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INTEGRATING THE ARTIFICIAL INTELLIGENCE TECHNIQUES INTO BRIDGE INFORMATION MODELING (BRIM)

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Abstract: While the Bridge Management System (BMS) has a crucial role in bridge performance, Bridge Information Modeling (BrIM) has been introduced recently to enhance the proceedings of the whole phases of bridge life-cycle starting with concept and design, through construction and operation, and ending with maintenance and rehabilitation. Different software applications have been developed and commercially spread to implement these tools and to help decision makers in their tasks in order to visualize their choices. Available software focus on geometric implementations and cost analyses which are the main factors to be verified. In order to benefit from previously constructed bridge projects and leverage the historical knowledge and information they provide, this paper proposes a methodology to introduce bridge success and failure performances. Bridge elements and components have to be defined to cover the whole bridge types by establishing appropriate libraries stored in a database. The Data will be customized based on the available information related to bridge information resources. Afterward, an engine based on "machine technique", -a branch of Artificial Intelligence (AI)- using Artificial Neural Network (ANN) modeling with its back-propagation algorithm will be included part of the proposed methodology to identify and select the utmost solution based on the restricted factors like the Benefit/Cost value. An iterative process is considered to attend the desired and balanced results. The process will be automatic and will require minimal user intervention. The proposed methodology will help the decision makers (engineers and management’s agencies) to visualize their decision benefit based on previous projects performances for the good of society.

Keywords: Artificial Intelligence, Bridge Management System, Bridge Information Modeling.

1 Introduction

During the decision making process at conceptual phases, many parties are invited, directly or indirectly, to share their experiences, knowledge and opinion 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, favouritism 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 to merge between the Artificial Intelligence technique (AI) as a Decision support System engine and the BrIM technique to visualise and realize the decision 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

In order to plainly understand the bridge concepts, it was crucial to bring in the history and revolution of the bridge structures and the related philosophies. Many references, starting by website encyclopaedia and going throughout the researches, reports and other dissertations of bridge Architectural philosophies, are available to extract the required information to understand the bridge philosophy which is an essential component to the present research.

2.1 Bridge Development and types

An assumption has been made by (Tang, 2007) which led to divide the bridges evolution into two major periods within the last four thousand years: Arch Era (2000BC-18th Century) and Contemporary Era (19th century to date). It was clearly known how the techniques, from both insight design and construction, have been evaluated from the simple stone bridge to attend the most complicated type known as hybrid type combining the suspension bridge with the cable-stayed bridge to consider a suitable solutions for some esthetical and economic constraints. Bridges could be classified under many types; (Tang, 2007) mentioned that four types could be adopted to cover most of bridges, as shown in Figure 1, Cable-stayed Bridge, Girder Bridge, Suspension Bridge and Arch Bridge; while another reference as Wikipedia classifies the bridges within seven types: Beam Bridges, Cantilever Bridges, Arch Bridges, Suspension Bridges, Cable stayed Bridges, Movable Bridges and Double-Decked Bridges. On the other hand, and in order to well define such bridge types, it's necessary to recognize the elements and components of the possibility bridges. It is important to establish an inventory that will be as "geometric" database to help the decision makers in their selection.

