# BRIDGE CONDITION EVALUATION USING FUZZY LOGIC

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## Abstract

This paper deals with a modern approach of working with an information and data uncertainty – by the use of fuzzy logic and the Fuzzy Logic Toolbox – for building of classification models of the technical condition evaluation of bridge objects, both their superstructure and substructure. The proposed models have hierarchical architecture, built of the Mamdani's fuzzy inference systems. The models were validated on a data set of real bridges in operation. In the modelling process, the analysis of bridge rating methods in the Czech Republic and abroad was applied. The analysis of the amounts and shapes of input and output membership functions of given fuzzy sets was carried out, the numbers of fuzzy inference rules were determined and the appropriate choice of the defuzzification method was found out. On the basis of the achieved results, the utility of the presented method of soft computing in the evaluation of the bridge technical conditions was proved.

## 1 Introduction

Generally, a bridge object fulfills its function over several decades and thus it becomes a part of the environment. This social importance of a bridge puts substantial requirements on its *reliability*, *service life* and serviceability.

From the point of design of new, and the assessment of existing structures, we are interested in *quantification and qualitative expression* of its *reliability* level. According to the current level of knowledge and degree of processing of parameters entering into the process of structure evaluation, its reliability is quantified using reliability conditions [1]. These conditions are defined in relation to the applied *method of reliability theory.* According to the way of expressing of random variable character of reliability parameters; deterministic, semi-probabilistic and fully-probabilistic methods can be distinguished.

Generally, probabilistic methods are usable only in the cases when both mathematical models for evaluation of reliability, or service life are available, and also there is sufficient statistical data (probability distribution) for particular quantities entered into these calculations; namely loads and material properties. This data is, however, often missing.

The basic quantification of *reliability* of an existing bridge is (load-carrying capacity or) *load-carrying capability*, regarding its actual *technical condition* and representing also the basic *quantitative parameter of assessment*. Data obtained during inspection and condition assessment are crucial to estimate the current state of a bridge structures reliability [3]. So that the basis of reliability assessment of a bridge is the evaluation of its condition (rating), which in practical judging (inference) data is, however, often incomplete, numerically imprecise and also linguistic.

## 2 Methods of analysis and solution of the problem

### 2.1 Utilised data about bridges operation

According to the instruction S 5 of the Czech Railway Infrastructure Administration (SŽDC), supervising activity is to be carried out within bridge objects administration, it means general (annual) and detailed (three yearly) inspections. Protocol about a detailed bridge inspection quotes found faults and the proposal of total condition assessment of the railway bridge object using three degrees according to Table 1, and the condition evaluation of bridge superstructure and substructure is always recorded separately [4].

Table 1: Condition evaluation system of railway bridge objects SŽDC

| Degree | Condition state | Criteria |
|---|---|---|
| 1 | good | object requires only general maintenance |
| 2 | satisfactory | bridge object requires repair extending the general maintenance framework, and if necessary replacement of some parts, however the defects do not immediately threaten the safety of operation |
| 3 | unsatisfactory | bridge object requires full reconstruction, reconstruction of supports or the replacement of superstructure, and if necessary, even only the repair or replacement of some parts, whose condition do not immediately threaten the safety of operation |

For the modelling of the condition assessment of an existing bridge, I chose concrete constructional type – a composite railway bridge with a steel-concrete superstructure; with encased girders and with concrete and/or stone substructure for the solution. I chose, altogether, twelve bridge objects (of the given constructional type) with various proposed condition evaluations of their superstructure and substructure, evaluated by their inspectors. Then, data could be evaluated (only vicariously) about defects found from protocols about detailed inspections of these bridges. Afterwards, I described these defects quantitatively according to the principles, given in the guideline [2].

## 2.2 Applied principles for building models

The condition of bridge superstructure and substructure is always evaluated on the basis of their found defects. In Figure 1 of [2], bridge defects are hierarchically classified in 4 levels. In the highest level, there are defects classified into 6 types: 1. contamination (DT1), 2. deformation (DT2), 3. deterioration (DT3), 4. discontinuity (DT4), 5. displacement (DT5) and 6. loss of material (DT6). In the lower level, each defect type has more defect kinds, e.g. 6.1 loss of concrete, 6.2 loss of steel. In another of the remaining two levels, defect kinds can have categories and these then can have defect classes.

