Assessment of the Design for Organization production processes using fuzzy logic

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Featured Application: new method to assess design for manufacturability based on fuzzy variables.

Abstract: The paper presents design methodology for the production process of a new product from the point of view of the assembly operations technology criterion (Design for Assembly - DFA) in the conditions of high-volume production. Mentioned are DFA methods and techniques used in the implementation of a new product. Author presents a new method to assess design for manufacturability based on fuzzy variables based on fuzzy variables. An example was given to illustrate the proposed course of action

Keywords: production process design, design for manufacturability, fuzzy logic.

1. Introduction

In the conditions of high production volume, when implement new products, less attention is due to the ever-wider technological possibilities of contemporary workplaces, workshop aids, automation, the high performance achieved and relatively low costs, devoted to the processing of elements, components of final products. Hence reported in literature advanced evaluation methods of products design manufacturability tailored to evaluate the implementation of a new product in the conditions of high volume mass production and are directed to processes for assembly. This is due to the high proportion of manual work compared to machining, which is associated with high labour intensity and high costs of assembly processes.

In the production of individual and small-batch main attention is paid to the issue of the possibility to implement the plant, the possibility of cooperative companies, as well as the determinants of the logistic flow of resources. Therefore, much attention is paid to the performance of the production cost target, taking into account investments in new production lines and positions, defined in terms of having to be carried out also other products and vision of the future production program [19].

2. Production preparation process

In the automotive industry, proposals for the use of design-oriented assessment methods for assembly. "Design for Assembly" - DFA, was described by G. Boothroyd and P. Dewhurst in the work "Design for Assembly, A Designers Handbook" in 1983. The concept of "Design for Assembly" can be defined in various ways, from the narrow meaning of "product design from the point of view of manufacturability criterion" to the broader term associated with   "product and process design from the cost-effective criterion point of view and reliable manufacturing to ensure the state of customer satisfaction "[17]. Many DFA methods are presented in the literature. The chronology of these methods and their brief characteristics are presented in Table 1. [10,15,16].

Table 1. Summary and description of the methodology of selected Design of Assembly methods [17].

Nr	Metoda	Rok	Odkrywcy	Opis
1.	Lucas DFA	1980	Redford A. H., Swift K. G.	It is based on the assembly sequence diagram (SSM) assess the assembly design. Producibility is estimated on the basis of penalty points associated with the product installation problems.
2.	Hitachi Assemblability Evaluation Method (AEM)	1986	Miyagawa S., Ohashi T.	The method assesses the product's assemblability and the cost index to indicate project weaknesses.
3.	Product Assemblability Merit Analysis Tool (PDM)	1986	Zorowski C. F.	The method gives opinions on product and component assembly problems and oversize indicators in the project.
4.	Boothroyd and Dewhurst	1988	Boothroyd G., Dewhurst P.	The method is based on determine the costs associated with the manual or automatic assembly process and has three criteria for limit the number of components.
5.	Integrated Desing for Assembly Evaluation and Reasoning System	1991	Sturges R. H. Jr, Kilani M. I.	The method built on the basis of solid modelling, explores the possibility of product assemblability.
6.	Fuzzy Product Assemblability Merit Analysis Tool	1993	Jackson S. D., Sutton J. C., Zorowski C. F.	PDM developed with fuzzy logic.
7.	DFA REV-ENGE	1994	Kim G. J., Bekey G. A.	DFA method taking into account reverse engineering.
8.	Constraints Network System	1995	Oh J. S., Grady P. O., Young R. D. F.	Method of interrelated constraints.
9.	Virtual Disassembly Evaluation	1998	Srinivasan H.	Method taking into account virtual disassembly.

The first and the second method are presented in the paper, due to the largest application in practice. Market conditions have forced companies to rationalize a comprehensive approach to the design and marketing of a new product [2,3,4,24]. The need for a broader look at the assessment of the technology of the structure, including this problem, taking into account many other aspects, this way of design is illustrated in Fig. 1.
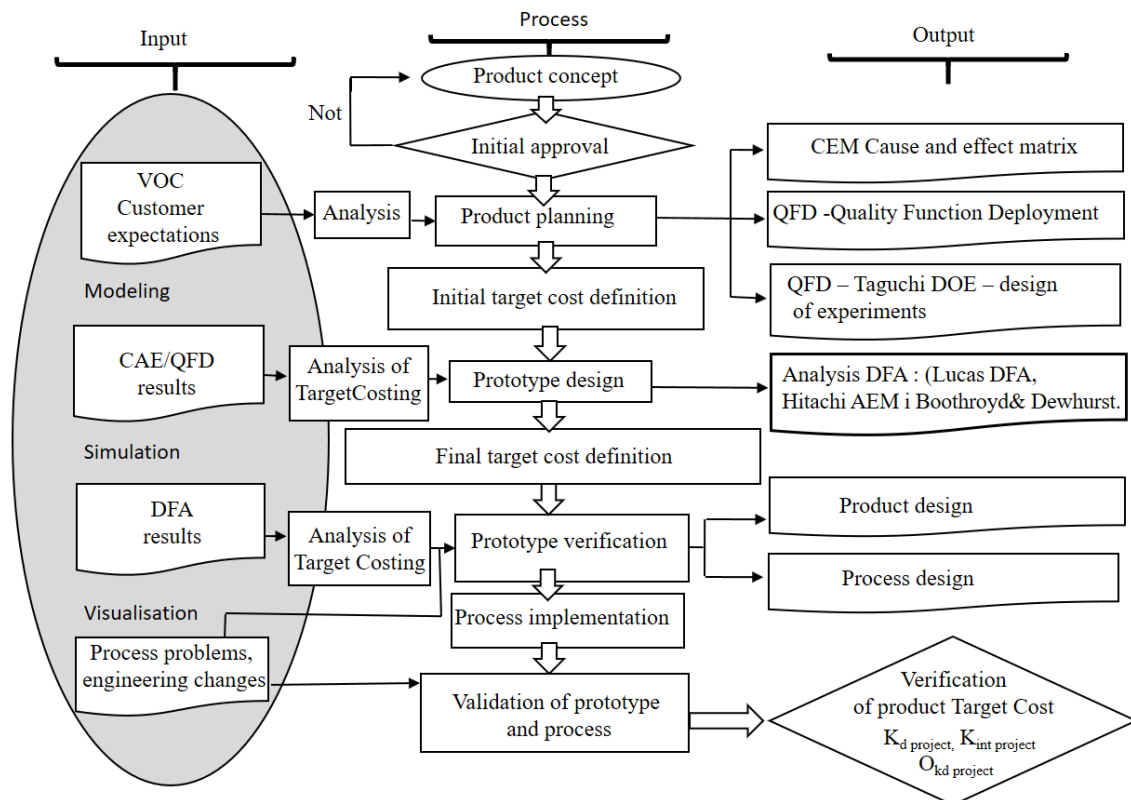
Figure 1. The use of methods to support the design of the production process of a new product.

