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Forecasting model of manufacturing time at the early design stage of product and process

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1. Introduction

The survival of manufacturing companies in new modern manufacturing environment with competition, productivity, globalization and people cleverness is related. The majority of manufacturers in East Europe are going to produce the separate parts or small batches orders proposing similar manufacturing cost, quality and delivery time. These factors become the main criteria of customers choosing the manufacturer [1]. The quotation of a new manufacturing order is very responsible work because it has a short time and must be more as possible precise. Moreover, customers are very hurry getting proposals for orders cost and delivery time; therefore, the definition of new orders time and cost requires advanced statistically based methods for evaluation and definition the work time and cost at the early every order negotiation stage. The forecasting model is more suitable for such objective, only one problem exists – how much it could be reliable and how quickly it could be developed. The benefit of a suitable forecasting model is as follows: it helps to make a proper planning of company resources, to keep the good partnership with customers and partners, to seek a better competitiveness in markets. On the other hand customers can quickly estimate the manufacturers' possibilities and attractiveness for one or another production order and proposal.

The manufacturing engineering is a creative, imperative process and needs of much specific knowledge, facts and experience, new technological ideas and collaborative work with products' designers, marketing managers and producers. Product and process development must be integrated and overlapped with various job steps applying concurrent engineering approach. These activities aiming to increase a new product performance and to upgrade the process decreasing manufacturing cost. The developers search various solutions of products and processes design using different design features (DF), quality, quantitative and functional parameters, materials, surface roughness and mutating product‘s work conditions. The classification of products, their parts and DF has the objective to facilitate and to accelerate product‘s process development at the early design stage where is necessary to create and evaluate some processes' alternatives [2].

The main objective of this research is to create and investigate the new methodology of manufacturing time forecasting model at the product and process early development stage. This new methodology on group technology [3] is based, when DF into separate classes level have been classified according to their design and manufacturing properties. The statistical data and equation of distribution separate DF classes in the mechanical parts have been acquired and created. The product and its parts development of 3D CAD model in virtual environment (VE) have been created. It shows how correctly is possible to develop the product virtual prototype from different and various DF seeking better manufacturability and least manufacturing cost. Created methodology considers the contradictions of a product design procedure and created properties and value and also among the principles of manufacturing engineering seeking best alternative with minimal cost. The paper considers described problems in manufacturing of large number product types and low production volumes in order handled manufacturing systems (OHMS). The findings and developments slightly can be used in mass production systems also. The mathematical formalization of a developed methodology is provided and appropriate techniques are created.

2. The consideration of removed material volume in fluence to the part machining time

First variant of such methodology [4] has been created seeking the definition of machining time at the early process design stage and applying computer-aided process planning (CAPP) systems. This methodology on the DF systematization, distribution in parts and products, and classification is grounded. It was successfully applied for some CAPP software developments using DF individually and developments have been implemented in various manufacturing companies. This methodology, however, has some disadvantages: complicated extraction of DF from parts and products, and definition of distribution allowances in various operations, impossible forecasting of manufacturing resources at the early stage of a new product and process design.

The second upgraded variant of a mentioned methodology in this paper is discussed. The consideration of new approach consists of four stages as follows: 1) part 3D CAD model creation in virtual environment (VE); 2) DF classes and subclasses attribution to parts and products; 3) definition of a removed material volume using created part 3D CAD model; 4) development of mathematical formalization for part‘s machining time definition.

2.1. Part design in virtual environment

During engineering design the main problem is finding the innovative ideas and how to keep creativity in designing procedure? The customers' and clients' requirements and consideration of markets often are general issue to product type acquisition and best process choosing. During the past decade the nature protection and ecological sustainability requirements in manufacturing industry increase the reliability of engineers' decisions. Mechanical engineers together with wide range of other people involved in manufacturing business also with customers and sellers must collaborate seeking all the best in a new product and process development. It includes the new ideas and technical solutions generation and implementation also strategy creation. They develop products and processes in VE, applying computerized systems and other infrastructure means and techniques. New ideas can seldom appear suddenly, using inventions or seeing them in fairs or in competitor's sites. Ideas can be usually stimulated by customers requirements upgrading already developed either outdated products and processes or discussing various possibilities and exchanging by sketches, photographs, virtual and physical prototypes and deep collaboration in experience and development [5]. Ideas generated by mechanical engineers often are the result of thorough and long job in the particular, separated field of development products and technologies satisfying the customers 'requirements or solving problems related with products 'performance, properties and characteristics. The time for this always is short and creativity of people involved for these tasks are uncompleted.

