Expert Functions in Bridge Management Systems

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ABSTRACT

Bridge design and construction processes consist of making models of the structures and then bringing the models into reality. In Bridge Management Systems (BMS) a reverse operation is necessary, i.e., creating computer models of already existing structures. The variety of bridge constructions and complex and changeable environmental, operational and economical conditions require advanced tools making the systems intelligent by equipping them with the ability of learning, recognizing, concluding, and even choosing and achieving goals. The proposed concept of the expert functions supporting main decision processes in the Bridge Management Systems can fulfil the above mentioned requirements. The expert functions are based on data collected in the system as well as on the knowledge represented in the computer system. A prototype creator of the expert functions based on the artificial neural networks and analytic functions is described and the Bridge Evaluation Expert Function, which is being applied in the Railway Bridge Management System in Poland, is presented as a practical example of the proposed solution.

INTRODUCTION

Development of the transportation infrastructure requires a higher standard of the Bridge Management Systems. The most important trends in the BMS evolution seems to be application of the advanced methods of structures and process modeling as well as extensive knowledge representation in the systems. The proposed concept of the expert functions is trying to join both the above trends and to create intelligent, knowledge-based tools supporting decision processes in the BMS. The expert functions can be defined as software imitating intelligence in solving tasks on the basis of the data and knowledge stored in the computer memory. The paper presents the expert functions based on the artificial neural networks as well as on the hybrid networks consisting of the neural networks and analytic functions.

The proposed idea of the expert functions is based on the 10-year experience of the Bridge Group of the Wroclaw University of Technology in designing and implementation of the BMS for the General Directorate of Public Roads in Poland as well as for the Polish State Railways (*1–11*). The expert functions have also been developed in the years 1994–1998 as a part of the Research Project *Evaluation of Bridges Structures* (*12*), executed as the common project of the Wroclaw University of Technology (Poland) and the Istanbul Technical University (Turkey). The NATO Program *Science for Stability* has sponsored the project.

The idea of expert functions is also taken into account in the conception of the ECOBRIDGE (ECOnomical BRIDGE) System (*13*), which is elaborated by the Technical Subgroup Bridges (7J22) of the International Union of Railways (UIC). The main objective of the project is elaboration of a system that could be adapted by all interested railway organizations for international exchange and integration of the knowledge accumulated in the Bridge Management Systems.

APPLICATION OF EXPERT FUNCTIONS IN BMS

The general functional scheme of the Bridge Management System with expert functions is presented in Figure 1. For all types of bridge structures occurring in the BMS the following basic system functions (modules) can be distinguished:

1. *Inventory*: administrative data (structure identification, location, etc.), basic technical data (construction type, dimensions, materials, etc.), structure photos and drawings;
2. *Technical Condition & Safety*: data collected during all types of inspections (damages, need for maintenance works, estimated costs, etc.), evaluation of technical condition and safety, deterioration models;
3. *Serviceability & Operation*: service parameters of the structures (load capacity, clearance, speed limit, etc.), evaluation of serviceability and service life, important events in the life of the structure (maintenance works, collisions, etc.), administration of over-standard transports;
4. *Planning & Budget*: maintenance strategies, economic evaluation, optimization of maintenance works, short- and long-term budgeting.

The meaning of some of the above used terms here is interpreted as follows:

- Maintenance—the total technical activities keeping the structure in a good technical condition so that the structure can fulfil its functions,
- Technical condition—the conformity between designed and current technical parameters (geometry, material properties, stiffness, etc.),
- Serviceability—the conformity between current service parameters of the structure (load capacity, clearance, speed limit) and service parameters required by the users,
- Service life—the period of time during which technical condition and serviceability of the structure exceed the minimal acceptable values when routinely maintained.

Decision processes in all modules of the BMS can be supported by the expert functions. A list of the expert functions which are designed for the Railway Bridge Management System *SMOK* (*14*) illustrates the possible application area (Table 1).

EXPERT FUNCTION CREATION

Creation Procedure

Main steps of the expert function creation are presented in Figure 2. In the first step of the creation process is analysis of the problem, which should be supported by the expert