In the design process under the aforementioned philosophies have been used methods such as QFD (Quality Function Deployment) [1,9,13] using in processes of implement products customer requirements, FMEA (Failure Mode and Effect Analysis) [18] - related to the prediction and prevention of problems at the product design stage, DFX (Design for X) [24] - e.g. Design for Manufacturing (DFM) regarding the shaping of the design process of components and the product itself [5,21]. Decisions taken at the product design stage have a significant impact on production costs, efficiency and quality of production. Supporting methods such as modelling, simulation and animation of production processes and systems as well as stimulating innovation such as brainstorming, TRIZ is of great importance in carrying out these works [8,10,14].

3. The project according to the new integrated DFA method based on fuzzy inference

3.1. Assumptions for the new DFA method

The justification for the emergence of a new fuzzy method for assess the technology of the structure results from the observed lack of flexibility of the described methods of Boothroyd-Dewhurst and Lucas. These methods were created in the 1980s in the conditions of needs of the economy focused on serial and mass production. The current development of the economy and technology means that the modern economic system is characterized by a much greater need for flexibility in terms of production methods: high volume, low volume and unit. The need to create a more flexible method adaptable to the type of production is noticeable[3].

The design process should be determined from the point of view of various usability criteria - Fig. 2. The assessment should take into account many other various factors, sales, service, spare parts availability, production series, types of equipment, available assembly techniques, level of automation, cooperative services, possibilities of application commercial components, crew technical culture, etc. In small-lot and serial production conditions, the design process of new product production is based on simplified production documentation. Due to the low production series, production data result from the project are rarely verified at the production stage, while the

experience gained from this stage is used in the production projects of new products. In relation to mass production and mass production, particular attention from the point of view of cost criterion is paid to: the possibility of using unified and standardized elements included in the final product, the use of work stations and workshop aids for processing and assembly of various elements included in the products making up the program production and introduction of group machining processes, process phases, group operations for various elements [11,22]. The newly proposed method using fuzzy inference is characterized by such flexibility.
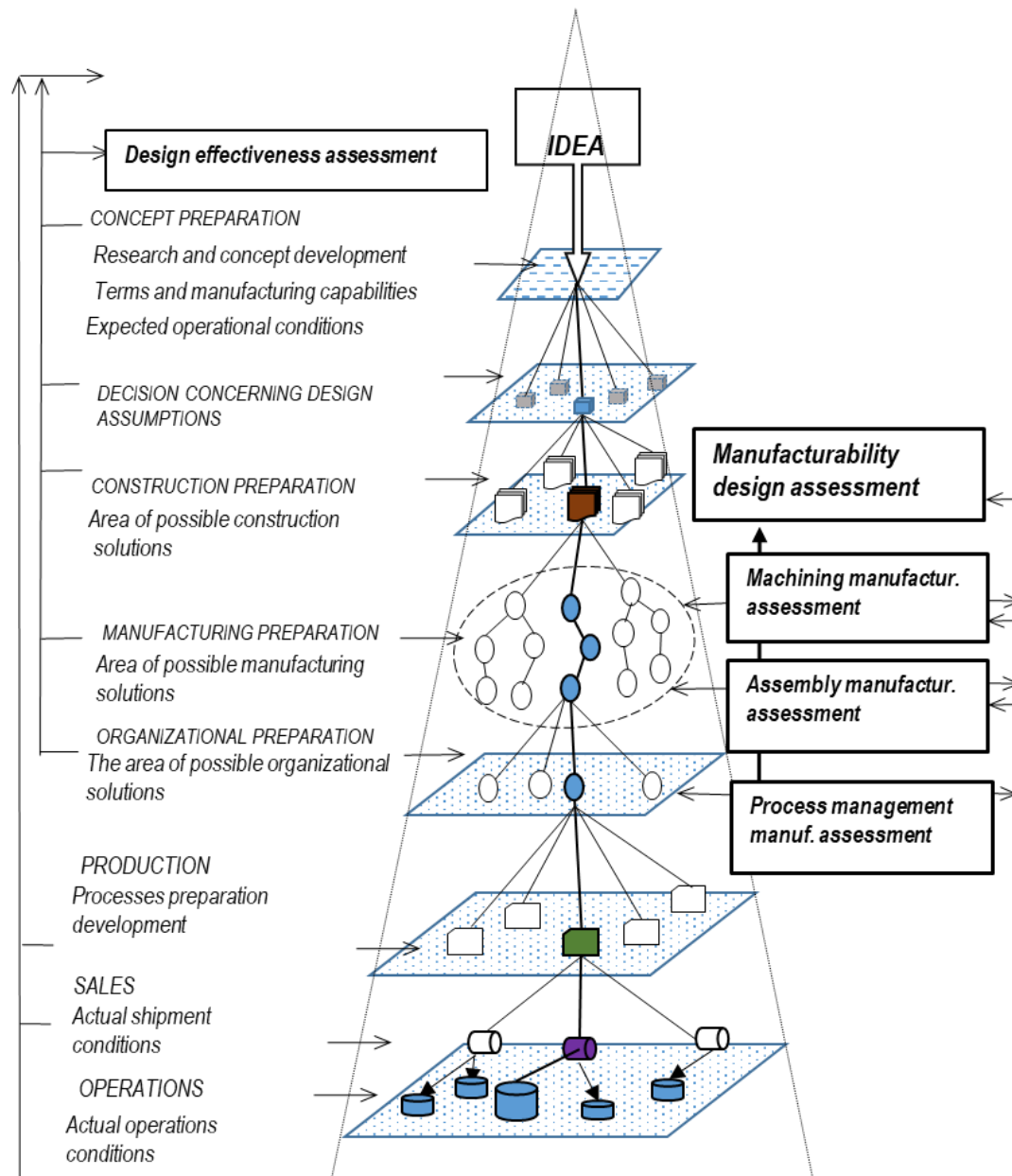
Figure 2. Modified design and development process for the production of a new product