In modern manufacturing environment dominates minimal production cost, products' performance and quality. This depends on number of quality errors and equal consumption of manufacturing resources. The prevention of product and process development errors and defects at the early design stage becomes very important. The virtual reality (VR) technologies and means as design, modeling and simulation systems in VE are more and more prevalent and useful [6]. The shareholders of manufacturing companies and organizations make significant investments for above mentioned techniques and bigger part of engineers from manufacturing divisions are displaced to work in development of mentioned means. The traditional and non-traditional ways for this aim is used. Traditional way with development of new modern machinery and tooling, materials and manufacturing methods in many cases are related while non-traditional way is divided for development of infrastructure systems and techniques that are capable to decrease a manual work level in shop floor and routine work of engineers in research and development (R&D) departments. VR technologies award new and innovative capabilities for humans applying advanced new and innovative products and processes development systems based on artificial intelligence (AI). If two – three decades earlier in R&D departments of companies and organizations dominated human-machine systems as computer-aided design (CAD), computer-aided process planning (CAPP) and enterprise resources planning (ERP), so now tendency slightly is going to use the AI based systems [4] in products and processes development procedures. The knowledge-based (KB) and expert systems (ES), also VR technologies are divided for product and process conception and pilot project development and visualization in virtual environment [7, 8]. Fig. 1 presents the main functions of part development in VE: 3D dimensions' data acquisition and sharing among users in computerized development environment, work piece design, basic surfaces accuracy and roughness, available customers and partners involvement in process development aiming high quality and minimal manufacturing cost [9-12]. Engineers' work in VE helps to precisely perceive how it looks in reality and to estimate the engineering value and incurred cost. This gives good possibility for optimization of product and process performance and properties at the early design stage solving tradeoffs among developers, customers and manufacturers.

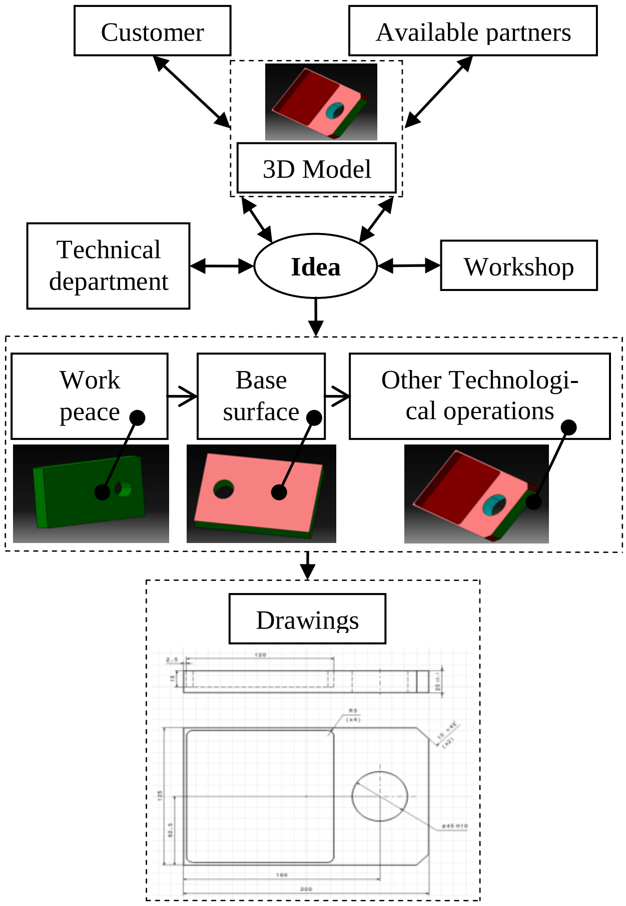


Fig. 1 Part design process in VE

2.2. Parts' design features classification and definition applying group technology in manufacturing

The engineering value of every part by applied DF type, size and their quantitative-qualitative parameters and dimensions are defined. Designer has to understand that each additional DF in product or part will increase the manufacturing time and cost. This must be strongly related with checking of value engineering and efforts for minimization of materials consumptions and manufacturing time. On the other hand, the increase of product performance and functionality also is contemporized with DF quantity and concentration in whole part and product.

Every product has many characteristics distinguishing it's from other products. Such characteristics and properties are result of including the different DF and requirements of quality and quantity as well as material, surface roughness, manufacturing conditions, and so on. Classification of products or their DF is aimed to facilitating and accelerating the process of developing manufacturing technology. For easier and more convenient work, all the typical DF is classified into two classes' level: cylindrical (1.1- 1.5) Table 1 and non-cylindrical (2.1- 2.8) Table 2.