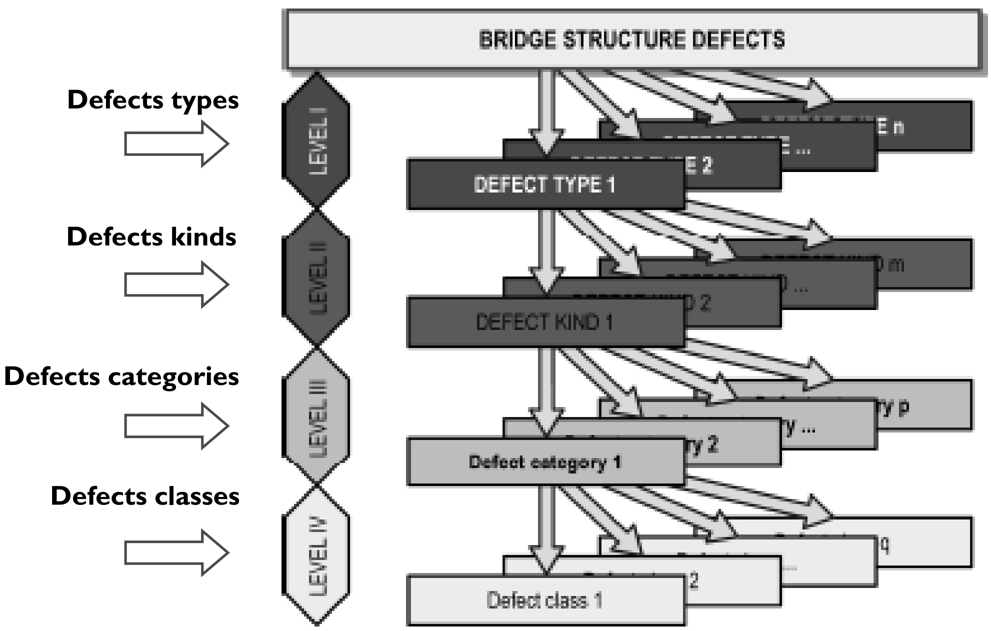


Figure 1: Hierarchical classification of railway bridge defects

Furthermore, according to [2] bridge defects are described by their 3 parameters; defect extent, defect intensity and defect location. In the applied non-dimensional bridge model, defect location is given by defining its part, where the defect occurs, in this case a defect location in the superstructure or substructure. The extent and intensity of the defect (type, kind etc.) are the input data into particular fuzzy inference systems (FIS's) of the proposed fuzzy models, the index of the defect (type, kind etc.) is the output data from these FIS's.

## 2.3 Models built using fuzzy systems

Proposed fuzzy models represent a hierarchical multi-level structure. Real inputs $x_1, x_2, \ldots, x_n$ concurrently activate antecedents of $k$ rules, then the weighted values of the consequents after defuzzification realise the output value $y$. Inputs and outputs are mutually connected within the structure.

The foundation of rules is expertly carried out and complies with these following premises:

- Gaussian (gaussmf) membership functions of the first type,
- the number of membership functions is defined in order to cover a field of input variables and output variable,
- the Mamdani fuzzy system is applied,
- the rules must never „cross“.

Each value from the field of values of input variables belongs at minimum into one and at maximum into two fuzzy sets.

In a choice of the input and output membership functions, a comparison with (starting) triangular (trimf) membership functions was carried out.

Fuzzy implication is then expressed for both proposed models by the sets both of 9 rules in all FIS's for the evaluation of kinds and types of bridge defects and of 729 rules in all 4 FIS's for the evaluation of index of bridge technical condition.

By the aggregation of these rules (fuzzy logical *or*), a resulting fuzzy set can be achieved. By the defuzzification of this set, a crisp value can be achieved. For defuzzification, in the end the method of the middle of maximum (MoM) was chosen, the crisp value is defined as the coordinate of the arithmetical average of the maximum value of the output set. This method does not take into account the overlapping of the individual functions, from which the resulting membership function is aggregated.

The creation, optimalisation and testing of proposed FIS's is enabled by the Fuzzy Logic Toolbox, designed for using with MATLAB. It is possible to work either from the command line or in the Graphic User Interface (GUI). The graphical FIS consists of three tools for the creation and editing of the fuzzy system (FIS Editor, MF Editor and Rule Editor) and the two (passive) viewers (Rule Viewer and Surface Viewer).

