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Proposal for an Integrated Decision Support System for Bridge Type Selection during the Conceptual Design Phase

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Abstract

Today, when it comes to selecting the most appropriate bridge type and defining its respective component and properties, no systematic procedure exists when the bridge is still in its conceptual design phase; selection is often based on the subjectivity of the decision-makers, which is regarded as a weakness in bridge project processes. A Decision Support System (DSS) that operates in an artificial intelligence (AI) environment and takes into account most of the relevant factors (e.g. acquisition cost, aesthetic appearance, and life-cycle cost (LCC)), is very much needed, in order to achieve decision consistency. The aim of the research addressed in this paper is to propose a methodology for developing systematic procedures that can help decision-makers select the most appropriate type of bridge, with its various components and parameters, in a given situation, as well as predict its LCC and other characteristics, such as the level of public satisfaction and environmental sustainability.

1. INTRODUCTION

Infrastructure management systems (IMS), in particular bridge management systems (BMS), have been pre-occupying decision-makers for many years, with various systems and commercial software (e.g. SQL, Oracle, Access, Delphi, and Power Builder) having been used throughout Europe and in countries in the Far East (Woodward, 2001). Many researchers and organizations work tirelessly to improve the decision support process as regards bridge type selection by developing new methodologies with the aim of meeting the demands of the respective bridge situation as much as possible. In all cases, the focus should be on what engineers need to consider when deciding which type of bridge to adopt; what parameters, factors, and matters of concern need to be taken into account, in order to avoid or minimize current and future shortcomings of the respective bridge, as the

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conceptual design phase of a bridge has a significant impact on the costs of the overall project, as also noted by Hendrickson (2008). Thus, the conceptual design phase of a bridge is of paramount importance as regards LCC optimization of the overall bridge project.

The research addressed in this paper is aimed at developing a DSS model that provides engineers with additional useful tools for selecting the most appropriate type of bridge, and its respective components, which leads to an optimization of the LCC of the respective bridge, and also meets other demands, such as aesthetic satisfaction and environmental protection. Thus, the objectives of the proposed methodology can be summarized as follows:

(a) to highlight the influence of human subjectivity on the decision-making process;
(b) to list and rank the potential alternatives in relation to their performance criteria;
(c) to ensure that equal and fair consideration is given to selected factors that are of influence on the decision-making process, using conventional decision-making approaches; and
(d) to develop a systematic methodology that, based on a relevant historical database and expert input, can be viewed as a guide for further use in any decision-making environment.

Thus, this research is aimed at reducing the subjectivity of decision-makers as regards bridge type selection by highlighting the factors that influence the decision. Using statistical methods, different subject-related factor types in combination with respective location-related factors are highlighted. Then, these factors are manipulated in an artificial intelligence (AI) environment, in order to find out how they influence the decision. Finally, various potential alternatives are evaluated based on the selected factors and according to the ranking of performance criteria. The reliability of the selected factors is checked and supported by a sensitivity analysis of the selected factors.

2. LITERATURE REVIEW

In order to have a clear understanding of bridge concepts, it is crucial to look at the history and development of bridge structures and the associated philosophies. Many references, reports, and dissertations on bridge architecture philosophies are available that give a well-informed insight into bridge philosophy, which is an integral part of this research (Tang, 2007).

Many references have indicated that bridge design embraces two phases: the conceptual and the analytical design phases (Miles & Moore, 1991; Chen Wai-Fah & Duan Lian, 2000). The analytical design phase is very well defined through the use of codes and formulas, while the conceptual design phase is not well defined. As regards the latter, the large number of studies conducted by various engineering firms and consultants have produced more or less different opinions, leading to different final decision outcomes (Smith et al., 1994 and Mahmoud, 2015). For instance, Thompson and Shepard (2000) proposed an inventory of elements that forms the basis for bridge inspection and maintenance tasks. The types of material used for bridges have their own specific influence; Smith et al. (1994) noted a number of material properties and their respective influence on bridge components. Smith noted a large number of factors that are of influence and should therefore be considered in the decision-making process as regards bridge type selection.

Other studies adopted the Analytical Hierarchy Process (AHP) to rank the key factors that have a significant impact on bridge type selection, on the basis of an official collection of data obtained for over thirteen hundred (1,300) highways. This collected data focused on non-structural factors that influence decisions as regards bridge materials. Choi (1993) grouped the factors that influence conceptual bridge design into two categories of design constraints: "Hard Constraints - HC" and "Soft Constraints - SC". Chen and Duan (2000) provided basic bridge parameters that take different factors into account: a) technical; b) functional; c) economical; d) construction; and e) materials and their respective geometric dimensions: these parameters define the quality of the bridge structure.

Bridgeman (2012) believes that before starting any bridge design, a significant amount of data should first be available, such as a site map that shows all the obstacles to be bridged; a longitudinal cross-section of the concerned bridge to illustrate the required distances; factors affecting the width of the bridge (e.g. capacity, sidewalks, safety railings); soil condition and soil difficulties; local conditions and buildability factors; climatic and environmental conditions; topography of the environment and aesthetic requirements. A totally different approach was noted by Hotaling et al. (2015), who examined a specialty in the area of decision making known as dynamic decision making, which is characterized by the fact that, in order to control and optimize the performance of a dynamic stochastic system, the decision-maker chooses between different actions at different points in time. The aspect of aesthetics was discussed by Moore et al. (1996) with reference to public opinion, rules for the acquisition, collection, and dissemination of a large number of subjective opinions in bridge aesthetics. Marzook et al. (2013) introduced a list of key factors that influence the sustainability of bridge projects, which was determined through interviews and surveys.

Further, artificial intelligence (AI) has been used to solve problems that are difficult to solve using conventional mathematical methods. Many researchers have found labeling methods to solve some aspects of *transportation* problems and ease the decision-making process while executing bridge replacement or maintenance plans by applying artificial intelligence (AI) paradigms to improve the efficiency, safety, and environmental sustainability of transportation systems (Sadek et al., 2003). For humans, as well as other living beings, the brain's neural network is considered to be the basic functional source of intelligence, encompassing perception, cognition, and learning (Toshinori, 2008). Many other models and methods exist (e.g. Quality Function Deployment (QFD), Knowledge-Based Systems (KBS) (Arain and Pheng, 2006), Case-Based Reasoning (CBR) (Dogan et al., 2006), Expert Systems (ES), Fuzzy Systems (FS) (Takagi, 1997), Genetic Algorithms (GA) (Toshinori, 2008)) that have already established themselves in the transportation sector and shown to be particularly useful in design decisions.

Finally, based on what has already been uncovered, a number of weaknesses have been identified: (1) there is no clear systematic method for defining the factors to be considered in the conceptual design phase (Smith et al., 1994); (2) technical judgments and subjectivity have been widely adopted without there being any consistent rules (Yao et al., 2011); (3) no flexibility can be observed in existing methods that are limited to specific cases and constrained conditions (Dekker, 2000); (4) there is no Bridge Information Modeling (BrIM) implementation in the conceptual design phase (Herman et al., 2008); (5) there exist discrepancies between different expert opinions (Nedev and Khan, 2011).

3. RESEARCH METHODOLOGY

Conceptual design is the first step in any type of structural design and, thus, also that of bridges. Bridges are a type of structure that must be evaluated well before proceeding with theoretical analysis and detailed design. When selecting bridge systems, the respective materials, proportions, dimensions, foundations, aesthetics and other factors, such as the prevailing surrounding landscape and environmental aspects, are taken into account in the conceptual design process, which is the first of six phases in the life of a bridge.

This paper looks at research that has been conducted to develop a Decision Support System (DSS) methodology for use in the "conceptual" design phase of bridges, thereby taking into account various criteria: technical, functional and economic, as well as the material and the geometric dimensions of the respective bridge system. To evaluate the influencing factors, they are divided into two main categories: hard factors and soft factors. Hard factors include, for instance, characteristics of the respective site, capacity and complexity of construction, while the soft factors may include those that define the level of performance (e.g. cost-benefit) assessment, aesthetic ranking and environmental impact level).

The main aim of the research is to attempt to emphasize and/or minimize subjectivity in decision-making and, thus, reduce and limit its effects; the purpose is to go from the ambiguity of subjectivity in decision-making to an accurate well-founded decision-making process, i.e. to control the said subjectivity, in order to reduce errors and/or inaccuracies when the bridge is still in its conceptual design phase.

To this end, this research aims to define a DSS methodology that offers an integrated, structured approach that takes into account a large number of influencing factors and constraints. The influencing factors are defined and evaluated by the DSS-user based on available data from existing projects, and taken into account to create a relevant data module.

3.1 Models and Methods

Structural design problems are often complex, and synthesizing a good solution requires human qualities, such as technical judgment, intuition, experience, and creative skills. The proposed DSS embraces three steps:

(a) building an accurate library of bridge types and their respective components by structuring the required data forms that store appropriate information from previous projects;
(b) defining a suitable model that allows the information to be handled in a user-friendly manner, and produces a reliable solution output; and
(c) using BrIM concepts and tools to provide a visualization of the solution output produced.

The performance of a bridge is predicted and assessed based on the evaluation of the following factors: Aesthetics, LCC, Environment and public satisfaction/capacity and services. This is based on existing bridges that have the same conditions as the proposed one. The DSS is set up in such a manner so as to make the parameters of the model as flexible as possible to allow users to include other parameters and conditions and to show how those parameters affect the DSS outputs. Dot-scale converters are introduced to convert some aspects, such as soil behavior, into numbers.

3.2 DSS Framework and Its Components

The main components of the DSS are: the data module, which contains the data on the various bridge types and their respective components (related to their geometric parameters) and the parameters that influence the performance of the respective bridges (such as overpass area, soil behavior, bridge capacity, number of lanes, number of spans, total length), the DSS engine, which contains input and output parameters and, finally, the BrIM process to ensure the correctness and appropriateness of the decisions made by the decision-makers correspond with those made by the DSS engine.

In Figure 1, the DSS Framework configuration is shown schematically. The DSS begins with collecting the necessary information from suitable resources that is to be included in the data module. Following the creation of the data frame, the necessary analysis is carried out, in order to convert the collected data into suitable numerical values that are to be implemented in the DSS engine. The DSS engine, which works in artificial intelligence (AI) environment (will be explained in more detail in the next sections), runs under this input data in order to provide the corresponding output values. The output values are verified and analyzed simultaneously through two processes: (1) through technical evaluation; and (2) through the implementation of the output values in BrIM tools. Finally, the decision is made whether to accept the output or to request any changes to be made.

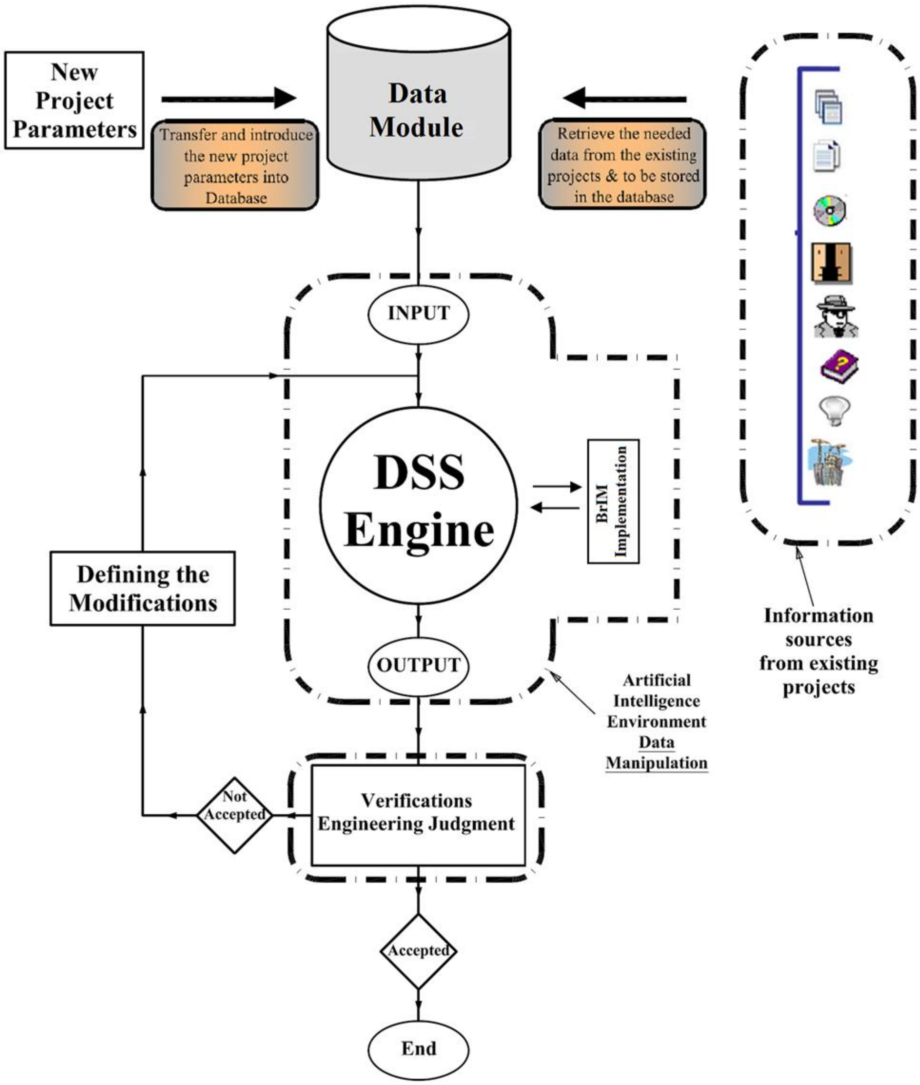


Figure 1. DSS framework

A data structure is a collection of information organized in such a manner that it can be easily accessed, managed and updated. In computer science, data is classified according to its organizational approach. The most widely used approach is the relational database, a tabular database in which data is defined in such a manner that it can be reorganized and retrieved in various ways. Figure 2 describes the relevant information that must be contained in a well-structured data frame so that, after appropriate analysis, it provides the correct values for the DSS engine. As Figure 2 reveals, the input criteria and their respective descriptions are grouped under the bridge information set, which is divided into two main groups:

(a) bridge components: in this group, the information collected is subdivided into:
    (i) administrative information (e.g. project name, project identification number, brief project description); and
    (ii) geometric and structure information, which describes the respective bridge elements, such as bridge type (BT), column type (CT), foundation type (FT), deck type (DT).

(b) bridge characteristics and parameters: in this group, the influencing factors are divided into:
  (i) controlled and uncontrolled variables, which are represented as hard factors; and

  (ii) criteria according to the values of which a decision is made, so-called output criteria (cost (LCC), Environmental Impact Rate (EIR), Aesthetic Impact Rate (AIR)), which are represented as soft factors.

