

Manufacturability assessment in assembly processes

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Abstract: In this paper, there is presented the problem of assessing the manufacturability of complex products at the design stage of the manufacturing process considering the criterion of execution of assembly operations processes and production costs. Assessment of manufacturability was given on the example of the Boothroyd & Dewhurst method. This paper describes how to estimate the times and costs of assembly operations according to the mentioned above criteria with the use of the expert system. The presented example illustrates its practical application. The method of analysis presented in this article, developed by the authors, will be the subject of further research aimed at creation of an advanced expert system supporting the design of assembly systems.

Keywords: Manufacturing process design, assembly process, manufacturability.

1. INTRODUCTION

In today's global economy, manufacturing companies operate in the context of fierce competition and a dynamically changing market environment. Customer requirements for higher quality product, lower cost and shorter product lifecycles put pressure on the designing and implementation process for a new product. The costs and qualitative parameters should be considered in the early stages of the designing process. The need to understand the consequences of design decisions on manufacturing and product quality is decisive in assessing the efficiency and effectiveness of production systems (Furmann et al, 2017; Gola, 2014; Matuszek and Seneta, 2019).

In production practice, depending on the complexity of products, organisational and technical production preparation, various methods and techniques of project management are used to design and develop new product technology (Cohen, et al., 2013, Cohen and Goren-Bar, 2013, Singer, et al., 2014, Swift, 1987). Nowadays, the most important features of project activities are: teamwork, concurrent engineering, project management, digital factory tools, and lean management tools (Matuszek and Seneta, 2017, Matuszek and Seneta, 2020). More and more attention is given to the new concepts for implementing new products into like, for example, DFA (Design for Assembly) and PDM (Product Data Management) (Abdullah et al., 2003; Cohen, 2015, James et al., 2017; Shetty and Ali, 2015; Shukor and Adam, 2018).

To evaluate the assembly, to define guidelines for shaping the design process due to PDM, different methods may be used. In the automotive industry, widely recognized methods known as DFA (design for assembly) were proposed and described for the first time by G. Boothroyd and P. Dewhurst in 1983 at work "Design for Assembly". The DFA methods are due to technical progress constantly being refined. They

allow a more efficient evaluation of the possibility of reducing the number of product components and estimating the costs of machining processes and assembly of the analysed product. By introducing DFA methods into the design process, the new product design team has the opportunity to propose improved design solutions, which are characterized by better indicators, simpler construction and components, which directly affects the simplification of assembly operations (Matuszek and Seneta, 2016; Swift and Booker, 2013). For this reason, the DFA method was chosen as the basis for analysing of the assembly process, which is presented in more detail in the second section of the article.

Production process design involves numerous heuristic activities, due to the lack of a mathematical model of the designed object (e.g. variables are not defined, relations between variables are unknown), or the lack of possibilities of full calculations with an existing model (Rodriguez-Toro, 2002, Więcek, 2013). In such situations, attempts are made to write down heuristic knowledge (based on intuition, experience) formally, so that it could become a basis of creating computer systems. Therefore there is a need to create an analysis model that, on the one hand, takes into account constructional and technological parameters of products, and on the other hand assessment criteria, including costs. An attempt to develop such a model is presented in the third section of the article. Then the fourth section gives a practical example of the proposed solution and the fifth summarizes the presented analysis.

The presented solution were created for identifying the main set of manufacturing process parameters, which are the key to evaluating costs of the designed elements. The proposed solution was adapted for unit and small-batch production systems.

2. DESIGN FOR ASSEMBLY

It can be assumed that the first practical examples of designing the constructional form of the product components similar to the activities of "design for assembly" (PDM) can be seen in the early days of H. Ford around 1920. The plants began to produce products without significant difficulties in the sales markets. In this period, the focus was mainly on external appearance and functionality, not on the features of technological and production processes. In the 1960s, there was a growing discrepancy between the obtained quality parameters of products and the growing requirements of customers. An attempt was made to solve the problem using additional design solutions. A temporary effect was obtained, the quality improved, but the production costs of the products increased (Barnes, 1999). In the 1970s, global competition between enterprises grew, and more emphasis was put on improving the competitiveness of production. The high costs of designing and making the product were no longer acceptable. The emphasis has been placed on the effectiveness of project management for the implementation of new products due to the significant impact of the designed processes on the costs of production. Summary of errors made during the design process, during which the method was not used DFA shown in Fig.1.

