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Creating a Model of Technical Wear of Buildings in Mining Areas with the Use of Fuzzy Inference Systems**

1. Introduction

Technical wear is a measure of a technical condition of a building. The natural wear related to the ageing of building materials under specific environmental and exploitation conditions has a dominant influence on the rate of wear of a given object. On the other hand, the technical wear is affected by a number of additional factors, which are, in a statistical sense, random, and which also include the effects of mining (e.g. [1]).

The relationship between the technical condition s_t, usually referred to in the form of verbal description, and the value of a rate of technical wear of a building s_z, adopted in this work, have been presented in table 1.

Table 1. The technical state of a building and its technical wear

Technical state s_t	Technical wear s_z
very good	up to 10
good	11–20
satisfactory	21–30
average	31–50
bad	51–70
very bad	above 70

The studies, which have been conducted in recent years, have revealed a significant, in a statistical sense, influence of mining impacts, both of deformations and continuous mining tremors, upon the rate of technical wear of buildings

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(e.g. [1–4]). In these studies statistical methods were used, examining correlations between variables, as well as conducting regression and variance analyses.

The idea behind the research presented in this paper was to bring the procedure of determining the rate of technical wear of buildings to multi-dimensional relationship of linking the causes with the technical wear. The identification of such relationships is tantamount to the need of building a model of technical wear process in a multidimensional field of potential causes giving rise to acceleration or delay in the process of wear.

This required a consideration of two additional problems resulting directly from the practice of conducting inventory works, upon which an assessment of the condition of buildings is based. The first one is an incomplete access to information on individual factors included in the description of the technical wear. This forces building experts to estimate their values based on the ambiguous linguistic wording, such as: *low, sufficient, satisfactory*. It must be also taken into account that some of the information on a building and environmental impacts is due to a subjective assessment, dependent upon expert's professional knowledge and experience. The second problem is a final forming of an evaluation of the technical condition of a building based on the obtained information about it. Building experts make their decisions on the classification of a building to a given technical condition category, making use of the information gathered during a review, which is often ambiguous.

Therefore, two objectives were formulated, which determined the directions of the search for methodology of the research presented in this work:

- objective no. 1 – to create a multidimensional model describing the process of technical wear of buildings in mining areas,
- objective no. 2 – to interpret the structure of the created model, and in particular, to examine the impact of mining factors on the acceleration of the technical wear.

Analysis of the literature allowed to narrow the search field to the family of methods belonging to artificial intelligence (AI). This will include, inter alia, artificial neural networks, the method of supporting vectors, or adaptive and expert fuzzy inference systems. They are characterized by the following properties (e.g., [5, 6]):

- versatility for the approximation of functions of several variables,
- the ability to generalize the acquired knowledge in the course of learning,
- no need to set home form of mapping,
- no requirements regarding data quality,
- the possibility of a sensitivity analysis against a fixed model,
- the possibility of model representation as a regulation base, taking into account uncertainty.

The database, in which information about the construction and technical condition of 1726 buildings located in the Upper Silesian Coal Basin (820 objects) and Legnica-Głogów Copper District (906 objects) was comprised, constituted the basis of the research. Also detailed information on potential factors affecting their technical wear, including the impacts of mining, was collected.

2. Research Methodology

After a preliminary analysis, a 3-staged procedure for building of a model, with the use of SVM method belonging to the family of neural network, was determined in the regression approach (ε-SVR, for example [7–9]) as well as fuzzy inference systems: the *Wang-Mendel* adaptive system and *Mamdani* expert-system [10].

It was determined that the first objective, which was to build a multidimensional model of the process of buildings technical wear, would be carried out using the *Mamdani* fuzzy inference system. In turn, the second objective of the research would be achieved through the use of the ε-SVR method at the initial stage, which would allow to analyse the relevance of particular input factors on the process of the technical wear.

The general diagram of such activities has been presented in figure 1.