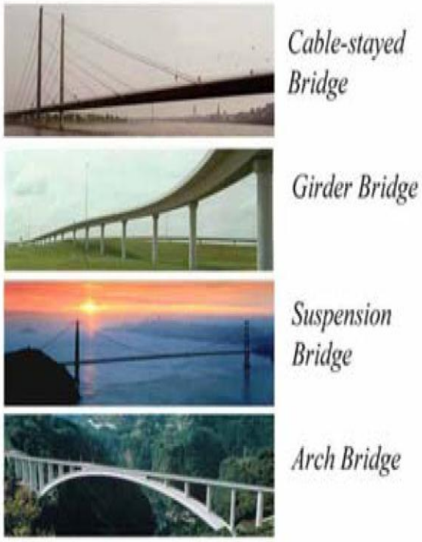


Figure 1 – Four Bridge Type - *(Tang 2007)*

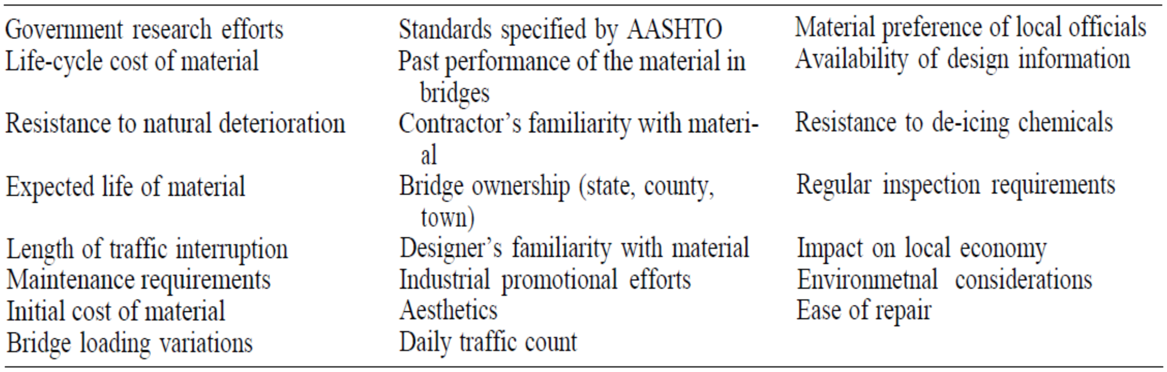
Thompson and Shepared (2000) conducted similar work and proposed an inventory to be the base for the inspection and maintenance tasks. Their report has divided the bridge components into four main groups: Superstructure, Substructure, Decks and Culverts. Those parts are important to rate especially from performance and sustainability perspectives.

2.2 Influence Factors and constraints

In order to cover all circumstances during a bridge type selection task, many factors and information have to be available. A research has been conducted to gather most of these factors by referring to many studies, researches and constructed projects using some of those factors. The NMDOT (2005), chapter Two, describes a development process from the perspective of the bridge designer. Smith et al. (1994) have cited many factors to be considered, which affect the decision to select bridge materials, Table 1 summarizes those factors while selecting the materials.

The analytical Hierarchy Process (AHP) has been used to rank the most important factors having high effects after collecting over thirteen hundred highways official data concerning importing nonstructural factors that influence the bridge material decision. The data collection process was based on the location and the level of the person interviewed. Among twenty-three factors, the following have been ranked as the most important ones: past performance, lifespan, maintenance requirement, resist to natural deterioration, initial cost & life cycle cost. Needless to say that the factors have to be divided into two main categories: "Uncontrolled Factors - UCF" and "Controlled Factors - CF". Basic parameters of the bridge have been stated by Chen Wai-Fah and DuanLian (2000) by considering different criteria: technical, functional, economic, construction and material with its geometric dimensions; those parameters define the quality of the structure. In order to publish a comparative study of the advantages and disadvantages between some types of bridges, eight factors are considered and taken into the study (Ogilvie and Shibley, 2005): Aesthetic, public input, operational flexibility, security, historic issues, constructability, environmental impacts, and construction cost and life cycle cost. Bridgeman (2012) lists a

Table 1 Criteria used to evaluate bridge materials *(Smith & al. 1994)*



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

substantial amount of data needed to start a Bridge Design like the site plan showing all obstacles to be bridged (rivers, streets, roads, railroads, valleys, alignments, etc…); longitudinal section to clarify the required clearances; factors affecting the bridge width (capacity, sidewalk, safety rails, etc…); soil conditions and ground difficulties; local conditions and constructability factors (availability of services, site accesses, equipment, etc…); weather and environmental conditions; topography of the environment and aesthetic requirements. It's obvious that the last reference has omitted the economic and LCC factors in the data needed for the proposed design process.

3 Bridges Management

3.1 Bridge management Systems (BMS)

The BMS is a huge and wide area where the bridge Life-Cycle is being managed. We can't separate the bridge LCC influence from the research purposes, the fact those issues are related indirectly to any decision could be made at conceptual and design phases. Al-Hajj and Aouad (1999) mentioned that design, construction and maintenance have to be addressed for any holistic productivity study. Life cycle costing elements are proposed to be added into the design phase which will allow the user to navigate inside the information about the components which need replacement or repair, and this research covers the building components and could be simulated to bridge constituents. Two major categories have been considered as obstacles while introducing the LCC into design phases; these categories are:

- **Managerial:** covering the failure of designers to be able to visualize and include life cycle cost goals; failure the owners or managers to consider effectively the longer-term impact while its responsibility goes within short-term; and general desires to minimize the initial expenditures.
- **Technical:** covering the lack of data, application and feedback; absence of a database; assumption and predictions for future expenditures.

