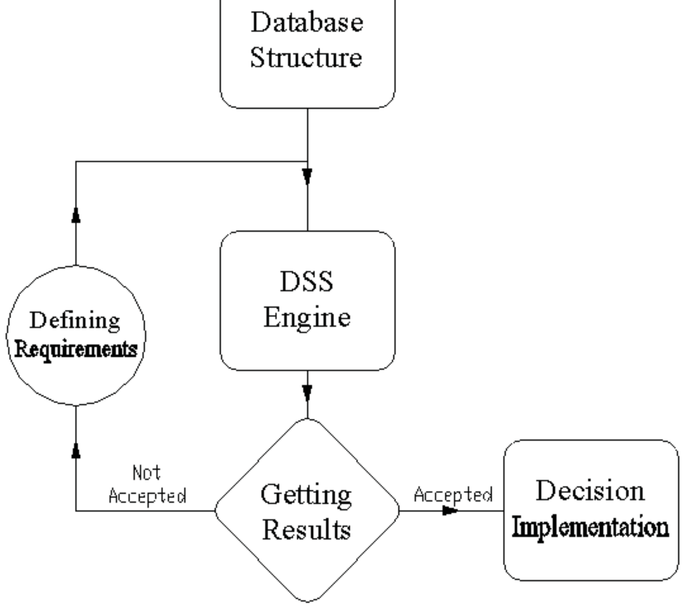


Figure 2: Methodology proposed by *(Malekely et al. 2010)*

3. PROPOSED METHODOLOGY

A rudimentary DSS will be proposed in the following sections. General DSS frame will be shown since the Database portion will be the most important section. The AI technique is integrated into the DSS engine through a back-propagation algorithm in ANN model. The results will be briefly interpreted and general overview and parameter explanation will be provided.

Since the subjectivity has been a main item midst those affecting the final decision, a research has been conducted to clarify and reduce the subjectivity since it cannot be completely eliminated. The methodology to be followed might be covered by some concentrated and limited human subjectivity and its influence might be mitigated by some type of sensitivity analysis.



3.1 DSS Framewo

The framework of the re 3. It begins by defining the resources a cting the previous cases with their perforı ɔ the Database. A well-defined database s to be compatible with the engine featur be evaluated and interpreted to meet the faction level. Any modification to the requ the calculation in order to provide the upc

3.2 Resources and

Many factors affect th ncontrolled group factors. Uncontrolled group cover the existing factors and there is no control to the decision makers to modify them like the land characteristics, span length, type of the over passed field, etc…; while the controlled factors are the benefit over cost value, environmental protection rate, aesthetic satisfaction, etc… The decision maker has to define those factors according to the previous cases of existing bridges and regional features to make the available data valuable for the DSS and reflect the final decision accuracy. Once the data has been collected, the factors affecting the decision have to be identified and short-listed. The next step would be to draw a preliminary chart for every factor showing the relation between the factor values and the existing bridge types. As shown in figure 4, the factor "F1" falling into the value interval "VF1i" for the previous case "PC1", its bridge type is "BT1", and so on for "PCi" previous cases have been presented. After collecting and presenting the factor/bridge type "BTj" relation, a normalized function will be shaped and presented for each factor to make it usable into the DSS engine as shown in figure 5.The Database graphical presentations will be used to retrieve the value for the DSS engine in use.

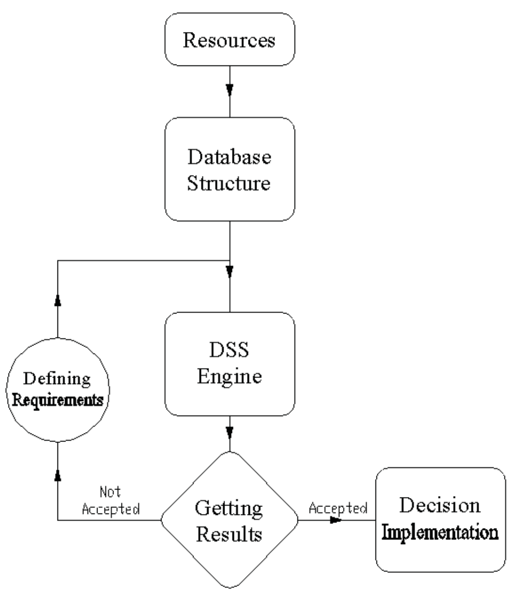
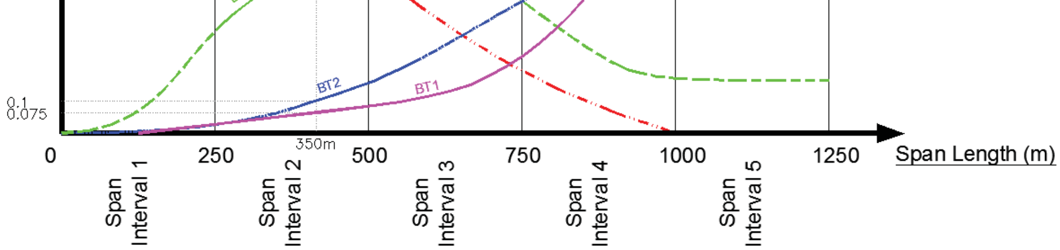