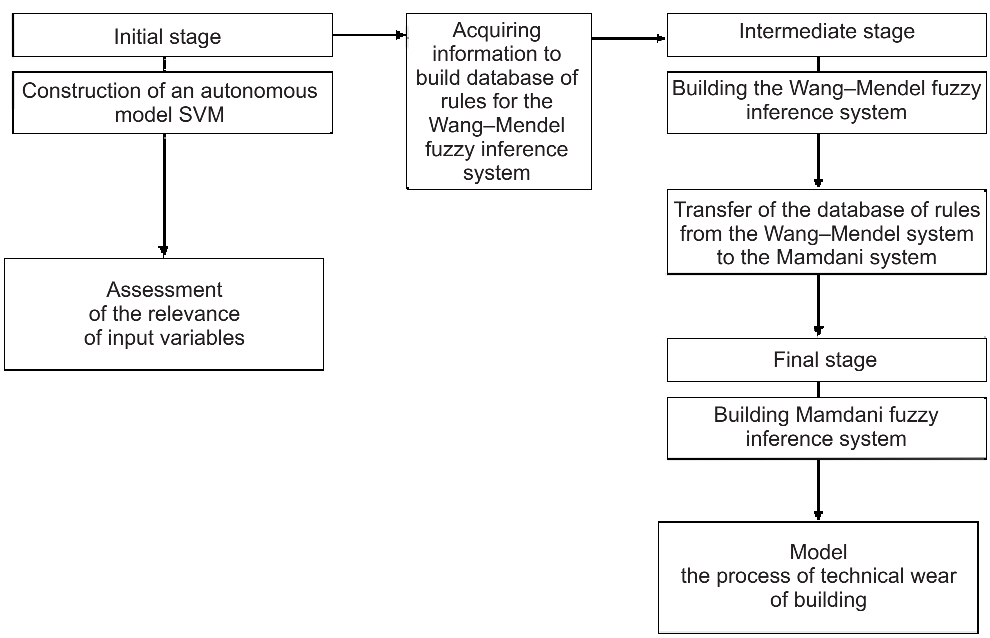

Fig. 1. Block diagram of the procedure

2.1. The Initial Stage of the Research

The analyses carried out at this stage were focused:

- on the assessment of the impact of specific input variables upon the process of the technical wear of buildings,
- to obtain the information needed to build a system of rules for the *Wang–Mendel* system (intermediate stage).

The analysis used 12 ε-SVR models dependent upon the location of the groups of buildings as well as upon a set of input variables. These models were positively assessed both in terms of fitting and generalization.

The analyses were carried out in two versions:

- it was examined how basic measures of model fitting to the reference data were changed, where a specific variable was excluded from the description of an approximator (amputation variable);
- the effect of each variable in the context of volatility of approximated ε-SVR models was estimated.

According to the results of the research included in the scope of the initial stage, the final set of input variables, which were implemented into further research, was determined.

These comprised:

- the age of a building,
- horizontal tensile strains ε^{+}, as a measure of the impact of surface deformations, calculated as maximum during the lifetime of a building;
- the indicator of dynamic influences a_{sg}, as an impact measure of mining tremors, defined according to [11] as follows:

$$a_{sg}(x,y) = \sqrt{\sum_{k=1}^{n} a_{H_k}(x,y)^2}, \quad a_{H_k}(x,y) \geq a_p \tag{1}$$

where:

(x, y) – coordinates of an object,

n – number of tremors that occurred during the lifetime of a building (until the conducted inventory works), for which the calculated peak value at the point (x, y) was greater than the pre-set threshold value a_p,

$a_{H_k}(x,y)$ – calculated peak value of horizontal component of acceleration of vibrations at frequencies up to 10 Hz at the point (x, y), individually for each of the n tremors.

Additionally, in order to account for the impact of construction interventions, the following were formulated:

– the index describing the scope of carried out renovations w_{REM},
– the index describing the degree of building protection against mining impacts w_{ZAB}, determined according to the applied analysis of preventive safeguarding.

2.2. The Intermediate Stage of the Research

The intermediate stage was to build the *Wang–Mendel* fuzzy inference system. The information about relationships in its database of rules was established based on the results of the initial stage.