Table 1

Cylindrical class of DF

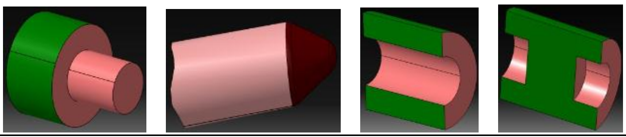
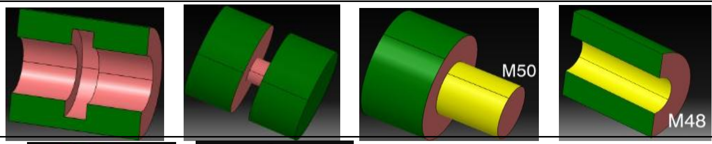
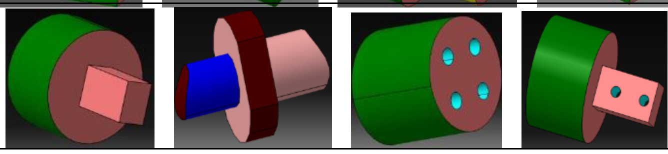
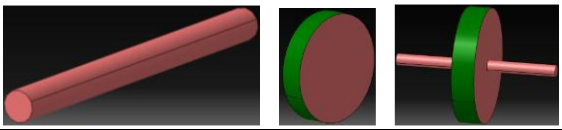
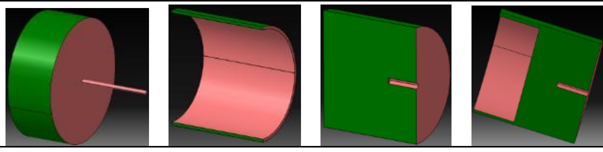
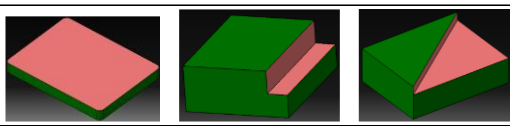
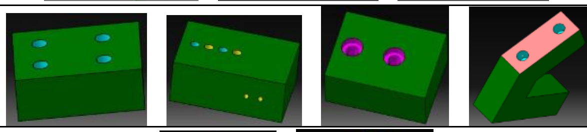
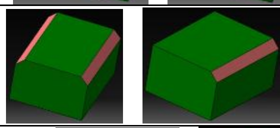
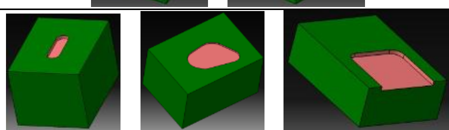
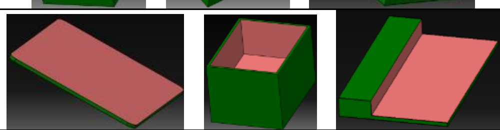
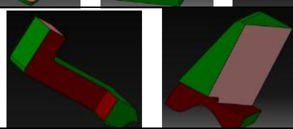
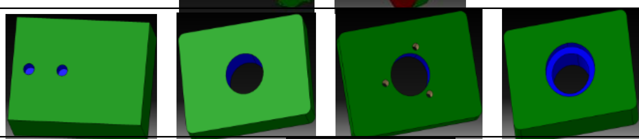
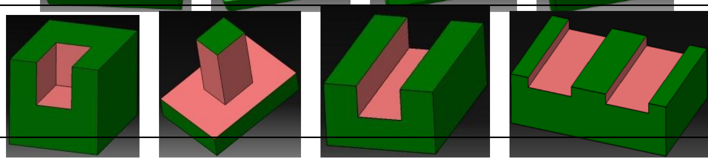
Subclass	Description of the Subclass	Typical DF of the Subclasses
1.1	Turning of outside surface of the tubes; holes tapping and boring	
1.2	Outside turning and tapping, inside tapping, groove turning and boring	
1.3	Holes processing out of centre, milling of rectangular DF	
1.4	Low volume, flexible DF processing, when $l/D > 5$	
1.5	Turning high amount of volume when $v/V \rightarrow 1$	

Table 2

Prismatic class of DF

Subclass	Description of the Subclass	Typical DF of the Subclasses
2.1	Milling of the opened planes	
2.2	Holes centering, drilling and tapping	
2.3	Milling of the chamfers and the angled grooves	
2.4	Contour milling, milling of the closed, hooked grooves	
2.5	Milling of the complex, low volume DF, when $v/V \rightarrow 0$, B^$H/L \rightarrow 0$	
2.6	Milling of the complex DF in the rigid parts	
2.7	Pin Holes centering, drilling, reaming, countersink, boring	
2.8	Milling of the rectangles withdrew	

There are several areas in which this classification can assist to engineers at the early design stage of products and processes. In particular, it helps as integrated valuable tool for creation the forecasting model of manufacturing time. It allows engineers to use these unified DF classes without having to use huge data bases and traditional calculations with many restrictions. This results in the elimination of the time spent by designers during early phase of the cost calculation and forecasting the manufacturing time. These data in nowadays are decisive wining orders and searching cheapest alternatives of a new product alternative.

2.3. The definition of a part machining time applying removed material volume in 3D CAD model

The definition of removed material volume applying the part 3D CAD model in virtual environment for forecasting the machining time at the early its design stage, or new order engineering stage is used. Together with this the definition of removed metal volume from all DF that are in part is carried out. The mentioned procedure is presented in Fig. 2. It shows a sequence of volume definition of whole part 3D CAD model and it's every DF applying standard design software Solid Works. An extraction of the part's DF and data input is performed at the interactive regime.

