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FUZZY ASSESSMENT OF MANUFACTURABILITY DESIGN FOR MACHINING

Abstract

The article attempts to assess the manufacturability design taking into account the assessment due to the processing, assembly process and organization of production. The evaluation was conducted by the fuzzy inference methods. An assessment was presented for machining based on the proposed fuzzy inference database.

1. INTRODUCTION TO APPLICATION METHODS FOR FUZZY SETS

Knowledge representation in the fuzzy rule-based system is enhanced by the use of linguistic variables and the language of their values, which are defined by context-dependent fuzzy sets, which determine the importance of a gradual membership function (Zadeh, 1965). On the other hand, fuzzy set inference methods, such as generalized Modus Ponens, generalized Modus Tollens, etc., form the basis for approximate inference (Zadeh, 1975). Therefore, fuzzy logic provides a unique framework for inference computational systems based on rules. This idea suggests the presence of two clearly different concepts in the inference methods of fuzzy sets: knowledge and reasoning. This clear separation of knowledge and reasoning (knowledge base) and processing structure is a key aspect of knowledge-based systems, so from this point of view fuzzy set inference methods can be considered a kind of knowledge-based system. The methods of inference of fuzzy sets in which two input variables (x1 and x2) and a single output variable (s) are involved, for example, sets of terms are related as follows: {small, medium, large}, {short, medium, long} and {bad, medium, good}.

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The following base rule consists of five linguistic rules:

- R1W IF X1 is small and X2 is short, THEN Y is bad,
- R2W IF X1 is small and X2 is medium, then Y is bad,
- R3W IF X1 is medium and X2 is short, THEN Y is medium,
- R4W IF X1 is large and X2 is medium, THEN Y is medium,
- R5W IF X1 is large and X2 is long and Y is good.

The above method of inference can be represented by the decision table shown in Table 1.

Tab.1. Example table decision

	x1		
x2	small	medium	large
short	bad	medium	
medium	bad		medium
long			good

The Mamdani method (Fernández & Herrera, 2012) processing structure of fuzzy set inference consists of the following five elements – Fig. 1:

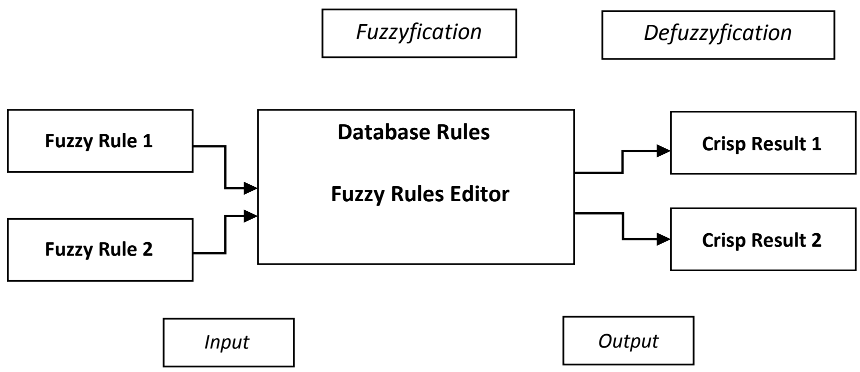

Fig. 1. Structure of the basic fuzzy model

- Input scaling that transforms parameter values – enter variables from its domain to the one in which the input fuzzy partitions are defined,
- A fuzzy interface that transforms explicit input into fuzzy values that serve as input to the fuzzy inference process,
- An inference engine that extracts data from blurry input data into several resulting fuzzy sets according to the information stored in the knowledge base,

- Defuzzification interface that converts fuzzy sets received from the inference process into a clear value,
- Output scaling that converts defragmented value from the output domain of fuzzy areas to output variables, creating a global result of the fuzzy set inference method.

Defuzzification (sharpening) is an action to provide the predicted value of a parameter. ***The center of gravity method*** consists in determining the value of y^*, which is the center of gravity of the area under the curve $\mu_{wyn}(y)$.

$$y^* = \frac{\int y \cdot \mu_{wyn}(y) dy}{\int \mu_{wyn}(y) dy} \tag{1}$$

The project reference model is of the type: multiple entries – multiple outputs (multiple input-multiple output MIMO).

