

COST CONDITIONS OF MASS CUSTOMIZATION MANUFACTURING

1. Introduction

The main goals of nowadays production are quick product changes, increasing numbers of variants and short planning [12]. The manufacturing industry has evolved over the past several decades in response to changing customer needs. Previously the primary source of competitive advantage for manufacturing companies in many industries was related to price. Therefore, all manufacturing strategies were driven by attempts to reduce the cost of the product. Technological advances, in manufacturing as well as in information, have provided the impetus for change in many paradigms, including customer expectations. Customers have become more demanding and want products that can meet their specific individual requirements. Thus customization is turning out to be essential to maintaining competitive advantage in many industries [5]. Producing customized products at a low cost, which seemingly is a paradox, is the purpose of many enterprises [3]. This main purpose, which is considered as fulfilling customer needs, results in production by unit and small batch process. The production cycle consists of, among others: the processing time and setup time. For high-variety production the cumulative amount of setup time results from the number of changeovers [1].

To shorten the production time and reduce costs the methods of group technology have been used for many years [10]. The above research inspired the author to prepare a method of setup time process based on the similarity of the products. In order to do this a classifier of a new kind was introduced – the classifier works at the level of process in the operation production plan. The objective of the classifier is to aggregate processes into organizationally similar groups. It allows production tasks to be completed inside groups: in sequences, without changeovers or by significantly shortening the setup process. The above classification is based on the features of tasks having influence on changeover times and optimization of task arrangement [15].

The changing organizational conditions of products and semi-products manufacturing, including the use of dynamic grouping and alternative production routes causes difficulty in determining the cost of production.

The paper is structured as follows. First, the studied problem is briefly described. Then, an example to illustrate the problem is presented. The main part of the article consists of the method of calculating production costs in conditions of mass customization. Computational results are also discussed. The article concludes with some summary remarks.

2. Problem background

Increased product portfolio in response to customer requirements has an impact on costs and delivery time. The main questions are: What are the options and how many

offer product variants to customers? How to manufacture the products? How to shorten delivery time at the lowest cost?

The way of addressing these questions is the concept of Mass Customization. The concept of Mass Customization (MC) producing customized goods at low costs received considerable attention in research literature [11, 19, 21]. To implement product customization, many companies have changed their business models from make-to-stock to configure-to-order [23]. Configure-to-order (CTO) has been recognized as an ideal model that provides the right amount of product variety and a quick response time to customer orders [2, 23]. In CTO, final products are configured from a set of predefined modules and components subject to the constraints among them. While production in CTO starts after receiving a customer order, order fulfillment starts from order processing [23].

Focusing on reducing the cost of offering product variety, Gupta and Krishnan [6] propose a methodology for designing product family-based assembly sequences. Kusiak et al. discuss the design of assembly systems for modular products [3, 7].

Variability management by software is becoming an interesting topic for SME with expanding portfolios and increasingly complex product structures. Sinnema & Deelstra classified variability modeling techniques [20].

Software product family process evaluation is relatively a young area of research. Currently, scientists have to invent a systematic way to measure the functionality of the software product family process [4]. Software variability management is a key factor in the success of software systems and software product families. In [4] Deelstra et al. described the requirements for software variability management. To utilize commonality, underlying product diversity and process variation, it has been a widely accepted practice to develop product families, in which a set of similar variants share common product and process structures and variety differentiates within these common structures [8, 9]. The concept of product configurators is that they are designed for product families. The product family is composed of possible configuration solutions $P = \{P_1, P_2, \dots, P_n\}$ with AND relation. Each solution $P_i | \forall i \in [1, N]$ could be derived through adjusting the configurable modules, $M = \{M_1, M_2, \dots, M_n\}$. Each configurable module $M_i | \forall i \in [1, K]$ may possess several available module instances $M_k^* = \{CA_{k1}, CA_{k2}, \dots, CA_{kL}\}$ with OR relation, out of which, one and only one instance can be selected for a certain configuration solution. While customers always purchase products according to product performance, each module instance is characterized with the corresponding product attributes $A = \{a_{kq}\}$, and their values $D = \{d_{kqr}\}$ where d_{kqr} indicates the r th value of the q th attribute associated with the k th module.