Al-Hajj and Aouad (1999) show the type of information within a LCC model frame as indicated on Figure-2, whereby the design factor is considered among the elements level affecting the LCC.

The following section will address and summarize the available software used while studying a bridge performance like Pontis and Bridgit software, besides other conducted researches focusing on problem prediction and preventive actions to be considered in order to avoid or reduce any miss-functionality in the future.

3.2 Bridge Information Modeling (BrIM)

Two main parts will be discussed in this section: "Bridge Information Modeling, (BrIM)", and "Bridge Analysis & Design" which is a part of BrIM. The first part is a 3D geometric modeling including the BrIM components as bridge elements' definitions with the relevant data. The second part will cover the design and structural analysis aspects using a relevant analysis programs as "Autodesk Robot Structural Analysis Professional" and "Sap 2000 from CSI" or any other similar programs. Already the structure analysis and design part is one of BrIM components but its extracting laid down for research structure purposes. Limited researches have previously touched the Bridge Information Modeling and this topic has been recently introduced into the research fields.

3.3 Evolution of Bridge Information Modeling (BrIM)

For many years, 2D drawings were the main tool for bridge design work, nowadays, the 3D modeling is becoming more and more useful for the bridge design process, therefore, many researchers have been influenced by this environment in order to enhance and ameliorate the 3D modeling. 5D-bridge consortium from Finland has board meetings every three months to discuss and share their experience and their Research and Development R&D advancements in the bridge construction cluster. Their works are based on many software tools as Tekla and CAD tools (Kivimaki and Heikkila, 2010). Furthermore, machine control has been used experimentally with some limitations where research was restricted to theory level. Contractors' concerns were the practicability to facilitate the flow of information between different parties involved in a bridge design and construction process and to reduce the waste of resources. The main objective of the consortium was to produce a library of frequently used components. In order to meet and achieve their goals, the connectivity between the 3D softwares to site work surveys has been carried out through GPS tool and is known as machine control.

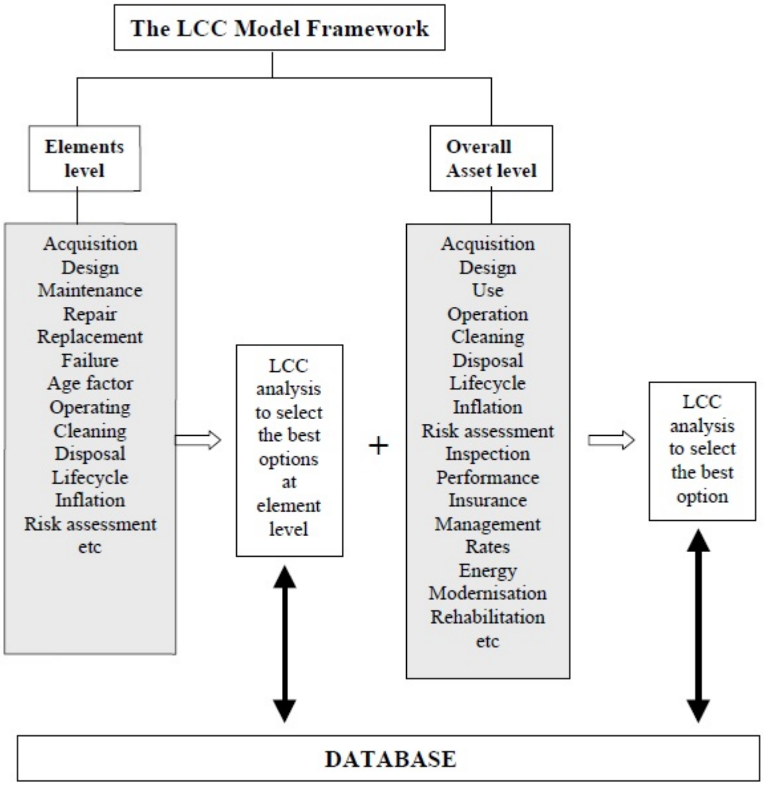


Figure 2 – LCC Framework – (*Al-Hajj and Aouad, 1999)*

An efficiency study and BrIM benefit verification have been conducted by Don (2009) for the "Sutong Bridge, China", in order to highlight the competence of BrIM in Bridge LCA. Many requirements have been raised for this bridge; starting by the design and resistance capacity to environmental factors (Wind, earthquake, ship impact, etc…), through the complexity of fabrication and construction, ending with the required performance and safety level for 120 years. A set of processes were described to cover the used model for the mentioned bridge study as shown in Figure 3. These processes cover the whole life-cycle of the bridge from planning and bridge selection to operation, maintenance and rehabilitation and covering all intermediate phases. All these phases are highlighted by the bently software with the following components:

- Bentley RM Bridge; for design purposes and supported by specialized engineering for bridges of all types.

- Bentley LEAP Bridge; additional parameters for design covering the precast, cast-in-place, reinforced and port tensioned concrete.

- Bentley Bridge Modeler and Bently LARS; Companion products for bridge load-rating, analysis, and analytical modeling for existing and planned bridges with conformity with ASHTO specifications and Database.

- Bentley SUPERLOAD; for oversize ad overweight units permitting and routing that takes account of bridge load-rating and analysis data.

Figure 3– Processes Covered by the Model *(Don 2009)*

Another point view comes from Kivimaki and Heikkila (2009). They state in their study that also the Tekla Structures and CAD softwares did not become widely used probably because, in the past, bridge design has been done in 2D. By proposing to integrate 5D product modeling, tests indicate that they have viable tool for surveying, but still need further development in usability and measuring features. Meanwhile, the cost effectiveness is increased by using this approach to survey and save the data into a server or central memory, for instance, the data used for as built documents, and to detect errors during the construction phase and those needed to be repaired avoiding additional errors. Chen and Tangirala (2006), in turn, declared that the principal missing link is an industry standard bridge data modeling language that is sufficiently robust to support interoperability of bridge information for entire bridge life cycle, and they presented a number of suggestions and enhancement procedures in order to leverage maximum benefit from 3D parametric of Bridge Information Modeling. Certainly, it was not desirable to reduce engineers role to data-entry clerks, since a practical result of robust 3D BrIM software and workflows must be able to free up engineers for more creative work that only humans can do in exploring a wider set of options for a given bridge crossing.

3.4 Models and Methods

Construction management areas have captured many methods based on a combination of the artificial intelligence (AI) and human reasoning processes. In recent years, there was increased interest among transportation researchers in exploring the feasibility of applying artificial intelligence paradigms in order to improve the efficiency, safety, and environmental-compatibility of transportation systems (Sadek, 2007). AI techniques are used to solve problems that, so far, are difficult to solve by classical mathematics. Many researches and applications described different methodologies to solve some aspect of transportation problems and to help with the decision making process while a replacement or maintenance plans have to be applied. Quality Function Deployment (QFD), Knowledge-base 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 established in the transportation areas and especially into the design decision making.

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

Srinivas and Ramanjaneyulu (2007) carried out a study using a trained ANN for feasibility of a T-girder bridge deck in order to reduce computational efforts and design space. The study for T-Girder deck section capacity and design responses has been carried out using ANN under live loads (LL) and dead loads (DL). Input parameters were: Span length, carriage-way width, total depth, number of longitudinal girders, number of cross-girders, spacing of longitudinal girders, spacing of cross-girders, thickness of deck slab at mid, thickness of cantilever end slab, thickness of web, width of bottom flange of main girder and thickness of bottom flange of main girder; while the output parameters were: max bending moment due to DL, max bending moment due to LL, shear due to DL and shear due to LL. The Architecture of the ANN was highlighted and carried a great attention in order to define the number of the hidden layer and the number of Processing Elements (PE) (or neurons) for each layer; the root mean square (RMS) error has been presented through a chart showing its values according to the selected hidden layer numbers and the number of processing elements. Mukherjce and Deshpande (1993) explained the development of a net and how it was processed while selecting the Input, Hidden and output layers components. Accordingly, the input layer has to be configured taking into account the possible parameters that may influence the output; the threshold function depends on the intended use of the network and method of learning, usually the Sigmoidal non-linear nodal function is used; the selection of the hidden layer numbers and the number of nodes takes a long time in order to train the network and to achieve the required convergence; the output of the parameters selection is the simplest task and it is related to the number of desired output parameters. Normalization is required for both the input and output parameter's values.