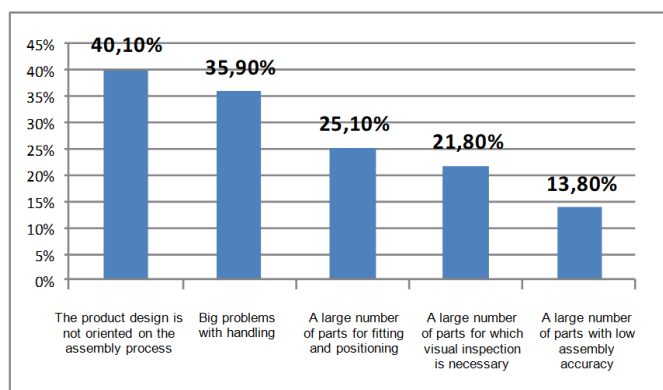


Fig. 1. The most important obstacles in assembly processes.

The most popular methods of DFA are: Lucas DFA, Boothroyd and Dewhurst (1983; Boothroyd, 1988; Dochibhatla et al., 2017), Hitachi AEM (Ohashi and Miyakawa, 1986). The Boothroyd and Dewhurst method was developed at the end of 1970 by Professor Geoffrey Boothroyd at the University of Massachusetts in Amherst in collaboration with the University of Salford in England (Knight and Boothroyd, 2005). The proposed analysis is used to assess and improve the existing structure of the product and manufacturing processes. It is most often used to evaluate the prototype evaluation phase. The Boothroyd-Dewhurst method contains eight principles (guidelines) that are important when designing for manual assembly (listed in order of priority):

- reduction in the number of the assembled components,
- elimination of corrections after assembly operations,
- ensuring a sufficiently large number of self-positioning and self-depositing components,
- ensuring adequate access and unlimited field of view,

- providing ease of assembling the components,
- minimizing the need for re-orientation during assembly,
- maximizing the number of components, which could not be fitted correctly,
- maximizing the number of components characterized by symmetry.

In the first stage of manual assembly analysis, two characteristic parameters are determined for each part: thickness and size. Next, designers evaluate the symmetry of the element and determine the number of degrees of rotation around both axes for correct orientation and positioning (Boothroyd and Dewhurst, 1983). The next stage of the analysis is to check whether the given part can be eliminated. The scheme of the procedure for the elimination of parts is given in Fig. 2 (evaluation of the possibility of several parts in the form of one whole).

The authors of this paper try to attempt to modify this method and connect it with different kinds of production (mass production and small-lot production) and with other analysis like cost calculation. The Boothroyd method, due to its simple construction, may be susceptible to such modification (Ahmad, 2016). The final step is to calculate: the sum of the number of operations, the total operation time, the total cost of the operation and the theoretical minimum number of parts.

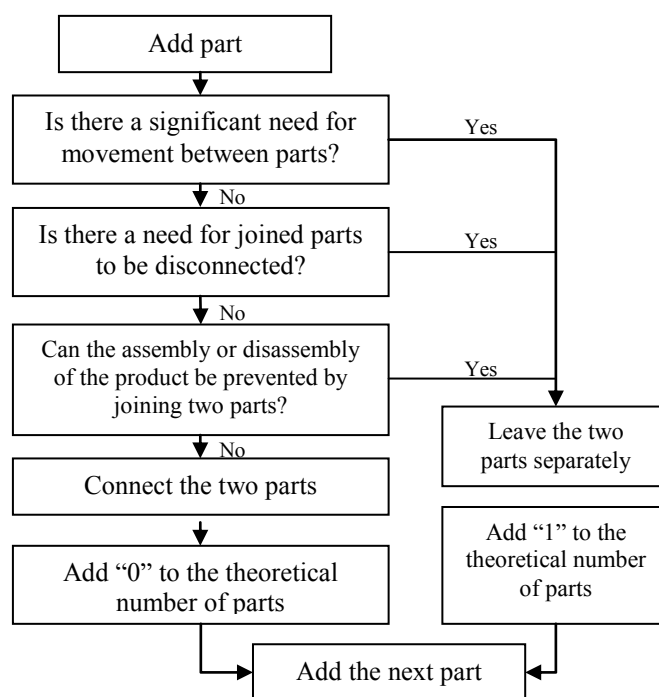


Fig. 2. Component elimination scheme Design for Assembly B&D (Boothroyd and Dewhurst, 1983).

3. ESTIMATING OF PRODUCTION COSTS WITH THE USE OF THE EXPERT SYSTEM

Production process design involves numerous heuristic activities, due to the lack of a mathematical model of the designed object, or the lack of possibilities of full calculations with an existing model (Bocewicz et al., 2016).

In such situations, attempts are made to write down formally the knowledge based on intuition and experience. It could become a basis of creating computer systems. Among others, the following methods of artificial intelligence, related to production process design, are used: artificial neural networks, expert systems and genetic algorithms (Turban, 1992). Expert Systems (ES) give the possibility of solving specialized problems which require professional expertise, which means that they can replace an expert in a given field, often without a need of direct expert's support (Ignazio, 1991). The structure of ES is presented in Fig. 3.