3.2. The course of the new DFA method

The product design analysis process is carried out by experts representing as experts: product design, machining process design, assembly process design, quality assurance, product cost analysis, OHS and environmental protection in accordance with Figures 3 and 4.
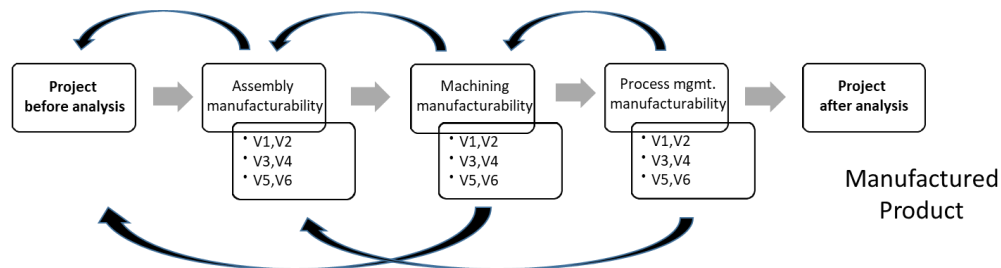
Figure 3. Structural analysis of the structure's technology in the proposed method.
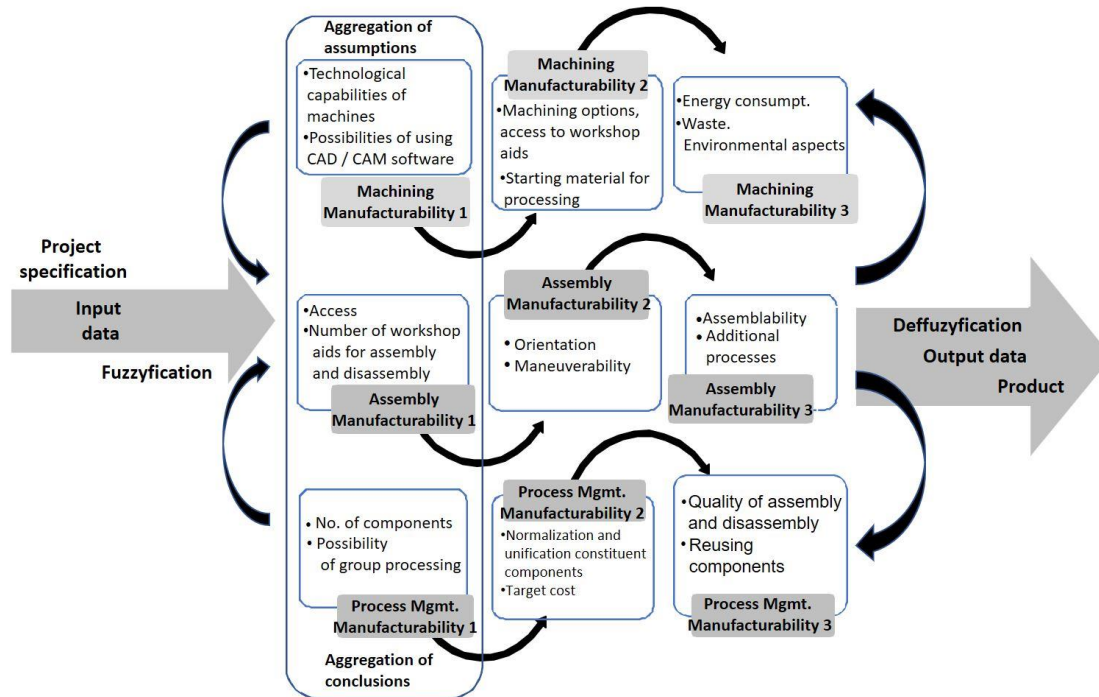
Figure 4. Model of the new DFA method based on three successive stages and sub-stages of fuzzy inference.

Experts determine the use of method tables, e.g. Boothroyd or Lucas, in accordance with the order of the process for each component of the product design, make an assessment on a scale of 0 to 100. Then the process of the machining process and the assembly process are evaluated. The method was developed on the basis of the proposed General Scheme of Technology Assessment and consists of three stages: assessment of machining efficiency, assessment of assembly efficiency, assessment of production organization efficiency.

The assessment is related to the set of linguistic variables $V_i = \{V_1, ..., V_n\}$, and $\in N - \{0\}$, defining the input and output criteria of technology. The linguistic variable V_i is described by a quadrangle:

$$[L_i, T_i(L), \Omega_i, M_i] \tag{10}$$

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

The assessment of machining processability and subsequent assembly technology assessment correspond to the prototype stage during product design and development, and the assessment of

production organization technology corresponds to the plot series and production series during validation and then serial production. The applied variables V1, V2, V3, V4, V5, V6 in the scope of machining technologies, assembly, production organization are shown in Fig. 4. The assessment, depending on the scope of information obtained, can be carried out for individual components of the product, groups of elements, its assemblies or also in a holistic way[12].

4. Example

4.1   Input assumptions

Based on the analyzes of the above methods of assess the product's producibility, an improved proprietary approach was proposed in the process to shape the product's productiveness. The illustration of the presented proposals is presented on the example of a single-stage gear in Fig 5. General purpose gearboxes are designed in the form of a series of types from the point of view of market demand, production costs and delivery time to the customer. The gearbox shown in Fig. 5 was designed in a traditional way (welded body, a large number of bolted joints, etc.).
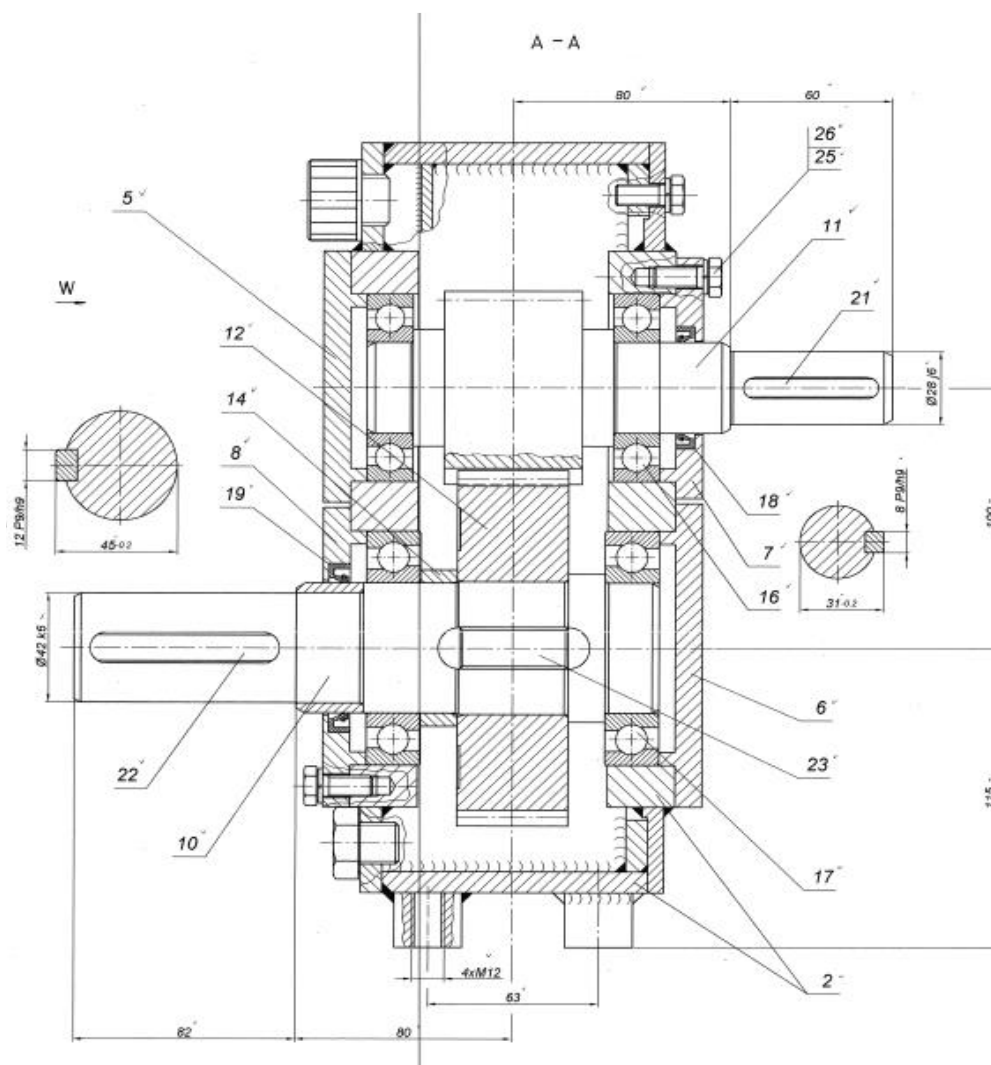
Figure 5. Diagram of the analyzed gearbox, 2- body, 5, 6, 7, 8- bearing caps, 10- shaft, 11-pinion, 12-tooth gear, 14- spacing rings, 17, 16- bearings, 18, 19, - seals, 21, 22, 23- keys, 25, 26-washers, screws.