Figure 3: DSS Main Components



3.

Once all factor functions are established, AI technique is used to implement the database of the previous cases. ANN with its back-propagation algorithm is used as learning machine technique to evaluate and calculate the weights of the model. After that, the factor values of the new case have to be extracted from the function-graphs (figure 5) already established based on the previous cases. Running the DSS engine under these values, a result will be generated, and according to these results, the bridge types are ranked through one of the hidden layers. If the new case results don't match the decision-maker opinion, more advanced process is conducted by launching a back-propagation to reach the required output values. The bridge type alternatives have been ranked according to the input values related to the "uncontrolled factors" of the project and the desired value for the "controlled factors" as output results. Looking at this in more details, the ANN Engine is formed by:

- Input layer.
- 2 hidden layers.
- Output layer.

The input layer is formed by the input neurons; their assigned values are considered as "important level" compared to the input neuron values. The first hidden layer, that will be considered as "semi-hidden" layer includes the bridge type ranking values, and this layer will be blocked during the learning process and it will be released during the back-propagation process once the parameters of the new case understudy is introduced with some of the desired output values. The second hidden layer is implemented for engine requirement purposes. The output layer consists of neuron values desired and fixed by the designer according to some required levels of satisfaction. To clarify the purpose and features of the engine, in reference to figure 6, the following is an explanation that serves to understand the process:

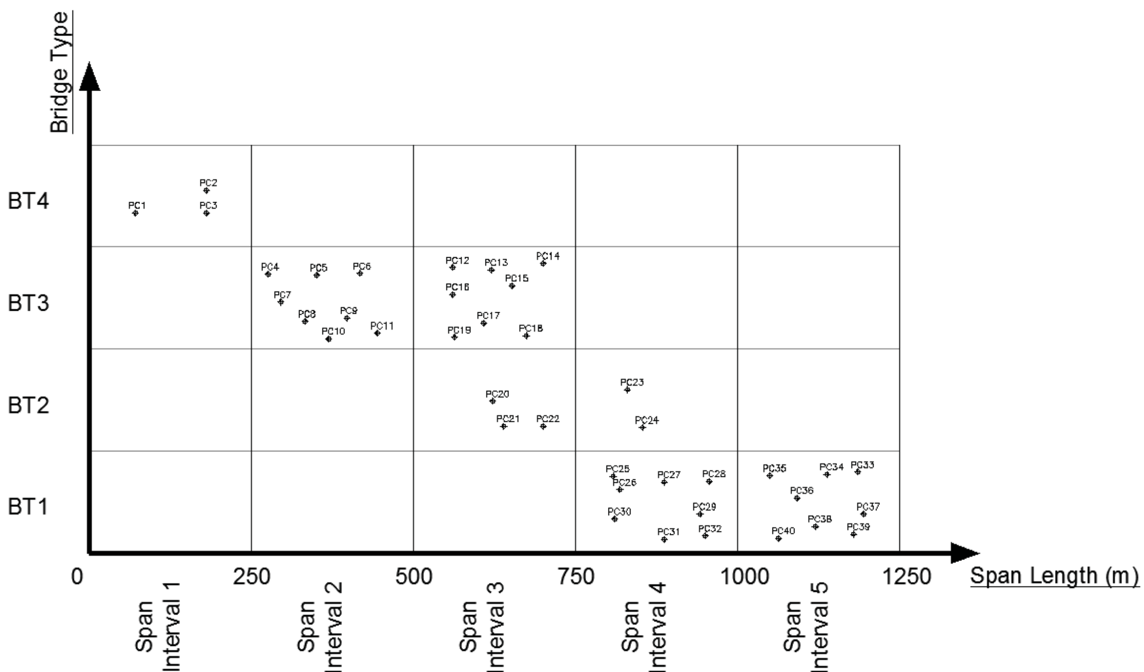


Figure 4: Bridge type BTi / F1 factor values “VF1i”