4 Proposed System Methodology

4.1 Introduction

Since the structural design problems are often ill-conditioned and require human qualities like the use of past experience and intuition for the synthesis of a good solution, and whilst it requires engineering judgment, intuition, experience, and creative abilities, the Rule-Based Expert System (RBES) approach had the capability to incorporate some of the above-mentioned requirements as suggested by Mukherjcet and Deshpande (1993). However, the RBES approach has major drawbacks as (1) lacks of the learning capability, (2) rules are required to be explicitly stated, (3) requires exhaustive engineering, and (4) difficulty to incorporate the number crunching routines; Therefore ANN has been proposed to provide an integrated solution to resolve the problems at hand.

The proposed DSS is based on 4 parts or sections: (a) establishing an accurate library of bridge types and their components, (b) structuring appropriate database forms, including an appropriate library, from the previous projects, (c) defining the model's engine to treat the information and to attend the required output and convenient solution, and (d) using the BrIM technology to realize and visualize the extracted outputs. The most important and difficult part of the model is how to define and convert to numbers some aspect and situations that an engineer requires as a decision base.

4.2 Decision Support System (DSS) frame

The objective of this research is to establish a DSS that allows the user to select an appropriate bridge type with the suitable components at conceptual design stages. The main parts of the DSS are: bridge types and components, database with an appropriate library, the DSS engine including the input and output parameters and the BrIM process to visualize and then verify the accuracy and suitability of the decision maker selections. For that, the DSS will be presented by the frame shown in figure 4. To start, the bridge types windows has to be established either as standard form or could be customized. Obviously, the bridge components also have some room in this window. The collected and gathered data from the previous projects will be assembled into a database structure. The database parameters also will be under a standard form or could be customized by the user. After establishing these basic settings, an interface will be required to transfer and introduce the collected data into the DSS engine. After running the calculation, the engine will provide the required parameter's values; these values will be verified through two processes: engineering opinion or judgment, and BrIM application. A final decision will be taken accordingly and either will be accepted or some modification will be required. The iteration, if needed, is shown in the figure 4.