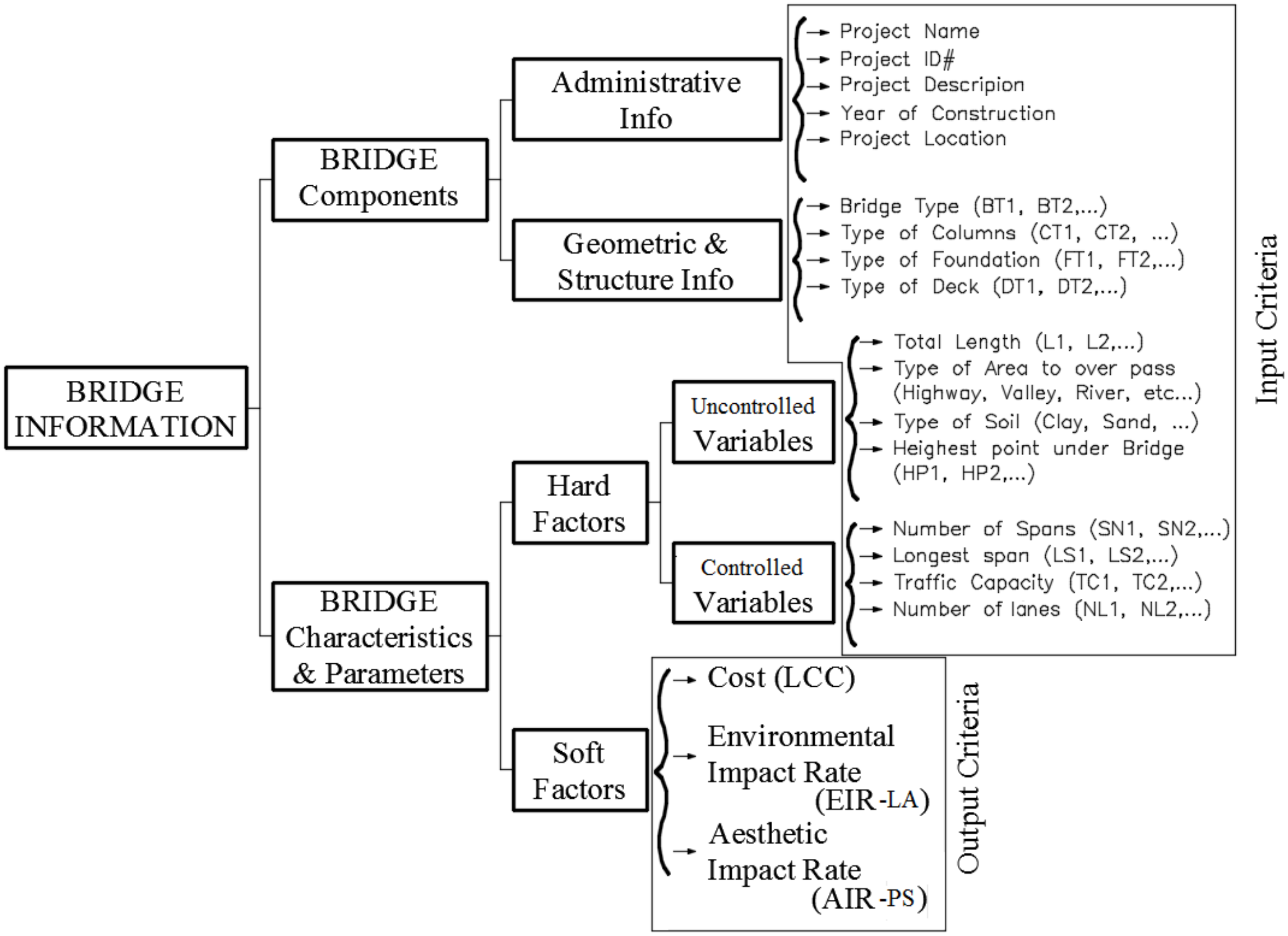


Figure 2. Bridge information algorithm

Subsequently, all criteria are divided into five categories: (I) Administrative Information, (II) Geometric and Structure Information, (III) Uncontrolled Variables, (IV) Controlled Variables, and (V) Soft Factors; it should be noted that the criteria listed in this research section may be the subject of some additional or retained elements later on in the final DSS development process. Some factors are defined by linguistic information, which must be converted into numerical values by point scales that are defined separately for each type of criteria. The point scale method is widely used to convert linguistic information into numerical data for ease of use. For the existing bridge projects, all the criteria values listed under the controlled and uncontrolled variables are defined according to the real and existing situation of the respective bridges, while for the new bridge project that is being analyzed, the criteria values found under the controlled variables are based on the results derived by the designer whereas the uncontrolled variables are considered immutable values with respect to the bridge position constraints. Among the various Category II factors, (a) Environmental Impact Rate (EIR) and (b)

Aesthetic Impact Rate (AIR) are two factors that must be assessed for each bridge as a function of many parameters.

The Environmental Impact Rate (EIR) is determined in the conceptual design phase after the bridge location has been determined with other related factors. Based on the "WAS" factors implemented in a Quality Function Deployment (QFD) system, the EIR is calculated based on equation [Eq.1], which relates to two factors:

(1) the indicator of the main impacts (MIi) related to CO_2 emissions; and
(2) the indicator of the Surround Impact (SIi), which includes factors related to the location of the bridge and neighboring people.

$$\mathbf{EIR_i = A.(MI_i) + B.(SI_i)} \qquad \textbf{[Eq.1]}$$

where i is a reference number-related existing project ID; A is a percentage importance factor that is assigned to the MI by the designer; B is a percentage importance factor that is assigned to the SI by the designer, where A + B = 100%. The (MIi) values should be obtained from the collected data and assigned to the existing bridges; otherwise, diagrams and values should be implemented in the model element, while the methodology to be assessed (MIi) is adopted from existing and/or future studies that provide a methodology for counting the environmental impact of a bridge based on the materials used and energy consumption. The final Values of (MIi) should be presented on a scale of 1-99. The values of (SIi) are calculated based on the defined factors implemented by "WAS" in a Quality Function Deployment (QFD) system. The mentioned factors are given an importance rating (IRj) according to their importance from the point of view of the decision-maker. The elements of the QFD are the existing bridges, and for each bridge case a value (Vj, i) on a point scale (e.g. 1-10) and according to the degree of the assigned correlation between existing bridges and WAS. The roof part represents the correlation that exists between elements and this QFD part is omitted from our study. The "n" bridges are arranged according to the "m" factors in the first columns. After entering the required data, the bottom two lines are calculated as follows:

Raw Score:

$$RS_i = \sum_{j=1}^{m} V_{j,i} \times IR_j \qquad \textbf{[Eq.2]}$$

Surround Impact:

$$SI_i = INT\left\{\frac{\dfrac{RS_i - MIN[RS_i]}{MAX[RS_i] - MIN[RS_i]}}{98} + 1\right\} \qquad \textbf{[Eq.3]}$$

Equation [Eq. 3] aims to adapt the (SIi) values to a 99-point scale based on the normalization method.

Like the Environmental Impact Rate (EIR) value, the Aesthetic Impact Rate (AIR) must also be reported for the use of the proposed DSS. A methodology for evaluating the Aesthetic Impact Rate (AIR) that is based on an innovative computational decision support tool is proposed, as most of the published work on bridge aesthetics is based on the judgment of bridge designers and some rudimentary calculations regarding bridge element dimensions and the location of the bridge, as well as the surrounding area. The Aesthetic Impact Rate (AIR) values, which are defined on the basis of various factors, are divided into the following 5 categories:

(1) **Proportion and Geometry**: ensuring that the bridge deck looks reasonably slim and is in keeping appropriate to the shape of the support pillars (i.e. round or rectangular);

(2) **Environment**: ensuring that the bridge is in harmony with its surroundings and that the bridges on a road have visual compatibility with one another;

(3) **Structural Harmony**: this refers to the load-bearing capacity of the bridge and the way in which the load is transferred from element to another (should be obvious and should "look right", e.g. bridge);

(4) **Attention Focus**: this refers to the identified problem with two-field bridges that the eye cannot focus on (bridges with an odd number of fields do not seem to suffer from this problem);

(5) **Weathering and Surface Properties**: Sustainability elements to be suitable and compatible with the overall bridge visual aspect.

Many more categories can be added by the designers during the development process and/or even later. After screening the appropriate factors, a QFD system could be used, in the same manner as previously described for the Environmental Impact Rate (EIR), to assess the Aesthetic Impact Rate (AIR) values for each bridge case, which can be calculated using the following relationship:

$$\mathbf{AIR_j} = \sum_{i=1}^{n} I_i * V_i \qquad \textbf{[Eq.4]}$$

where:

j is an ID reference number for the existing project,
i are parameter indices, and
V is a harmonic measure that exists between the bridge and its surroundings.

A model for evaluating the Aesthetic Impact Rate (AIR) value will be created and included as a set in the data file in the DSS and used when necessary; this model will relate to many research projects and methods already executed. The aim of the proposed DSS is to provide values for some performance factors that are defined as soft factors (output criteria). These soft factors can be Life Cycle Cost (LCC), Environmental Impact Rate (EIR) – assessment by local authorities, and Aesthetic Impact Rate (AIR) – public satisfaction.

After most of the criteria categories have been defined, a structure for the data module is defined as presented in Figure 3. The main component of the data framework is the Library block. The Library contains five defined categories, and the information contained in these categories (factors and variable definitions) is created from the resources according to the information available.

After the Library has been set up (covering all possible factors for the 5 categories), values (numeric and/or linguistic) are assigned to the Library items to define all of the criteria contained in the primary data module. Microsoft Excel (and/or Access) software is the tool that is used to computerize the data process content. It provides real control over the data, in that it allows data to be collected, sorted, analyzed, summarized, as well as the results to be reported. It combines data from different files, so that information never has to be entered twice. It makes data entry more efficient and accurate.

MS Excel will be much more than just a list or a table, because it will also contain the defined models (e.g. linguistic converter, point scale, QFD system) that aim to analyze the information and make it available in a suitable and usable format.

For the DSS engine, the Artificial Neural Network (ANN) is seen as its main component. An artificial intelligence (AI) network consists of a pool of simple processing units that communicate with each other by sending signals to one another over various weighted links. A number of main aspects of a parallel distributed model can be distinguished by the number of processing units (neurons), the state of each neuron (as output), the connection between the units (input, hidden and output neurons), the rules of propagation, and the activation function that the new activation level is determined based on the actual input and the current activation, the external input, the method of obtaining information (stored in a data structure and then implemented in the ANN learning rules) and the environment in which the system must function.

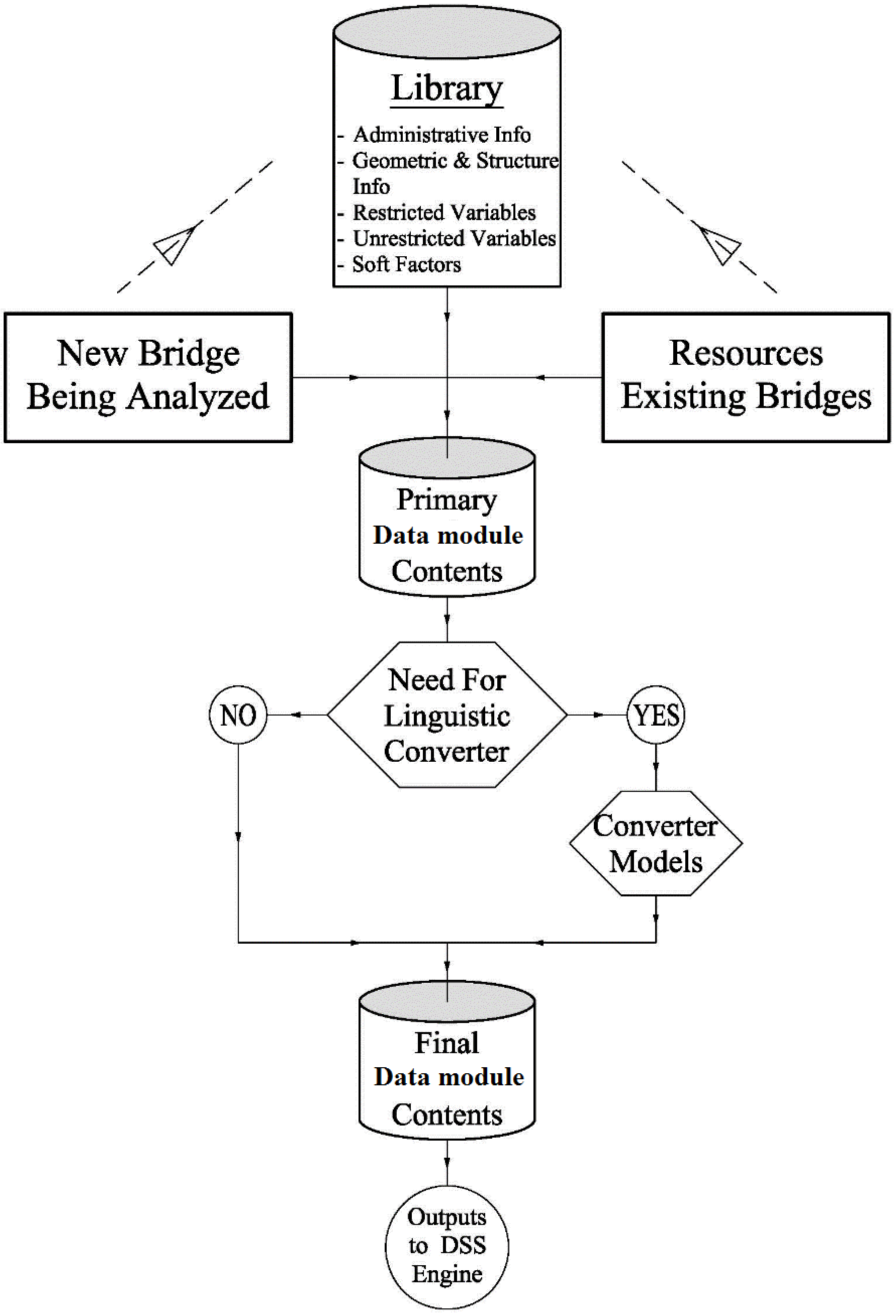


Figure 3. Global data framework

There are three types of layers within ANN systems: the Input Layer, which receives data from outside the neural network; the Output Layer, which sends data from the neural network; and Hidden Layers, the input and output signals of which remain within the neural network. The adaptation process using the ANN system is based on its main features:

(1) Backpropagation, which are learning rules to be followed;
(2) The number of hidden layers/neurons per layer, which are to be suitably defined; and
(3) The selection of the activation function for the purpose of solution convergence.

The Input Layer covers three categories:

(1) Geometric and Structural Information;
(2) Uncontrolled Variables; and
(3) Controlled Variables.