Expert Systems are able to (Harmon and King, 1985):

- Gather complete knowledge from a given domain and update it constantly;
- Copy the way of thinking of an expert, which results in offering decisions and providing their variants;
- Explain the way of thinking of the user to the adopted solutions;
- Communicate in a language comfortable for the user.

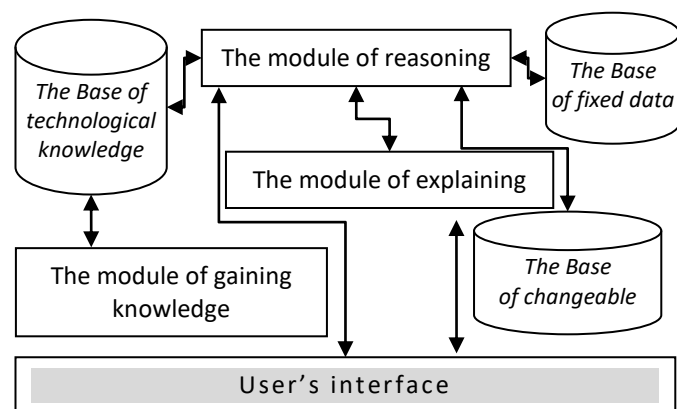


Fig.3. The general structure of the expert system.

The proposed method of cost estimation for machine elements bases on a formalized description of information with constructional, manufacture and organizational features related to a designed element. In the proposed approach various tools were used, which are connected with the automation of technological process design, group technology, artificial intelligence (expert systems), and the model of production cost estimation for machine elements based on Activity-Based Costing (Więcek, 2013).

The implementation of the method of Activity Based Costing is not easy in practice. The method is connected with processes and, within these processes, with separated activities, and not with subjects (departments, divisions), where the processes and activities are carried out, so it is not adapted to traditional production organization. Processes do not finish on the border of organizational units, but they spread into functional ranges. Implementing calculation based on activity analysis brings about not only the change of calculation procedure itself but the change of an organization, enterprise, reorganization of the way of cost measurement and record. This method, unlike the traditional cost account, seems to be easier to understand by workers, who have no contact with accounting.

The starting point for preparing activity cost account is creating a database of all activities performed in an enterprise. This can be made by means of the ISO system procedures, technological documentation (technological cards, machining manuals), documents on the run of production (production orders, work cards) and interviews with workers. Apart from activity identification, it is also necessary to describe them, that is: to determine by which departments the operations are carried out, how many people perform actions which compose the given activity, what is their work time, what meaning the separated activities have for the enterprise, what data express effects of activities.

The production cost of a product covers the ensemble of activity cost, as a consequence of which a finished product of a given value is created from raw material or materials. The complexity of manufacturing is determined by the level of difficulty and constructional and manufacture connections taking place between different levels of a product (sets, subsets, elements) - (Ignazio, 1991).

Values of parameters related to manufacturing processes designed by means of the variant method or generation method do not relate strictly to the variables influencing the value of particular components of production cost. Hence, it is necessary to determine a set of cost's driving factors: that is factors which equivocally determine the value of variables related to the separated cost components and the way of their determination. A basic task to be done is to determine the value of cost-driving factors on the basis of the description of a designer element using the COPE sets and values of parameters describing particular COPE. This task may be realized in three ways, by means of the variant, generation or hybrid approach (Więcek, 2013).

The presented solution relates to generating a set of parameters of a manufacturing process connected with features which describe the designed element (COPE). Particularly the module, on the basis of the COPE set and values of parameters describing the designed element, generate a set of values for production process parameters. The values are connected to sub-activities, which are here understood as technological treatments needed for a given feature to obtain qualities complying with constructional assumptions. The functioning of this module is shown in the Fig. 4.

The basic analysis tool is a dedicated expert system – Fig 5. According to the assumptions of expert systems' structure, a database of the analysed objects was established in the proposed system in the form of COPE sets and sets of parameters describing COPE. The proposed base of technological knowledge stores basic technological knowledge which was gained from an expert. The knowledge gathered in the base has to enable for determining the values of manufacturing process parameters. It relates information about sets of technological treatments and assembly for a given feature, required to achieve the assumed values of usable parameters in the accepted variant of a manufacturing process, and for each treatment- information about production workplace, as well as grouping workers adequately for the given technological treatment.

The run of activities in the proposed method was divided into several phases, which use the information generated on different stages of production process design aided by the CAx systems or information stored in databases of such systems.

A very significant stage of database design is determining the way of knowledge representation. On the basis of the conducted analyses, knowledge representation was accepted in the form of frames and rules. Representation of technological knowledge in form of frames was dictated by plurality and diversity of the gathered information for particular COPE. Hence, the knowledge divisions into frames for particular COPE.