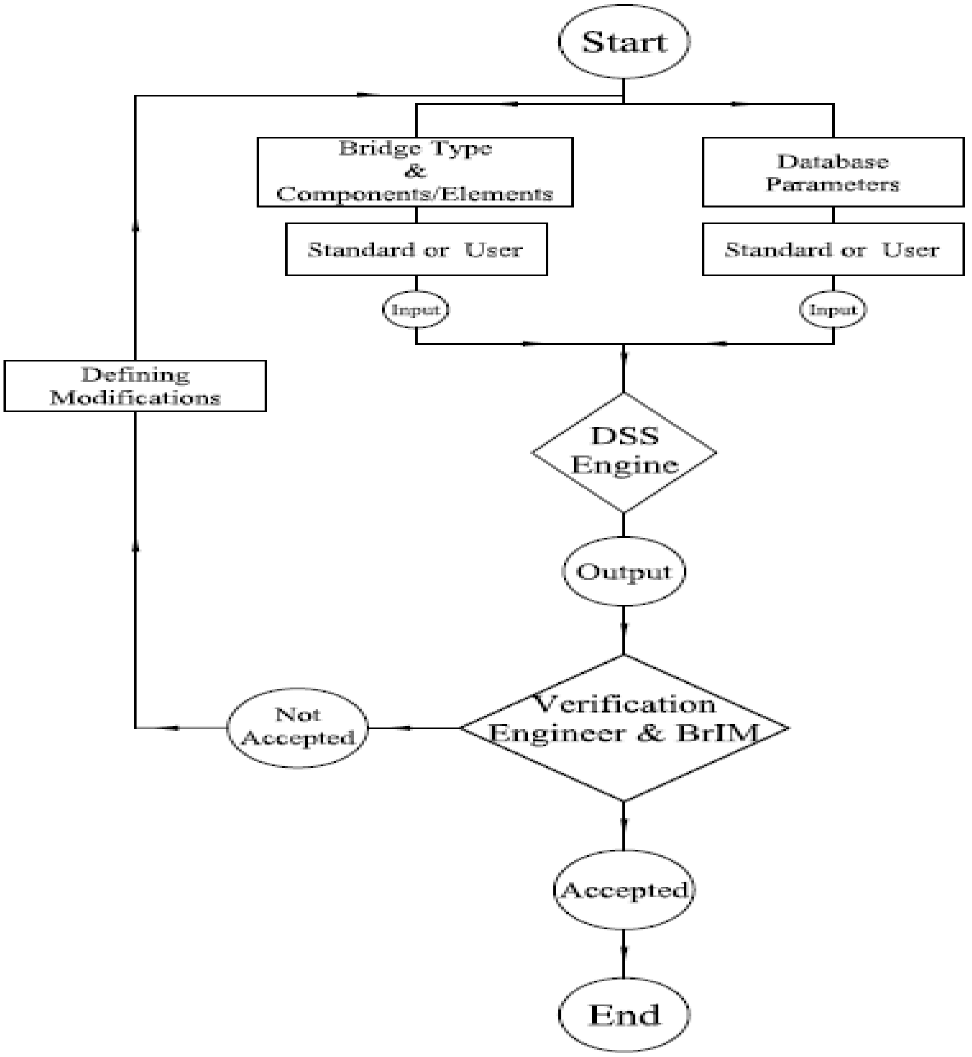


Figure 4 – DSS Frame

4.3 Resources and Database structure

The primary and principal part of the DSS is to determine, as much as possible, a "complete" library covering the bridge types, as first level, and then the components for each bridge type arrayed over many lower levels according to their functions and importance.

The bridge types will be listed under standard form (Common Information Model – CIM), established by the DSS, or could be designed according to the user requirements and implementation. As presented in Figure 5, the bridge library part is divided into many levels; the first one will cover the bridge types as one entity, then the lower level will cover the bridge components. On the other hand, the influencing factors have also some kind of structure. As mentioned earlier, factors are grouped within two categories: uncontrolled factors and controlled 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 these factors according to the previous cases of existing bridges and regional features to make the available data valuable for the DSS and reflect the accuracy of the final decision. 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 assigning some scale for each factor's behavior by selecting an appropriate function as shown in Figure 6.

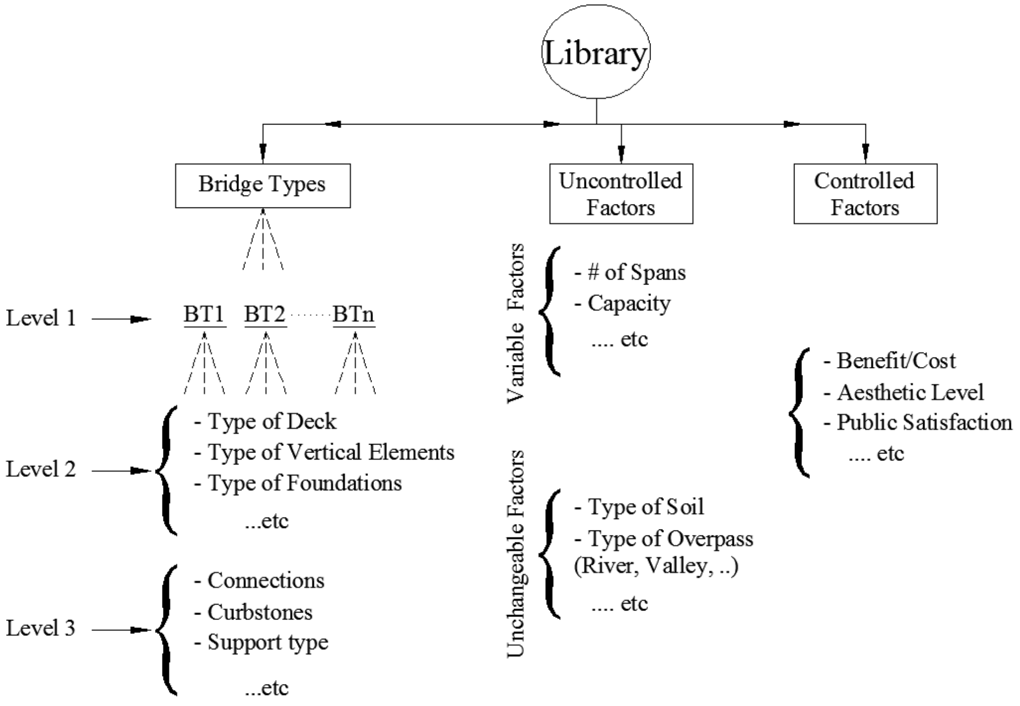


Figure 5 – Library and Database Items Structure

4.4 DSS Engine

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 6) already established based on the previous cases. Running the DSS engine under these values, a result will be generated (Uj), and according to these results, satisfying the controlled factors will be evaluated. If the new case results don't match the decision-maker opinion, more