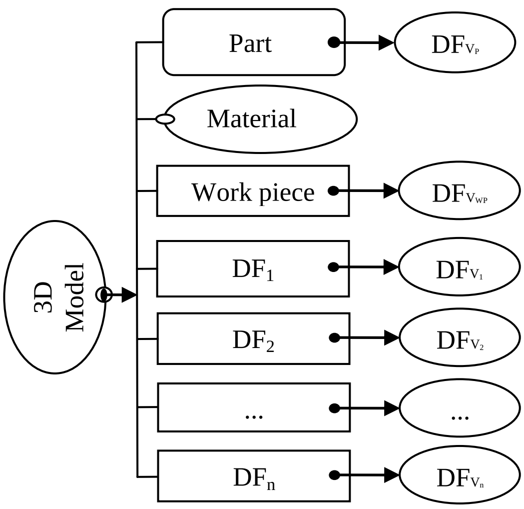


Fig. 2 Volume definition sequence of a part and its design-features

The removed material volume V from part work piece during machining operation as a main criterion of machining time T_m has been used [4]. The appropriate dependences $lg\ T_m$ and $lg\ V$ have been created for every DF. It is said that other factors influencing to the value of machining time T_m as material (t_1), accuracy and surface roughness (t_2), tool material (t_3), production volume (t_4) and specific peculiarities of a part (t_5) are conditionally constant and are expressed in Eq. (1). The influence of latter variables to the value of manufacturing time T_m is defined by appropriate correction coefficients.

$$T_m = f_1(t_1, t_2, t_3, t_4, t_5). \tag{1}$$

The typical dependences of $lg\ T_m$ and $lg\ V$ or nomograms are presented in Figs. 4 and 5. The data of T_m applying theoretical calculations with optimal cutting speed and various materials, cutting tools, different qualitative and quantitative parameters and experiments forming all considered DF have been used. As a result of these procedures the following equation for definition a theoretical machining time T_m^T estimating the influence of DF complexity and quantity has been created:

$$lg\ T_{m_i}^T = m_i\ lg\ v_i + lg\ C_i\ , \tag{2}$$

where m is slope of a regression trend line and C is intercept of a regression trend line. Removed material volume is calculated as follows:

$$v = V_{WP} - V_P\ , \tag{3}$$

where V_{WP} is part's work piece volume, mm^3, V_P is a part's volume, mm^3.

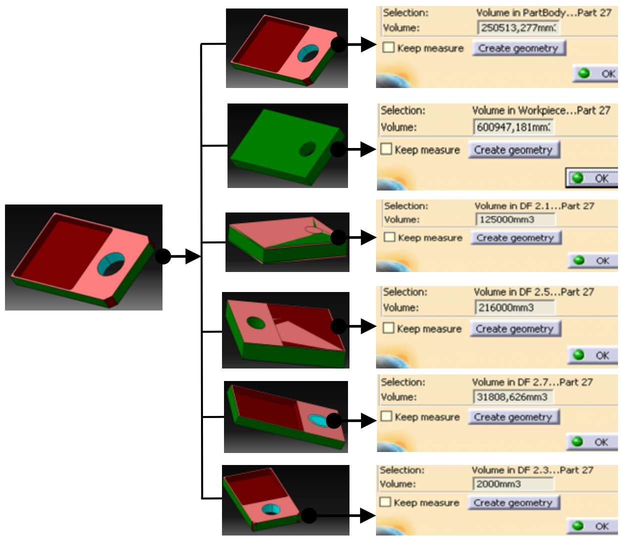


Fig. 3 Suitable part 27 for volume definition sequenceof a part and its design features

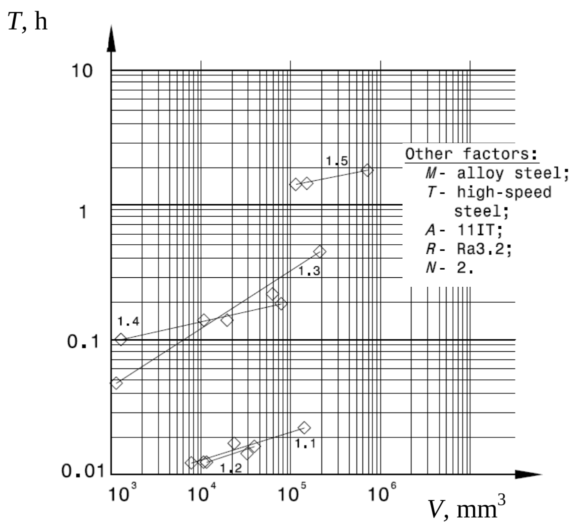


Fig. 4 Non-cylindrical class of DF machining time dependence of the removed volume