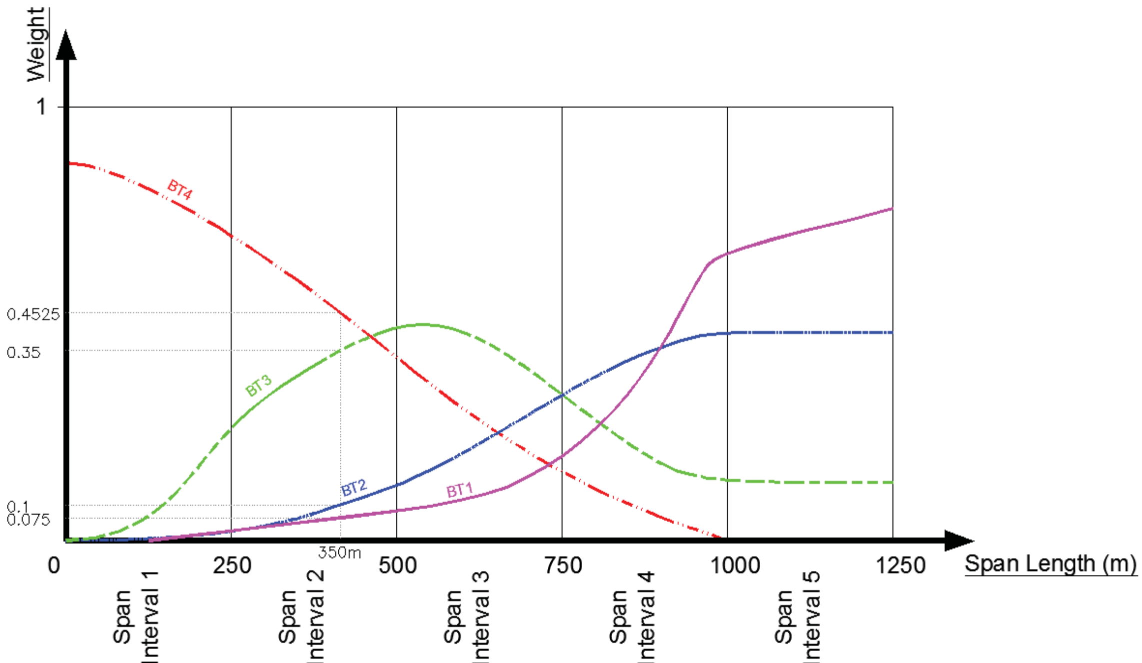


Figure 5: Normalized Function-graphs for Factor

- The Input neuron values are considered as how much the assigned factor is more important than the other factors. Usually all input values are equal unless the designer feels that some factors should be more important than others and accordingly have more influence on the output.
- The weights related to the input neurons of the first hidden layer "Wik" are extracted from the database graphs previously established based on the previous cases. At learning stage, those weights are blocked; once a new case is launched, they will be released.
- The first hidden layer, which is reserved to bridge type alternatives, is blocked as well at the learning stage; it is the most important part of the engine wherein we settle for the best decision according to ranking values.
- The weights Wkl and Wlj are random values without any scientific means.
- The output neuron values give us the satisfaction level that could be selected based on the bridge types hidden layer. As mentioned, these values could be adjusted by the designer and a back-propagation might be launched to recalculate the alternative ranking values.