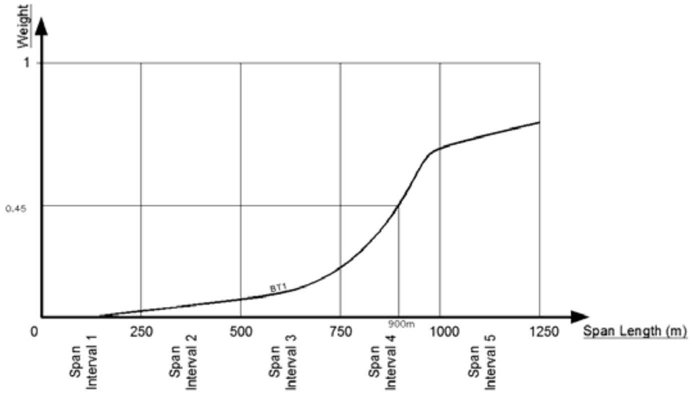


Figure 6 – Parameter Function – Span Length

advanced process is conducted by launching the engine after modifying some of the bridge parameters mentioned by BT and Ei neurons in the ANN frame as illustrated in Figure 7.

4.5 BrIM Implementation

Many tools and software are available. Both parts of BrIM (Geometric and Design) are implemented through commercial software to be used into the construction industry in order to control and mitigate the engineer's tasks. These softwares will receive the results from the DSS engine and will transform them to a real word environment. The decision makers (engineers) will verify all the bridge aspects in real 3D images and also they will conduct a verification over the feasibility from structural point view; then a decision will be extracted, either the received results are acceptable, or they should be rejected in which case launching another iteration will be required. For this purpose, many types of software will be run like Tekla structure, Bridge CSI for the structure realization, and Autodesk 3D civil design for geometric aspect verifications.

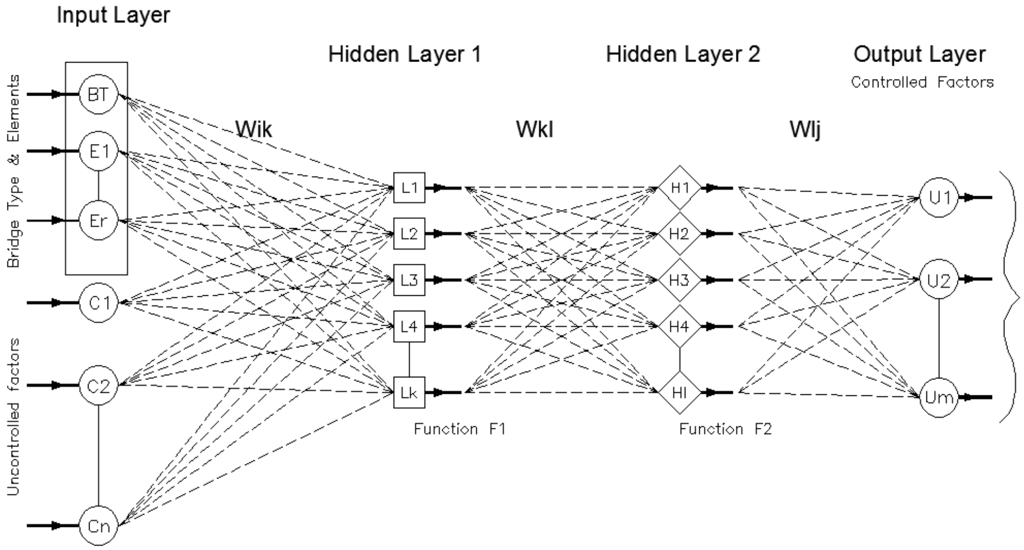


Figure 7 – Decision Support System Engine – Neurons & Layers

5 CONCLUSION AND FUTURE WORKS

5.1 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 the 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. 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.

5.2 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, going down to lowest level for bridge components and introducing appropriate functions and procedures will enhance the prediction of bridge performance through its Life-Cycle. 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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