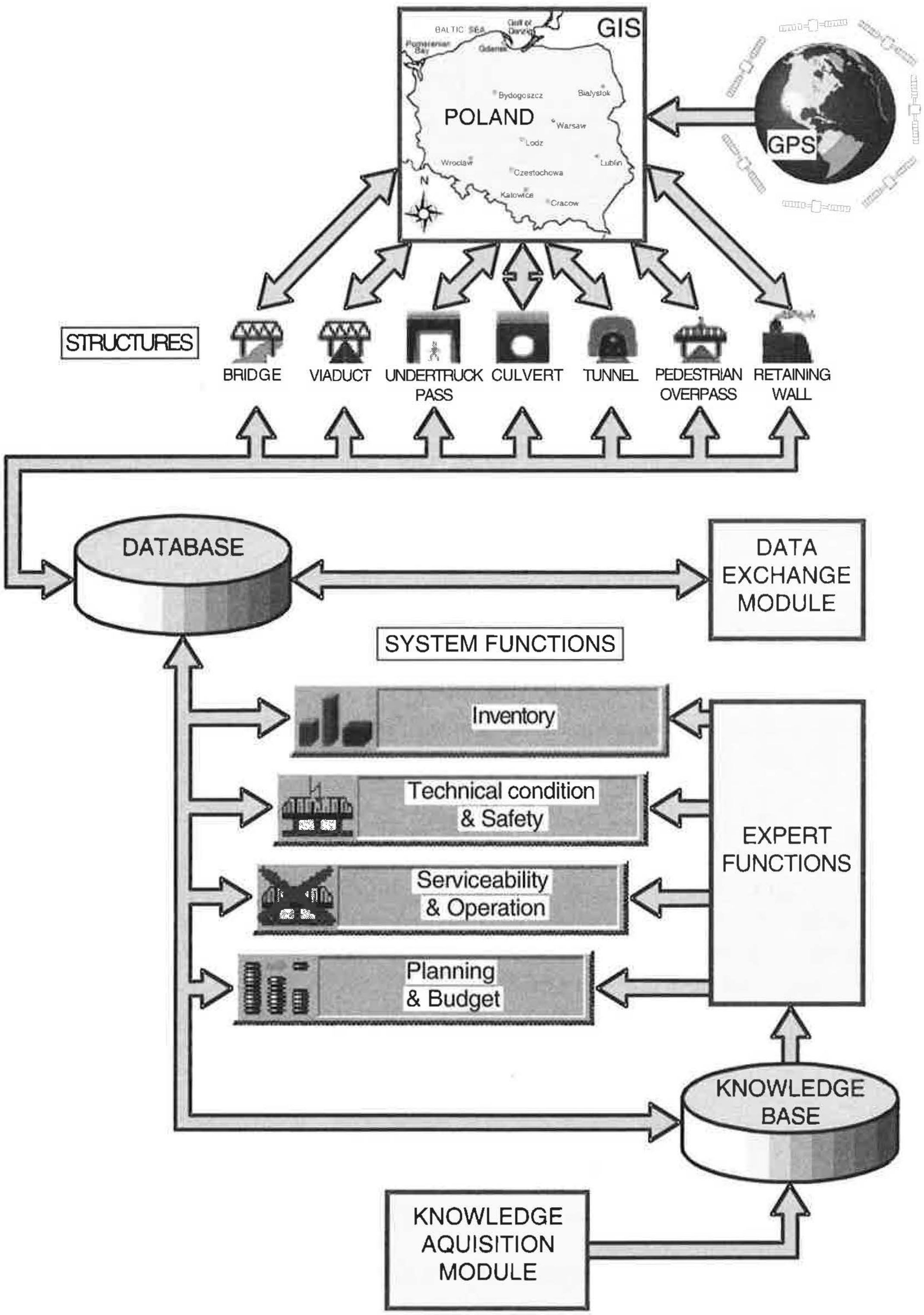

Figure 1: Architecture of the BMS with the expert functions.

Table 1: Expert Functions in the Polish Railway Bridge Management System SMOK

No.	EXPERT FUNCTION	SYSTEM FUNCTION			
		Inventory	*Technical Condition & Safety*	*Serviceability & Operation*	*Planning & Budget*
1.	Data Compatibility Expert Function (DCEF)	☒	☒	☒	☒
2.	Bridge Evaluation Expert Function (BEEF)		☒		
3.	Diagnostic Expert Function (DEF)		☒		
4.	Forecasting Expert Function (FEF)		☒	☒	
5.	Load Capacity Expert Function (LCEF)			☒	
6.	Clearance Expert Function (CEF)			☒	
7.	Serviceability Expert Function (SEF)			☒	
8.	Transport Planning Expert Function (TPEF)			☒	
9.	Rehabilitation Expert Function (REF)		☒		☒
10.	Planning Expert Function (PEF)				☒
11.	Optimisation Expert Function (OEF)				☒

function. As a result of the analysis a set of input and output parameters should be defined with respect to the selected method of problem modeling. All solutions presented in this paper are based on applications of the neural networks.

In the next step the general architecture of the expert function has to be designed. The following three main types of the expert function architecture have been analyzed:

1. A single neural network with n neurons in the input layer and p neurons in the output layer (Figure 3a),
2. A multi-level composite network consisting of the neural networks, with n neurons in the input layers of all first-level networks and with p neurons in the output layers of all last-level networks (Figure 3b),
3. A multi-level hybrid network consisting of the neural networks and analytic functions of one or several variables; the network has also n inputs and p outputs (Figure 3c).

The next steps of the creation procedure are as follows:

- Design of each component architecture—determination of network topology or definition of the analytic function,
- Training (learning) of the neural network components,
- Testing of the components.

After positive evaluation of all components the whole expert function is evaluated and its usefulness in the Bridge Management System is determined.