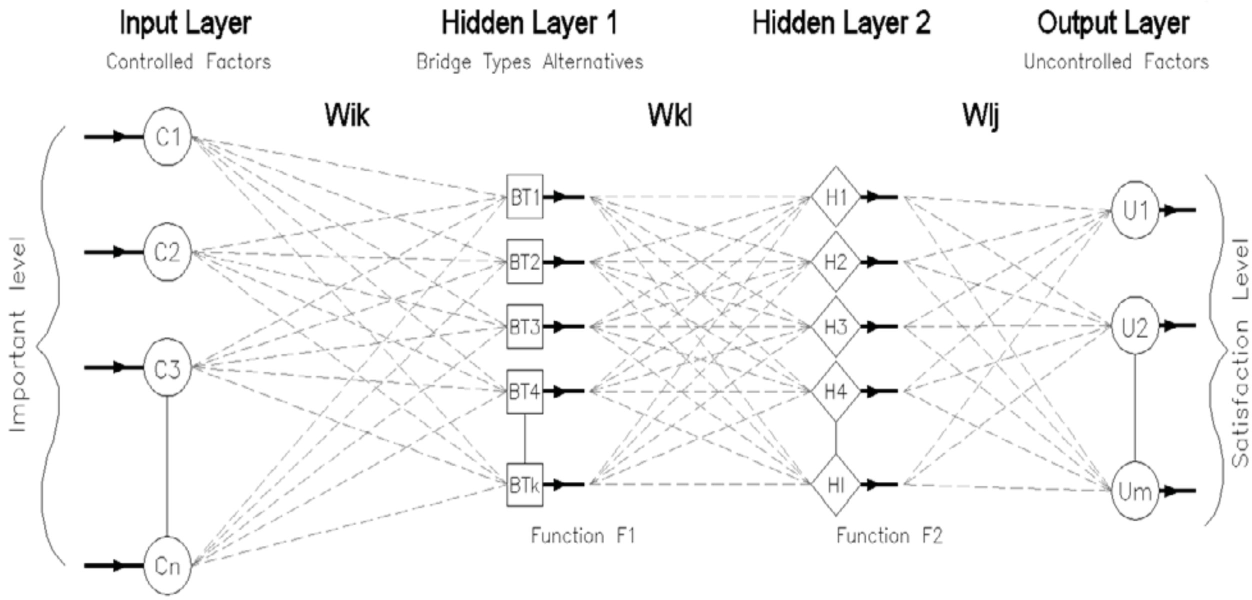


Figure 6: DSS Engine

3.4 Input, Output and Results' Interpretation

To summarize the scientific notions for the values covered by the DSS engine, four main parts are necessary to be identified:

a. the input values assigned to the Input neurons are related to the uncontrolled factors and related to the project characteristics. Site behavior, span length, bridge clear height, facilities to be over-passed by the bridges, constructability, existing road network, etc… are the factors that will affect the selection of the bridge type. The values assigned to these input neurons, generally, have to be equal, therefore if the decision maker has some other perception and has some preference over the other, in this case he/she has to identify the preference level and give some means to this decision. Normalization has to be conducted through the all steps and all values.

b. The weight's values Wik are extracted from the database graphs. These are the main values that represent the existing bridge characteristics. Those values have to be blocked while learning process is being launched. For the new case, and after unblocking these values, they will represent the new bridge characteristics and how much they will deviate if the results have to be adjusted.

c. Bridge type's values give us the ranking between alternatives. The ranking levels for a new project could vary according to the level of satisfaction required by the designer for the output factors.

d. Maybe it will be necessary to establish some rules to identify the satisfaction levels. For learning phase, the values will be proposed based on the designer subjectivity. Once they have been established, and for the new case, these values give us some ideas about the level of satisfaction, and the decision maker has the right to ask for some other levels. The factors that could be introduced as output neurons are: Benefit/cost factor, environmental satisfaction, Aesthetic satisfaction, Safety level, and any other factors might be proposed by the designer.

4. CONCLUSION AND FUTURE WORKS

4.1 Conclusion

This paper is intended to be considered as a guideline for a novel oriented direction and the base for further research that could be conducted to improve and generate consistency between the DSS models to make a decision during selection of an appropriate bridge type at conceptual and design phases. Additional study, research, verification and evaluations have to be conducted through the Input/output neuron values, as well as significant values of weights have to be investigated. As ANN technique, it's commonly known that the weights that relate the layer between them have no scientific sense; the proposed engine could introduce some exception to this idea by interpretation to the weights with some scientific means. Fuzzy logic as well as Markov chain and other similar techniques might be integrated into the proposed DSS to standardize the Input/output processing and to make the results and decisions more reliable. The subjectivity of the decision maker always exists, but it is minimized and restricted to some “punctual” location and, if needed, a sensitivity analysis might be integrated to verify how much the subjectivity has influenced the results.

4.2 Future Works

Additionally to the effort mentioned in the previous section moving from theory aspect to the practice requires much more enhancements and usability studies might need to be introduced in the proposed DSS.

The DSS could be used and launched to cover the bridge components, superstructure and substructure parts, as well as to select the appropriate elements matching the desired output values and based on the previous cases history. On the other side, and to make the decision more realistic, a Bridge Information Modeling (BrIM) is another important feature to be introduced in order to realize and visualize the decision. Geometric aspect of the decision is verified and quick structure aspect is checked by introducing the (BrIM) techniques at conceptual design phase. It is a novel perception process to make the decision more appropriate; many techniques and methods could be integrated through it as well as this DSS might be used for other field as construction management and building design.

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