## 2.4 Proposed models for bridge condition evaluation

### 2.4.1 Model of bridge superstructure condition evaluation

The superstructure of the chosen constructional type of bridge has two main structural materials – steel and concrete. Therefore, in this case, at least in three (i.e. half) of the defect types, which have a bigger impact (weight) on the resulting condition index, I created another level of the model, introducing for these defects types also defect kinds.

In the following Figure 2, there is the proposed fuzzy system (model) for the evaluation of the technical condition of the steel-concrete bridge superstructure, on the basis of its found defects, which are classified and described according to the guideline [2]. This fuzzy model has the hierarchical three-level architecture and it is built from individual, peculiarly FIS's [6] [7].

Real data about the extent and intensity of defects is the input of the model.

The (first) model level (highlighted) on the left is created by 6 FISs' and represents the evaluation of indices of (some) defect kinds of bridge superstructure. Values of input variables are the extent and intensity of chosen defect kinds of bridge superstructure.

The (second) model level (highlighted) in the middle is created by 6 FISs' and represents the evaluation of indices of (all) defect types of bridge superstructure. Values of input variables are both the index of chosen defect kinds and the extent and intensity of other defect types of bridge superstructure.

The (third) model level (highlighted) on the right is created by 4 FISs' and represents the evaluation of the (one) index of the technical condition of bridge superstructure – the output (real data) of the model. Values of input variables are the index of all defect types of bridge superstructure in the range from 0.00 to 1.00, value of the output variable (i.e. four times) is from 1.00 to 3.00, in agreement with Chapter 2.1.

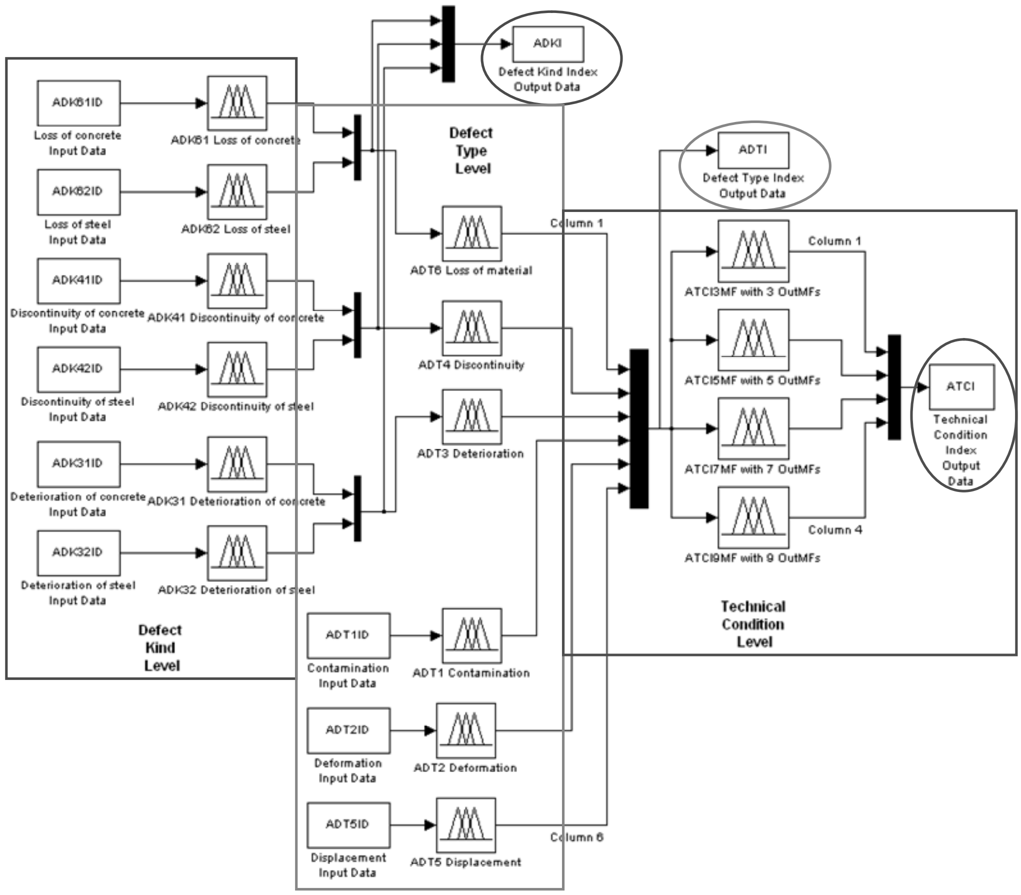


Figure 2: Architecture of the proposed three-level fuzzy system for the technical condition evaluation of steel-concrete bridge superstructure

### 2.4.2 Model of bridge substructure condition evaluation

The substructure of the chosen constructional type of bridge has only one main structural material – concrete or stone. Therefore, in this case, in none of the defect types I created another level of the model, introducing for these defects types also defect kinds.