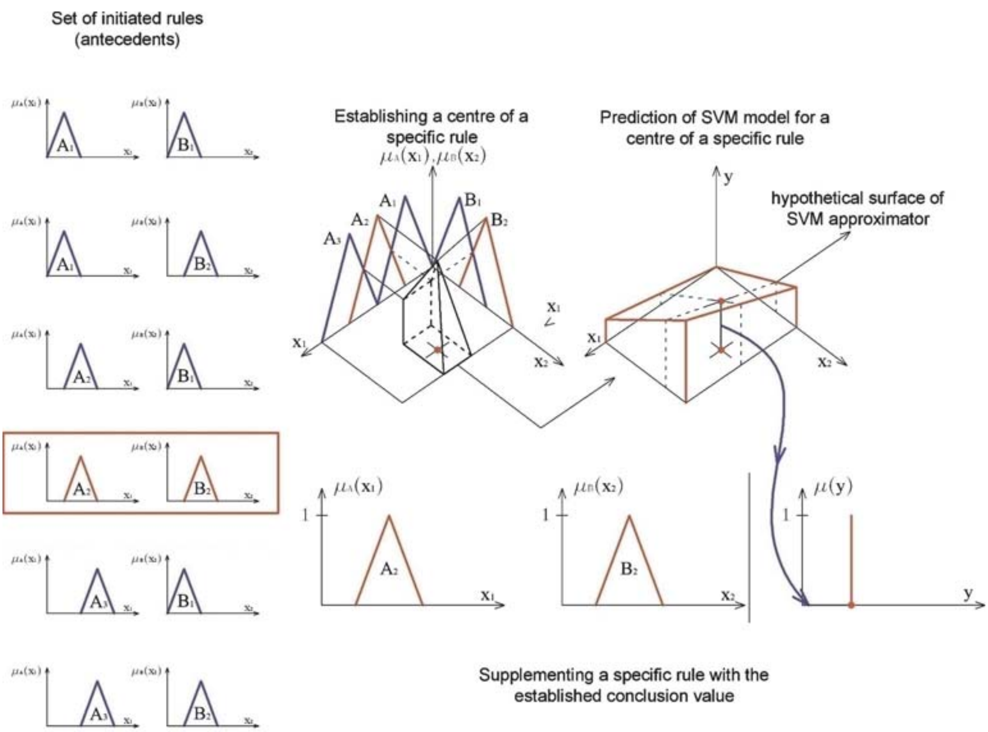

Fig. 2. Diagram for determining the conclusions for the *Wang–Mendel* system with the use of the assisting ε-SVR model

Demonstrative diagram for determining the value of the conclusions for the initiated rules of the *Wang–Mendel* system was presented in figure 2.

2.3. The Final Stage of the Research – Construction of a Model for the Process of Technical Wear of Buildings in Mining Areas

The final stage resolved the construction of the *Mamdani* fuzzy inference system. The basis for analyses at this stage was to determine:

- fuzzy categorization for each input variable,
- fuzzy categorization for approximate output variable,
- the relationship between input and output variables, which form the database of rules for the fuzzy inference system.

The overriding concern was to establish relationships in the database of rules for the *Mamdani* system. Therefore, a transfer of the database of rules set up during the intermediate stage (*Wang–Mendel* system) to the *Mamdani* system was executed. This meant the assignment for each set of antecedents in the database of rules of the *Wang–Mendel* system, an optimal conclusion, in the form of a fuzzy set that defines a specific category of the technical state.

Demonstrative diagram of the transfer of the database of rules from the *Wang–Mendel* system to the *Mamdani* system has been presented in figure 3.

In accordance with the adopted procedure for the final model construction, a structure of the *Mamdani* inference system was determined, in which the number of relationships in the database of rules equals 240.

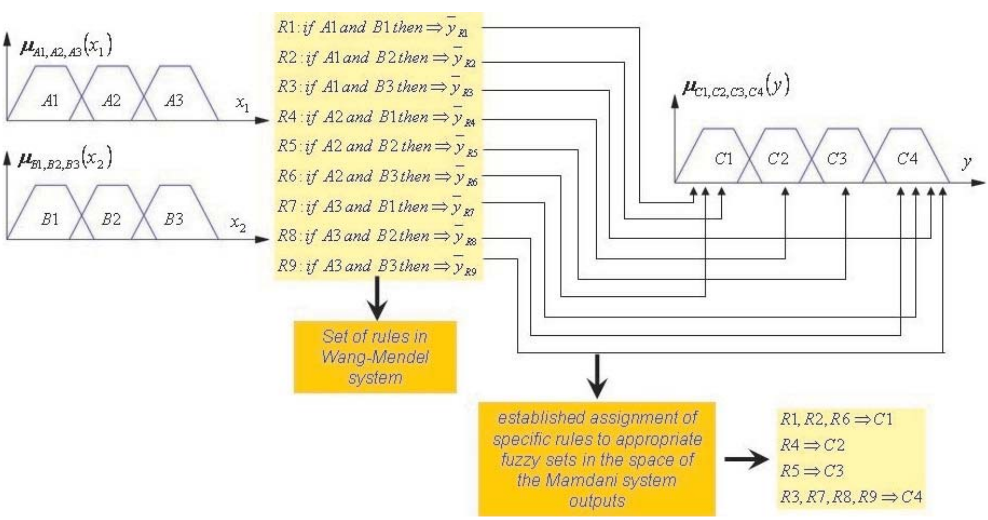

Fig. 3. Conceptual diagram of the information transfer from the structure of the *Wang–Mendel* system to the *Mamdani* system

3. Analysis of the Obtained Solution

Using the fact that the final model is based on the rule-based structure making use of formalisms of fuzzy sets theory, a method was proposed, which could reflect the uncertainty occurring during the evaluation of the technical condition of buildings.

Four cases were considered to cover all possible scenarios that may take place in practice when assessing the technical condition:

- case 1: determination of the value of the building technical wear, with the knowledge of the exact value of the input factors;
- case 2: determination of the value of the building technical wear, taking into account uncertainty about the values of all input factors;
- case 3: determination of the value of the building technical wear, with some clarification on the linguistic assessments of the value of each variable input;
- case 4: determination of the value of the building technical wear, when some of the variables are provided in a uncertain manner and described by means of linguistic expressions.