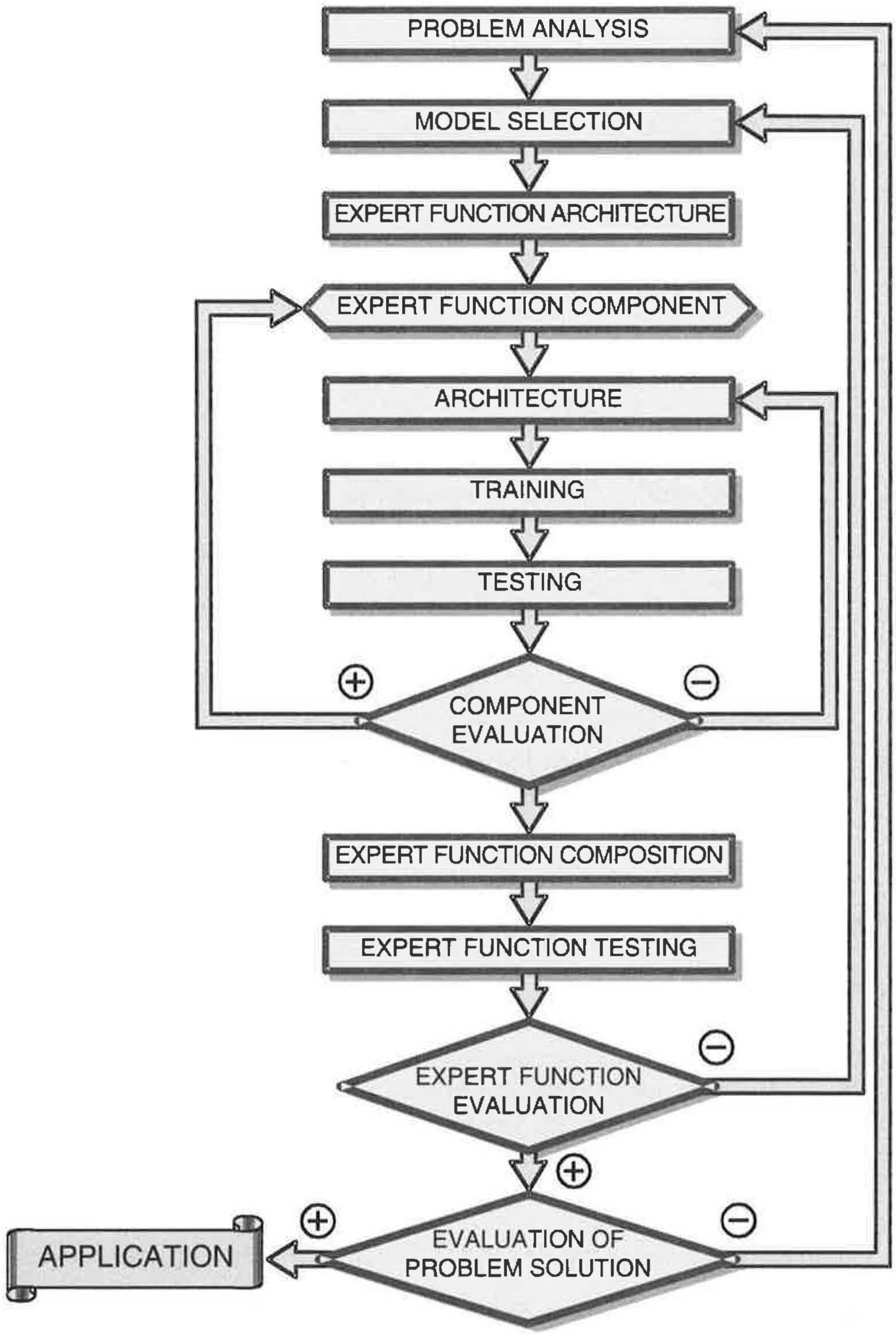

Figure 2: Creation of the expert functions based on the neural networks.

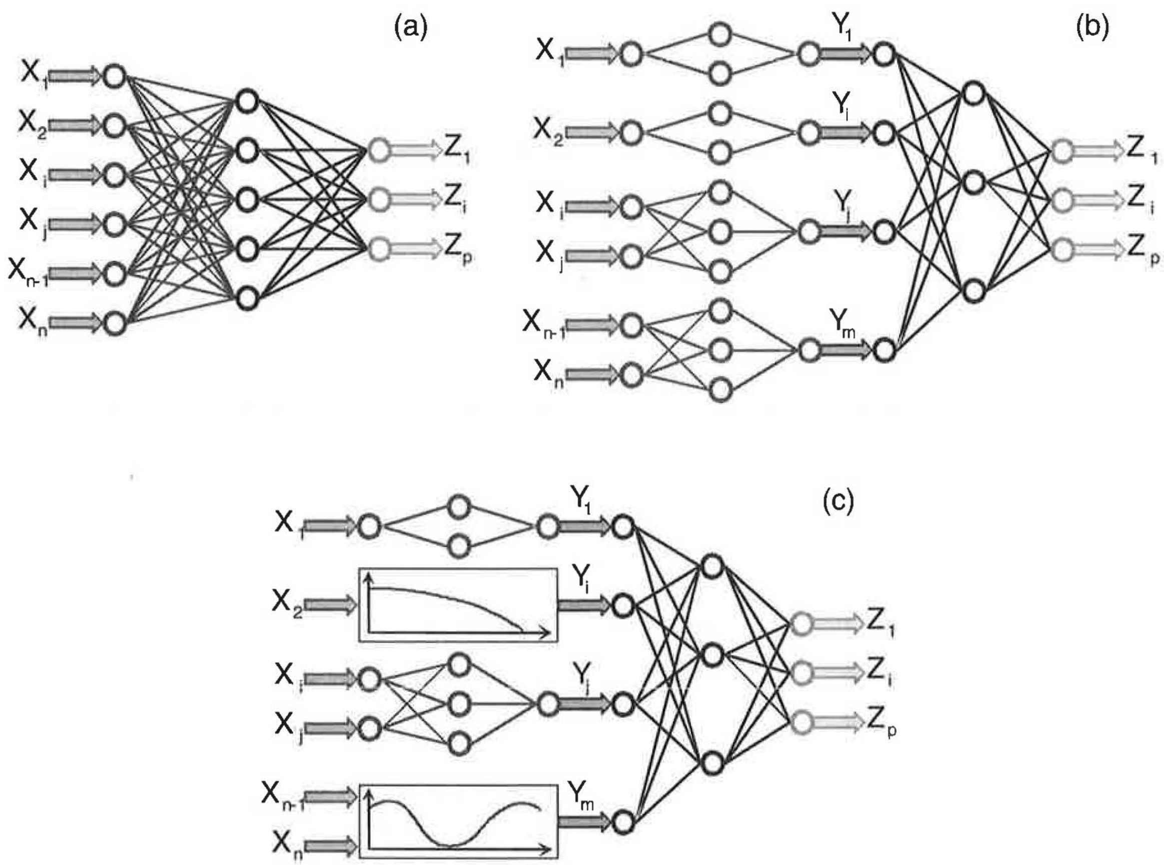

Figure 3: Analyzed types of expert functions architecture: (a) single multi-layer neural network; (b) multi-level composite network; (c) multi-level hybrid network.

The last step in the creation procedure is generation of the expert function in the form of application software with user-friendly interface.

Expert Function Wizard

For expert function construction a special software tool called the Expert Function Wizard *NEURITIS* (*15*) has been designed and implemented. The program has been coded in C++ in a WINDOWS 95/NT environment. The results of many former works concerning computer-aided bridge management and methods of knowledge representation in information systems (*1–11*) have been applied in this program. The title screen of the program is presented in Figure 4.