2. FUZZY ASSESSMENT OF MANUFACTURABILITY

2.1. General description of the variables

A set of linguistic variables $V_i = \{V_1, ..., V_n\}$, and $\in N - \{0\}$ is given, defining input and output criteria of technology.The linguistic variable V_i is described by the quadrangle $[L_i, T_i(L), \Omega_i, M_i]$ where:

- $L_i = \{L_1, ..., L_n\}$, and $\in N - \{0\}$ is a set of linguistic variable names,
- $T_i(L_i) = \{T_1(L_1), ..., T_n(L_n)\}$, and $\in N - \{0\}$ is a set of countable determinations of linguistic variables,
- $t_{ij} = \{t_{11}, t_{12}, ..., t_{nm}\}$, $i, j \in N - \{0\}$, $t_{ij} \in T_i(L_i)$ is set of linguistic values of linguistic variables,
- $\Omega_i = \{\Omega_1, ..., \Omega_n\}$, $i \in N - \{0\}$ is a set of linguistic ranges of V_i variables,
- $M_i = \{M_i, ..., M_n\}$, $i \in N - \{0\}$ is a set of semantic rules,
- $m_{ij} = \{m_{11}, m_{12}, ..., m_{mn}\}$, $i, j \in N - \{0\}$, $m_{ij} \in M_i$ is a range of variation of the linguistic value t_{ij} with an assessment of belonging from 0 to 1.

2.2. Procedure – list of variables

The fuzzy method course of action results from project management schemes adopted according to PMI – according to AIAG (Kuo, Huang & Zhang, 2001). Assessment of machining processability and subsequent assembly process assessment, correspond to the prototyping phase during product design and development (Lalaoui & El Afia, 2018), and the assessment of the production organization technology corresponds to the pilot series and preserver phase during validation and then serial production (Favi, Germani & Mandolini, 2016).

In terms of manufacturability processing variables being indicators evaluating product design for the future feasibility of the machining technology (Deka & Behdad, 2019) and compliance with selected requirements – Fig. 2:

- V_1 – Technological Capabilities of the Machine Park/Accuracy,
- V_2 – CAD/CAM Software Capability,
- V_3 – Machining Capabilities of Available Tools,
- V_4 – Material meeting the project requirements,
- V_5 – Energy Consumption,
- V_6 – Waste Environmental Aspects.

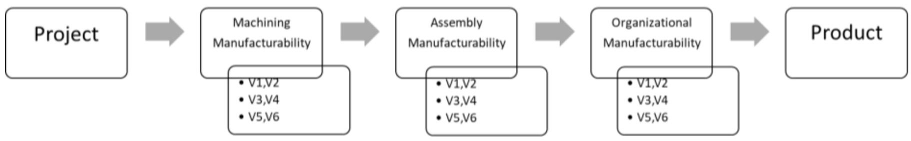

Fig. 2. Procedure – list of variables

In terms of manufacturability assembly (Matuszek & Seneta, 2017) variables being indicators evaluating product design for the feasibility of installation in accordance with the principles assemblability and shortest installation time :

- V_1 – Access,
- V_2 – Maneuverability,
- V_3 – Orientation,
- V_4 – Maneuverability,
- V_5 – Assemblability,
- V_6 – Processes.

In terms of manufacturability organization of production variables being indicators evaluating product design in terms of organizational and technical capabilities, quality and maintenance (Matuszek, Seneta & Moczała, 2018):

- V_1 – Disassembly,
- V_2 – Reuse,
- V_3 – Standardization of components,
- V_4 – Target cost,
- V_5 – Mounting quality,
- V_6 – Number of special elements in maintenance.

Sets of V_i variables can be modified and changed depending on the nature of the target process for which we design the product. This gives the fuzzy method a significant advantage in terms of flexibility. In the example presented, the set of variables V_i was prepared for medium-sized plant and small-lot production.

3. EVALUATION OF MACHINING MANUFACTURABILITY

3.1. The manufacturability evaluation processing procedure

An example of the assessment of machinability of processing consists of three sub-stages of analysis for which linguistic variables are described in Table 2:

Tab. 2. Sub-stages of machining efficiency evaluation - linguistic variables Sub-step 1

V_i	L_i	$T_i(L_i)$	t_{ij}	Ω_i	M_i
V_1	Technological Capabilities of the Machine Park/Accuracy	$T_1(L_1)$	t_{11} – unfulfilled t_{12} – deviates significantly t_{13} – deviates slightly t_{14} – fully meets	[0–4]	M_1
V_2	CAD/CAM Software Capability	$T_2(L_2)$	t_{21} – unfulfilled t_{22} – deviates significantly t_{23} – deviates slightly t_{24} – fully meets	[0–4]	M_2