In order to illustrate the operation of the created model, an exemplary simulation of the case was presented, where the variables were provided in a linguistic form, with the possibility for some clarification (case 3).

A set of input variables has been specified in table 2.

Table 2. Summary of input variables for a simulated case

Type of variable	Value of variable
building age [years]	rather "average" with an orientation to "old"
horizontal tensile deformations ε^{+} [mm/m]	rather "category IV" with an orientation to "category III"
renovation indicator w_{REM}	rather renovated without an orientation due to two fuzzy sets defining the categories of this variable
protection indicator w_{ZAB}	rather "category 2" with an orientation to "category 1"

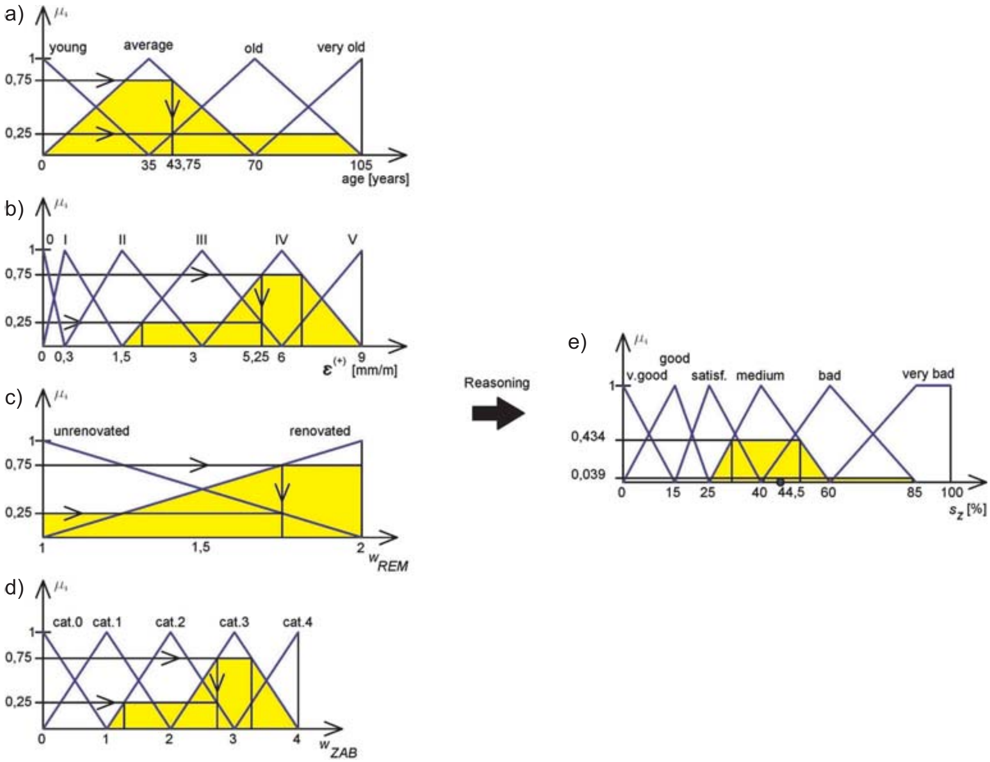

Fig. 4. Activation levels of fuzzy sets for input variables and approximate output variable of the system

The estimated value of the rate of technical wear in this case equals $s_z = 44.5\%$. In turn, the analysis of the aggregated final set points to the average condition of the building – see figure 4e. Thus, the presented model allows for the approximation of the rate of technical wear s_z while indicating the category of technical condition s_t. This possibility seems to be particularly valuable in cases where input data are given in the form of uncertain linguistic formulations. Then the advantage of the fuzzy inference systems over the methods used exclusively for approximations (e.g. multiple regression, neural networks, etc.) is revealed, in which it is essential to provide strictly determined input numerical values for each input variable.

4. Summary and Conclusions

Due to the fact that the process of the technical wear of buildings is affected by numerous factors, it was determined that the description of the phenomenon requires the creation of the model in a multidimensional field of variables describing it.

Taking also into account the uncertainty about the value of these factors, which are determined during inventory works, it was agreed that the most effective solution would be to create a model whose operation will be determined by a cause and effect rule-based record, taking into account uncertainty. The 3-stage procedure proposed in this work allowed to construct the *Mamdani* fuzzy inference system as the model for the process of technical wear of buildings in mining areas, as well as it helped to assess the impact of various factors determining its process. The analysis of the obtained results and the interpretation of the created model operation allow to indicate that this type of an approach may also be effective for assessing the technical condition of buildings. This follows from the fact that approximated rate of the technical wear of buildings sz is also the foundation for categorization of the technical state s_t. This also applies to cases in which the values of specific input factors are provided in the form of uncertain linguistic formulations.

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