The functional range of the *NEURITIS* contains the following main elements:

- Cascade binding of the specialized components (neural networks and analytic functions) for modeling of complex problems that are solved by the expert functions;
- Application of special tools—Network, Function and Dictionary Galleries—supporting creation of the expert function (project) tree and the Expert Graph; the tools enable editing of the component's inputs/outputs;

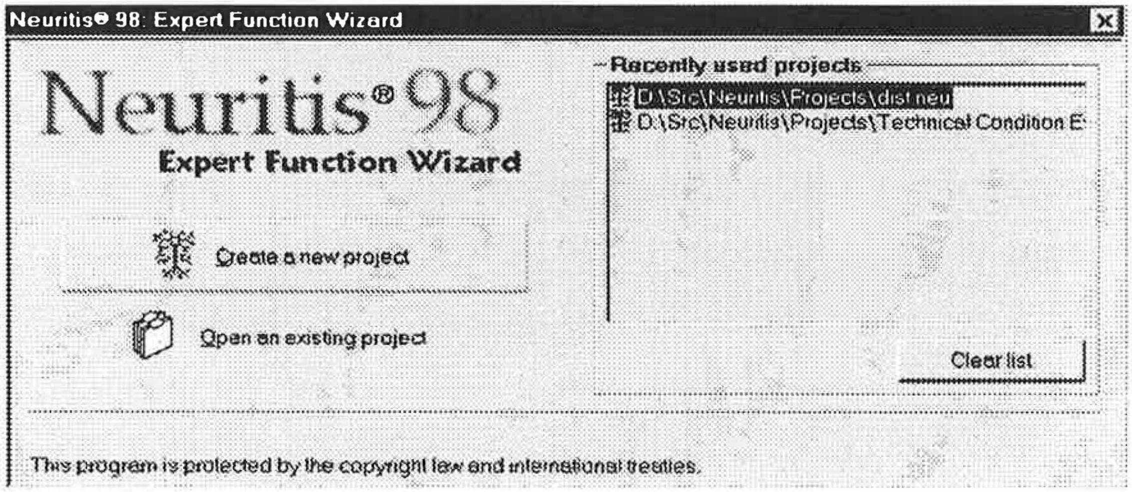

Figure 4: Expert Function Wizard NEURITIS—title screen.

- Application of an intelligent Link Editor and visual tools for presentation of the project and each type of component;
- Easy supplementing of the system with new types of components;
- Systematization of components used in the expert function by means of the universal tree structure, whose successive levels represent less and less abstractive element classes;
- Creation of the Expert Graph for any element of the tree; the Expert Graph composes "prefabricates" from the Network and Function Galleries; the possibility of attaching a graph to any level of the tree allows optimization of the component's specialization for a given abstraction level to avoid inessential details.

The primary element of a single project (expert function) is a multi-level problem tree, created preliminarily with the Project Wizard. The elements from a selected dictionary can be placed on each level of the tree. For each tree node an Expert Graph can be created. The graph can contain one or more component types: neural networks or analytic functions. In the main window's caption there are placed: system and current project information, menus and toolbars. Beneath lies a project workspace, divided into the tree view and the graph view (Figure 5).

The tree view is functionally compatible with a standard Microsoft® Windows™ tree control (contracting, expanding, sorting, etc.). Selecting a tree element causes its attached Expert Graph to be displayed in the graph view. Graphs can be presented in either graphical or tabular view, according to the user's needs. Additionally, a context menu can be viewed for each element of a tree by pressing the right mouse button on it.

In the graphical view, networks and functions are treated as linked objects. The user can display their icons, descriptions, links and graph layer borders. Individual objects can be processed by means of context menu or edition window shown after selecting an object. In the tabular view, inputs and outputs of the components are arranged alternately and sorted by layers (Figure 6).