In the following Figure 3, there is the proposed fuzzy system (model) for the evaluation of the technical condition of the mass concrete or stone bridge substructure, on the basis of its found defects, which are classified and described according to the guideline [2]. This fuzzy model has the hierarchical two-level architecture and it is built from individual, peculiarly FIS's [6] [7].

Real data about the extent and intensity of defects is the input of the model.

The (first) model level (highlighted) on the left is created by 6 FISs' and represents the evaluation of indices of (all) defect types of bridge substructure. Values of input variables are the extent and intensity of all defect types of bridge substructure.

The (second) model level (highlighted) on the right is created by 4 FISs' and represents the evaluation of the (one) index of the technical condition of bridge substructure – the output (real data) of the model. Values of input variables are the index of all defect types of bridge substructure in the range from 0.00 to 1.00, value of the output variable (i.e. four times) is from 1.00 to 3.00, in agreement with Chapter 2.1.

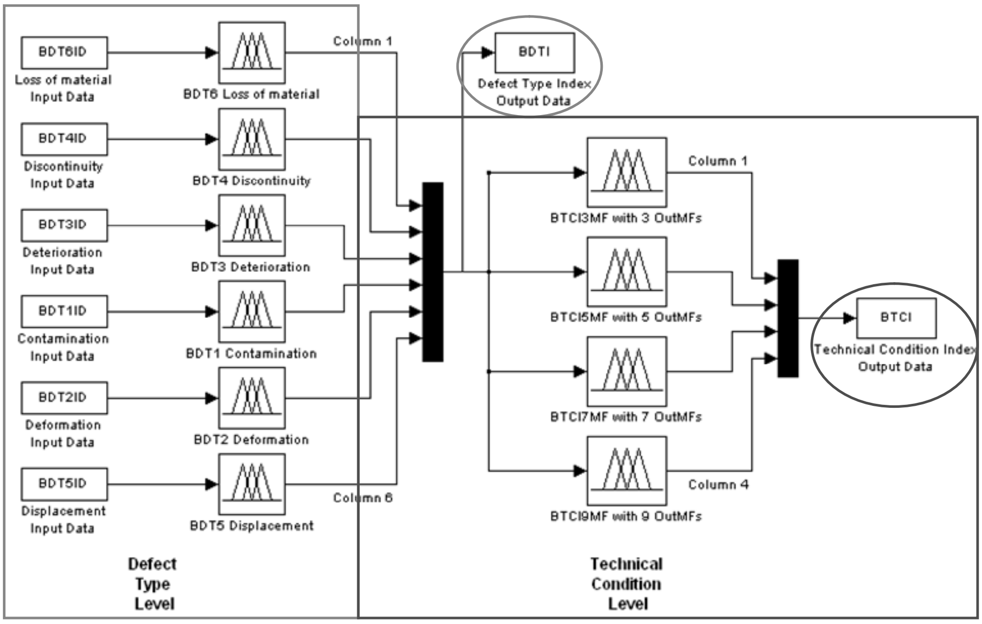


Figure 3: Architecture of the proposed two-level fuzzy system for the technical condition evaluation of mass concrete and/or stone bridge substructure

## 3 Analysis of results

During the phase of model creating, it concerned a proposal for the simulating system and its realisation in a appropriate simulator (most often on a numerical computer) [5]. The proposal of the model can, but must not, come from the mathematical description of the actual idea about the simulating system. Only such a model which adheres, whilst simulating, to a sequenced arrangement of time changes in the simulation of the dynamics of the simulated system is considered.

Let us emphasize that to be able to discuss simulation, then to ascertain knowledge of a simulated system must be the aim of the experiments with the simulator. In designing a simulator we must determine, whether an inappropriate method is applied in it or not. This process is named the confirmation of accuracy of a model, or verification. The model is considered to be correct, if the course of the simulating calculation corresponds to the actual conception expressed in the conceptual model, otherwise it is functionally correct.

After successful verification, it is necessary to corrigate the validation of the simulation model (whether the simulator reflects the object of examination with the required accuracy, which is expected from it and which was given in the initial targets) [5]. The validation can be ascertained by various methods, for example; to compare the model with a real system by means of statistical methods, or empirically, when an independent expert verifies the veracity of the model's behaviour.