Substage 2

V_i	L_i	$T_i(L_i)$	t_{ij}	Ω_i	M_i
V_3	Machining Capabilities of Available Tools	$T_3(L_3)$	t_{31} – unfulfilled t_{32} – deviates significantly t_{33} – deviates slightly t_{34} – fully meets	[0–4]	M_3
V_4	Material meeting the project requirements	$T_4(L_4)$	t_{41} – unfulfilled t_{42} – deviates significantly t_{43} – deviates slightly t_{44} – fully meets	[0–4]	M_4

Substage 3

V_i	L_i	$T_i(L_i)$	t_{ij}	Ω_i	M_i
V_5	Energy consumption	$T_5(L_5)$	t_{51} – unfulfilled t_{52} – deviates significantly t_{53} – deviates slightly t_{54} – fully meets	[0–10]	M_5
V_6	Waste Environmental Aspects	$T_6(L_6)$	t_{61}– unfulfilled t_{62} – deviates significantly t_{63} – deviates slightly t_{64} – fully meets	[0–10]	M_6

3.2. Machining Manyfacturability Assessment – sub-step 1

The processability of the workpiece (sample housing) is determined, assuming that it depends on two factors, which are:

- Technological Capabilities of the Machine Park/Accuracy,
- CAD/CAM Software Capability.

Tab. 3. Fuzzification of input variables

Technological Possibilities Of The Machine Park/Accuracy	Rating
Fully fall within the capabilities of machines/accuracy	100
It deviates slightly from the machine's capabilities/accuracy	60
It deviates from the machine capabilities/accuracy significantly	30
Machine capabilities/accuracy not met completely	0
CAD/CAM SOFTWARE CAPABILITY	**Rating**
CAD/CAM capabilities not met	0
It deviates significantly from the CAD/CAM	30
It deviates slightly from the CAD/CAM	60
Fully fits CAD/CAM capabilities	100

Tab. 4. Fuzzy relations for the variable TECHNOLOGICAL POSSIBILITIES

TECHNOLOGICAL POSSIBILITIES				
	Unfulfilled	**It deviates significantly**	**It deviates slightly**	**Fully meets**
0	1	0	0	0
30	0	1	0	0
60	0	0	1	0
100	0	0	0	1

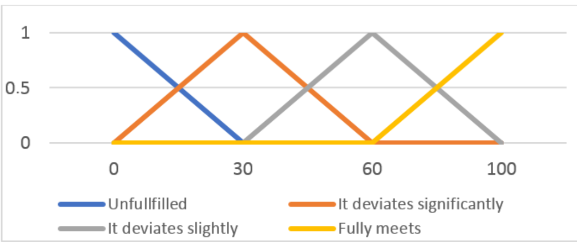

Fig. 3. Membership function graph for TECHNOLOGICAL POSSIBILITIES

The membership function for Technological Capabilities is described by the formulas:

$$\mu_{\text{UNFULFILLED}}(x) = \begin{cases} \frac{30 - x}{30 - 0} \; for \; 0 < x < 30 \\ 0 \; for \; 30 \; \leq x \; \leq 100 \end{cases}$$

$$\mu_{\text{DEVTES SIGNIFICANTLY}}(x) = \begin{cases} \frac{x}{30 - 0} \; for \; 0 < x < 30 \\ \frac{60 - x}{60 - 30} \; for \; 30 < x < 60 \\ 0 \; for \; 60 \; \leq x \; \leq 100 \end{cases}$$

$$\mu_{\text{ DEVIATES SLIGHTLY}}(x) = \begin{cases} 0 \; dla \; x \; \leq 30 \\ \frac{x - 30}{60 - 30} \; dla \; 30 < x < 60 \\ \frac{100 - x}{100 - 60} \; dla \; 60 < x < 100 \end{cases}$$

$$\mu_{\text{FULLY MEETS}}(x) = \begin{cases} 0 \; dla \; x \; \leq 60 \\ \frac{x - 60}{100 - 60} \; dla \; 60 < x < 100 \end{cases}$$

Tab. 5. Fuzzy relations for the variable SOFTWARE CAPABILITY

SOFTWARE CAPABILITY				
	Unfulfilled	**It deviates significantly**	**It deviates slightly**	**Fully meets**
0	1	0	0	0
30	0	1	0	0
60	0	0	1	0
100	0	0	0	1