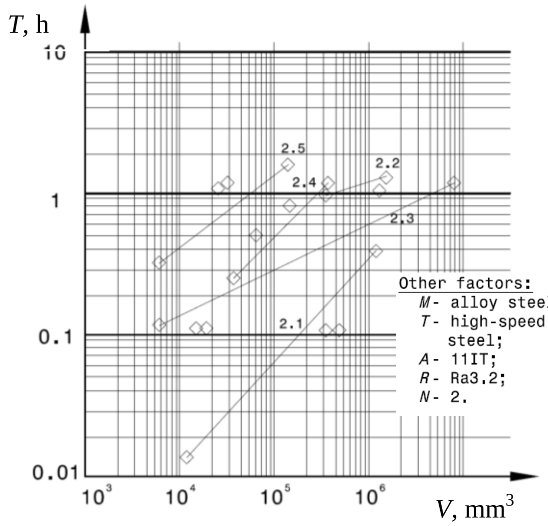


Fig. 5 Prismatic class of DF machining time dependence of the removed volume

Values of m and C are calculated using appropriate nomograms (Figs. 4 and 5) [13]. The floor-to-floor time $T_{vnt.k}$ of a part production at the early design or order engineering stage is calculated as follows:

$$T_{vnt.k} = \left(T_{pp} / r\right) + T_{past} + T_m , \tag{4}$$

where T_{pp} is a set up time, h; T_{past} is a part's gripping time in machine tool, h; T_m^c is a machining time after correction, h; r is a manufacturing batch.

Table 3 presents the value of slope m and intercepts C of all DF placed in Tables 1 and 2. Employing these data the part's floor-to-floor or manufacturing time $T_{vnt.k}$ is defined at the early product and part design stage.

Table 3

The coefficients' values of DF classifier for prismatic parts

F	*m*	*lgC*
2.1	0.4471	-3.0894
2.2	0.9378	-3.7096
2.3	0.3665	2.3847
2.4	0.5441	-2.7871
2.5	0.8196	-3.9522
2.6	-0.0203	-0,3872
2.7	0.6269	-3.0455
2.8	0.4745	-2.175

$$T_m^c = T_m \, k_1 \, k_2 \, k_3 \, k_4 \, k_5 , \tag{5}$$

where k_1 is a correction coefficient of machining material; k_2 is a correction coefficient of cutting tool material; k_3 is a correction coefficient of machining accuracy; k_4 is a correction coefficient of surface roughness; k_5 is a correction coefficient of batch size. These coefficients are defined in previous our job [4].

2.4. Part's DF statistical repartition and regularity creation for forecasting of a machining time

The twenty six parts of prismatic class applying their 3D CAD models have been considered. Table 4 shows parts, work pieces and DF volumes and their repartition in percents while Table 5 presents parts' and their DF theoretical and statistical machining times (whole part theoretical T_m^T and statistical T_m^s). T_m^s machining time and every DF statistical repartition P in a part are defined as follows:

$$p_i = \sum_{j=1}^{n} V_{DF_{ij}} / V_{Rj} / n , \tag{6}$$

where V_{DF} is removed material volume of DF mm^3; V_R is a removed total material from part work piece, mm^3; n is the number of considered parts, i is considered part and j is the considered DF.

The statistical average p_i of removed material for every considered part and every DF is defined (Table 6). Then knowing p_i values and total removed material volume from work piece V_R, the statistical machining time T_m^s of the DF is calculated:

$$lg\, T_{m_i}^S = m_i \, lg\, V_{R_j} \, p_i + lg\, C_i . \tag{7}$$

The bias P between part's theoretical machining time T_m^T and statistical machining time T_m^s), is computed as follows:

$$P_j = T_{m_i}^T / T_{m_i}^S . \tag{8}$$

Table 6

The statistical average p_i of DF

DF	Statistical average p_i	DF	Statistical average p_i
2.1	0.42	2.5	0.04
2.2	0.11	2.6	0.05
2.3	0.01	2.7	0.03
2.4	0.16	2.8	0.18

The Fig. 6 presents the bias of theoretical machining time T_m^T and statistical machining time T_m^S. The bias fluctuated in limits of 5 – 22% and for biggest number of considered parts goes to be equal 18%.