The confirmation of the accuracy (verification) of models built by means of individual fuzzy systems is a question of choice of fuzzification, determination of evaluation criteria and defuzzification. The building of models was conceived in an expert manner. Although the practise of building certain rules is adhered to; the variability of results is *(very) great*.

Proving the exactness (validation) of models built by means of particular fuzzy systems is carried out on the basis of the comparison of data values presented in the protocols about detailed inspections of bridges with output data generated by both proposed simulation models [5]. Comparisons of all obtained values were carried out in an expert manner in the following Table 5 and Table 7.

### 3.1 Model validation of superstructure condition evaluation

Validation of this model (fuzzy system) of the condition evaluation of bridge superstructure (SpS) in Figure 2 was carried out by means of real bridge values according to the bridge expert's findings regarding real bridge superstructure defects as follows:

The model level on the left was validated by means of real bridge values of input variables, presented in the following Table 2. Then, the real bridge values of output variable of these FIS's for defect kind evaluations of bridge superstructure are presented in the following Table 3 as some inputs.

Table 2: Real bridge values of the input data of bridge superstructure defect kinds

| Defect kind parameter | ADK31E | ADK31I | ADK32E | ADK32I | ADK41E | ADK41I | ADK42E | ADK42I | ADK61E | ADK61I | ADK62E | ADK62I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bridge No. | 100 % | *40 %* | 100 % | *20 %* | 100 % | *20 mm* | 100 % | *20 %* | 100 % | *40 %* | 100 % | *20 %* |
| 1 | 50 | 20 | 50 | 10 | 17 | 20 | 33 | 7 | 17 | 7 | 33 | 7 |
| 2 | 33 | 27 | 33 | 13 | 33 | 7 | 33 | 7 | 17 | 13 | 33 | 17 |
| 3 | 67 | 33 | 50 | 13 | 33 | 10 | 33 | 7 | 33 | 13 | 33 | 10 |
| 4 | 83 | 33 | 67 | 13 | 100 | 10 | 50 | 10 | 50 | 20 | 33 | 7 |
| 5 | 50 | 20 | 50 | 10 | 33 | 10 | 33 | 7 | 33 | 33 | 33 | 7 |
| 6 | 33 | 27 | 50 | 10 | 33 | 20 | 33 | 10 | 33 | 13 | 33 | 7 |
| 7 | 100 | 27 | 83 | 13 | 67 | 13 | 67 | 13 | 67 | 27 | 50 | 13 |
| 8 | 67 | 40 | 67 | 17 | 67 | 13 | 67 | 13 | 83 | 33 | 83 | 13 |
| 9 | 100 | 33 | 100 | 13 | 83 | 13 | 67 | 13 | 33 | 40 | 83 | 13 |
| 10 | 83 | 40 | 67 | 17 | 83 | 17 | 83 | 17 | 100 | 27 | 83 | 17 |
| 11 | 50 | 40 | 67 | 13 | 100 | 10 | 67 | 13 | 100 | 33 | 83 | 17 |
| 12 | 33 | 33 | 67 | 13 | 100 | 20 | 67 | 13 | 33 | 27 | 67 | 13 |

The model level in the middle was validated by means of real bridge values of input variables, presented in the following Table 3. Then, the real bridge values of output variables of these FIS's for defect type evaluations of bridge superstructure are presented in the following Table 4 as some inputs.

Table 3: Real bridge values of the input data of bridge superstructure defect types