4.2. Fuzzy assessment of design for machinability - for example

To decrease the number of components of a product may increase its complexity and increase its manufacturing costs. The final product can be easy to assemble and expensive to process its components.

The condition for the correct determination of the cost-related factors involved in the production process of a given element is information about the characteristics that this element has from the point of view of construction, production and organization of production. The main task that must be performed is to determine the value of the costs of implementing individual operations. The cost of product processing and organization of production includes material costs, costs of cooperation and processing of a given operation. Classification of elements should include its type, e.g. shaft, sleeve, specify dimensions, accuracy of workmanship, etc. Based on technological similarity, the costs of individual operations can be determined in accordance with the data in the database of costs of operation of technologically closest components [7,20,22,23].

Figure 6. Example of the first level of the production item classifier- restrictions on unnecessary diversity.

The assessment is based on a multi-level classification of elements, assemblies made in the enterprise, etc. - Fig. 6. The new element is assigned to a given shape representative based on the designer's decision - Fig. 4. Based on the shape and design parameters from the manufacturing processes database, the process of the element with the same shape code and parameters most similar to the parameters of the new element is searched. Having the process of manufacturing the nearest element at your disposal and data on the value of cost factors in connection with the cost calculation system, you can specify the production costs of the designed element [12,17,20].

For example, the assessment of body technology, assume that it depends on two factors, which are: technological capabilities of the machine park and the possibility of using CAD / CAM software, experts rated: technological capabilities = 20, software capability = 55. Aggregations of both parameters are shown in Fig. 7 and 8 [6,10].
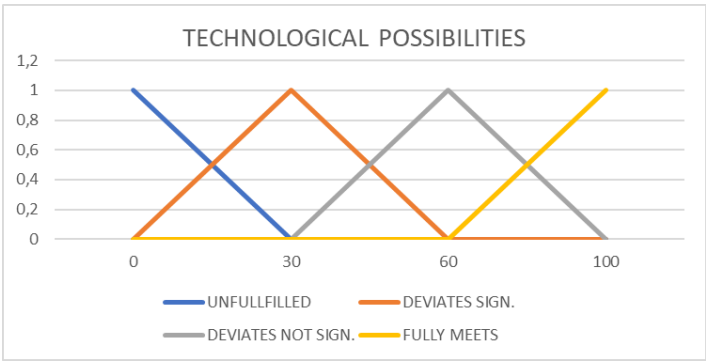
Figure 7. Graphical representation of linguistic variables for Technological Capabilities
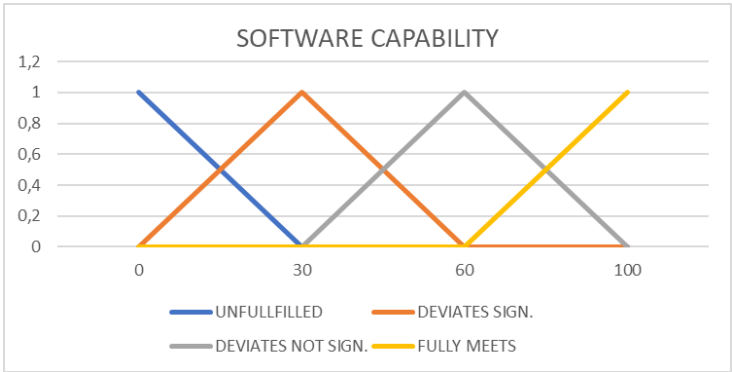
Figure 8. Graphical representation of linguistic variables for Software Capability

Aggregation of rules for Design for Machining Technology 1 was presented in Fig. 16
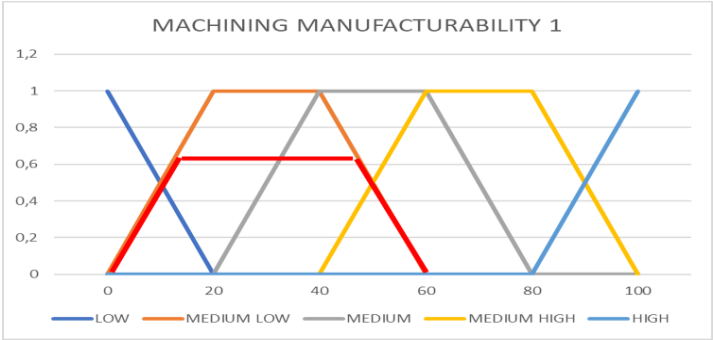
Figure 9. Aggregation of rules for Machining Technology 1

The Design for Machining Technology - Machining Processing Assessment for sub-step 1 is 29.9.

Design for Machining Processing - Assessment 2

In a similar procedure, the assessment was determined: Tool Machining Capability = 10, Compliance Requirements = 35. Aggregation of rules for Machining Processing 2 is given in Fig. 10.
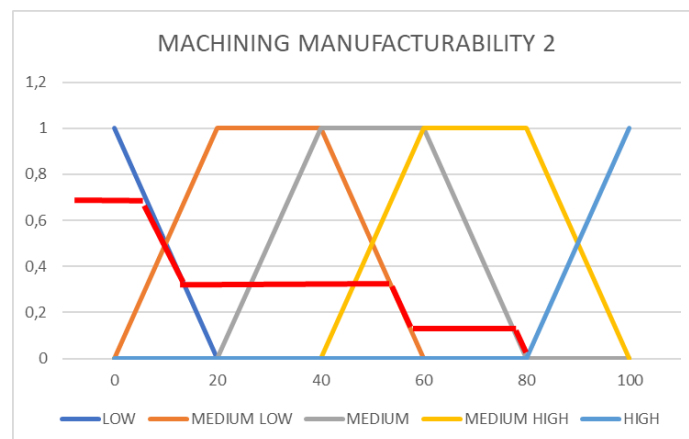
Figure 10. Aggregation of rules for Machining Technology 2

The value of Technology (Design for Machining Processing - Assessment 2) is 30.6.

Design for Machining Processing - Assessment 3

Assume that the assessment depends on two factors: experts have established the assessment: Energy consumption = 70, Waste, environmental aspects = 10. Technology 3 takes the value for Technological Capabilities in 70 and Software Capability 10:
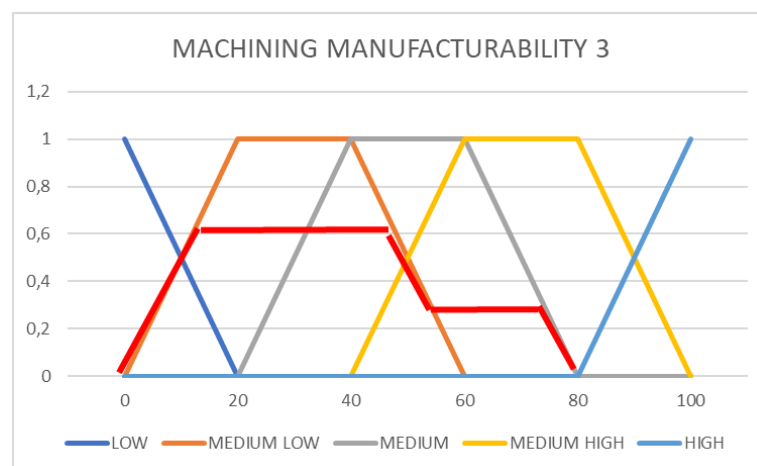
Figure 11. Aggregation of rules for Design for Machining Technology 3

Design for Machining Processing - Assessment Technology 3 value is 36.