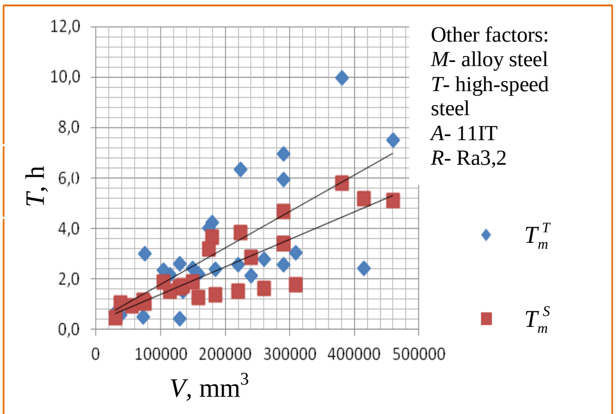


Fig. 6 The comparison of theoretical and statistical machining time

Table 4

The considered parts, work pieces and DF volumes and their repartition

Part No.	V_{WP}, mm^3	V_P, mm^3	V_R, mm^3	$V_{DF_{2.1}}$ mm^3/%	$V_{DF_{2.2}}$ mm^3/%	$V_{DF_{2.3}}$ mm^3/%	$V_{DF\,2.4}$ mm^3/%	$V_{DF_{2.5}}$ mm^3/%	$V_{DF_{2.6}}$ mm^3/%	$V_{DF_{2.7}}$ mm^3/%	$V_{DF_{2.8}}$ mm^3/%
1	1.1×10^{6}	8.4×10^{5}	2.4×10^{5}	2.2×10^{5}/91.7	1.6×10^{4}/6.7	–	–	–	–	7.2×10^{3}/3	–
2	4.9×10^{5}	3.4×10^{5}	1.8×10^{5}	4.3×10^{4}/23.9	2.7×10^{4}/15.1	–	–	–	7.7×10^{4}/42.8	5.5×10^{3}/3.1	2.5×10^{4}/13.9
3	8.9×10^{5}	5.9×10^{5}	2.9×10^{5}	2.7×10^{5}/93.1	2.1×10^{4}/7.2	–	–	–	–	3.4×10^{3}/1.2	–
4	3.2×10^{5}	2.4×10^{5}	1.3×10^{5}	1.2×10^{5}/93.3	2.2×10^{4}/16.9	–	–	–	–	3.5×10^{3}/2.7	–
5	2.6×10^{5}	2×10^{5}	5.6×10^{4}	4.6×10^{4}/82.1	5.7×10^{3}/10.2	–	5.2×10^{3}/9.3	–	–	–	–
6	1.2×10^{6}	1×10^{6}	2.2×10^{5}	–	–	–	9.9×10^{4}/45	–	–	–	1.2×10^{5}/54.5
7	5×10^{4}	3.1×10^{4}	3×10^{4}	2.3×10^{4}/76.7	4.3×10^{3}/14.3	–	–	–	–	2.2×10^{3}/7.3	–
8	9.8×10^{4}	5.3×10^{4}	1.7×10^{4}	1.3×10^{4}/76.5	2.1×10^{3}/12.4	–	–	–	–	1.9×10^{3}/11.2	–
9	2.4×10^{5}	1.7×10^{5}	7.5×10^{4}	3.4×10^{4}/45.3	2.4×10^{4}/32	–	–	–	–	1.7×10^{4}/22.7	–
10	5×10^{6}	4.7×10^{6}	2.9×10^{5}	1.8×10^{5}/62.1	6.1×10^{4}/21	–	–	–	–	4.7×10^{4}/16.2	–
11	2.6×10^{6}	2.1×10^{6}	4.6×10^{5}	3.8×10^{5}/82.6	7.1×10^{4}/15.4	–	–	–	–	1.3×10^{4}/2.8	–
12	4.4×10^{5}	3×10^{5}	1.3×10^{5}	1.2×10^{5}/89.9	1.1×10^{4}/8.1	–	–	–	–	3.4×10^{3}/2.5	–
13	1.1×10^{5}	7.2×10^{4}	3.8×10^{4}	2.1×10^{4}/55.3	5.9×10^{2}/1.6	–	–	–	1.5×10^{4}/39.5	9.6×10^{2}/2.5	–
14	1.4×10^{6}	1.3×10^{6}	1.5×10^{5}	1.3×10^{5}/86.7	2×10^{4}/13.3	–	–	–	–	3.9×10^{3}/2.6	–
15	1.6×10^{6}	1.4×10^{6}	1.2×10^{5}	9.4×10^{4}/80.3	1.7×10^{4}/14.5	–	–	–	–	6.2×10^{3}/5.3	–
16	1.7×10^{6}	1.3×10^{6}	4.2×10^{5}	3.1×10^{5}/75	1.7×10^{4}/4.1	–	–	–	8.7×10^{4}/21	$5,3\times10^{3}$/1.3	–
17	6.1×10^{5}	5.4×10^{5}	7.3×10^{4}	6.9×10^{4}/94.5	2.2×10^{3}/3	–	1.7×10^{3}/2.3	–	–	–	–
18	1.1×10^{6}	9.6×10^{5}	1×10^{5}	4.9×10^{4}/46.7	1.7×10^{4}/16.3	–	–	–	3.4×10^{4}/33.1	4.6×10^{3}/4.4	–
19	1×10^{6}	8.4×10^{5}	1.8×10^{5}	–	–	–	7.9×10^{4}/42	–	–	–	1.1×10^{5}/58
20	9.1×10^{6}	7.5×10^{5}	1.6×10^{5}	–	–	–	6.7×10^{4}/42.5	–	–	–	9.1×10^{4}/57.5
21	1.4×10^{6}	1.2×10^{6}	2.6×10^{5}	–	–	–	1.2×10^{5}/45.8	–	–	–	1.4×10^{5}/54.2
22	1.7×10^{6}	1.4×10^{6}	3.1×10^{5}	–	–	–	1.4×10^{5}/45.9	–	–	–	1.7×10^{5}/54.1
23	1×10^{6}	8.1×10^{5}	2.2×10^{5}	–	3.9×10^{4}/17.3	–	7.9×10^{4}/35.3	–	–	–	1.1×10^{5}/47.4
24	9.1×10^{6}	7.3×10^{5}	1.8×10^{5}	–	1.7×10^{4}/9.7	–	6.7×10^{4}/38.3	–	–	–	9.1×10^{4}/52
25	1.4×10^{6}	1.1×10^{6}	2.9×10^{5}	–	3.1×10^{4}/10.7	–	1.2×10^{5}/41	–	–	–	1.4×10^{5}/48.6
26	1.7×10^{6}	1.6×10^{6}	3.8×10^{5}	–	7.1×10^{4}/18.8	–	1.4×10^{5}/37.2	–	–	–	1.7×10^{5}/43.7
27	6×10^{5}	2.5×10^{5}	3.7×10^{5}	1.3×10^{5}/33.5	–	2×10^{3}/0.5	–	2.1×10^{5}/57	–	3.18×10^{4}/9	–
28	9.7×10^{5}	4.9×10^{5}	5.3×10^{5}	1.7×10^{5}/32	–	2.5×10^{3}/0.5	–	2.8×10^{5}/52.5	–	8×10^{4}/15	–
p_i				0.43	0.11	0.01	0.16	0.04	0.05	0.03	0.18