Each frame is linked to a set of rules, on the basis of which a set of activities is determined. The activities enable to achieve parameter values assumed for certain features with fixed parameter values describing the remaining COPEs for a

given element, including which variant of a manufacturing process it is dedicated for. Decision tables were used for knowledge representation due to the fact that knowledge record within decision frame is based on reasoning rules, and a conclusion of a given rule related to choosing a set of technological treatments together with attributed production workplaces and groups of workers is of activity type.

The structure of the module of knowledge acquisition is closely connected with the adopted method of its acquisition. The paper proposes a direct method of knowledge acquisition called 'learning by heart'. The designed module of knowledge acquisition is a dialogue interface, through which an expert records his knowledge about creating such sets of technological treatment (variants of manufacturing) with the given factory conditions and according to parameter values adopted through COPE which describe the elements of a given type of production.

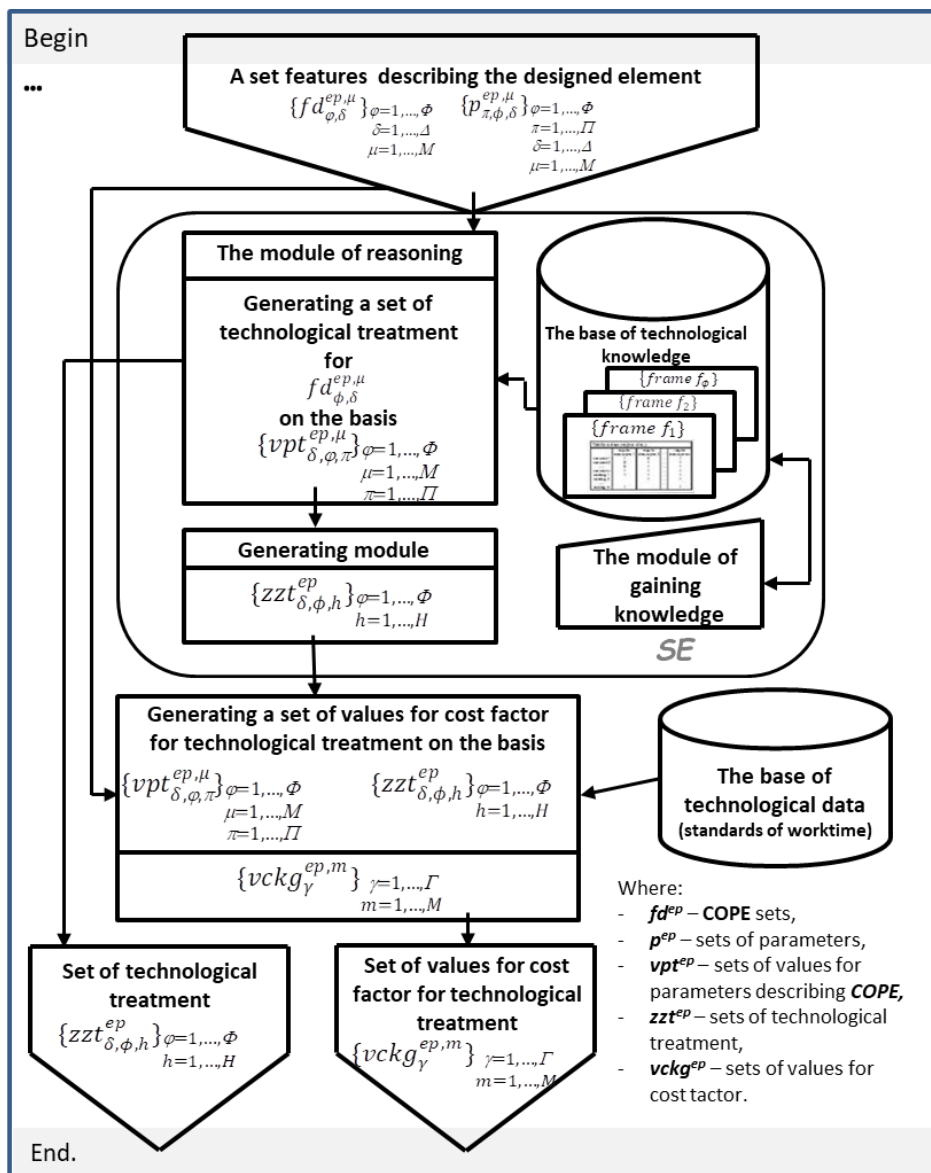


Fig.4. An outline of generating parameter values for a manufacturing process and for COPE.

conditions, level of automation, cooperative services, using commercial components, length of the production cycle, crew technical culture, etc.

Application of the proposed solution in one dedicated expert system consists in simplifying the construction, reducing the number of assembled parts, decreasing production costs, in the easier evaluation of the product and production structure. The creation of such an expert system will be the goal of our further research.

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