Figure 1 illustrates the decision framework of product family design and development along the entire spectrum of product realization according to the concept of design domains.

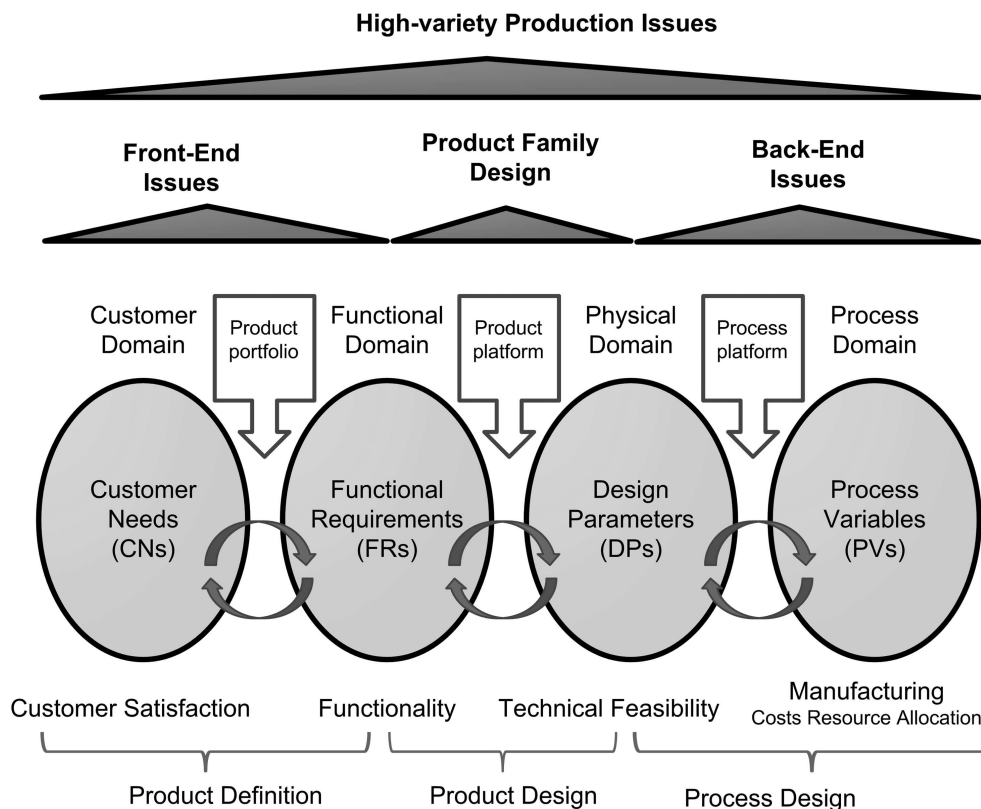


Fig. 1. High-variety production issues

Based on such a view, product family design and development encompasses five consecutive domains, namely the: customer, functional, physical, process and logistics domains. Product family decision-making involves a series of “what, how” mappings between these domains. The customer domain is characterized by a set of customer needs (CNs) representing the segmentation of markets that have demand for the product families and triggering downstream product family design mappings in a cascading manner. The CNs are first translated into functional requirements (FRs) in the functional domain, in which designers take into account engineering concerns and elaborate these requirements based on available product technologies [9].

The mapping between the customer and functional domains constitute the front-end issues associated with developing product families. Such a product family definition task is always carried out within an existing product portfolio and manifests itself through those common practices of order configuration and sales force automation. Product family design solutions are generated in the physical domain by mapping FRs to design parameters (DPs) based on the shared product platform. This stage involves typical decisions regarding product family design and configuration. At the front-end, the product portfolio articulates detailed achievement of customer satisfaction in the customer domain in the form of specifications of functionality in the functional domain. On the other hand, the main focus of platform-based product family design is the technical feasibility of DPs in terms of fulfilling the specified functionality [9].