Table 5

Parts‘ DF theoretical and statistical machining times

Part No.	Part’s DF machining theoretical times T_m^T , h									Part’s DF statistical machining times T_m^S , h									P
	$T_{2.1}$	$T_{2.2}$	$T_{2.3}$	$T_{2.4}$	$T_{2.5}$	$T_{2.6}$	$T_{2.7}$	$T_{2.8}$	$\sum T_m^T$	$T_{2.1}$	$T_{2.2}$	$T_{2.3}$	$T_{2.4}$	$T_{2.5}$	$T_{2.6}$	$T_{2.7}$	$T_{2.8}$	$\sum T_m^S$	
1	0.2	1.7	0	0	0	0	0.2	0	2.1	0.1	2.5	0	0	0	0	0.3	0	2.9	0.8
2	0.1	2.8	0	0	0	0.3	0.2	0.8	4.2	0.1	1.9	0	0	0	0.5	0.3	0.2	3.6	1.2
3	0.2	2.2	0	0	0	0	0.2	0	2.6	0.2	3	0	0	0	0	0.4	0	3.4	0.8
4	0.2	2.3	0	0	0	0	0,2	0	2.6	0.1	1.4	0	0	0	0	0.2	0	1.7	1.6
5	0.1	0.7	0	0.2	0	0	0	0	0.9	0.1	0.6	0	0.2	0	0	0	0	0.9	1
6	0	0	0	0.9	0	0	0	1.7	2.6	0	0	0	0.5	0	0	0	1.0	1.5	1.7
7	0.1	0.5	0	0	0	0	0.1	0	0.7	0.1	0.4	0	0	0	0	0.1	0	0.5	1.4
8	0.1	0.3	0	0	0	0	0.1	0	0.4	0.1	1.4	0	0	0	0	0.2	0	1.7	0.3
9	0.1	2.5	0	0	0	0	0.4	0	3.0	0.8	0.8	0	0	0	0	0.1	0	1.0	2.9
10	0.2	6	0	0	0	0	0.8	0	6.9	0.2	3	0	0	0	0	0.3	0	3.4	2.1
11	0.3	6.9	0	0	0	0	0.3	0	7.5	0.2	4.6	0	0	0	0	0.4	0	5.1	1.5
12	0.2	1.2	0	0	0	0	0.2	0	1.5	0.1	1.4	0	0	0	0	0.8	0	1.7	0.9
13	0.1	0.1	0	0	0	0.3	0.1	0	0.6	0.1	0.4	0	0	0	0.5	0.1	0	1.1	0.5
14	0.2	2.1	0	0	0	0	0.2	0	2.4	0.1	1.6	0	0	0	0	0.2	0	1.9	1.3
15	0.1	1.8	0	0	0	0	0.2	0	2.2	0.1	1.2	0	0	0	0	0.2	0	1.5	1.4
16	0.1	1.8	0	0	0	0.3	0.2	0	2.4	0.2	4.2	0	0	0	0.5	0.3	0	5.2	0.5
17	0.1	0.3	0	0.1	0	0	0	0	0.5	0.1	0.8	0	0.3	0	0	0	0	1.2	0.4
18	0.1	1.8	0	0	0	0.3	0.2	0	2.4	0.1	1.1	0	0	0	0.5	0.1	0	1.9	1.3
19	0	0	0	0.8	0	0	0	1.6	2.4	0	0	0	0.4	0	0	0	1	1.4	1.7
20	0	0	0	0.7	0	0	0	1.5	2.2	0	0	0	0.4	0	0	0	0.9	1.3	1.7
21	0	0	0	0.9	0	0	0	1.9	2.8	0	0	0	0.5	0	0	0	1.1	1.6	1.7
22	0	0	0	1.1	0	0	0	2	3.0	0	0	0	0.6	0	0	0	1.2	1.8	1.7
23	0	4	0	0.8	0	0	0	1.6	6.3	0	2.3	0	0.5	0	0	0	1.	3.8	1.7
24	0	1.8	0	0.7	0	0	0	1.5	4.0	0	1.9	0	0.4	0	0	0	0.9	3.2	1.3
25	0	3.1	0	0.9	0	0	0	1.9	5.9	0	3	0	0.5	0	0	0	1.2	4.7	1.3
26	0	6.9	0	1.1	0	0	0	2.0	10	0	3.8	0	0.6	0	0	0	1.3	5.8	1.7
27	0.2	0	0.1	0	2.6	0	0.6	0	3.3	0.2	0	0.1	0	0.3	0	0.3	0	0.8	4.2
28	0.2	0	0.1	0	3.3	0	1.1	0	4.5	0.2	0	0.1	0	0.4	0	0.4	0	1	4.5