The selected factors to be included in these categories is selected on the basis of expert opinions obtained through interviews and questionnaires in which the factors are proposed, rated and appropriately selected, thereby taking into account the specifics of the respective bridge site, as well as the available data that should be used. The values assigned to the input neurons are taken from the corresponding tables in the data module according to existing bridge cases, which are used for the learning process of the network.

The Output Layer, which represents the soft factors, is defined as the “performance criterion”; it is also selected on the basis of expert opinions obtained through interviews and questionnaires. Hidden Layers, which are linked by the weights (Wik, Wkl, Wlj) and a corresponding activation function (sigmoid functions F1 and F2). One or two hidden layers are enclosed with a defined number of neurons according to the number of input and output neurons and patterns. The mentioned weights and the hidden neuron values are defined after the network training based on the existing cases, which should be considered and used in the specified methodology. Based on the previous and existing bridge cases, a training process is started to generate the appropriate weights. Sample sets are selected to test the results.

As soon as all parameters of the ANN are clearly defined, the data is processed for a new case to be implemented in the ANN, in order to obtain the required results. The data of Categories 3 and 4 is well recognized for the new case due to the constraints related to the project location, whereas the data of Category 5 is generated by the networks and a decision is made based on the analysis of their values. That leaves the data of Category 2. The method for determining the values of this data category is based on a statistical study in which different alternatives are defined on the basis of different values that could be assigned to the factors.

Another method could also be used in which the values for the appropriate alternatives are defined based on the run for a "first order" of the ANN by considering the factors of Categories 3 and 4 as input data, and those of Category 2 as output data from ANN; the latter method is used in this proposed DSS. Based on the existing bridge cases, diagrams are created for all parameters, in order to retrieve suitable values for the ANN implementation. In this way, the criteria values of Category 2 are selected according to a systematic procedure.

3.3 BrIM Tools and Sensitivity Analysis

Geometric (covering the architectural elements) and structural (regarding the resistance of the structural elements) factors are implemented by commercial software tools used by the construction industry to control and facilitate the tasks of the engineer. These tools receive the results from the DSS engine and transfer them to the real environment. The decision-makers (engineers) verify all bridge aspects already extracted from the input and output data of the DSS engine and carry out the verification via the project visualization using a 3D model; then, a decision by the decision-maker is taken into account. Either the extracted results are acceptable, or they should be rejected or changed. In this case, another iteration must be started.

As described in the previous sections, the DSS is based on many criteria (Categories 2, 3 and 4) that influence the results (criteria from Category 5). In order to check the influence of each input criterion on the results, a sensitivity analysis (SA) is carried out, in order to understand the relationships between input and output criteria.

The importance of the SA is also that it examines how the uncertainty in the output of the DSS can be distributed across various sources of uncertainty in its inputs, in that the SA will identify the DSS inputs that cause significant uncertainty in the output, in order to reduce non-conformity. Further, for each output value provided by the DSS engine, a realistic level (LR) is analyzed based on diagrams created from the sensitivity analysis. This interpretation aims to quantify the extent to which the results are realistic. This proposed methodology is based on a comparison process between the ratio of the estimated to the actual values of a certain criterion (from Category 5) from an existing case with the ratio of the estimated value to the criterion value specified by the DSS engine for a specific case. Through this comparison, a tool may be found that enables the extent to which the output values make sense to be assessed. To this end, the proposed methodology is intended to help the experts to convince themselves first and then convince others when there are doubts or contradictions in their opinions and decisions based on a scientific and systematic methodology. The above instruments could be seen as an argument to defend the expert's decision and convince others.

The results of the described DSS are intended to serve as a guide for a new type of tool that is to be adapted and later improved through additional examinations and tests. Based on the artificial intelligence (AI) environment, a systematic methodology is provided that helps decision-makers to make their decision as regards bridge type selection in the conceptual design phase, based on and taking into account the performance (e.g. costs, environment, aesthetics) of existing bridges, with the aim to convert the high level of subjectivity into objectivity for any conceptual bridge design process, in order to increase the objectivity as compared to the subjectivity of the decision makers.

4. DSS DEVELOPMENT

4.1 Data Structure and Analysis

The focus of the research described in this paper is to propose an approach to determining the appropriate type of bridge based on various performance indicators. Indeed, there are many factors to consider in this part, with respect to the influencing factors and the performance factors that are identified by performance criteria.

In addition, an analysis is carried out in this paper by selecting the appropriate factors to determine the alternatives and evaluate their performance. After selecting the appropriate factors, alternatives are defined. Each alternative is analyzed to rank the proposed alternatives and identify their performance.

Since the proposed DSS is aimed at reducing subjectivity and move further towards objectivity in decision-making, it is important to provide a detailed methodology known as Flexible Methodology to help the decision-maker make changes during any part of the DSS, and observe their respective effects.

Figure 4 shows the three components to be adjusted and analyzed that define the different parts of the DSS delivered.

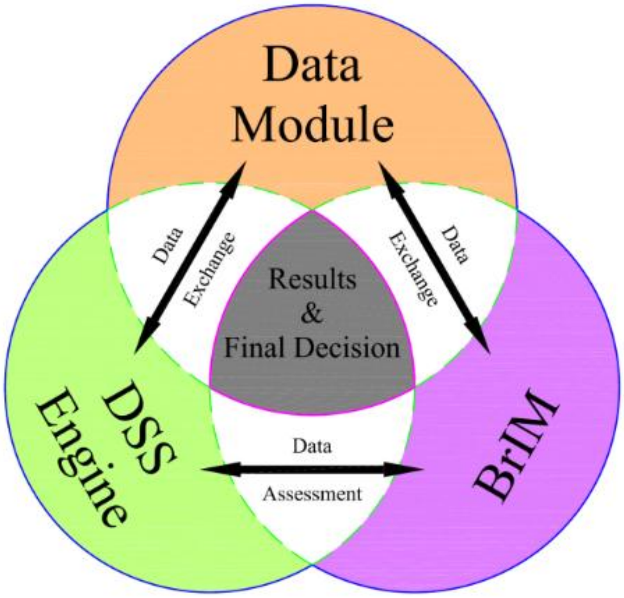


Figure 4. Interconnection of DSS components

The data module frame, with its various sections and the relevant gathered information, is structured as follows:

(1) influencing factors are established and grouped into five categories;
(2) an expert and professional questionnaire is conducted to define the factors mentioned;
(3) the appropriate values for the foregoing factors are defined as follows:
    (a) numerical information collected directly from existing bridges through simple investigation and data search;
    (b) linguistic information (e.g. bridge type, soil type) that requires a conversion;
    (c) formula creation to define a number of other variables (e.g. EIR, AIR, AIR-PS);
(4) a complete data plan is established;
(5) statistical analyzes are carried out for two purposes:
    (i) to highlight the homogeneity/heterogeneity of the data; and
    (ii) to provide guidance to the decision-maker as to what alternatives might be proposed based on existing bridge cases;
(6) based on existing bridge cases, the ANN is structured and executed in order to extract the performance of each alternative; and
(7) factors that are considered input neurons and the factors that are considered as output (performance criteria) are used in the final run in order to evaluate the performance of the decision.

Given that special features must be observed for each region under study, a questionnaire is then sent to public and private bodies that are involved in bridge construction, bridge management and bridge design, in order to obtain their opinion on the common factors that have the greatest influence on their decision-making. In order to organize the factors, different categories are defined to distinguish between different types of factors that are known to be related to bridge projects (existing or under construction). The first category includes administrative information: bridge "ID", bridge name "BN", bridge location "BL", and any other factor that could be useful. This information is made available when needed by storing it in a data frame to be suitable for many projects with different locations and years of construction. Two further categories (Categories II & V) define the alternatives and their performance indicators, and present a number of results for the final decision. Category II factors, entitled “Geometric and Structural Information”, includes those that define the bridge components. The following bridge elements are shown for a specified bridge: bridge identity “ID”; bridge type "BT", column type "CT", foundation type "FT". All of these factors with their associated values are provided for various existing bridge projects, as well as for proposed alternatives for new projects. In the case of existing bridges, the values assigned to the factors in Category II are collected from the real situation. For a new bridge to be examined, the relevant values are assigned on the basis of the proposed alternatives and from the Bridge Infrastructure Management (BrIM) analysis after implementation in the corresponding tools. Category V variables are collected from existing bridge cases based on their performance level; for a new bridge to be examined, the variables are extracted from the DSS engine, which works in an ANN environment. The factors presented in Category V are known as performance indicators. Suitable factors defined as performance indicators are, for instance: actual acquisition costs - PV "IC", operating and maintenance costs over 100 years "OC".

In addition to the performance indicator factors, there remain two categories of factors that are defined by the aforementioned questionnaire; these categories are: (a) Category III, known as "Uncontrolled Variables", which include the "Immutable Variables" that are automatically recorded once the location of the bridge has been proposed; (b) Category IV, known as “Controlled Variables”, which include the “Changeable Variables” that could be modified to achieve an optimal solution. Categories III, IV and V are divided into two main types of factors: (i) Hard Constraints, which cover Categories III and IV, and (ii) Soft Constraints, for Category V. In addition, the opinions of the experts are gathered regarding the factors that influence the performance of the selected bridge alternative. Based on the experts’ opinions, a simple evaluation is carried out to classify the various factors, using the following equation (Eq. 5).

$$RFC_j = \frac{\sum_{i=1}^{n} R_{ij}}{\sum_{j=1}^{m}\sum_{i=1}^{n} R_{ij}} \qquad \text{(Refer to Tables 4 to 6)} \qquad \textbf{[Eq. 5]}$$

where:

n	is the number of participants of the questionnaire Q01
i	indicates a specific participant
m	is the number of factors considered
j	indicates a specific factor
R_{ij}	is factor j of participant i
RFC_j	is the rate value for factor j

The decision-maker will consider the appropriate factors based on their ranking RFCj. The aforementioned procedure highlights the factors to be considered in Categories III, IV and V. The factors embedded in Category I are easy to define, because they represent administrative information and do not require any technical knowledge. For the Category II, bridge components are defined according to the required and proposed details of the selected bridge alternatives. In general, the following factors are considered in Category II, with the flexibility to add or *reduce* related factors: Bridge Type (BT), Column Type (CT), Deck Type (DT), Foundation Type (FT), and Material Type (MT). In addition to these factors, others can also be considered, such as: Concrete Volume (CV), Industrial Steel Weight (ISW), exposed concrete surface (CS), and exposed concrete surface (SS), which will be retrieved following the implementation of the alternatives in the BrIM tools. In addition, the Estimated Initial Costs (EIC) calculated using the traditional method could also be taken into account. Further, two other factors, Environment Impact Rate (EIR) and Aesthetic Impact Rate (AIR), can also be calculated and taken into account. Three types of variables are considered: (i) those variables that can be defined automatically without the need for interpretation, since they are numerical values (i.e. total bridge length (TL), number of fields (NL), maximum load (ML), maximum speed (MS)); (ii) factors such as the Environmental Impact Rate (EIR), the Aesthetic Impact Rate (AIR); these factors require formulation in order to be assessed; (iii) a linguistic converter model that converts alphabetic variables into numeric variables. In the conceptual design phase of bridges, parameters that affect the environment must be verified. This is due to the lack of detailed construction drawings, construction procedures and equipment required. Thus, the analysis in this phase is based on the estimation of the CO_2 emissions by considering the energy consumption and its effects on the environment by indirectly taking into account the amount of material used according to the equation (Eq. 6):

$$\boldsymbol{EIR}\text{i}= ANA_{Ni} + CV_{Ni} + ISW_{Ni} \qquad \textbf{[Eq. 6]}$$

where:

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

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

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

$$\rightarrow \quad ANA_{Ni} = \frac{[ANA/TBA]_i - MIN[ANA/TBA]_i}{\dfrac{MAX[ANA/TBA]_i - MIN[ANA/TBA]_i}{9}} + 1\} \qquad \textbf{[Eq.6a]}$$

$$\rightarrow \quad ISW_{Ni} = \frac{[ISW/TBA]_i - MIN[ISW/TBA]_i}{\dfrac{MAX[ISW/TBA]_i - MIN[ISW/TBA]_i}{9}} + 1\} \qquad \textbf{[Eq.6b]}$$

$$\rightarrow \quad CV_{Ni} = \frac{[CV/TBA]_i - MIN[CV/TBA]_i}{\dfrac{MAX[CV/TBA]_i - MIN[CV/TBA]_i}{9}} + 1\} \qquad \textbf{[Eq.6c]}$$

where:

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

A method using the given parameters described by the Maryland Department of Transportation (2005) is used for aesthetic evaluation. Among these parameters, the following are considered: (1) the ratio of deck span to depth; (2) the ratio of deck span to pillar height; (3) the ratio of deck depth to pillar width; (4) deck curvature in height; (5) deck elevation; (6) bridge skew angle; (7) integrity to the surrounding topography; (8) structural impression (strength through shape); (9) clear display; (10) lighting, shadows; (11) relationship to the substructure; (12) pillar dimension ratios; (13) color and textures; (14) consistency of architectural elements.

After highlighting the Factors/components, two values must be identified for each one: firstly, "I", the importance factor, rated between 1 and 10, which defines the level of importance of the respective feature for the decision-maker; and, secondly, the "V" factor, which helps to determine the harmonic state that exists between the bridge and its surroundings. For the expression of Aesthetic Impact Rate (AIR), the equation (Eq. 7) is used to check the bridge performance from an Aesthetic point view:

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

$$\longrightarrow \quad AIR = INT\left[\left(\frac{(\sum_{i=1}^{14} I_i * V_i) - 14}{1386}\right) * 9 + 1\right] \qquad \textbf{[Eq.7]}$$

where:

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

The above formula is used to categorize the results between 1 and 10, with 10 referring to the most important factor in bridge aesthetics. One of the performance criteria is aesthetic behavior from the viewpoint of public satisfaction. A questionnaire will be created to assess public satisfaction with the aesthetic appearance of existing bridges. Many aesthetically relevant features needed to be checked. The following features are examined and assessed using the questionnaire: (1) proportion and geometry; (2) environment; (3) structural harmony; (4) attention focus; (5) weathering and surface quality.