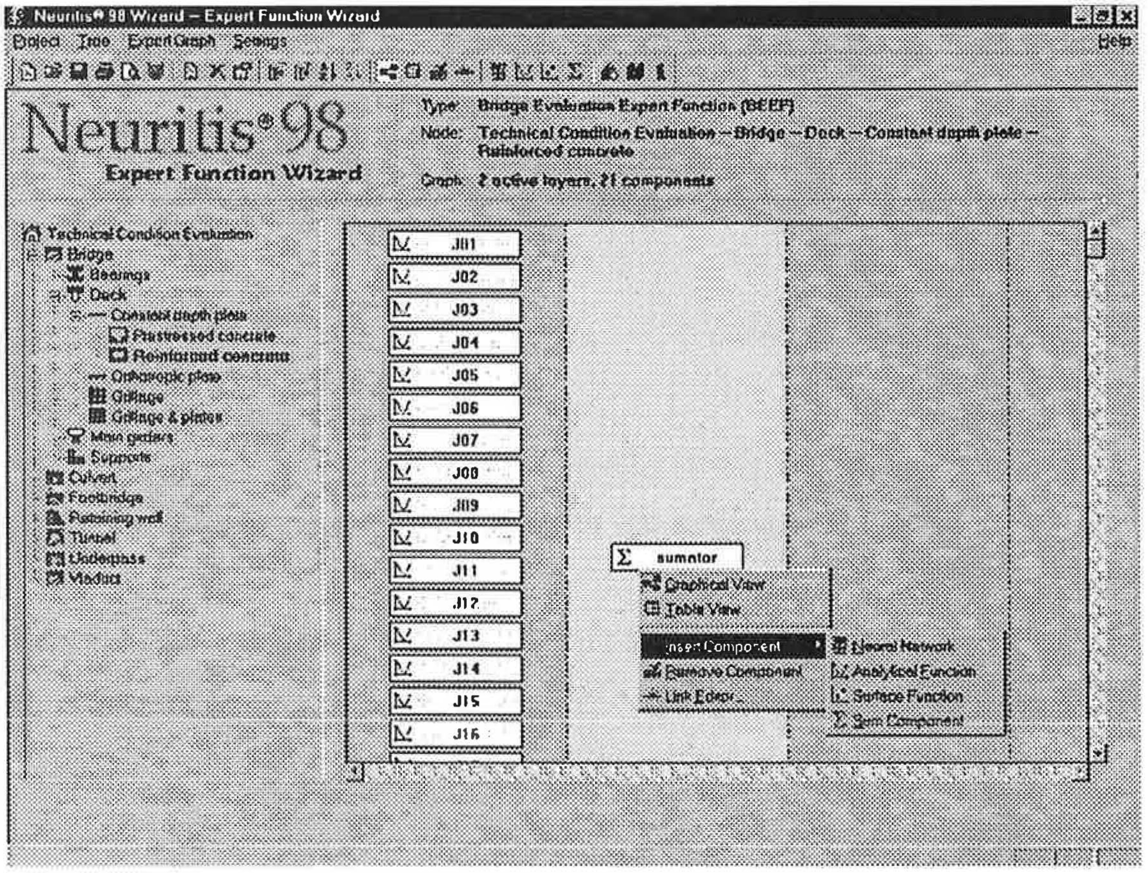

Figure 5: NEURITIS—view of the Expert Graph.

BRIDGE EVALUATION EXPERT FUNCTION

Evaluation of Technical Condition

The Bridge Evaluation Expert Function (BEEF) is an example of the general idea presented above. This expert function is dedicated to the evaluation of the technical condition of bridge structure elements in the Polish Railway Bridge Management System *SMOK* (*6,7,10,14*). The function supports a structure technical condition evaluation based on the visual observations during the basic inspections. The Technical Condition Index (TCI) describes the technical condition of each element, taking into account damages of the element. The range of the TCI is from 5.00 (very good condition) to 0.00 (element failure).

The evaluation procedure is based on the damage data collected during the inspections and therefore a uniform system of damage classification and identification has to be ensured. In the presented application an individual *List of damages* has been defined for each existing combination of the following parameters:

- Type of the structure (bridge, viaduct, culvert, underpass, retaining wall, etc.),
- Type of the structure element (support, main girder, deck, etc.),

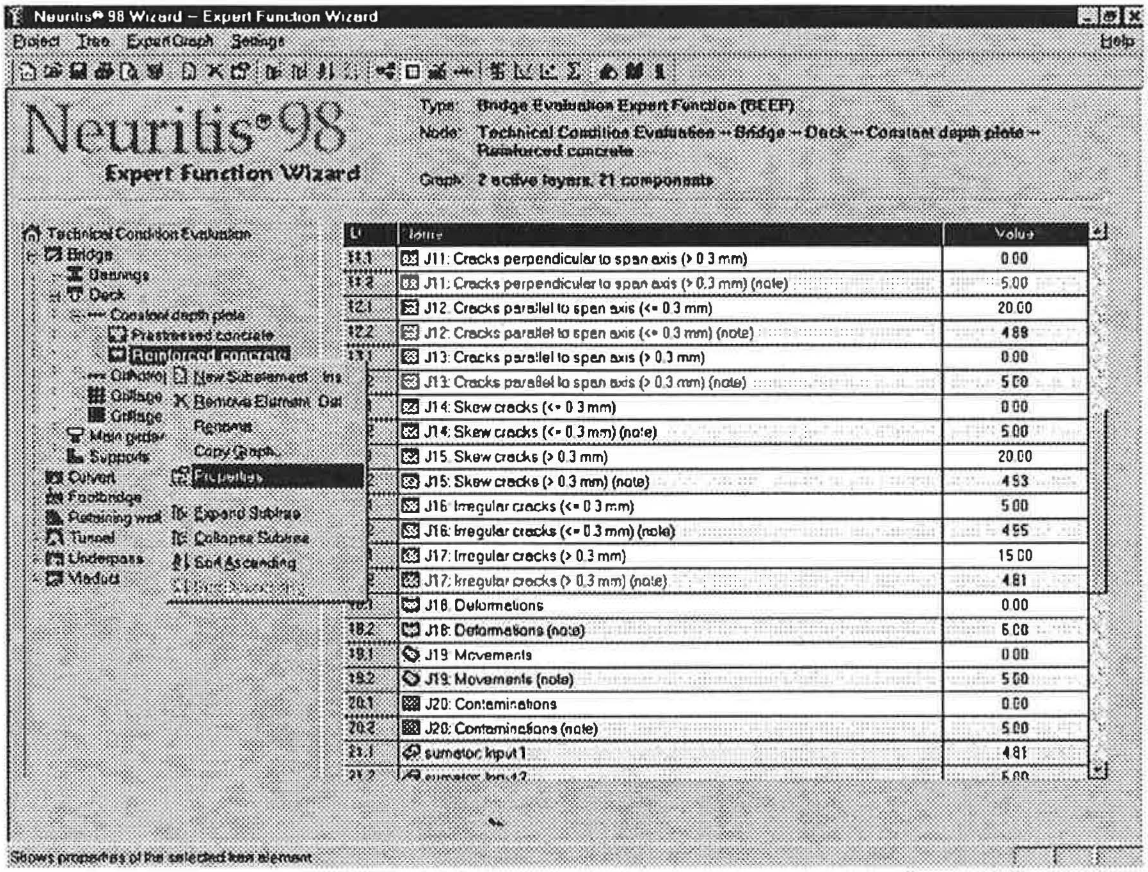

Figure 6: NEURITIS—tabular view of the Expert Function architecture.

- Type of the material (steel, reinforced concrete, prestressed concrete, stone, etc.),
- Type of the construction (plate girder, box girder, etc.).