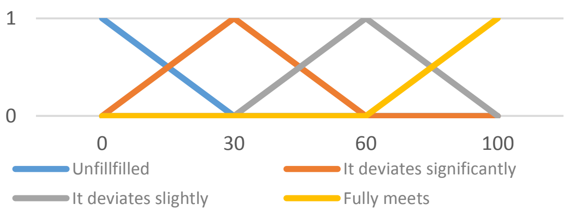

Fig. 4. Membership function graph for SOFTWARE CAPABILITY

The membership function for Software Capability is described by the formulas:

$$\mu_{\text{UNFULFILLED}}(x) = \begin{cases} \dfrac{30 - x}{30 - 0} \; for \; 0 < x < 30 \\ 0 \; for \; 30 \; \leq x \; \leq 100 \end{cases}$$

$$\mu_{\text{DEVIATES SIGNIFICANTLY}}(x) = \begin{cases} \dfrac{x}{30 - 0} \; for \; 0 < x < 30 \\ \dfrac{60 - x}{60 - 30} \; for \; 30 < x < 60 \\ 0 \; for \; 60 \; \leq x \; \leq 100 \end{cases}$$

$$\mu_{\text{ DEVIATES SLIGHTLY}}(x) = \begin{cases} 0 \; for \; x \; \leq 30 \\ \dfrac{x - 30}{60 - 30} \; for \; 30 < x < 60 \\ \dfrac{100 - x}{100 - 60} \; for \; 60 < x < 100 \end{cases}$$

$$\mu_{\text{FULLY MEETS}}(x) = \begin{cases} 0 \; for \; x \; \leq 60 \\ \dfrac{x - 60}{100 - 60} \; for \; 60 < x < 100 \end{cases}$$

The course of fuzzification with the Mamdani rule, the basis of inference rules (tab. 6) was carried out for the selected workpiece according to expert assessments:

- Technological capabilities = 20,
- Software capability = 55,
- Rule 10 Technological capabilities – Deviates significantly and Software capability – Deviates significantly in min (0.67, 0.17) = 0.17,
- Rule 11 Technological possibilities – Deviates significantly and Software capability – Deviates slightly to a degree of min (0.67, 0.83) = 0.67,
- Rule 14 Technological possibilities Unfulfilled and also Software capability – Deviates significantly to a degree of min (0.33, 0.17) = 0.17,
- Rule 15 Technological possibilities Unfulfilled and Software capability – Deviates slightly to a degree of min (0.33, 0.83) = 0.33,
- **Inference processing for manufacturability – substep 1.**

From rules 10, 11, 14 and 15 – MAX, so we activate the rules: 11. Technology 1 takes the value for Technology Capabilities 20 and Software Capability 55:

Tab. 6. Base rules of inference manufacturability evaluation processing – Substage 1

1	IF	TECHNOLOGICAL POSSIBILITIES FULLY MEETS	AND	SOFTWARE CAPABILITY UNFULFILLED	THAN	MANFACTURABILITY 1 MEDIUM
2	IF	TECHNOLOGICAL POSSIBILITIES FULLY MEETS	AND	SOFTWARE CAPABILITY DEVIATES SIGNIFICANTLY	THAN	MANFACTURABILITY 1 MEDIUM HIGH
3	IF	TECHNOLOGICAL POSSIBILITIES FULLY MEETS	AND	SOFTWARE CAPABILITY DEVIATES SLIGHTLY	THAN	MANFACTURABILITY 1 MEDIUM HIGH
4	IF	TECHNOLOGICAL POSSIBILITIES FULLY MEETS	AND	SOFTWARE CAPABILITY FULLY MEETS	THAN	MANFACTURABILITY 1 HIGH
5	IF	TECHNOLOGICAL POSSIBILITIES DEVIATES SLIGHTLY	AND	SOFTWARE CAPABILITY UNFULFILLED	THAN	MANFACTURABILITY 1 MEDIUM LOW
6	IF	TECHNOLOGICAL POSSIBILITIES DEVIATES SLIGHTLY	AND	SOFTWARE CAPABILITY DEVIATES SIGNIFICANTLY	THAN	MANFACTURABILITY 1 MEDIUM
7	IF	TECHNOLOGICAL POSSIBILITIES DEVIATES SLIGHTLY	AND	SOFTWARE CAPABILITY DEVIATES SLIGHTLY	THAN	MANFACTURABILITY 1 MEDIUM HIGH
8	IF	TECHNOLOGICAL POSSIBILITIES DEVIATES SLIGHTLY	AND	SOFTWARE CAPABILITY FULLY MEETS	THAN	MANFACTURABILITY 1 MEDIUM HIGH
9	IF	TECHNOLOGICAL POSSIBILITIES DEVIATES SIGNIFICANTLY	AND	SOFTWARE CAPABILITY UNFULFILLED	THAN	MANFACTURABILITY 1 MEDIUM LOW
10	IF	TECHNOLOGICAL POSSIBILITIES DEVIATES SIGNIFICANTLY	AND	SOFTWARE CAPABILITY DEVIATES SIGNIFICANTLY	THAN	MANFACTURABILITY 1 MEDIUM LOW
11	IF	TECHNOLOGICAL POSSIBILITIES DEVIATES SIGNIFICANTLY	AND	SOFTWARE CAPABILITY DEVIATES SLIGHTLY	THAN	MANFACTURABILITY 1 MEDIUM LOW
12	IF	TECHNOLOGICAL POSSIBILITIES DEVIATES SIGNIFICANTLY	AND	SOFTWARE CAPABILITY FULLY MEETS	THAN	MANFACTURABILITY 1 MEDIUM
13	IF	TECHNOLOGICAL POSSIBILITIES UNFULFILLED	AND	SOFTWARE CAPABILITY UNFULFILLED	THAN	MANFACTURABILITY 1 LOW
14	IF	TECHNOLOGICAL POSSIBILITIES UNFULFILLED	AND	SOFTWARE CAPABILITY DEVIATES SIGNIFICANTLY	THAN	MANFACTURABILITY 1 MEDIUM LOW
15	IF	TECHNOLOGICAL POSSIBILITIES UNFULFILLED	AND	SOFTWARE CAPABILITY DEVIATES SLIGHTLY	THAN	MANFACTURABILITY 1 MEDIUM LOW
16	IF	TECHNOLOGICAL POSSIBILITIES UNFULFILLED	AND	SOFTWARE CAPABILITY FULLY MEETS	THAN	MANFACTURABILITY 1 MEDIUM