4.3. Fuzzy assessment of the design for manufacturing organization

Assessment of Design for Manufacturing organization 1

The body's technology, assume that it depends on two factors, which are: Number of components and The possibility of group processing, experts have determined the rating as Number of components = 20, The possibility of group processing = 20. Technology 1 takes:
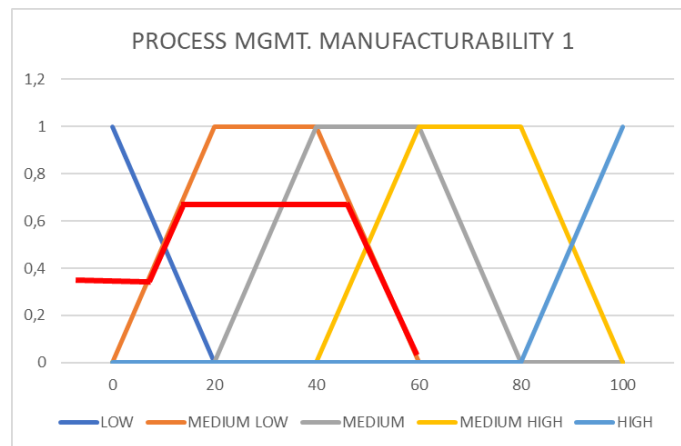
Figure 12. Aggregation of rules for Process management manufacturability1

The value of Process management manufacturability 1 for the value for Disassembly 20 and The possibility of group processing 20 is 40.

Assessment of Design for Manufacturing organization 2

Technology depends on two factors, which are: Component normalization, Target cost. The expert group made the following assessment: Component unification = 20, Target cost = 55.
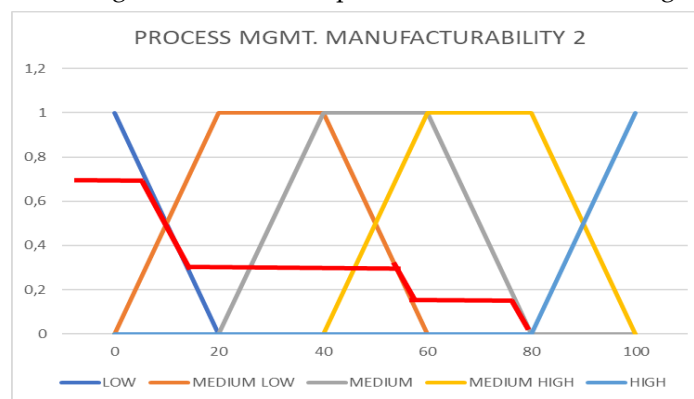
Figure 13. Aggregation of rules for Process management manufacturability (organization) 2

The value of Process management manufacturability – 2 is 31.

Assessment of Design for Manufacturing organization 3

The technology of the 3rd component is determined, assume that it depends on two factors, which are: quality of assembly, Reuse components. Experts have determined the following: Quality of assembly = 70, Reuse components = 10.
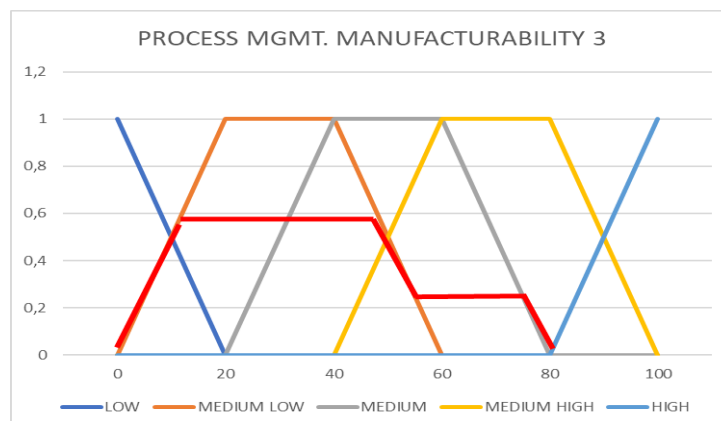
Figure 14. Aggregation of rules for assessment of Design for Manufacturing organization 3

The Value of Assessment of Design for Manufacturing orgsnization 3 was 36.

4.4. A fuzzy assessment of design fortechnology

A complete fuzzy analysis of the technology was carried out in the same stages as for the sample "body" component. Each component of the analyzed transmission was assessed by a group of experts according to their best knowledge in the field of technology, organizational and cost options. Expert assessments were entered in Table 1. and are used in subsequent stages as input to fuzzy analyzes. The table contains a summary of all stages for each component. The stages of the analysis are identical to those presented above. Calculations of the fuzzy technology assessment method were made using the Fuzzy Logic Toolbox package, which is an addition to the Matlab program. The analysis selected a uniform representation of the membership function. It can be obtained by using a membership function with a uniform shape and parametric definition of the function. In the case of the aforementioned assessability of technology, triangular and trapezoidal functions were used. This is justified by the ease of obtaining a parametric description of the membership function, the minimum amount of memory needed for its storage, and the efficiency of processing.

For each group of components, calculations were made using the above scheme using Matlab R2017b - the "Fuzzy Logic Designer" module. The results are shown in Table 2.

In order to make the method comparison with traditional methods transparent, the evaluation and results were scaled. The best theoretical value for the design feasibility of the structure may be 100. After scaling, this rating may have a maximum value of 1.00. The assessments of the efficiency according to the new method will be equal to x /100 where x is the given assessment of the structure's efficiency.

The development of an approximate representation of knowledge and fuzzy inference methods enables the construction of models for assessing technology to support decision making in conditions of uncertainty and lack of complete information about the problems being solved.

Premises and conclusions in these systems were developed using fuzzy logic elements. The knowledge contained in the system should come mainly from a field expert, and the effectiveness and efficiency of the system operation depend mainly on the ability to model this knowledge by the system designer. The elements of fuzzy logic presented in the article are used in solving tasks in the field of technological preparation of production. An important problem is the correct definition of fuzzy sets by determining for them the course of belonging functions. [source-Fuzzy Logic Toolbox - user's guide]

Table 2 presents a summary of the results of individual components obtained in the fuzzy transmission analysis. An acceptability criterion of 0.55 was adopted for each component (modeled on the recommendations of the Lucas method and other DFA methods as well as the opinions of experts from industrial practice), elements of lower value should be redesigned. The following transmission components need to be redesigned as a result of the above assessment: body, cover, breather, oil level indicator, covers, additional processes, nameplate, shaft assembly and inlets. Elements rated as not requiring redesign are: gears, bearings, washers, screws.