It gives altogether about 200 individual *Lists of damages*. As a consequence for each *List of damages* an individualized version of the Bridge Evaluation Expert Function is needed. To ensure more precise identification of the damages in the system the *Bridge Damage Album* (*16*) has been elaborated for the users of the Bridge Management System. The *Album* consists of a printed manual and a CD with about 1000 photographs of bridge structure damages.

Damage Classification and Identification

Application of the expert function needs unification of damage classification and damage description within the BMS. In the Railway Bridge Management System *SMOK*, the following main classes of damages are distinguished:

- Damages of surface protection,
- Material destruction,

- Losses of material,
- Cracks,
- Fractures,
- Deformations,
- Movements,
- Contamination.

The main classes can be divided into subclasses, e.g., class: *cracks* can contain subclasses: *vertical cracks*, *horizontal cracks*, etc.

Basic parameters describing the damage are as follows:

- Type of damage,
- Damage location,
- Damage intensity,
- Damage extent.

In the presented version of the Bridge Evaluation Expert Function three of the above parameters are used to define the *Lists of damages*. For example: type of damage—*vertical cracks*, damage location—*support No. 1*, damage intensity—*crack width < 3 mm*. Uniform rules of the damage type identification and the damage intensity description are described in the *Bridge Damage Album*. An example is presented in Figure 7.

For each type of damage detected in the evaluated structure element an extent of the damage should be given as input data. How to define the damage extent is described in the *Bridge Damage Catalogue* (*17*). Figure 8 presents one page from the *Catalogue* illustrating the definition of the material deterioration extent for a massive concrete bridge support.

BEEF Application

The presented version of the BEEF is built as a multi-level composite neural network (see Figure 3*b*). Each component of the network is a three-layer perceptron trained by means of the back-propagation method. For training and testing the neural networks have used data from two sources:

- An expert elicitation process where the data is derived from experienced engineers (bridge inspectors);
- Analysis of historical data gathered during the inspections.

In the SMOK system the BEEF can be activated:

- In the context mode—when the function is called from a selected element of bridge structure—the parameters of damages are automatically written by the BEEF from the data base and the Technical Condition Index is proposed;

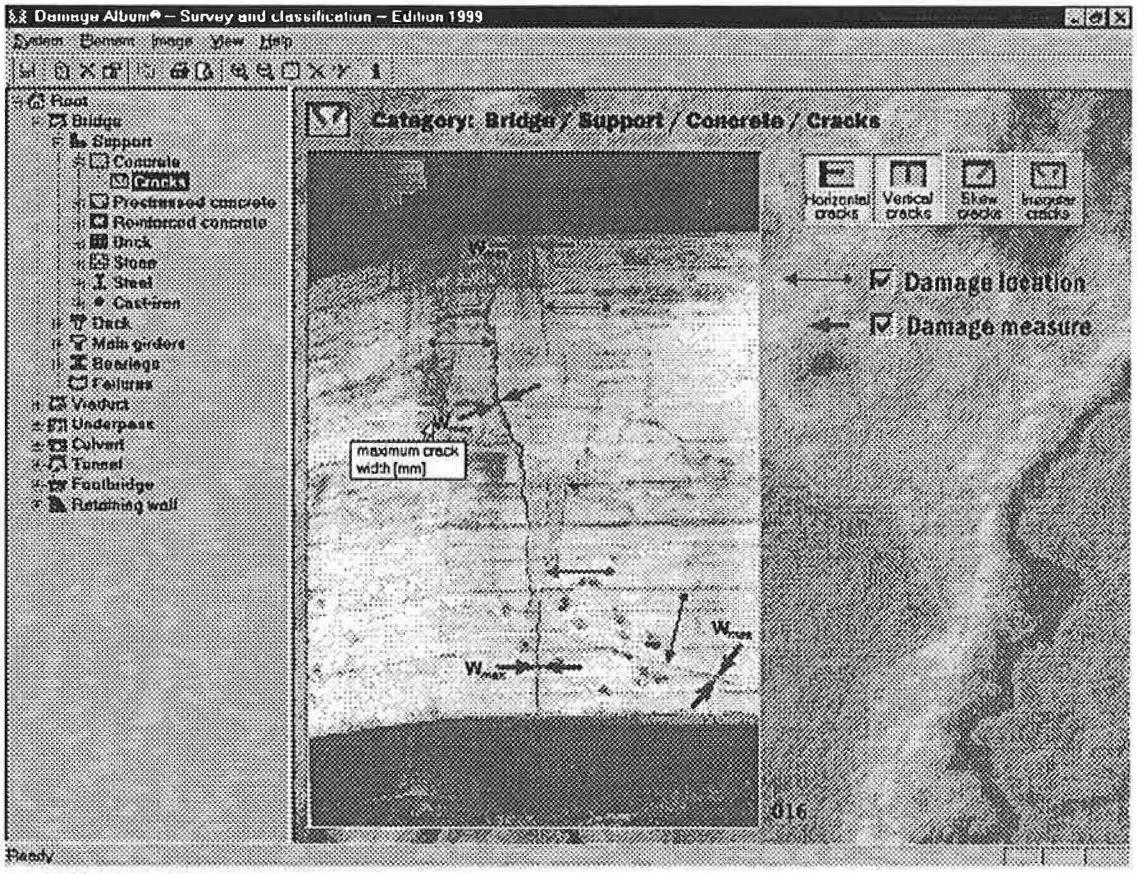

Figure 7: Bridge Damage Album—example of the damage identification.

- In the non-context mode—when the function is called independently—first the type of bridge structure, element, material and construction must be selected and in the next step the parameters of damages have to be described for evaluation of the Technical Condition Index.

The functional scheme of the technical condition evaluation by means of the BEEF is presented in Figure 9. Taking into account the inventory data, the system selects the proper part of the expert function, and on the basis of the described damages, the Technical Condition Index (TCI) for the element is defined (Figure 10). The Technical Condition Vector (TCV) contains the TCI of all elements and characterizes the technical condition of the whole structure.