Subsequently, all public questionnaires are compiled and evaluated using a linear interpolation assumption according to equation 8 (Eq.8), in order to estimate the “AIR-PSj” for each existing bridge that contain values of between 1 and 10 (10 is assigned to the design if fully satisfied). The importance rating “I” and the value “V” are also highlighted.

$$AIR - PS_j = INT\left(\frac{\sum_{i=1}^{n} I_i * V_i}{495} * 9 + 1\right) \qquad \textbf{[Eq.8]}$$

where:

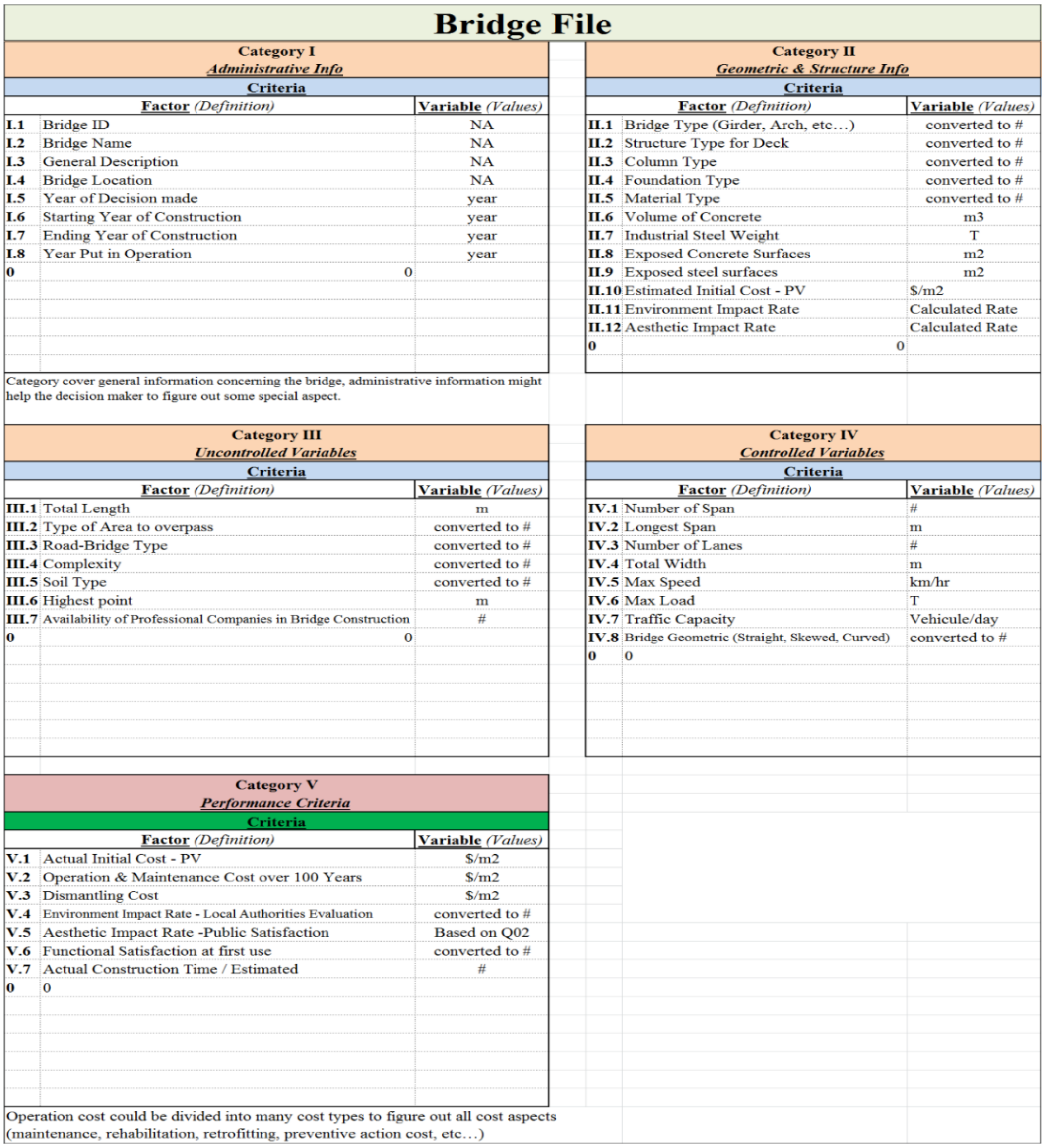
INT ( )	is the Integer Function
AIR-PS$_j$	Aesthetic Impact Rate – Public Satisfaction - Category V
j	Related to one of “m” persons investigated for a specified bridge

Then, for a specified Bridge, the “AIR-PS” is given by the equation 9 (**Eq.9)**:

$$AIR-PS = INT\left(\frac{\sum_{j=1}^{m} AIR-PS_j}{m}\right) \qquad \text{[Eq.9]}$$

where m is the number of investigated persons.

For non-numeric (linguistic) information, the data must be converted to a numeric value and used in the appropriate DSS engine. In order to convert the information about these factors into numeric values, suitable modules must be used, with each bridge type assigned a numeric value, in order to be able to use it in the DSS engine input data. Figure 5 shows a bridge file that groups five categories as previously defined. After all the necessary data has been collected from existing bridges, a unique schedule is created that covers all candidates. Statistical analysis is performed to observe the scattered data points, and tables and charts are provided to help decision-makers control their subjectivity. After drawing the appropriate diagrams between the criteria, the bridge type can be statistically defined. This method can be applied to any related project based on the variables gathered from Categories III and IV.



Bridge File

Category I
Administrative Info
Criteria

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

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

Category II
Geometric & Structure Info
Criteria

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

Category III
Uncontrolled Variables
Criteria

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

Category IV
Controlled Variables
Criteria

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

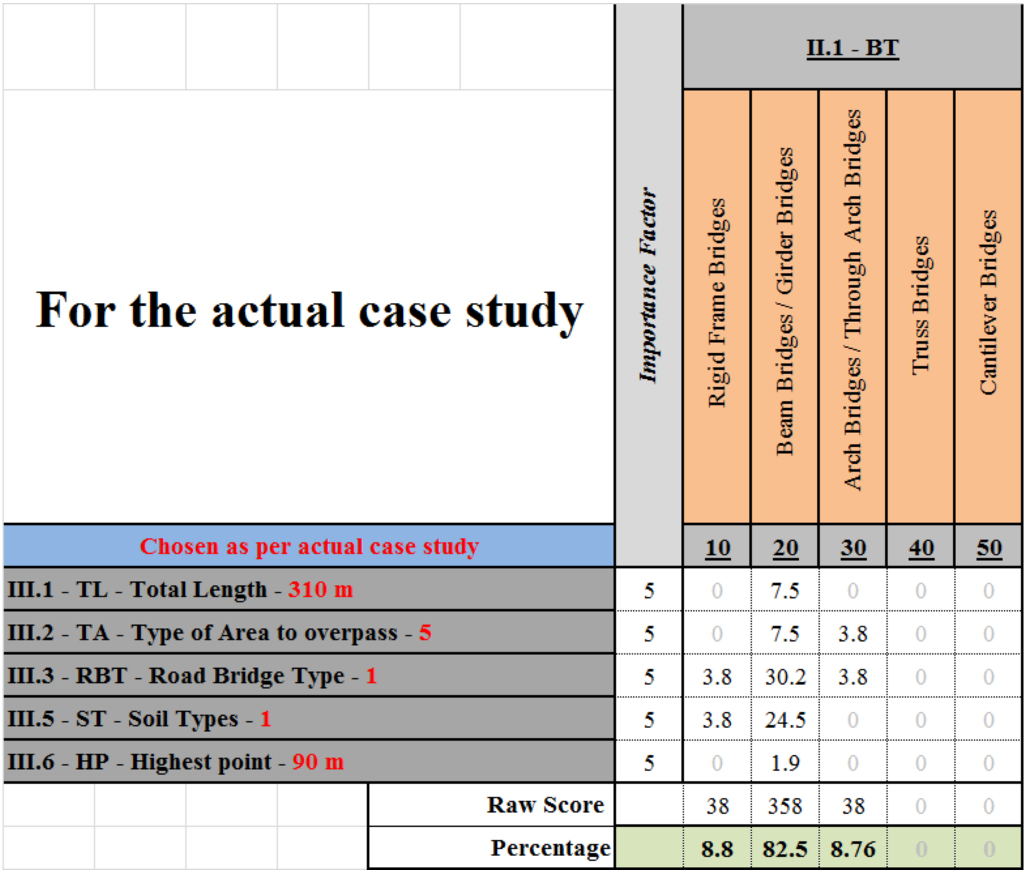
Category V
Performance Criteria
Criteria

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

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

Figure 5. Bridge ID file

Figure 6 shows the relationship between Total Bridge Length (TL), (TA), Road Bridge Type (RBT), Soil Type (ST), and Highest Point (HP), as based on the selected Bridge Type (BT). It should be noted that the values shown in Figure 6 are retrieved from the diagrams already clarified and previously created. In addition, the values shown are to be understood as guide values without any specific meaning.



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

Figure 6. Statistical definition for a bridge type

4.2 Information Modeling Tools with Conceptual Design Procedures

The benefits of using BrIM tools are extended to the bridge lifecycle. The purpose of using such software in the conceptual design phase is to reduce possible conflicts in the detailed analysis and to retrieve the required quantities for the DSS engine, which can be used for further 3D visualization options. The interoperability between these modules is semi-automatic because they come from the same product family. Adapting the software mentioned leads to the maximum benefit that can be applied from the current version. However, these unpleasant shortcomings are not major problems that can affect the use of the BrIM, since their primary function is to exchange data.

4.3 DSS Engine – Procedures and Analysis

Applying an artificial intelligence (AI) approach would have a huge impact on the goals of this research, firstly by reducing subjectivity in decision-making and, secondly, by providing a systematic methodology that offers the optimal solution for each related problem within a project. Also, since this research examines a system that behaves rationally like a human, it is important to select subsets of artificial intelligence (AI); ANN can be used. The advantage of the selected software is the Simulink option, a graphic programming environment for modeling, simulating and analyzing dynamic multidomain systems. Its primary user interface is a graphical block diagram tool and a customizable set of block libraries to make it easier to work with. On the other hand, normalization, training, validation and test sets are started automatically to provide the best solution taking into account all ANN concerns, such as avoiding overfitting and the cross-validation process. The learning process for the ANN is divided into two steps: first arrangement and final arrangement. As defined, the factors from Category I are not to be used in the direct calculation. The factors from Categories III and IV are used for the initial design of the learning process, in order to provide possible alternatives that define the factors from Category II according to the location characteristics of the new bridge project. Then, based on the factors from Categories II, III and IV, a final arrangement is made to predict the performance criteria for the new bridge to be built. The first agreement aims to provide the potential alternatives for a new bridge project defined by its characteristics (based on the location constraints). These characteristics will assess some of the variables related to the factors from Categories III and IV.

Figure 7 shows the flow diagram of this process. The data from Categories III and IV is used as input neurons, and the data from Category II is selected as target values (as output for the training process). After the training, the validation and the test, the trained ANN is used to define the possible alternatives, and after expert judgment and suggestions, the bridge types with their components (Bridge Type (BT), (CT), (DT), (FT) are defined and they are included in Category II. Then, the variables of Categories II, III and IV are defined for the new proposed bridge, which is implemented in the BrIM tool environment. From the first arrangement, the new project features are implemented for various alternatives in the BrIM environment.

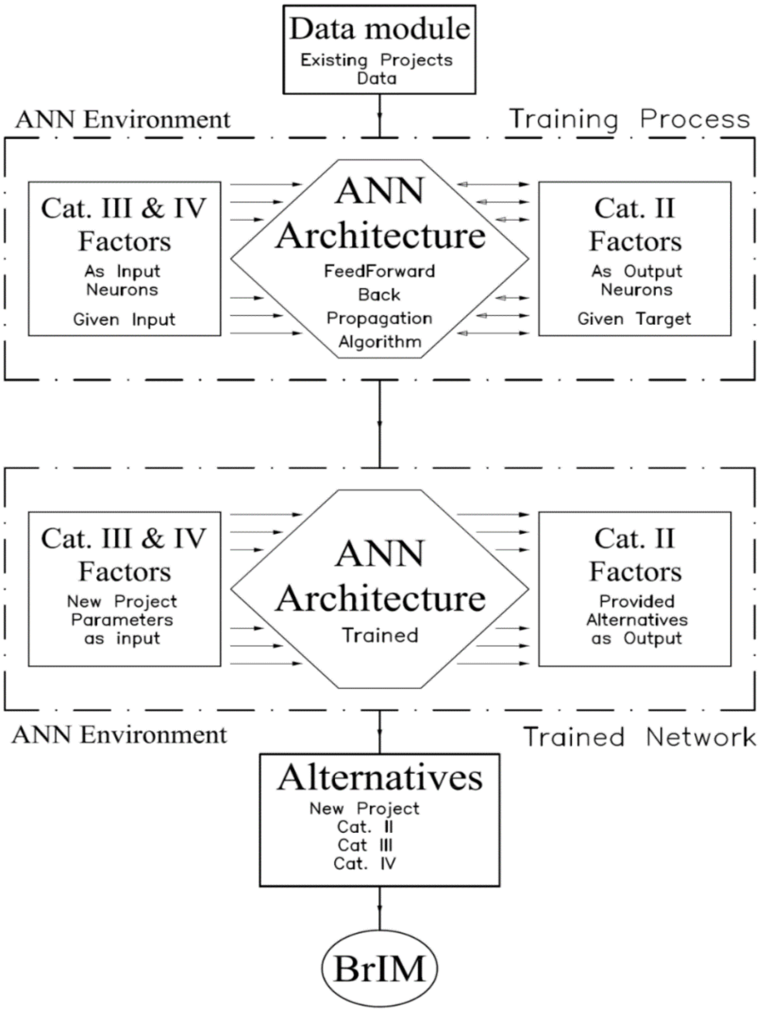


Figure 7. First arrangement flow chart

The respective flowchart is shown in Figure 8; the data are implemented into the Revit module, which geometrically interprets the elements based on an architectural perception. Then, the model is sent to Robot for preliminary design verification; the data exchange between these two modules (Revit and Robot) is based on the coordination between the architecture and structural disciplines. After the architecture and structure constraints have been compared, the final data is provided for each alternative and then transferred to the final arrangement process. Using the same procedure as in the first arrangement, an ANN must be trained based on the established data module shown in Figure 9.