| Defect type parameter | ADT1E | ADT1I | ADT2E | ADT2I | ADK31X | ADK32X | ADK41X | ADK42X | ADT5E | ADT5I | ADK61X | ADK62X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bridge No. | 100 % | 100 % | 100 % | 100 % | *1.00* | *1.00* | *1.00* | *1.00* | 100 % | 100 % | *1.00* | *1.00* |
| 1 | 50 | 50 | 17 | 17 | 0.5 | 0.5 | 0.5 | 0.495 | 17 | 100 | 0.085 | 0.495 |
| 2 | 33 | 50 | 17 | 17 | 0.5 | 0.495 | 0.495 | 0.495 | 0 | 0 | 0.5 | 0.915 |
| 3 | 67 | 83 | 17 | 17 | 0.915 | 0.5 | 0.495 | 0.495 | 0 | 0 | 0.5 | 0.495 |
| 4 | 83 | 83 | 17 | 17 | 0.915 | 0.495 | 0.5 | 0.5 | 0 | 0 | 0.5 | 0.495 |
| 5 | 50 | 50 | 17 | 17 | 0.5 | 0.5 | 0.495 | 0.495 | 17 | 100 | 0.915 | 0.495 |
| 6 | 33 | 67 | 17 | 17 | 0.5 | 0.5 | 0.915 | 0.495 | 33 | 100 | 0.5 | 0.495 |
| 7 | 100 | 100 | 17 | 17 | 0.5 | 0.5 | 0.495 | 0.495 | 0 | 0 | 0.5 | 0.5 |
| 8 | 67 | 100 | 17 | 17 | 0.915 | 0.915 | 0.495 | 0.495 | 0 | 0 | 0.915 | 0.5 |
| 9 | 100 | 100 | 17 | 17 | 0.915 | 0.5 | 0.5 | 0.495 | 0 | 0 | 0.915 | 0.5 |
| 10 | 83 | 100 | 17 | 17 | 0.915 | 0.915 | 0.915 | 0.915 | 0 | 0 | 0.5 | 0.915 |
| 11 | 50 | 100 | 17 | 17 | 0.975 | 0.495 | 0.5 | 0.495 | 0 | 0 | 0.915 | 0.915 |
| 12 | 33 | 83 | 17 | 17 | 0.915 | 0.495 | 0.975 | 0.495 | 0 | 0 | 0.5 | 0.495 |

The model level on the right was validated by means of real bridge values, presented in the following Table 4 as input variables. Then, the real bridge values of the output variable of these FIS's for the evaluation of the technical condition index of bridge superstructure are presented in the first four columns of the following Table 5.

Table 4: Real bridge values of the input data of bridge superstructure technical condition index

| Defect type index | ADT6X | ADT4X | ADT3X | ADT1X | ADT2X | ADT5X |
|---|---|---|---|---|---|---|
| Bridge No. | 0 to 1 | 0 to 1 | 0 to 1 | 0 to 1 | 0 to 1 | 0 to 1 |
| 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.085 | 0.5 |
| 2 | 0.96 | 0.5 | 0.5 | 0.5 | 0.085 | 0.025 |
| 3 | 0.5 | 0.5 | 0.5 | 0.915 | 0.085 | 0.025 |
| 4 | 0.5 | 0.5 | 0.5 | 0.915 | 0.085 | 0.025 |
| 5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.085 | 0.5 |
| 6 | 0.5 | 0.5 | 0.5 | 0.495 | 0.085 | 0.915 |
| 7 | 0.5 | 0.5 | 0.5 | 0.975 | 0.085 | 0.025 |
| 8 | 0.5 | 0.5 | 0.96 | 0.915 | 0.085 | 0.025 |
| 9 | 0.5 | 0.5 | 0.5 | 0.975 | 0.085 | 0.025 |
| 10 | 0.96 | 0.96 | 0.96 | 0.915 | 0.085 | 0.025 |
| 11 | 0.96 | 0.5 | 0.5 | 0.975 | 0.085 | 0.025 |
| 12 | 0.5 | 0.5 | 0.5 | 0.915 | 0.085 | 0.025 |

Comparison of the technical condition assessment of bridge superstructure by means of index, according to the model (fuzzy system) calculation in the first four columns and according to the proposal of a bridge expert in the protocol about a detailed inspection in the last column of the following Table 5 is made. It is shown and proved the fact that this model calculation assessment is more precise.

Table 5: Comparison of the real bridge superstructure technical condition index resulting from the evaluation by fuzzy system computing and bridge expert's proposal