CONCLUSIONS

The main purpose of the expert functions presented in this paper is to provide users of the Bridge Management Systems a friendly support for decisions undertaken in the management process. The proposed solution enables easy composition of data and

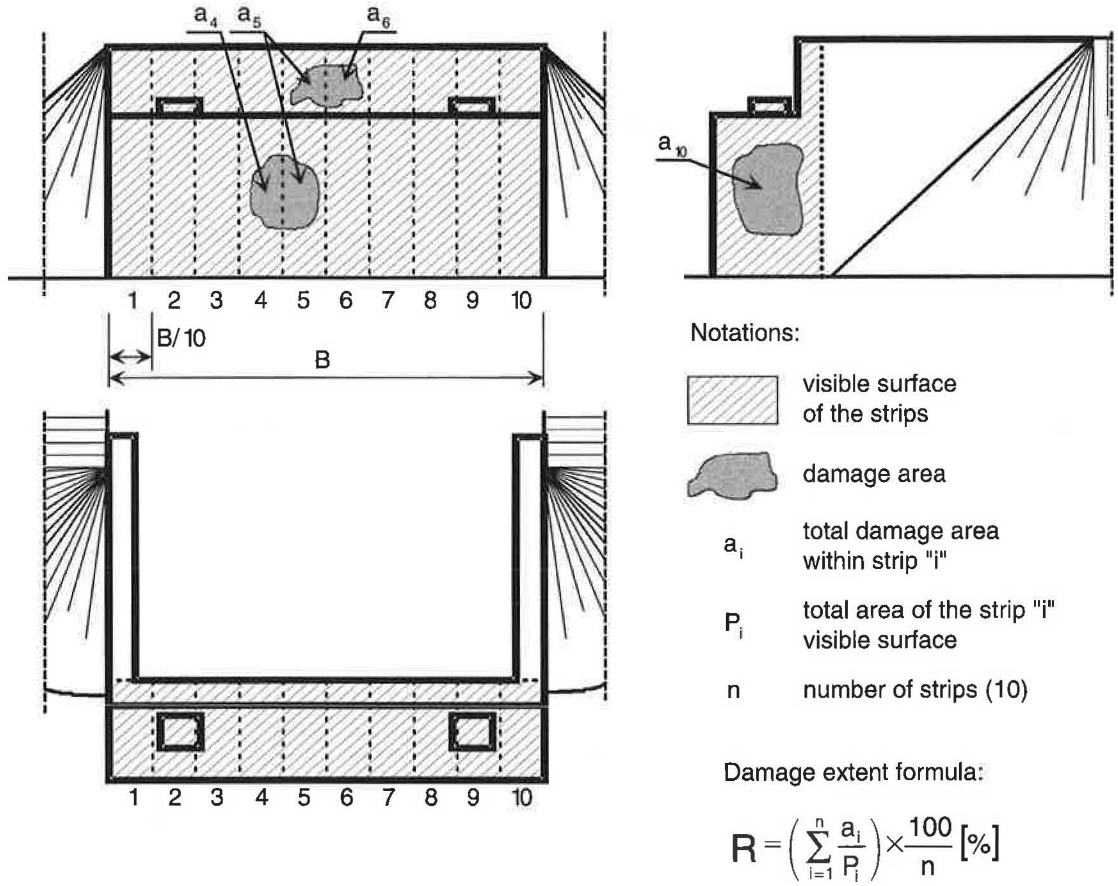

Figure 8: Bridge Damage Catalogue—example of the damage extent description.

knowledge accumulated in the BMS and ensures uniformity of the decision procedures within the whole system. Utilization of the expert functions requires minimal computer knowledge and is easily operable. It enables even the users with limited knowledge and experience to analyze and solve successfully complex bridge engineering problems.

On the contrary the expert functions creation requires very wide experience in knowledge acquisition and representation in the computer systems as well as a versatile bridge engineering and economic knowledge. A presented prototype of the Expert Function Wizard demonstrates high effectiveness in design and implementation of the functions. First applications (e.g., the Bridge Evaluation Expert Function) have shown a considerable potential in the multi-level composite and hybrid networks. Development of the prototype should be provided by integration of tools for dealing with information on different levels of uncertainty.

Current works to create a more comprehensive system of expert functions include application of fuzzy logic components, implementation of graphical input and development of self-modification mechanisms.