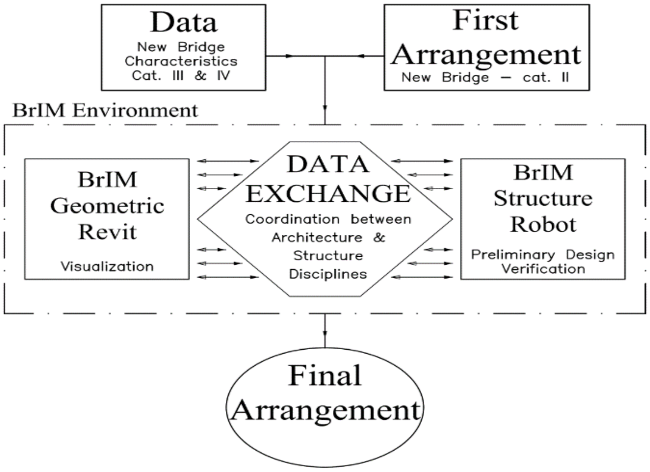


Figure 8. BrIM data interchange flow chart

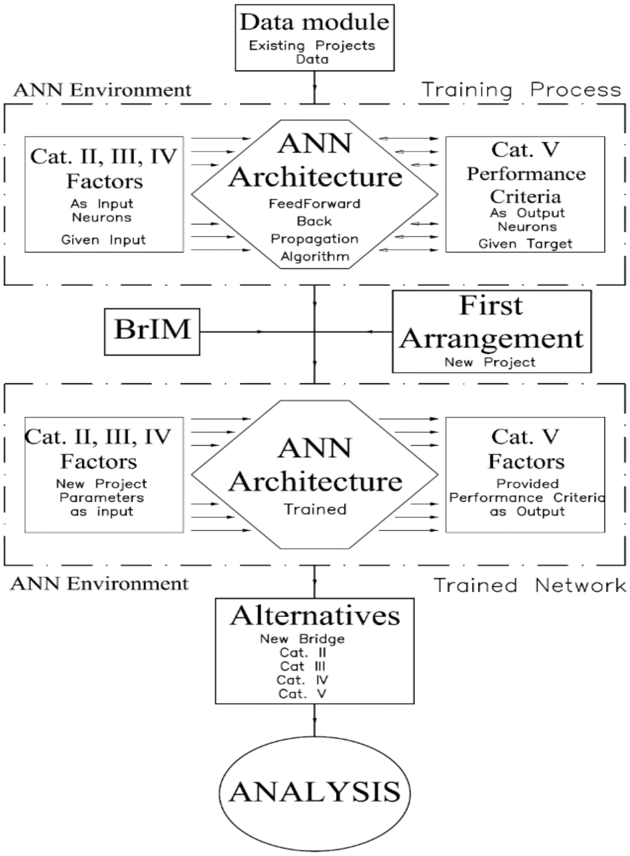


Figure 9. Final arrangement flow chart

For the training of the ANN, data from the existing projects are used, with the variables of Categories II, III and IV as input neurons, and the variables of Category V as output neurons (target values). The trained ANN is used to define the performance criteria for each alternative, with the input neurons being those of the variables from Categories II, III and IV of a new bridge project. The analysis of the results is then performed by: (1) Testing the ANN reliability and verifying many parameters from the ANN tools. The R values for the overall response should be greater than 0.95 to be in the acceptable ranges in which highlighting the influence of the parameters on the results that the ANN delivers after its training; (2) Examining the uncertainty of the results (outputs) using Sensitivity Analysis (SA) techniques, which identify the impact of each factor on each performance criterion through the final assembly network. Taking into account that the ANN is a non-linear process in terms of the output values, it is logical that the curves of the sensitivity analysis can take any shape; (3) Definition of the realistic level of results with a process of comparison between results of a proposed new method and results of an existing method that produces the same type of results, in order to assess how reliable the results provided are. All data and results from the modules and networks are collected and presented, but a final decision is still pending. For each performance criterion, the optimized value can be related to another alternative. For example, if the decision-maker is more interested in the performance criteria D1, he or she will suggest an alternative that provides an optimized value. The different values of D1-i (i = 1 to n) and so on. For this reason, a Quality Function Deployment (QFD) is proposed, in order to make an unambiguous final decision based on the importance factors (IFj) assigned to the various performance criteria and the optimized raw score value (RSi) (Eq. 11). It is important to mention that the values used in the proposed Quality Function Deployment (QFD) should be normalized (NDj-i) with a linear interpolation between 1 and 10, considering that 10 is assigned to the best scenario (and not the highest value), based on the equation (Eq. 10):

$$ND_{j-i} = \left[9 * \frac{D_{j-i} - Min(D_{j-i})}{Max(D_{j-i}) - Min(D_{j-i})} + 1 \right] \qquad [\mathbf{Eq.10}]$$

where:	j	Performance criteria indices
	m	Total number of performance criteria
	i	Alternative indices
	n	Total number of alternatives
	$D_{j\text{-}i}$	Performance criteria value
	N	Normalization symbol

Then, the raw score values are calculated based on Equation 11:

$$RS_i = \left[\sum_{j=1}^{m} IF_j * ND_{j-i} \right] \qquad [\mathbf{Eq.11}]$$

where:	IF	Importance Factor
	ND	Normalized performance criteria value
	j	Performance criteria indices
	m	Total number of performance criteria
	i	Alternative indices

5. CASE STUDY - LEBANON

5.1 Introduction

In order to validate the results based on the previously discussed methodology, a case study was undertaken to verify the proposed DSS method using a bridge project designed and planned in Lebanon.

It should be noted that Lebanon is considered an exceptional case in terms of design, tendering and other concerns that directly and indirectly affect the results and behavior of Artificial Intelligence (AI) in the analysis. Hence, it is expected that a wide variety and heterogeneity of data with differing opinions is obtained from among experts working in the Middle East.

In addition, the application of the DSS is applied to identify all kinds of inaccuracies as much as possible and to validate the proposed DSS. Congestion and traffic problems are the main reasons that have led to the construction of a new bridge to provide a direct connection between two areas and to relieve the traffic on the coastal road.

The global information regarding the new bridge to be built is:

(1) Total Length, TL = 310 m;

(2) Type of area to be crossed, TA = Valley;

(3) Road Bridge Type, RBT = non-highway;

(4) Soil Type, ST = rock;

(5) Highest Point, HP = 90m;

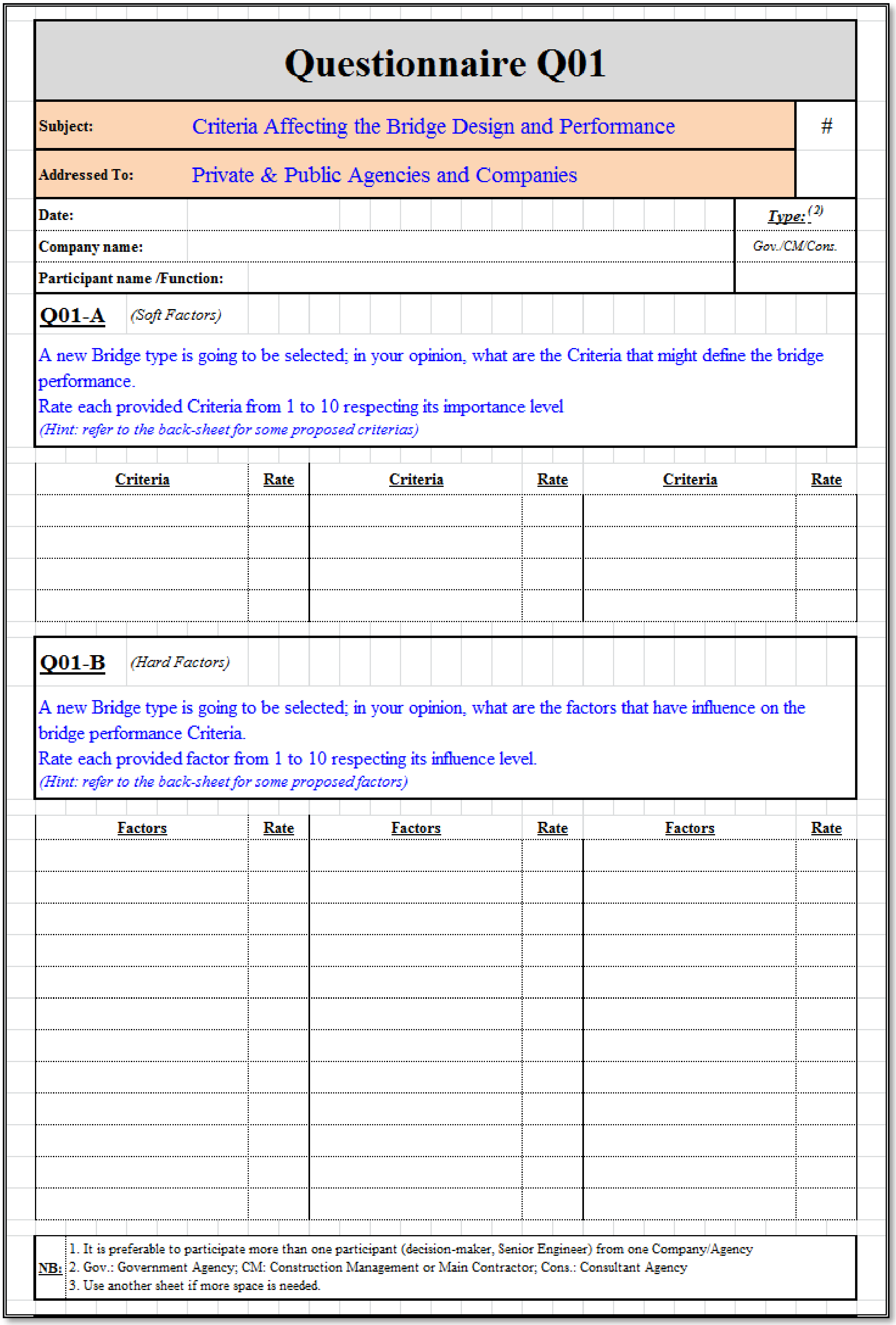
(6) Maximum Speed, MS = 50 km / h;

(7) Maximum Load, ML = 50T; (8) Traffic Capacity, TRC = 6,000 vehicles/day.

5.2 Data Collection and Analysis

A new data module was created and defined for the DSS. In order to be consistent in the analysis, social and economic constraints were also taken into account with the Q01 questionnaire (Figure 10). In order to define the criteria to be taken into account, 49 experts were interviewed and the results were summarized in a time schedule. The report was analyzed and the factors with the highest values were taken into account in the data module to be assigned for Categories III, IV & V. After defining the factors to be considered, an additional study of the project area was carried out, in order to determine the appropriate variables for the selected factors. Information for 53 existing bridges was collected and saved in a corresponding time schedule. Some of the data were collected directly; others were derived from statistical analyses and the application of defined procedures.

Questionnaire Q02 (see Figure 11) was used for data collection and later formulated to provide the previously discussed "Aesthetic Effect Rate - Public Satisfaction (AIR-PS)". In the statistical studies, the traffic was calculated for each existing bridge and saved in questionnaire Q02; later, information was transferred to the corresponding factor in Category IV (traffic capacity).



Questionnaire Q01

Subject:	Criteria Affecting the Bridge Design and Performance	#
Addressed To:	Private & Public Agencies and Companies	

Date:		***Type:*** (2)
Company name:		*Gov./CM/Cons.*
Participant name /Function:		

Q01-A *(Soft Factors)*

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

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

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

Criteria	Rate	Criteria	Rate	Criteria	Rate

Q01-B *(Hard Factors)*

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

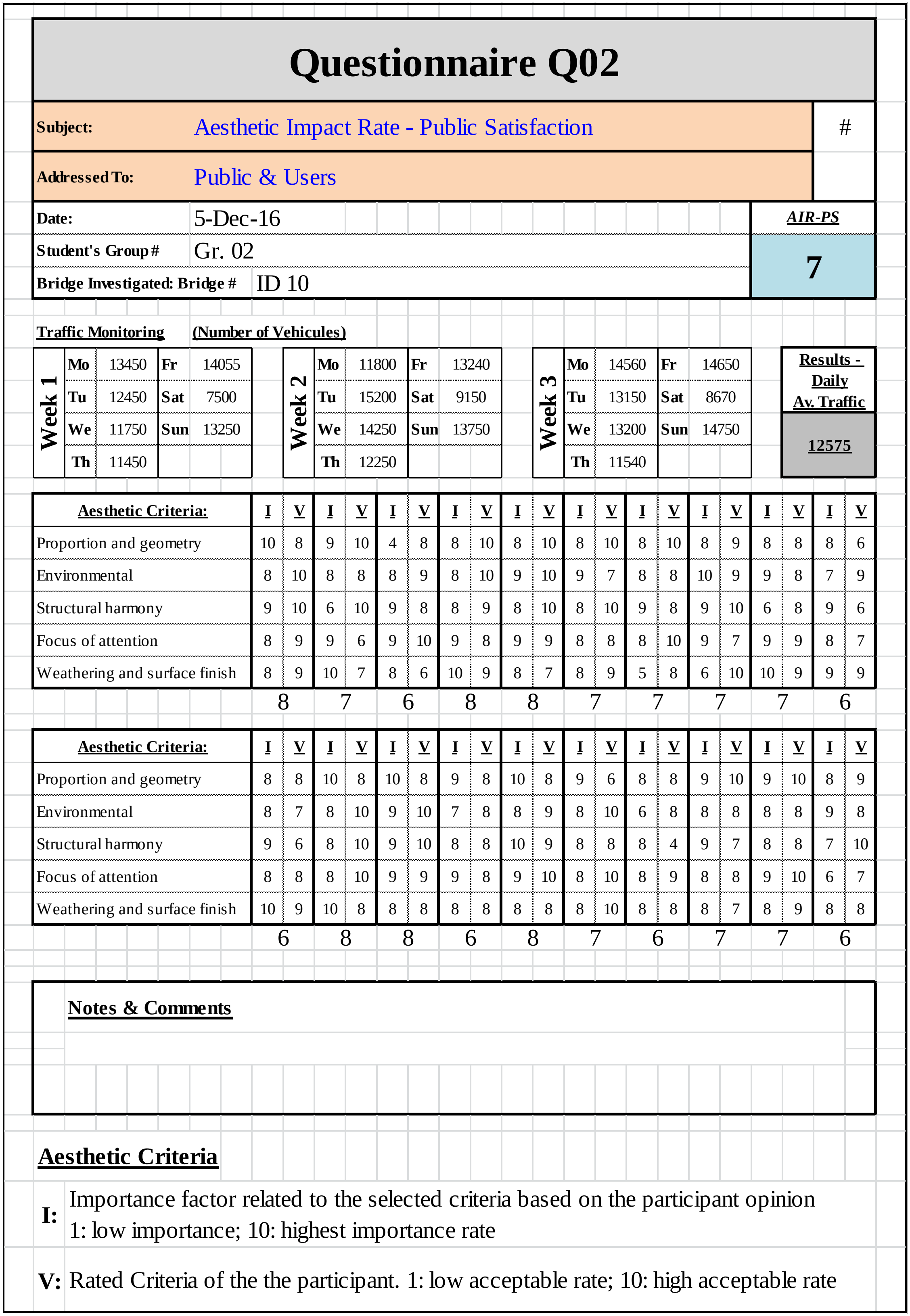
Rate each provided factor from 1 to 10 respecting its influence level.