| **FIS No.** | ATCI3MF | ATCI5MF | ATCI7MF | **ATCI9MF** | **ATCI 1+** | **ATCI 1-** | **ATCI 2+** | **ATCI 2-** | **ATCI 3+** | **ATCI 3-** | **Consensus** | **Bridge expert** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bridge No. | 1.00 3.00 | 1.00 3.00 | 1.00 3.00 | **1.00 3.00** | **1.00** 1.33 | 1.33 **1.67** | **1.67** 2.00 | 2.00 **2.33** | **2.33** 2.67 | 2.67 **3.00** | ✓X | **1 2 3** |
| 1 | 2 | 2 | 2 | 1.75 | | | **1.75** | | | | ✓ | 2 |
| 2 | 2 | 2 | 2 | 2 | | | 2 | | | | ✓ | 2 |
| 3 | 2 | 2 | 2 | 2 | | | 2 | | | | ✓ | 2 |
| 4 | 2 | 2 | 2 | 2 | | | 2 | | | | ✓ | 2 |
| 5 | 2 | 2 | 2 | 1.75 | | | **1.75** | | | | ✓ | 2 |
| 6 | 2 | 2 | 2 | 2 | | | 2 | | | | ✓ | 2 |
| 7 | 2 | 2 | 2 | 2 | | | 2 | | | | X | 3 |
| 8 | 2 | 2 | 2 | 2 | | | 2 | | | | X | 3 |
| 9 | 2 | 2 | 2 | 2 | | | 2 | | | | X | 3 |
| 10 | 2.92 | 2.5 | 2.67 | 2.5 | | | | | **2.5** | | ✓ | **3** |
| 11 | 2 | 2 | 2 | 2 | | | 2 | | | | X | 3 |
| 12 | 2 | 2 | 2 | 2 | | | 2 | | | | X | 3 |

## 3.2 Model validation of substructure condition evaluation

Validation of this model (fuzzy system) of the condition evaluation of bridge substructure (SbS) in Figure 3 was carried out by means of real bridge values according to the bridge expert's findings regarding real bridge substructure defects as follows:

The model level on the left was validated by means of real bridge values of input variables, presented in the following Table 6. Then, the real bridge values of output variable of these FIS's for defect type evaluations of bridge substructure are presented in the following Table 7 as all inputs.

Table 6: Real bridge values of the input data of bridge substructure defect types

| Defect type parameter | BDT1E | BDT1I | BDT2E | BDT2I | BDT3E | BDT3I | BDT4E | BDT4I | BDT5E | BDT5I | BDT6E | BDT6I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bridge No. | 100 % | 100 % | 100 % | 100 % | 100 % | *40 %* | 100 % | *20 mm* | 100 % | 100 % | 100 % | *40 %* |
| 1 | 17 | 17 | 0 | 0 | 17 | 7 | 33 | 7 | 0 | 0 | 17 | 27 |
| 2 | 50 | 17 | 0 | 0 | 17 | 7 | 67 | 7 | 0 | 0 | 50 | 7 |
| 3 | 50 | 33 | 0 | 0 | 67 | 13 | 67 | 3 | 0 | 0 | 33 | 7 |
| 4 | 17 | 17 | 0 | 0 | 67 | 13 | 33 | 13 | 17 | 17 | 17 | 27 |
| 5 | 67 | 50 | 0 | 0 | 67 | 20 | 100 | 20 | 17 | 83 | 17 | 40 |
| 6 | 67 | 50 | 0 | 0 | 67 | 27 | 50 | 10 | 17 | 83 | 17 | 27 |
| 7 | 17 | 17 | 0 | 0 | 50 | 40 | 100 | 20 | 100 | 100 | 50 | 40 |
| 8 | 50 | 83 | 0 | 0 | 100 | 40 | 50 | 17 | 17 | 33 | 50 | 33 |
| 9 | 67 | 100 | 0 | 0 | 67 | 33 | 67 | 3 | 0 | 0 | 17 | 7 |
| 10 | 67 | 100 | 0 | 0 | 67 | 33 | 50 | 13 | 0 | 0 | 33 | 33 |
| 11 | 50 | 33 | 0 | 0 | 83 | 40 | 50 | 17 | 50 | 67 | 83 | 27 |
| 12 | 50 | 67 | 0 | 0 | 33 | 13 | 100 | 20 | 100 | 83 | 100 | 33 |

The model level on the right was validated by means of real bridge values, presented in the following Table 7 as input variables. Then, the real bridge values of the output variable of these FIS's for the evaluation of the technical condition index of bridge substructure are presented in the first four columns of the following Table 8.