3. Further research

The developed model partially is implemented in industry of Lithuania. The implementation results in some companies have shown that the model is able to forecast manufacturing time at the early stage of new order engineering. It is planned to investigate and to upgrade of developed model seeking better accuracy and application for bigger variety of works and operations. Further research is devoted to the new products as moulds and dies manufacturing time forecasting at the early design stage. It could help to the better collaboration among customers, suppliers, developers and manufacturers aiming lower cost and higher performance.

4. Conclusions

The research in this paper presents an intelligent forecasting model of manufacturing time at the early design stage of product and process. The new product and process design is the essential task of the manufacturing enterprise, in particular, for order handled manufacturing system (OHMS). The forecasting model works in virtual environment (VE) and is created considering products design features. The model is based on dependence of removed material volume and machining time considering parts material, accuracy, surfaces roughness and various machines and tooling. It has been stated that machining time depends on the removed material volume and type of a part design feature. The achieved theoretical and statistical research results in close cooperation with industrial companies have been gotten. Briefly it is concluded as follows:

1. The basic dependence and regularity among removed material volume, type of design feature and machining time has been found.

2. The mathematical formulation has been created that is able to forecast the manufacturing time of a part at the early design or manufacturing order engineering stage with sufficient accuracy

3. The bias between theoretical machining time T_m^T and statistical machining time T_m^S fluctuated in limits of 5 – 22% and for biggest number of considered parts goes to be equal 18%.

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GAMINIO IR PROCESO GAMYBOS LAIKO PROGNOZAVIMO ANKSTYVOJE JŲ KŪRIMO STADIJOJE MODELIS

R e z i u m ė

Straipsnyje tiriamas sukurtas gamybos laiko prognozavimo ankstyvoje gaminio ir proceso projektavimo stadijoje modelis. Sukurtas modelis gamybos laiką prognozuoja pagal mechaninio apdirbimo operacijoms pašalinamą medžiagos tūrį ir pasiekiamas detalės kiekybines ir kokybines charakteristikas. Pateikta gamybos laiko prognozavimo metodologija pagrįsta gaminių ir juos sudarančių tipinių konstrukcinių elementų klasifikavimu pagal geometrinę formą. Visi tipiniai konstrukciniai elementai suklasifikuoti į dvi klases – sukinių ir prizmės formos. Tyrimai atlikti virtualioje aplinkoje; atliktas gamybos laiko prognozavimo matematinis formalizavimas bei statistinės analizės būdu apskaičiuotas tipinių konstrukcinių elementų pasiskirstymas naujai sukurtuose ar gaminamuose mechaniniuose gaminiuose. Straipsnyje pateikiama pasiūlymų, kaip galima klasifikuoti gaminių konstrukcinius elementus ir nustatyti jų įtaką mechaninio apdirbimo trukmei atsižvelgiant į pašalinamą atskirų konstrukcinių elementų medžiagos tūrį.

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FORECASTING MODEL OF MANUFACTURING TIME AT THE EARLY DESIGN STAGE OF PRODUCT AND PROCESS

S u m m a r y

This paper considers the developed forecasting model of a manufacturing time at the early product and process design stage. Developed model forecasts the manufacturing time of machining operations by removed material volume and achieved part's quantitative-qualitative characteristics. Presented methodology of manufacturing time forecasting on products and their design features classification is based. The design features into two separate class level – rotational and prismatic geometrical form are classified. Consideration on the virtual environment is made; the mathematical formalization of forecasting manufacturing time and repartition of design features in mechanical parts and products applying statistical analyses methods are defined. The proposals how would be possible to classify the design features of products' and how to define their influence to the manufacturing time by the removed material volume of separate design features.

Keywords: design feature, virtual environment, machining time, forecasting model.

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