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

Factors	Rate	Factors	Rate	Factors	Rate

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

Figure 10. Questionnaire Q01



Questionnaire Q02

Subject: Aesthetic Impact Rate - Public Satisfaction #

Addressed To: Public & Users

Date: 5-Dec-16

Student's Group # Gr. 02

Bridge Investigated: Bridge # ID 10

AIR-PS

7

Traffic Monitoring **(Number of Vehicules)**

Week 1			
Mo	13450	**Fr**	14055
Tu	12450	**Sat**	7500
We	11750	**Sun**	13250
Th	11450		

Week 2			
Mo	11800	**Fr**	13240
Tu	15200	**Sat**	9150
We	14250	**Sun**	13750
Th	12250		

Week 3			
Mo	14560	**Fr**	14650
Tu	13150	**Sat**	8670
We	13200	**Sun**	14750
Th	11540		

Results - Daily Av. Traffic

12575

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

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

Notes & Comments

Aesthetic Criteria

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

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

Figure 11. Questionnaire Q02 – Gr.02 – Bridge ID10

Public opinions were stored in questionnaire Q02 to obtain opinions on aesthetic satisfaction based on the five characteristics as noted in the previous sections. The performance criteria for the bridge aesthetics were evaluated using the [Eq. 8] and [Eq. 9]. In addition, two further variables, Environmental Impact Rate (EIR) and (b) Aesthetic Impact Rate (AIR), from Category II were also formulated and evaluated according to the equations [Eq. 6] and [Eq. 7]. The existing Bridge (# 010) required the following information to evaluate its Environmental Impact Rate (EIR) and (b) Aesthetic Impact Rate (AIR) variables:

Total Bridge Area	11,832	**TBA (m^2)**
Affected Natural Areas	3,550	**ANA (m^2)**
Total Concrete Volume	12,450	**CV (m^3)**
Total Industrial Steel Weight	0	**ISW (T)**

Using equations [Eq. 6; 6a; 6b; 6c], the Environmental Impact Rate (EIR) variable was obtained using the associated quantities that were collected during the examinations of the existing bridge (# 010). After establishing the data module, it was important to analyze its content for clarity and consistency and to find out whether it is homogeneous, heterogeneous, asymmetrical and realistic.

The goal of the first step is to define the alternatives in terms of Category II (i.e. Bridge Type (BT), (DT) and (CT)). On the basis of the criteria mentioned in Categories III and IV, a statistical analysis was carried out to link the factors (ANN nodes/weights and elements) from Categories III and IV to Category II.

Further, the statistical relationship between the Bridge Types (BT) with their Total Lengths (TL), using the data plan, showed that the bridge number of a particular bridge type is distributed according to its total length. In addition, similar relationships were established between all factors of Categories III and IV with different bridge types and linked to every other category II factor that defines the bridge components (Bridge Type (BT), (DT), (CT), (FT), (MT)). The relationship between the bridge types with "type of area to be crossed", "road bridge type (RBT)", "soil type (ST)" and "highest point (HP)" was examined.

With reference to Figure 6 and based on the various statistical analyzes of the associated graphical representations, the alternatives for a new type of bridge were defined and presented in the Quality Function Deployment (QFD) system. For the Total Length (TL) input data (row), the assigned value "7.5" was obtained by taking into account a section of the total length of between 300 and 400 m; this provided a figure of 7.5% for the given bridge type. In the same way, the values "7.5" and "3.8" regarded as statistical values as per the Type of Area to Overpass (TA) / Bridge Type (BT) diagram, the values "3.8", "30.2" and "3.8" as per the Road Bridge Type (RBT) / Bridge Type (BT) diagram, the values "3.8" and "24.5" as per the Soil Type (ST) / Bridge Type (BT) diagram and, finally, the value "1.9" as per the Highest Point (HP) / Bridge Type (BT) diagram.

It should be noted that the raw score for each bridge type candidate must be calculated based on the importance factor assigned to each influencing factor (TL, TA, RBT, ST, HP) using the following equation:

$$\text{Raw Score for } BT_I = \Sigma[\text{Importance factor} * Q_I]_J \qquad \textbf{[Eq.12]}$$

where:

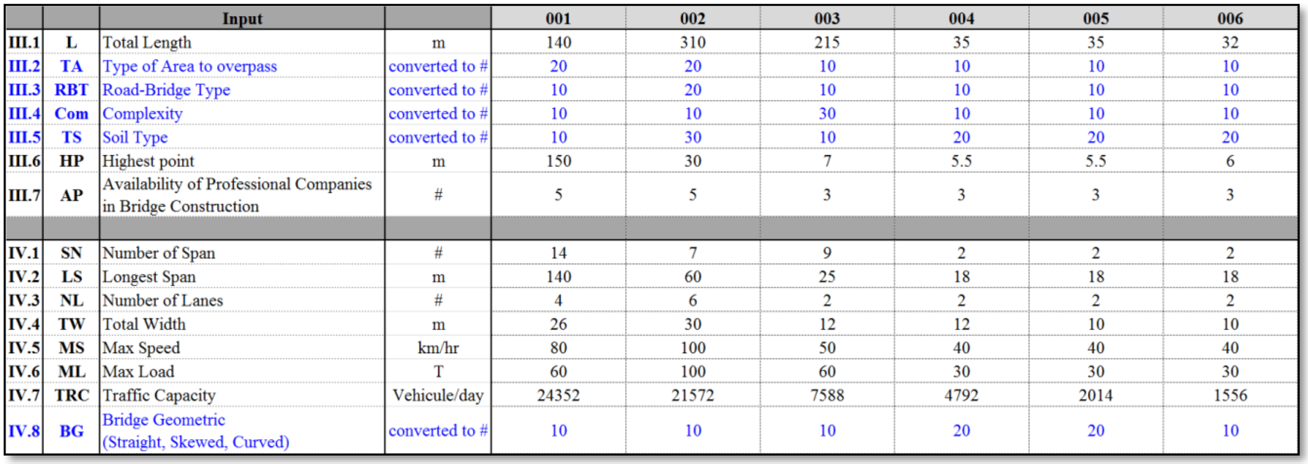
J = TL, TA, RBT, ST, HP (Influence factors considered)
I = 10, 20, 30, 40, 50 (Bridge Types)

Then, a percentage is calculated and presented in the last row.

5.3 DSS Engine and Brim

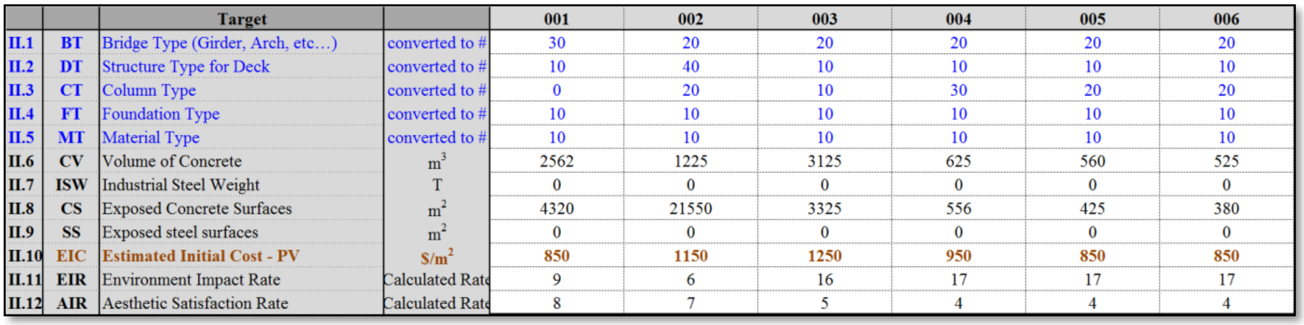
As a first arrangement and based on the retrieved data, ANN was trained according to Table 1, which represents the input data for the ANN, and Table 2, which represents the target (output) values. For the new case project, the relevant data as shown in Table 3 were used in the trained ANN to obtain the predicted results, as shown in Table 4. Based on these results, various alternatives are suggested in Table 5, which - in the final arrangement - are possible solutions. When proposing alternatives, technical judgment is emphasized as the technical aspects (geometry and structure) need to be checked, especially during the BrIM implementation phase. The BrIM implementation was done based on the suggested alternatives, and five perspectives were created using the Autodesk Revit software, and then transferred to the robot module for preliminary design reviews. Following many interpretations and work on the corresponding software, the complete data for the variables of Category II were determined; these are shown in Table 6.

Table 1 – Input data for the first arrangement (for 6 of 53 existing bridge cases)



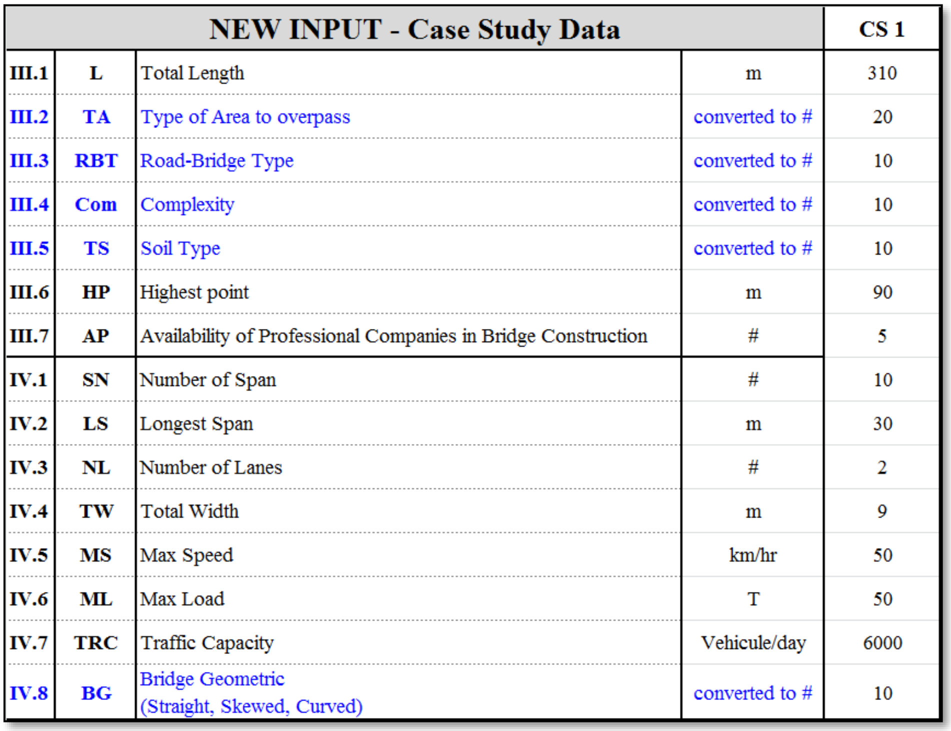
		Input		001	002	003	004	005	006
III.1	**L**	Total Length	m	140	310	215	35	35	32
III.2	**TA**	Type of Area to overpass	converted to #	20	20	10	10	10	10
III.3	**RBT**	Road-Bridge Type	converted to #	10	20	10	10	10	10
III.4	**Com**	Complexity	converted to #	10	10	30	10	10	10
III.5	**TS**	Soil Type	converted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

Table 2 – Target Data for the first arrangement (for 6 of 53 existing bridge cases)



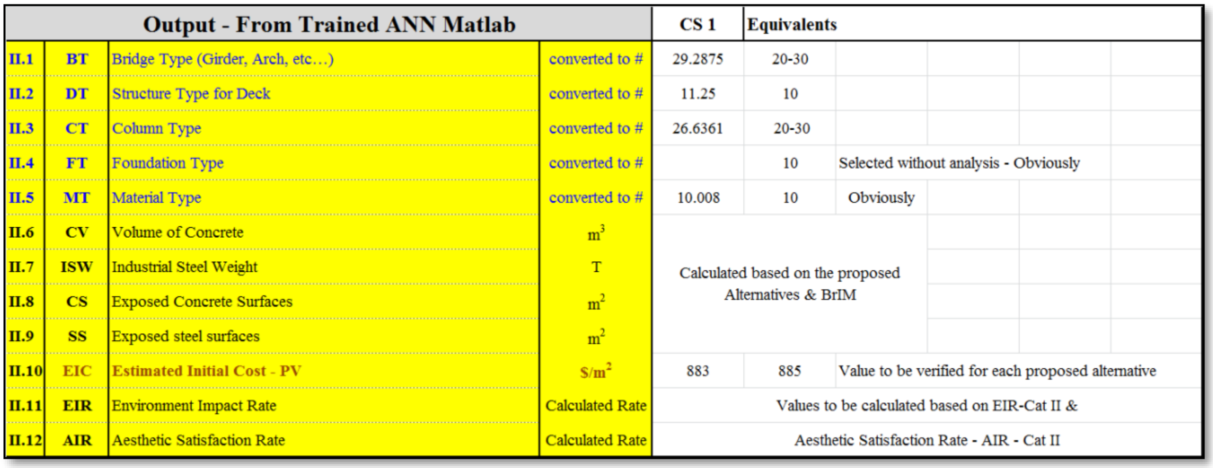
		Target		001	002	003	004	005	006
II.1	**BT**	Bridge Type (Girder, Arch, etc…)	converted to #	30	20	20	20	20	20
II.2	**DT**	Structure Type for Deck	converted to #	10	40	10	10	10	10
II.3	**CT**	Column Type	converted to #	0	20	10	30	20	20
II.4	**FT**	Foundation Type	converted to #	10	10	10	10	10	10
II.5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

Table 3 – Input data for new case project – first arrangement



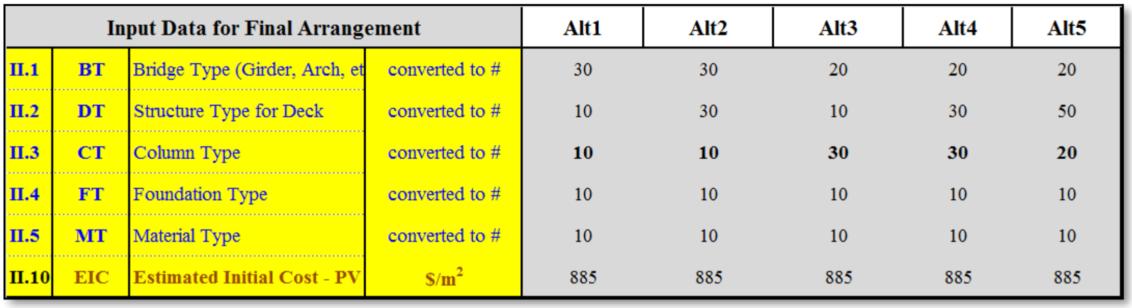
NEW INPUT - Case Study Data				CS 1
III.1	L	Total Length	m	310
III.2	TA	Type of Area to overpass	converted to #	20
III.3	RBT	Road-Bridge Type	converted to #	10
III.4	Com	Complexity	converted to #	10
III.5	TS	Soil Type	converted to #	10
III.6	HP	Highest point	m	90
III.7	AP	Availability of Professional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

Table 4 – Predicted outputs for new case project – first arrangement



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

Table 5. Proposed Alternatives for new case project – first arrangement



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

Table 6. Proposed Alternatives for new case project – Cat. II variables following BrIM implementation

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

The final arrangement is the final step of extracting and analyzing the results. In this phase, to train the corresponding ANN, the variables of Categories II, III and IV from the data module are considered as input data and the variables of Category V as target values (outputs). Tables 7 and 8 summarize some of these variables. After training the ANN, verification was carried out by testing the existing cases and the differences between the target and output values were highlighted. Table 9 shows the input values for new bridge cases (alternatives) to be examined by the trained ANN, in order to extract the performance criteria for the various alternatives. The performance criteria for the various alternatives are shown in Table 10. All necessary verifications, validations and tests were carried out, in order to assign an optimal level of reliability to the trained ANN, without ignoring that the ANN environment could lead to a certain probability of dissatisfaction and uncertainty; this required an additional analysis in relation to the sensitivity analysis and the realistic level.