Table 7: Real bridge values of the input data of bridge substructure technical condition index

| Defect type index | BDT6X | BDT4X | BDT3X | BDT1X | BDT2X | BDT5X |
|---|---|---|---|---|---|---|
| Bridge No. | 0 to 1 | 0 to 1 | 0 to 1 | 0 to 1 | 0 to 1 | 0 to 1 |
| 1 | 0.5 | 0.495 | 0.085 | 0.085 | 0.025 | 0.025 |
| 2 | 0.085 | 0.495 | 0.085 | 0.085 | 0.025 | 0.025 |
| 3 | 0.085 | 0.085 | 0.5 | 0.495 | 0.025 | 0.025 |
| 4 | 0.5 | 0.495 | 0.5 | 0.085 | 0.025 | 0.085 |
| 5 | 0.5 | 0.975 | 0.495 | 0.495 | 0.025 | 0.5 |
| 6 | 0.5 | 0.5 | 0.5 | 0.495 | 0.025 | 0.5 |
| 7 | 0.975 | 0.975 | 0.975 | 0.085 | 0.025 | 0.975 |
| 8 | 0.915 | 0.93 | 0.975 | 0.915 | 0.025 | 0.495 |
| 9 | 0.085 | 0.085 | 0.915 | 0.915 | 0.025 | 0.025 |
| 10 | 0.915 | 0.5 | 0.915 | 0.915 | 0.025 | 0.025 |
| 11 | 0.5 | 0.93 | 0.915 | 0.495 | 0.025 | 0.495 |
| 12 | 0.915 | 0.975 | 0.5 | 0.495 | 0.025 | 0.915 |

Comparison of the technical condition assessment of bridge substructure by means of index, according to the model (fuzzy system) calculation in the first four columns and according to the proposal of a bridge expert in the protocol about a detailed inspection in the last column of the following Table 8 is made. It is shown and proved the fact that this model calculation assessment is more precise.

Table 8: Comparison of the real bridge substructure technical condition index resulting from the evaluation by fuzzy system computing and bridge expert's proposal

| **FIS No.** | BTCI3MF | BTCI5MF | BTCI7MF | **BTCI9MF** | **BTCI 1+** | **BTCI 1-** | **BTCI 2+** | **BTCI 2-** | **BTCI 3+** | **BTCI 3-** | **Consensus** | **Bridge expert** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bridge No. | 1.00 3.00 | 1.00 3.00 | 1.00 3.00 | **1.00 3.00** | **1.00** 1.33 | 1.33 **1.67** | **1.67** 2.00 | 2.00 **2.33** | **2.33** 2.67 | 2.67 **3.00** | ✓X | **1 2 3** |
| 1 | 1.08 | 1.5 | 1.33 | 1.25 | **1.25** | | | | | | ✓ | **1** |
| 2 | 1.08 | 1.04 | 1.02 | 1.02 | **1.02** | | | | | | ✓ | **1** |
| 3 | 1.08 | 1.04 | 1.33 | 1.25 | 1.25 | | | | | | **X** | 2 |
| 4 | 1.08 | 1.5 | 1.67 | 1.5 | | 1.5 | | | | | X | 2 |
| 5 | 2 | 2 | 2 | 2 | | | **2** | | | | ✓ | **2** |
| 6 | 2 | 2 | 2 | 1.75 | | | **1.75** | | | | ✓ | **2** |
| 7 | 2.92 | 2.5 | 2.33 | 2.5 | | | | | **2.5** | | ✓ | **3** |
| 8 | 2.92 | 2.5 | 2.67 | 2.75 | | | | | | **2.75** | ✓ | **3** |
| 9 | 2 | 1.5 | 1.67 | 1.75 | | | 1.75 | | | | **X** | 3 |
| 10 | 2 | 2.5 | 2.33 | 2.25 | | | | 2.25 | | | X | 3 |
| 11 | 2 | 2.5 | 2.33 | 2.25 | | | | 2.25 | | | X | 3 |
| 12 | 2.92 | 2.5 | 2.33 | 2.5 | | | | | **2.5** | | ✓ | **3** |

## 4 Conclusions

Within this work, the synthesis and analysis of models for the technical condition evaluation of railway bridges by one of the methods of soft computing – fuzzy logic – was carried out. The main goal of the work was fulfilled by creating a fuzzy logic model.

This main goal was achieved through fulfilling several partial aims. The methodologies of bridge evaluation both in the Czech Republic and elsewhere were analysed. The models for the evaluation of bridge superstructure and substructure were also analysed and proposed separately. The analysis of the needed amounts of input and output membership functions of given fuzzy sets and the most appropriate shapes of these membership functions was carried out, the numbers of fuzzy inference rules were determined and then the appropriate choice of the defuzzification method was found out. A real data matrix for the validation of models was created.

The proposed method of evaluation of technical condition of existing bridge using one of soft computing methods – fuzzy logic – is quite interesting and effective whereupon the best results were presented in [8]. At the same time it concentrates on its own contribution to practical application and indicates the way this system can proceed in its development.

## 5 References


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