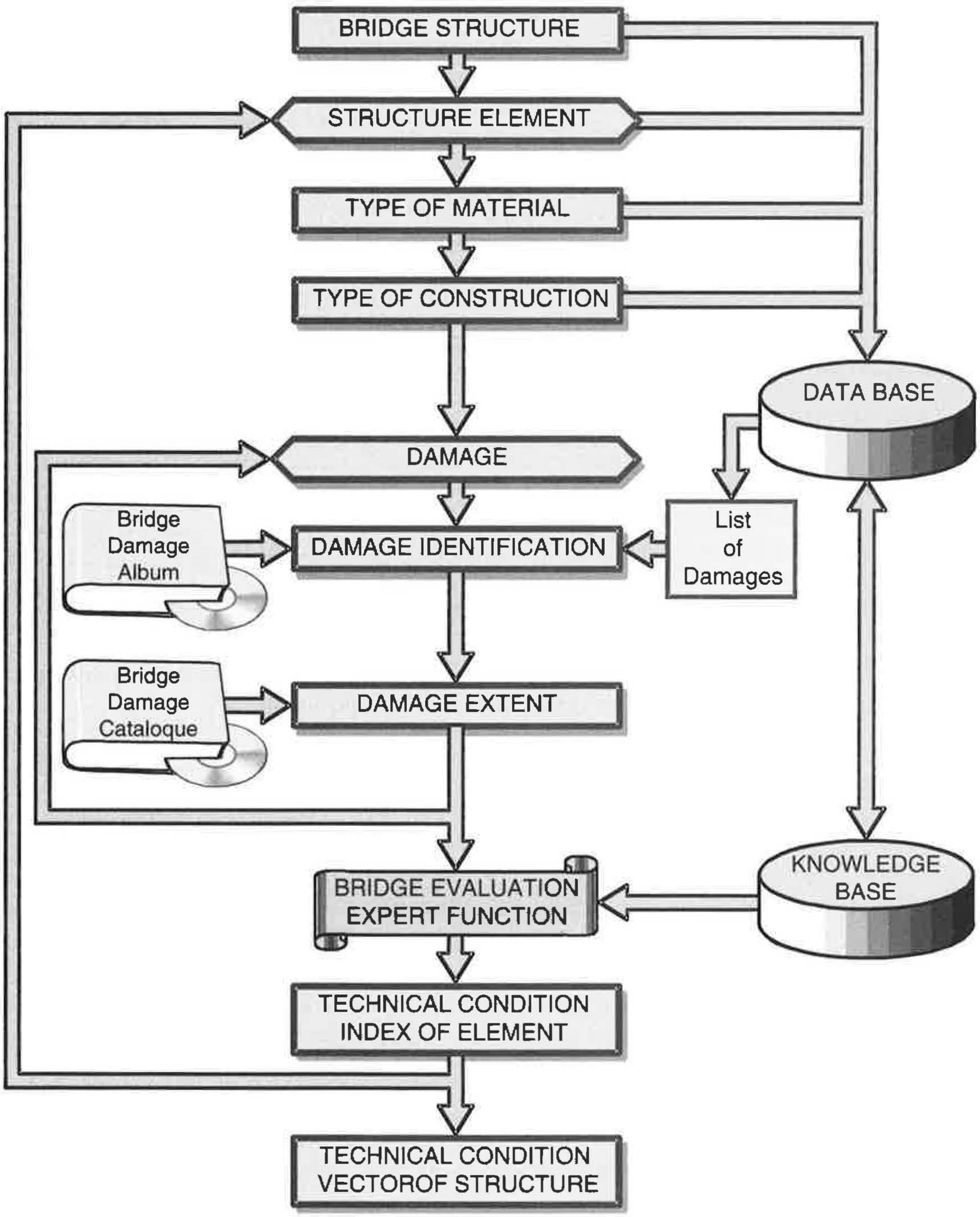

Figure 9: Functional scheme of bridge technical condition evaluation by means of the BEEF.

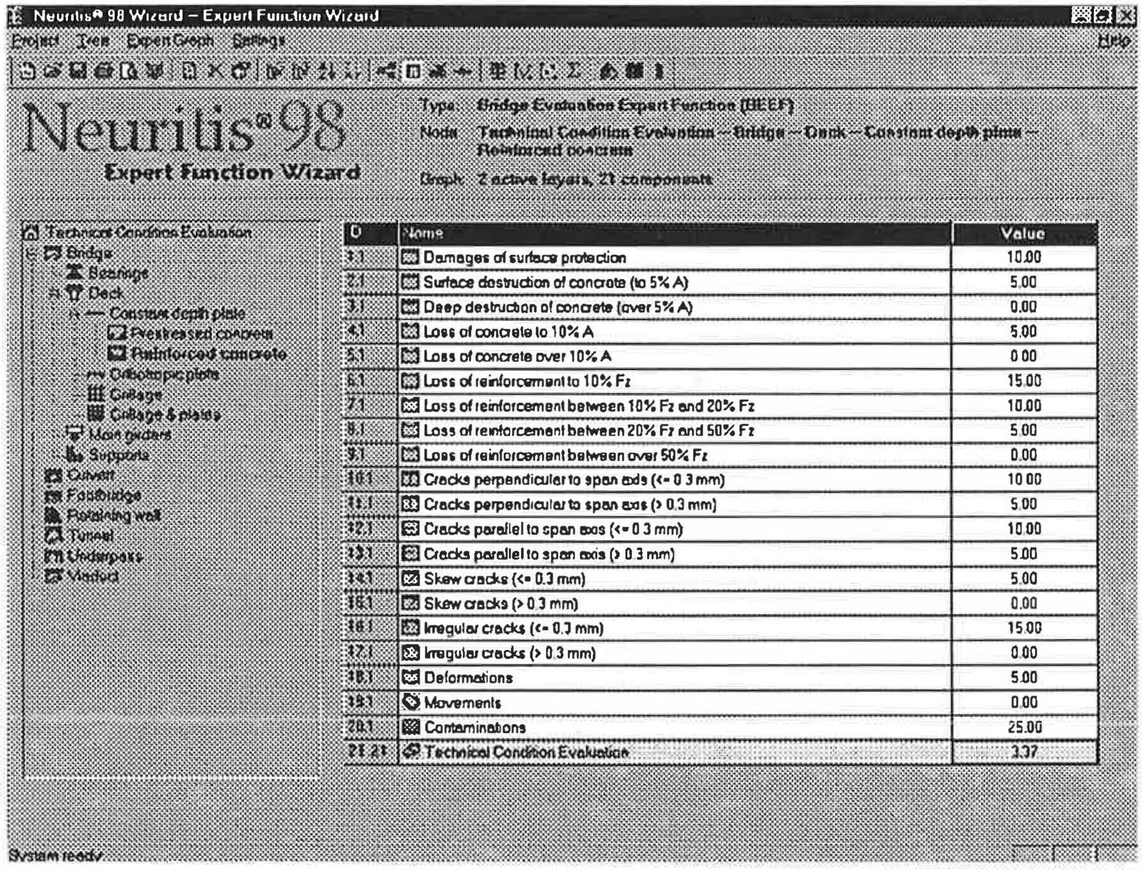

Figure 10: BEEF—example of the technical condition evaluation on the basis of damages registered during the visual inspection.

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