5.4 Results Analysis

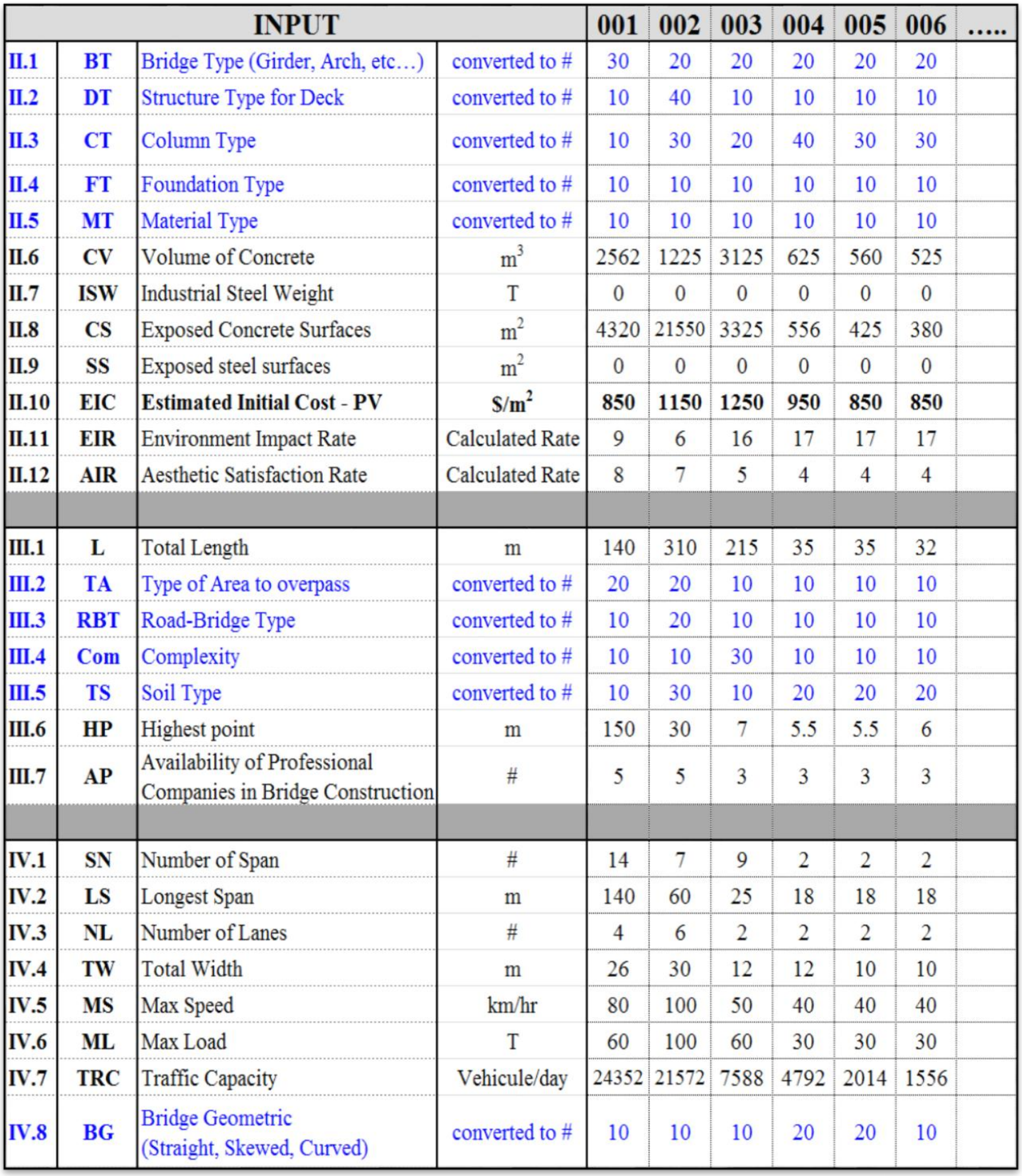
Before a final decision can be made on the basis of a systematic process, an analysis of the results is necessary, in order to understand the previous results with their possible degree of uncertainty. Therefore, for some factors, Sensitivity Analysis (SA) is an essential technique that must be used to highlight the uncertainty, and the realistic level is important to validate the extracted results.

The factors that influenced the decision were examined through interviews with the experts and then they were defined and implemented in the data module and exported to the DSS engine to make the appropriate decision. However, the level of their influence is still unclear, as is the uncertainty inherent in the values assigned to these factors.

To solve this problem, sensitivity analysis is the best tool. To do this, some factors are selected in the final arrangement to assess their impact by assigning different values and monitoring the variations in performance criteria. The selected factors to investigate are: (1) Concrete Volume, (2) Estimated Initial Cost, (3) Environmental Impact Rate, (4) Aesthetic Impact Rate, and (5) availability of professional bridge construction companies; the sensitivity analysis was only carried out for alternatives (1) and (3).

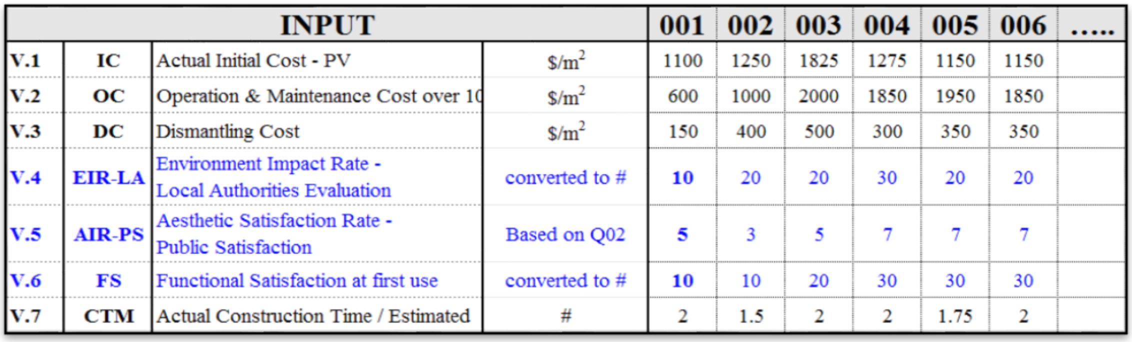
In the following, the variations of the performance criteria are presented. The fluctuations in the selected performance criteria were recorded as follows: (1) Actual acquisition costs - PV; (2) operating and maintenance costs over 100 years; (3) dismantling costs; (4) Environmental Impact Rate - assessment by local authorities; (5) Aesthetic Satisfaction Rate - Public Satisfaction; (6) first-time functional satisfaction; and (7) actual / estimated construction time.

Table 7. Input data for the final arrangement



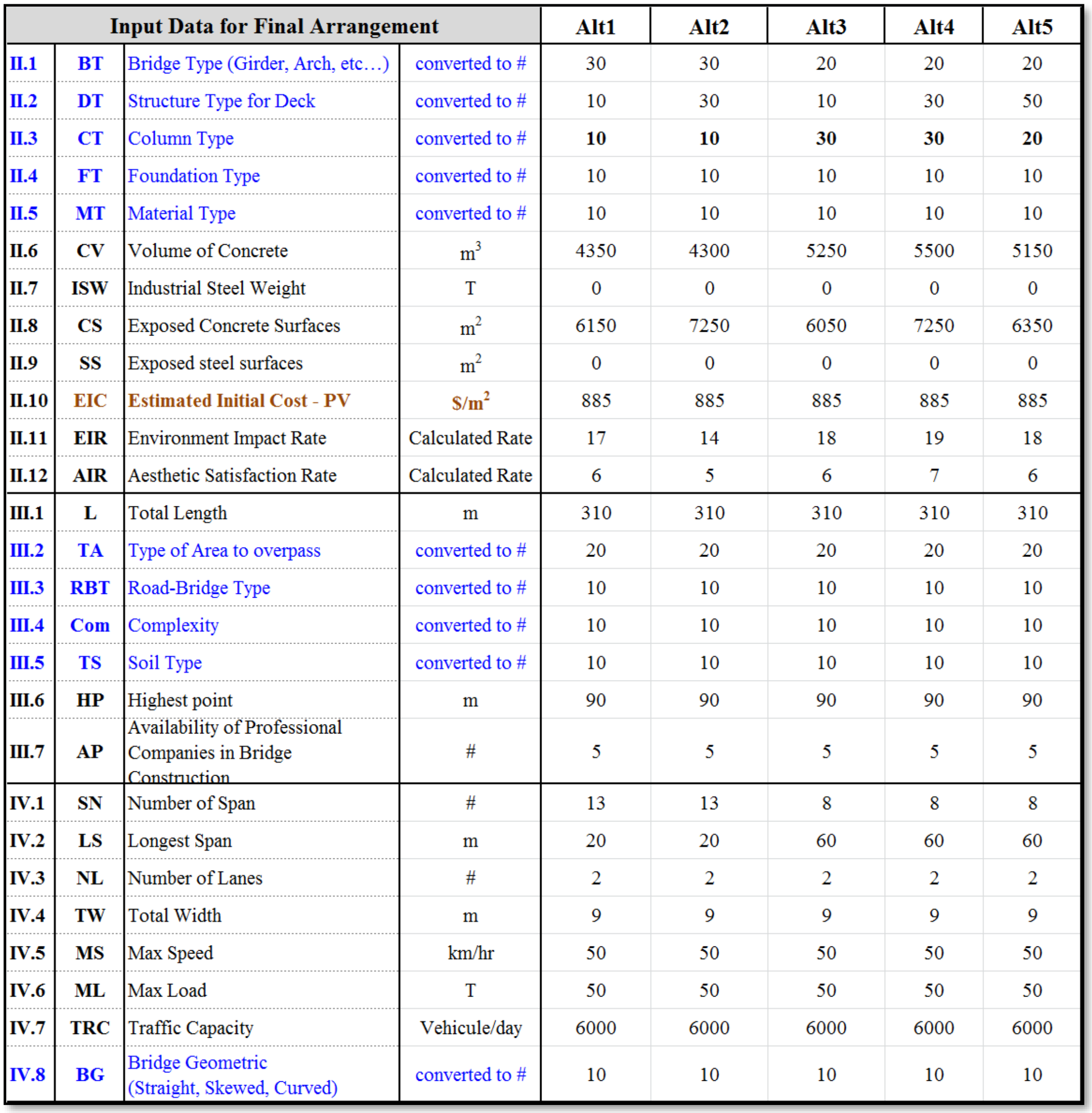
INPUT				001	002	003	004	005	006	…..
II.1	BT	Bridge Type (Girder, Arch, etc…)	converted to #	30	20	20	20	20	20	
II.2	DT	Structure Type for Deck	converted to #	10	40	10	10	10	10	
II.3	CT	Column Type	converted to #	10	30	20	40	30	30	
II.4	FT	Foundation Type	converted to #	10	10	10	10	10	10	
II.5	MT	Material Type	converted to #	10	10	10	10	10	10	
II.6	CV	Volume of Concrete	m^3	2562	1225	3125	625	560	525	
II.7	ISW	Industrial Steel Weight	T	0	0	0	0	0	0	
II.8	CS	Exposed Concrete Surfaces	m^2	4320	21550	3325	556	425	380	
II.9	SS	Exposed steel surfaces	m^2	0	0	0	0	0	0	
II.10	**EIC**	**Estimated Initial Cost - PV**	**$/m²**	**850**	**1150**	**1250**	**950**	**850**	**850**	
II.11	EIR	Environment Impact Rate	Calculated Rate	9	6	16	17	17	17	
II.12	AIR	Aesthetic Satisfaction Rate	Calculated Rate	8	7	5	4	4	4	
III.1	L	Total Length	m	140	310	215	35	35	32	
III.2	TA	Type of Area to overpass	converted to #	20	20	10	10	10	10	
III.3	RBT	Road-Bridge Type	converted to #	10	20	10	10	10	10	
III.4	Com	Complexity	converted to #	10	10	30	10	10	10	
III.5	TS	Soil Type	converted to #	10	30	10	20	20	20	
III.6	HP	Highest point	m	150	30	7	5.5	5.5	6	
III.7	AP	Availability of Professional Companies in Bridge Construction	#	5	5	3	3	3	3	
IV.1	SN	Number of Span	#	14	7	9	2	2	2	
IV.2	LS	Longest Span	m	140	60	25	18	18	18	
IV.3	NL	Number of Lanes	#	4	6	2	2	2	2	
IV.4	TW	Total Width	m	26	30	12	12	10	10	
IV.5	MS	Max Speed	km/hr	80	100	50	40	40	40	
IV.6	ML	Max Load	T	60	100	60	30	30	30	
IV.7	TRC	Traffic Capacity	Vehicule/day	24352	21572	7588	4792	2014	1556	
IV.8	BG	Bridge Geometric (Straight, Skewed, Curved)	converted to #	10	10	10	20	20	10	

Table 8. Target Data for the final arrangement



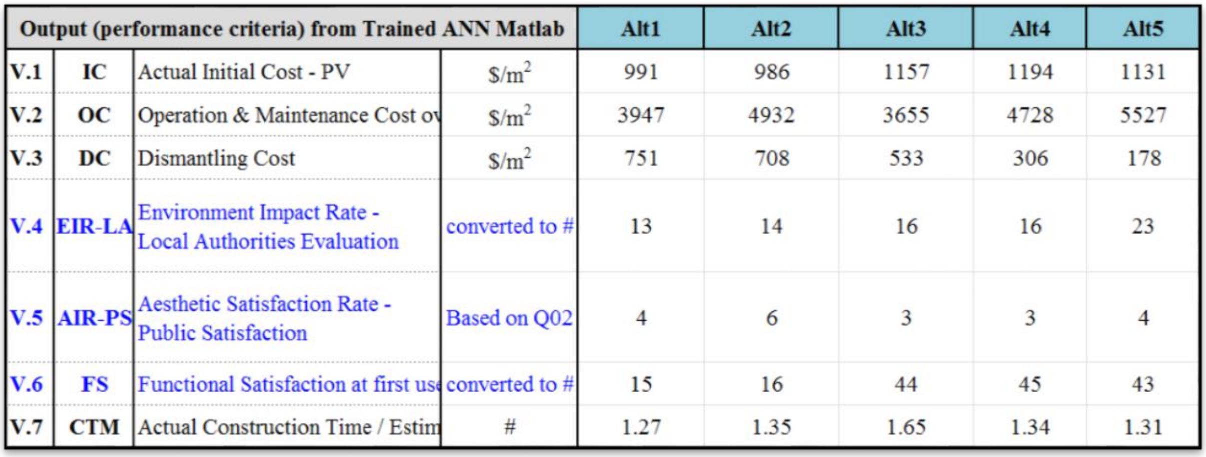
INPUT				001	002	003	004	005	006	…..
V.1	IC	Actual Initial Cost - PV	$/m^2	1100	1250	1825	1275	1150	1150	
V.2	OC	Operation & Maintenance Cost over 1	$/m^2	600	1000	2000	1850	1950	1850	
V.3	DC	Dismantling Cost	$/m^2	150	400	500	300	350	350	
V.4	EIR-LA	Environment Impact Rate - Local Authorities Evaluation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