An additional tool useful in the assessment of construction are surface charts - "Surface Viewer". With the help of such charts, we can quickly obtain the result of the Technology component without the need for complex calculations. In the chart below "Assembly technology 1" if, for example, the "Access" rating would change from 0.55 to 0.75 and the "Number of workshop aids" rating changed from 0.2 to 0.8, then from the surface chart in Fig. 15 we can read the value of Assembly technology 1 at the level of 0.6. In the process of selecting variants to improve the technology, it is a very useful tool that allows you to assess quickly how potential product changes can affect the result of the technology.

Table 1. Set of component assessments made by experts for established criteria

Group	Machining Manufacturability 1		Machining Manufacturability 2		Machining Manufacturability 3		Assembly Manufacturability 1		Assembly Manufacturability 2		Assembly Manufacturability 3		Process Mgmt. Manufacturability 1		Process Mgmt. Manufacturability 2		Process Mgmt. Manufacturability 3	
	Technological Capabilities	Software Capability	Tool Machining Capability	Compliance Requirements	Energy consumption	Waste, environmental aspects	Access	Number of workshop aids	Orientation	Manoeuvrability	Assemblability	Processes	Number of components	Possibility of group processing	Normalization, unification of components	Target cost	Quality of assembly and disassembly	Reusing components
Gear	60	50	40	70	40	20	60	70	80	70	60	70	50	60	90	80	60	60
Main housing	20	55	10	35	70	10	20	55	10	35	70	10	20	20	10	35	70	10
Bearing	80	70	80	70	30	20	60	90	80	90	70	70	50	60	90	90	60	90
Bearing	80	70	80	70	30	20	60	90	80	90	70	70	50	60	90	90	60	90
Bearing	80	70	80	70	30	20	60	90	80	90	70	70	50	60	90	90	60	90
Bearing	80	70	80	70	30	20	60	90	80	90	70	70	50	60	90	90	60	90
Vent	70	60	70	60	20	15	45	60	45	60	45	50	50	60	40	60	60	20
Oil sight	70	60	70	60	20	15	45	60	45	60	45	50	50	60	40	60	60	20
Washer	95	95	95	95	10	10	60	20	45	20	45	70	80	80	90	90	80	90
Washer	95	95	95	95	10	10	60	20	45	20	45	70	80	80	90	90	80	90
Washer	95	95	95	95	10	10	60	20	45	20	45	70	80	80	90	90	80	90
Washer	95	95	95	95	10	10	60	20	45	20	45	70	80	80	90	90	80	90
Washer	95	95	95	95	10	10	60	20	45	20	45	70	80	80	90	90	80	90
Washer	95	95	95	95	10	10	60	20	45	20	45	70	80	80	90	90	80	90
Washer	95	95	95	95	10	10	60	20	45	20	45	70	80	80	90	90	80	90
Washer	95	95	95	95	10	10	60	20	45	20	45	70	80	80	90	90	80	90
Cover	40	50	40	35	80	10	65	60	30	60	60	20	40	40	50	50	80	10
Cover	40	50	40	35	80	10	65	60	30	60	60	20	40	40	50	50	80	10
Cover	40	50	40	35	80	10	65	60	30	60	60	20	40	40	50	50	80	10
Cover	40	50	40	35	80	10	65	60	30	60	60	20	40	40	50	50	80	10
Add. Process	95	95	95	95	90	10	90	10	10	10	10	10	10	10	20	30	50	90
Add. Process	95	95	95	95	90	10	90	10	10	10	10	10	10	10	20	30	50	90
Add. Process	95	95	95	95	90	10	90	10	10	10	10	10	10	10	20	30	50	90
Add. Process	95	95	95	95	90	10	90	10	10	10	10	10	10	10	20	30	50	90
Add. Process	95	95	95	95	90	10	90	10	10	10	10	10	10	10	20	30	50	90
Screw	80	70	80	70	10	30	50	70	35	70	55	60	60	40	70	60	70	90
Screw	80	70	80	70	10	30	50	70	35	70	55	60	60	40	70	60	70	90
Screw	80	70	80	70	10	30	50	70	35	70	55	60	60	40	70	60	70	90
Screw	80	70	80	70	10	30	50	70	35	70	55	60	60	40	70	60	70	90
Screw	80	70	80	70	10	30	50	70	35	70	55	60	60	40	70	60	70	90
Screw	80	70	80	70	10	30	50	70	35	70	55	60	60	40	70	60	70	90
Screw	80	70	80	70	10	30	50	70	35	70	55	60	60	40	70	60	70	90
Nameplate	70	60	70	60	20	15	45	60	45	60	45	50	50	60	40	60	60	20
Shaft	50	35	40	70	40	20	60	50	80	50	40	70	35	50	40	60	60	60
Shaft	50	35	40	70	40	20	60	50	80	50	40	70	35	50	40	60	60	60
Shaft	50	35	40	70	40	20	60	50	80	50	40	70	35	50	40	60	60	60
Shaft	50	35	40	70	40	20	60	50	80	50	40	70	35	50	40	60	60	60
Shaft	50	35	40	70	40	20	60	50	80	50	40	70	35	50	40	60	60	60
Groove	70	60	70	60	20	15	45	60	45	60	45	50	50	60	40	60	60	20
Groove	70	60	70	60	20	15	45	60	45	60	45	50	50	60	40	60	60	20

Table 2. A set of fuzzy method results for individual components for specified criteria