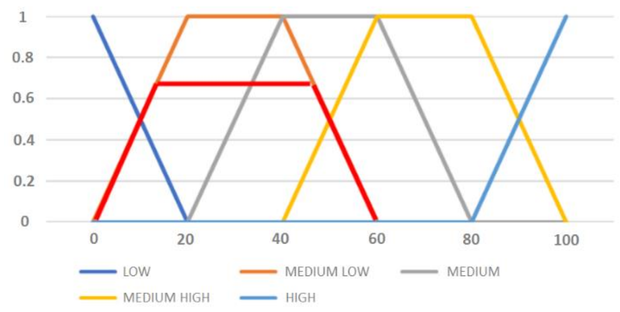

Fig. 5. Membership function graph Machining efficiency – sub-step 1

For technology – the low average (range <0; 60>) takes the value of min (0.67; technology – medium) – the value lower 0.67 or the value of the function technology – medium – low (Fig. 5).

Therefore, after the defuzzification process, the assessment is:

$$\begin{cases} y = \frac{x}{20} \\ y = 0.67 \end{cases} \qquad 0.67 = \frac{x}{20} \qquad x = 20 * 0.67 = 13.4$$

$$\begin{cases} y = \frac{60-x}{60-40} \\ y = 0.67 \end{cases} \quad 0.67 = \frac{60-x}{20} \quad 60 - x = 20 * 0.67 \quad 60 - x = 13.4 \quad x = 46.6$$

$$r = \frac{\int_0^{80} y \cdot \mu_{B'}(y) dy}{\int_0^{80} \mu_{B'}(y) dy}$$

$$r = \frac{\int_0^{13,4} y \cdot \frac{y^2}{20}\, dy + \int_{13,4}^{46,6} y \cdot 0.67\, dy + \int_{46,6}^{60} y \cdot \frac{60-y}{20}\, dy}{\int_0^{60} \mu_{B'}(y) dy}$$

$$\int_0^{60} \mu_{B'}(y) dy = P_1 \qquad P_1 = \frac{(60+33.2) \cdot 0.67}{2} = 31.2$$

$$r = \frac{y^3}{60} + \frac{y^2}{3} + \frac{1}{20} \cdot \left(30y^2 - \frac{y^2}{3}\right) = 40.1 + 664 + 229.24 = 933.34$$

$$r = \frac{933.34}{31.2} = 29.91$$

The value of the sample assessment of Machining Manufacturability Sub-step 1 is 29.9.

3. CONCLUSIONS

Attempt to assess manufacturability assessment takes into account the structure due to the machining, assembly process and organization of production. The assessment was carried out according to the fuzzy set inference methods. The manufacturability evaluation procedure is proposed in the steps, which start their ratings linguistic variables divided into sub-steps. An example of the evaluation due to machining on the basis of the proposed base of fuzzy inference can be extended for the assembly process steps and organization of production.

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