Table 9. Input data for new case project – final arrangement



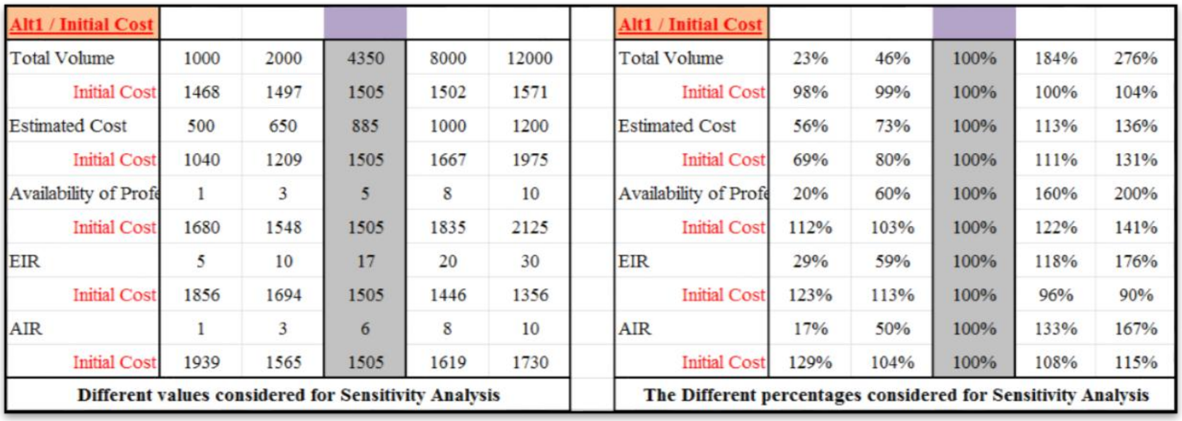
Input Data for Final Arrangement				Alt1	Alt2	Alt3	Alt4	Alt5
II.1	BT	Bridge Type (Girder, Arch, etc…)	converted to #	30	30	20	20	20
II.2	DT	Structure Type for Deck	converted to #	10	30	10	30	50
II.3	CT	Column Type	converted to #	**10**	**10**	**30**	**30**	**20**
II.4	FT	Foundation Type	converted to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

Table 10. Predicted outputs (performance criteria) for new case project case - final arrangement



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

Referring to Figure 12, a sensitivity analysis is performed on the initial cost prediction (performance criteria) by applying different values for the listed factors. For example, the projected initial cost increases as the estimated initial cost increases. With regard to the environment, it is clear that environmental protection and the forecast acquisition costs will also increase. Other factors, such as Concrete Volume, have no significant effect as their curves are either horizontal or parabolic.



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

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

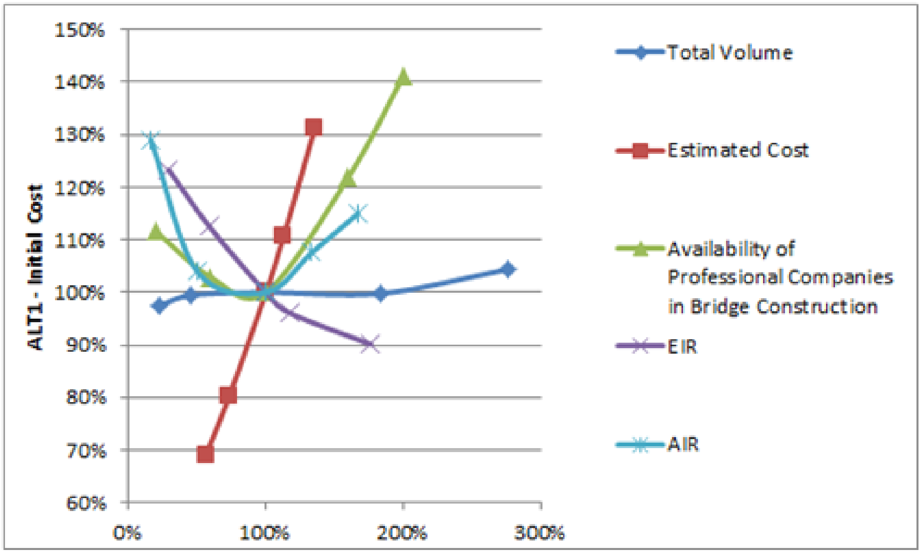


Figure 12. Sensitivity analysis for the predicted initial cost criteria

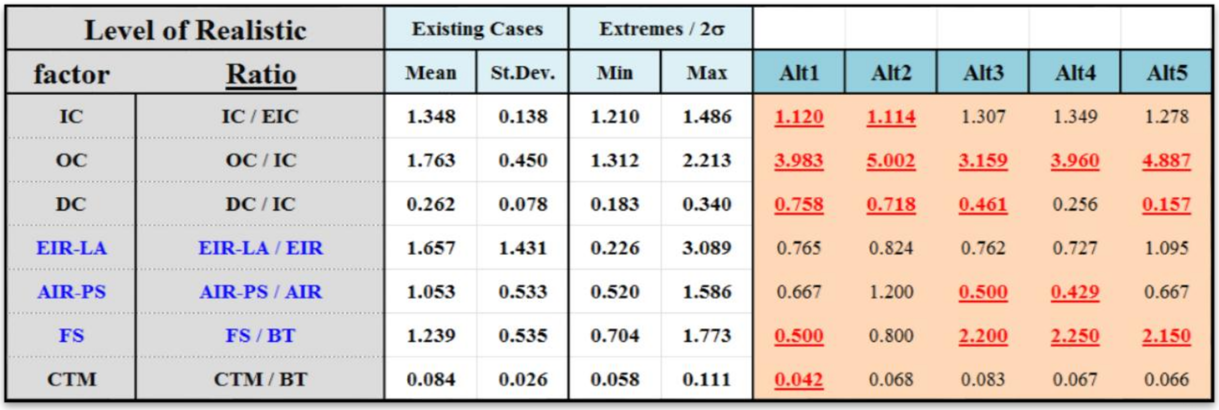
Many traditional methods may exist that provide a graphical solution to selecting an appropriate type of bridge or bridge deck, based on one or more factors. In order to assess the realistic level of the results of the methods mentioned, a comparison of the results with those of the actual DSS is carried out. What is proposed is based on the information already implemented in the data module.

It should be noted that the predicted initial cost (IC) can be compared to the estimated initial cost (EIC) by applying the following steps:

(1) calculating the mean and standard deviation for the EIC / IC ratio of the existing bridges; and
(2) comparing the new bridge ratio to the mean within a 2σ (2 times standard deviation) interval.

The same procedure is followed and compared to any predicted performance criteria for a new bridge project with some ratio. As shown in Table 11, the suggested interval for two standard deviations, some values were found to be outside the suggested interval. Another interval like the 6*sigma (6σ) adopted could be used, but the main problem is that, as it concerns the conceptual design phase, a miscalculation of up to 50% could be acceptable, as most of the values in Table 11 are within these limits.

Table 11. Realistic level



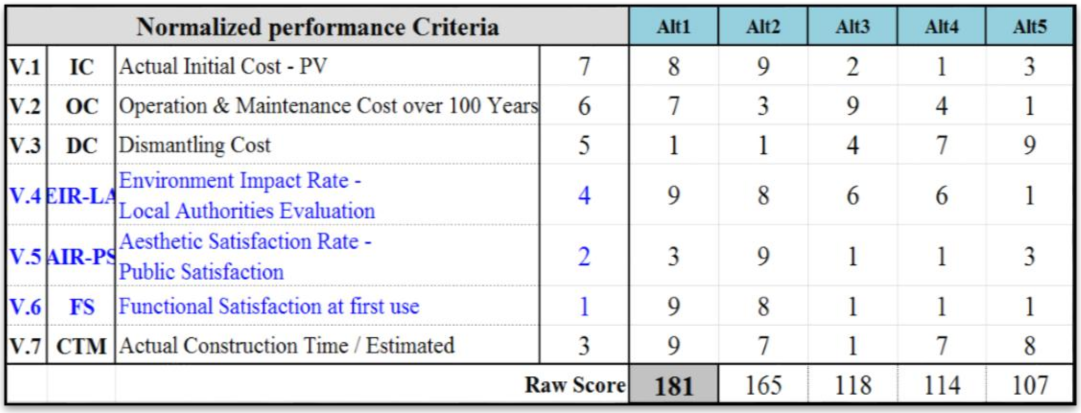
Level of Realistic		Existing Cases		Extremes / 2σ						
factor	**Ratio**	**Mean**	**St.Dev.**	**Min**	**Max**	**Alt1**	**Alt2**	**Alt3**	**Alt4**	**Alt5**
IC	IC / EIC	1.348	0.138	1.210	1.486	1.120	1.114	1.307	1.349	1.278
OC	OC / IC	1.763	0.450	1.312	2.213	3.983	5.002	3.159	3.960	4.887
DC	DC / IC	0.262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

5.5 Final Decision

After the analysis has been completed, an obvious final step in the process is required to define a definite final decision. For this purpose, a Quality Function Deployment (QFD) system using the values noted in Table 10 must be considered with an importance factor for each criterion. The latter could either be assigned by the decision-maker himself on the basis of some constraints or by reference to the priority among the performance criteria defined on the basis of the expert opinions (values related to subjectivity). The importance factor for each performance criterion is selected within the interval {1, 2, 3, 4, 5, 6, 7} (1 low importance, 7 high importance).

Table 12 calculates the raw score by applying [Eq.6] for the normalization process and [Eq.7] for the raw score values and, based on these values, an appropriate final decision (alternative) is selected.

Table 12. Factors and values considered for sensitivity analysis



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

6. CONCLUSION

This paper aimed to provide a methodology for analyzing subjectivity based on the indispensable expert opinion by providing some tools to support and, if necessary, defend your decision and link your decision to appropriate performance criteria as well as any potential alternatives to be ordered based on expert subjectivities. In this work, a pragmatic method for bridge type selection in the conceptual design phase was developed. It was aimed at: (1) reducing, controlling and emphasizing subjectivity in decision-making, and turning it into objectivity; (2) providing a clear methodology for categorizing and ranking the potential alternatives; (3) taking due account of the beneficial factors proposed by the experts; and (4) providing a systematic methodology based on data from existing projects and expert opinions. There is always bias, because the analysis is made on the basis of different opinions, but the decision-maker has to identify the principles, in order to judge the alternatives.

With regard to the DSS components, it should be noted that the data module is built using a systematic methodology based on expert opinions. Some of the advantages of the three DSS components are: (1) they provide arguments for the subjectivity of the decision maker; (2) they offer flexible and clear steps; and (3) they help accommodate any subjectivity that could be carried forward during the design process. In addition, the data analysis offers the decision-maker the possibility to recognize the degree of uniformity of the data collected. As a result, the decision-maker can see the homogeneity, heterogeneity and asymmetry of the data. Great attention is paid to the data components by disclosing all data processes and giving the decision-maker the flexibility to adapt the data module structure within a systematic methodology to the new case constraints. The properties of the ANN environment, such as the training processes, the number of neurons to be selected within the hidden layer, the checking of the relationship between the number of input neurons and the training cases under consideration, are all regarded as tasks of precision.

A considerable number of studies found in the literature have been checked for their correct work with the ANN, in particular the subject field, data types and the number of cases considered for training. Although a comprehensive analysis was performed using the ANN environment, the final verification of accuracy was due to two factors: (1) training, validation and testing processes; and (2) the level of realistic results with the aim of generalizing the errors. In fact, any technical data analysis is fraught with variability, and it is evident that the compatibility and accuracy of the results will not be 100% achieved; therefore, two aspects must be considered: 1) working in the conceptual design phase means that errors with an accuracy of up to 50% can be acceptable; and 2) the errors and accuracy are well highlighted, and any additional modifications made in the first few steps of the methodology can lead to some improvement. For BrIM tools, their roles are defined by the following objectives: (1) providing the required quantities and specifications; (2) visualizing the alternatives, in order to check how realistic the proposed alternatives are; and (3) minimizing as much as possible the modifications and adjustments that may occur during the detailed design phases. The sensitivity analysis, which was carried out at the end of this investigation, gives the decision maker a great deal of leeway in order to evaluate and evaluate well every possible decision that could be made and to identify the possible areas of error.

The notable contributions of the present research are characterized by the following: (1) the final decision is based on many factors that are defined according to the individuality of the respective site and proposed and approved by the experts who provided valuable tools that to one the appropriate decision; This task was solved in a special and critical approach on the basis of the collected data and corresponding questionnaires, in order to determine the influence of the different expert opinions in the region under study; (2) the subjectivity of decision-makers is clearly highlighted and controlled, resulting in a transparency of subjectivity arranged so that it can be compared with other opinions; where the sensitivity analysis and flexibility of the DSS result in maximum control of subjectivity; (3) the different alternatives are ranked on the basis of the importance of the performance criteria that are used to clarify the importance of each alternative; the importance of the performance criteria could differ between one decision maker and another, and this problem gives value to the DSS and can provide a way to analyze the data and provide alternatives based on different viewpoints; (4) the use of BrIM techniques is introduced in the conceptual design phase in a way that maximizes utility; this part consists of determining the life cycle costs resulting from different opinions; (5) the flexibility of the DSS mentioned enables the easy implementation of suitable models from other studies so that this DSS can be applied also to other locations by adopting the available data and technologies. Therefore, the means of DSS flexibility are presented and highlighted.

The manner in which the required data is collected has a great influence on the realism and objectivity of the results. In accordance with expert opinions, important factors are highlighted; therefore, other decision makers may agree with the results and they may be convinced by the analysis. Site characteristics has also taken into account the selected existing similar projects for the engine learning processes. The method used to analyze and manipulate this data affects the determination of its accuracy and its validity for use in the DSS. To this end, among many important concerns of this research, one of the most important is to empower the decision-maker to defend his decision, to fight for it and to convince others of his decision, which is based on a systematic methodology.

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