	Machining Manufacturability 1	Machining Manufacturability 2	Machining Manufacturability 3	Assembly Manufacturability 1	Assembly Manufacturability 2	Assembly Manufacturability 3	Process Mgmt. Manufacturability 1	Process Mgmt. Manufacturability 2	Process Mgmt. Manufacturability 3
Gear	0,56	0,55	0,36	0,5	0,71	0,55	0,64	0,76	0,59
Main housing	0,3	0,3	0,36	0,42	0,31	0,36	0,4	0,31	0,35
Bearing	0,71	0,61	0,3	0,5	0,76	0,56	0,64	0,56	0,59
Bearing	0,71	0,61	0,3	0,5	0,76	0,56	0,64	0,56	0,59
Bearing	0,71	0,61	0,3	0,5	0,76	0,56	0,64	0,56	0,59
Bearing	0,71	0,61	0,3	0,5	0,76	0,56	0,64	0,56	0,59
Vent	0,7	0,55	0,29	0,5	0,6	0,42	0,64	0,56	0,52
Oil sight	0,7	0,55	0,29	0,5	0,6	0,42	0,64	0,56	0,52
Washer	0,83	0,76	0,24	0,29	0,39	0,56	0,73	0,78	0,59
Washer	0,83	0,76	0,24	0,29	0,39	0,56	0,73	0,78	0,59
Washer	0,83	0,76	0,24	0,29	0,39	0,56	0,73	0,78	0,59
Washer	0,83	0,76	0,24	0,29	0,39	0,56	0,73	0,78	0,59
Washer	0,83	0,76	0,24	0,29	0,39	0,56	0,73	0,78	0,59
Washer	0,83	0,76	0,24	0,29	0,39	0,56	0,73	0,78	0,59
Washer	0,83	0,76	0,24	0,29	0,39	0,56	0,73	0,78	0,59
Washer	0,83	0,76	0,24	0,29	0,39	0,56	0,73	0,78	0,59
Cover	0,44	0,36	0,38	0,53	0,5	0,3	0,44	0,56	0,43
Cover	0,44	0,36	0,38	0,53	0,5	0,3	0,44	0,56	0,43
Cover	0,44	0,36	0,38	0,53	0,5	0,3	0,44	0,56	0,43
Cover	0,44	0,36	0,38	0,53	0,5	0,3	0,44	0,56	0,43
Cover	0,44	0,36	0,38	0,53	0,5	0,3	0,44	0,56	0,43
Add. Process	0,83	0,76	0,37	0,36	0,24	0,24	0,24	0,29	0,44
Add. Process	0,83	0,76	0,37	0,36	0,24	0,24	0,24	0,29	0,44
Add. Process	0,83	0,76	0,37	0,36	0,24	0,24	0,24	0,29	0,44
Add. Process	0,83	0,76	0,37	0,36	0,24	0,24	0,24	0,29	0,44
Add. Process	0,83	0,76	0,37	0,36	0,24	0,24	0,24	0,29	0,44
Add. Process	0,83	0,76	0,37	0,36	0,24	0,24	0,24	0,29	0,44
Screw	0,71	0,61	0,25	0,5	0,54	0,5	0,56	0,71	0,57
Screw	0,71	0,61	0,25	0,5	0,54	0,5	0,56	0,71	0,57
Screw	0,71	0,61	0,25	0,5	0,54	0,5	0,56	0,71	0,57
Screw	0,71	0,61	0,25	0,5	0,54	0,5	0,56	0,71	0,57
Screw	0,71	0,61	0,25	0,5	0,54	0,5	0,56	0,71	0,57
Screw	0,71	0,61	0,25	0,5	0,54	0,5	0,56	0,71	0,57
Screw	0,71	0,61	0,25	0,5	0,54	0,5	0,56	0,71	0,57
Screw	0,71	0,61	0,25	0,5	0,54	0,5	0,56	0,71	0,57
Screw	0,71	0,61	0,25	0,5	0,54	0,5	0,56	0,71	0,57
Nameplate	0,7	0,55	0,29	0,5	0,6	0,42	0,64	0,56	0,52
Shaft	0,47	0,55	0,36	0,44	0,62	0,55	0,47	0,56	0,52
Shaft	0,47	0,55	0,36	0,44	0,62	0,55	0,47	0,56	0,52
Shaft	0,47	0,55	0,36	0,44	0,62	0,55	0,47	0,56	0,52
Shaft	0,47	0,55	0,36	0,44	0,62	0,55	0,47	0,56	0,52
Shaft	0,47	0,55	0,36	0,44	0,62	0,55	0,47	0,56	0,52
Shaft	0,47	0,55	0,36	0,44	0,62	0,55	0,47	0,56	0,52
Groove	0,7	0,55	0,29	0,5	0,6	0,42	0,64	0,56	0,52
Groove	0,7	0,55	0,29	0,5	0,6	0,42	0,64	0,56	0,52

Figure 15. Surface Viewer - The surface of the dependence of the variable "Installation technology 1" on the input variables for "gears"

4.5. Comparison of the use of methods on the example of a gear fragment - a drive shaft set

In the study, the indicators of the assessment of the manufacturability of the structure were determined for the sample product presented in Fig. 5. As a result of the analysis after the proposed changes, the new form of the gear structure change is illustrated in Fig. 16. Fig. 17 presents the values of the indicators according to the traditional methods and the proposed method
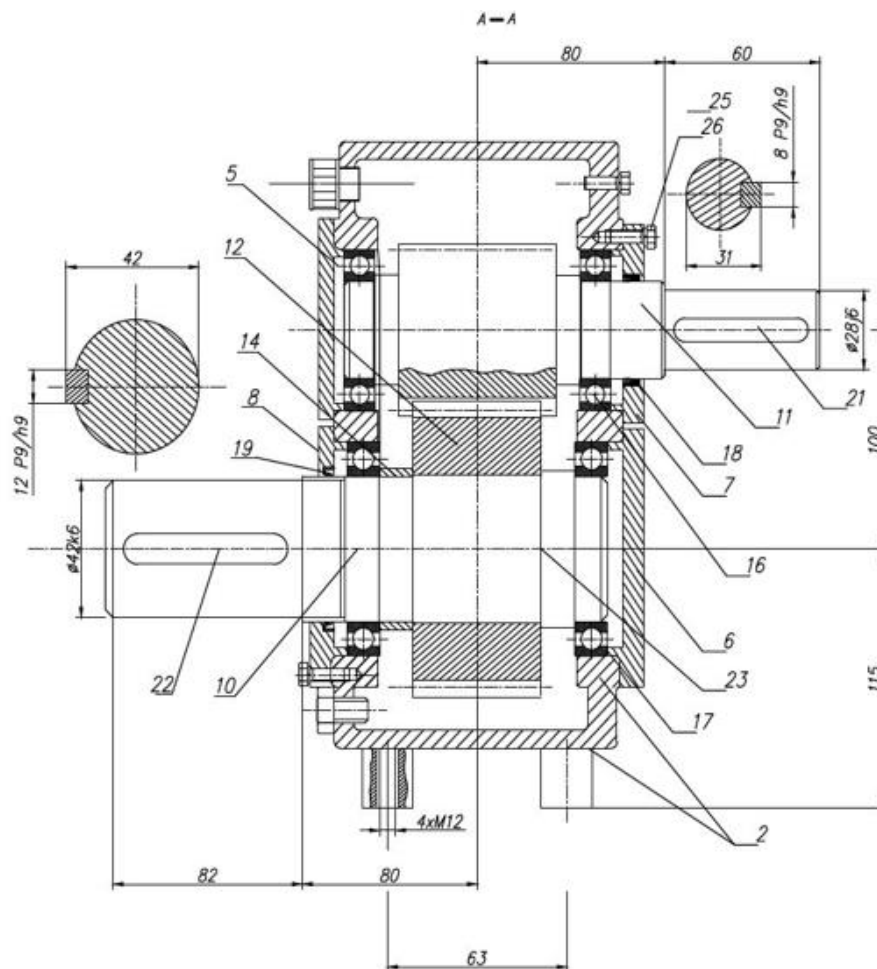
Figure 16. Construction form of the gearbox after the changes have been made

Table 3. Comparison of DFA methods

Lucas

				Operation											
Pressing to bearing 16	Pinion shaft	A	1	Pick up and hold down	1	0	0	0	0	0	0	1	1	1	1
Pick up	Main shaft	A	1	Pressing to bearing	2	0	0	0,7	0,7	0	0	0	3,4	4,4
Assembly	Wedge 23	B	1	Pick up and place	1	0	0	0	0,7	0	0	0	1	5,4
Assembly on shaft subassy	Gear 5	B	1	Assembly on shaft subassy	2	0,1	0	0,7	0,7	0	0	0,7	3,5	10,6
Assembly on shaft subassy	Spacer sleeve 14	B	1	Assembly on shaft subassy	1	0,1	0	0	0	0	0	0	1,1	11,7
Preheating gear to 180 deg.	Preheating	B	1	Assembly on shaft subassy										
				Preheating	0	0	0	0	0	7,5	7,5	1	7,5	19,2
		6	2												59,4

Manufacturability index 0,3

Boothroyd

										Operation										
Gear	prasowanie do łożyska 16	1	37	194	360	0	0,36	6,35	41	Pick up and hold down	7,5	13,85	1	0	0	0	0	0	1	0,52
Drive gear	Pick up and place	1	28	216	360	360	0,36	1,95	01	Pressing to bearing		1,95	2	0	0	0	0	Y	Y	1	0,52
Groove	Assembly	1	16	40	180	360	0,29	1,8	01	Pick up and place	2,5	4,3	1	0	0	0	N	N	0	0,52
Gear no. 5	Assembly on shaft sub	1	41	136	180	360	0,36	6,35	31	Assembly on shaft subassy	5	11,35	1	0	0	0	N	N	0	0,59
Sleeve no. 14	Assembly on shaft sub	1	4	60	180	0	0,3	1,13	01	Assembly on shaft subassy	2,5	3,63	1	0,1	0	0	N	N	0	0,59
Preheating	Preheating gear to 180 deg.									Assembly on shaft subassy	12	12	1	0,1	0	0	N	N	0	0,44
Shaft subassembly	Pressing to bearing	1	136	216	360	360	0,36	1,95	51	Preheating	9	10,95	0	0	0	0	Y	Y	1	0,52
		7							99			58,03							3	

Manufacturability index 0,24

Fuzzy

Shaft to bearing	Pressing to bearing	0,47	0,55	0,36	0,44	0,62	0,55	0,47	0,56	0,7	0,52
Shaft	Assembly	0,47	0,55	0,36	0,44	0,62	0,55	0,47	0,56	0,7	0,52
Groove	Assembly	0,7	0,55	0,29	0,5	0,6	0,42	0,64	0,56	0,44	0,52
Gear	Assembly on shaft sub	0,56	0,55	0,36	0,5	0,71	0,55	0,64	0,76	0,7	0,59
Sleeve	Assembly	0,71	0,61	0,3	0,5	0,76	0,56	0,64	0,56	0,7	0,59
Preheating	Preheating gear to 180	0,83	0,76	0,37	0,36	0,24	0,24	0,24	0,29	0,64	0,44
Shaft subassembly	Assembly	0,47	0,55	0,36	0,44	0,62	0,55	0,47	0,56	0,7	0,52

Manufacturability index 0,53

The result of a single method does not give a picture of effectiveness or not a new fuzzy method. For this purpose, a comparison of a selected transmission fragment of the new method and existing methods was carried out. From the overall assessment of the transmission, was selected fragment in the form of a drive shaft assembly and was compared in Table 3. Comparison shows that for small lot production assessment B&D with 0,3 result , Lucas with 0,24 result versus Fuzzy defined for small lot with 0,53 result less restrictive approach of Fuzzy method. This is very important as small lot production usually has much less capital available.
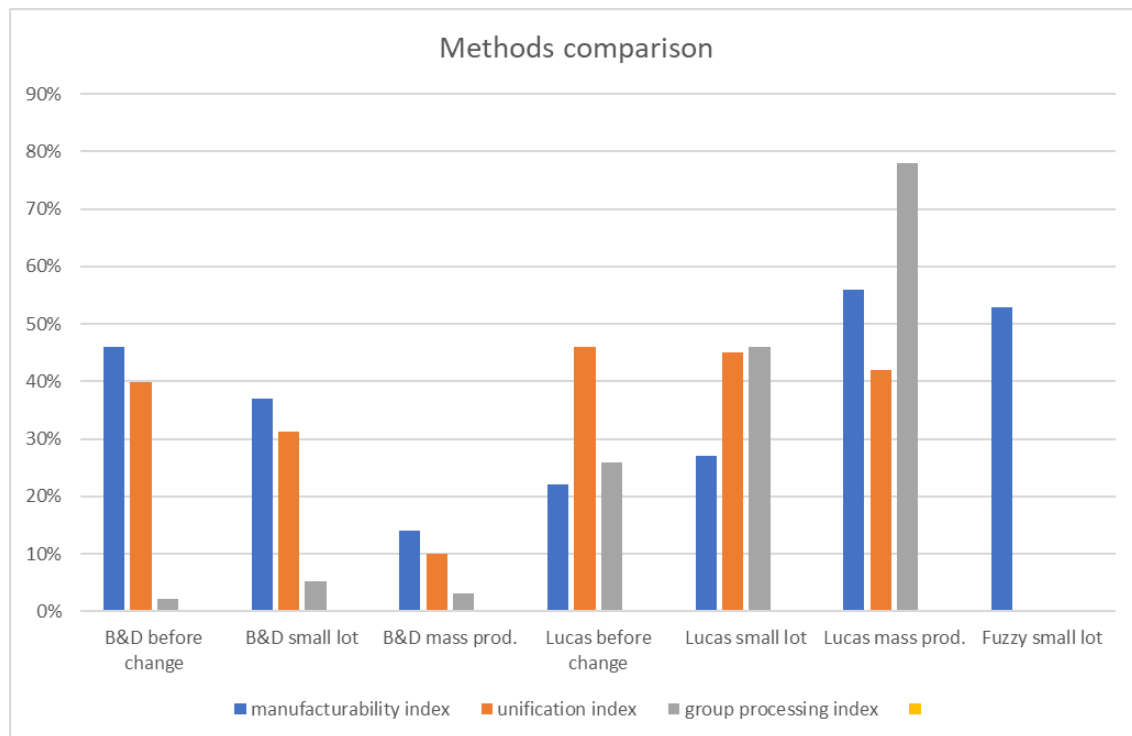
Figure 17. Comparison of methods for gear group.

The comparison should be read as follows, the lower the score, the more you need to redesign / reduce the product design. From the comparison of the assessment, it can be concluded that the Boothroyd & Dewhurst method is the most stringent and focused on reduce / simplify the components of the project. At the same time, in the case of production not qualified for high-volume production, the result of such assessment may be a product with a small number of components, but a very complicated form, and therefore a high cost of processing and quality and other in the field of production organization. The Lucas method in a more balanced way assesses the above project, but the difference from Boothroyd-Dewhurst is not large, which means that it will also work best in mass production.

5. Conclusions and comments

In standard technology analyzes according to B&D and Lucas DFA, it is associated with a reduction in the number of components that have no significant effect on the product's functions or their change consist in improvement in terms of assembly time and costs. In the traditional arrangement of the above mentioned the methods are oriented towards mass production. The proposed proprietary method based on the analysis of the obtained values of the parameters of the assessment of the efficiency of the entire process enables

- unification of components, application of group processing methods, standardization of machining and assembly operations, and thus save of investment in machines and shorter overall assembly time, shorten of times, elimination of errors, reduction of process costs

- taking into account, in addition to assembly, many other various factors, e.g. availability of spare parts, production seriality, production conditions in the form of equipment types, available assembly techniques, level of automation, scope of external cooperation orders

- the method can be used for smaller series of manufactured products,

- assessment of technology in the form of given indicators and coefficients should be carried out by experts with extensive production experience,

- arouse designers' creativity when designing new products, rationalizing works at the stage of improving and expanding the range of implemented production.

The presented method is universal. The use of fuzzy logic gives the opportunity to express incomplete and uncertain information in natural language, in a simple way for humans based on expert knowledge and empirical data. The method takes into account the analysis of the production process in a holistic way.

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