The back-end issues associated with product families involve the process and logistics domains, which are characterized by process variables (PVs) and logistics variables

(LVs), respectively. The mapping from DPs to PVs entails the process design task, which must generate manufacturing and production planning within existing process capabilities and utilize repetitions in tooling, setup, equipment, routings, etc. Corresponding to a product platform, production processes can be organized as a process platform in the form of standard routings, thus facilitating production configuration for diverse product family design solutions [9]. Since the main concern in the process domain is manufacturability and cost commitment, process design is the fact enabler of mass production efficiency [9].

3. Problem Formulation

The problem discussed in this paper concerns the analysis of the cost of producing product families. It is connected with the development of methods for calculating the cost of the product family in a multivariate analysis taking into account dynamic classification. Hence the need to answer the question: Are the standard methods of calculating costs available for use in conditions of mass customization? The main problem depends on the variability in organizational conditions. The method should be accurate and computationally efficient so that at the stage of confirmation of order the value and cost of products produced in the current organizational conditions can be determined. Due to the number of changeovers to mass customization profitable, production must be based on group technology (GT). Using the GT methods the similarity of the products can be analyzed. Unless organizational factors, such as the desired delivery date, the current availability of resources are included the cost calculations would include errors. Cost calculations

too high in value-will result in rejection of the contract by the customer while too low will result in a sale below cost. In summary, the methodology to solve the problem of calculating the cost of customized products is to find an answer to the following questions:

How to define the algorithm of calculating the cost of products and their components manufactured in conditions of GT? Is it possible to determine the cost of the product at the stage of confirmation of order? To illustrate the above problem a simple example is given.

4. Illustrative Example

4.1. Product family

The example in this paper is the customization and production of product families for roller shutters manufactured in SME. Roller shutters are one example of family products. The shutter can be made in many options. The main optional features are: system profile, dimensions: height and width of the blinds, color, drive type and others.

4.2. Manufacturing process

The production of the product (product family) as shown in Figure 2 assumes zero waste of roller shutters. A crucial role in waste-free manufacturing of roller shutters is played by the rollforming line.

It's possible to produce, in one process, a complete roller shutter curtain. The rollforming line is equipped with tooling suitable to produce the foamed roller shutter profiles in different sizes.

The process consists of foaming, punching and cutting to length operations. The line is designed for high density or low density foamed profiles. It is also possible to add a stacking bench to make packages or cut to length curtains complete with side caps. Depending on the type of profile

the line can reach a productivity of approximately 50-60 m/min. Unfortunately, the changeover time of the line is 2 hours.

An alternative manufacturing process is based on semi-products, profiles supplied in 6m sections. The profile is then cut to length according to individual customer requirements. The next stages of the process are the curtain assembly, the box cutting and the final assembly of other materials and components. Manufacturing from 6m profile sections does not allow for waste-free production. Waste free production is possible only on the rollforming line with cutting to length according to individual customer requirements. The above line is computerized numerical controlled (CNC) and the controlling data are transmitted automatically by the manufacturing execution system (MES). The process can be implemented by alternative routes [18].

5. Solution method

The basic element of the above method is defining the features of the product family which have an impact on the changeover times. The above features are defined from the perspective of workstations and process production operations.

Defining parameters of tasks having influence on changeovers time

For the manufacture product families dynamic the grouping method was used. In this method [14-16], groups were divided into homogenous types by those parameters which have an influence on changeover time. For each element of the set of machines $M = \{m^1, \dots, m^a, \dots, m^A\}$, (A - means the amount of machines) a choice was made of those parameters which have an influence on changeover times and they were assigned to:

$$\begin{aligned}
 P^1 &= \{P_1^1, \dots, P_x^1, \dots, P_X^1\}, \dots, \\
 P^a &= \{P_1^a, \dots, P_x^a, \dots, P_X^a\}, \dots, \\
 P^A &= \{P_1^A, \dots, P_x^A, \dots, P_X^A\}
 \end{aligned}
 \tag{1}$$

where:

P_x^a - parameter having a significant impact on the changeover time for machine type a ,
 x - identifier of parameter,
 X - amount of parameters.

The assignment of parameters will not be sufficient; the influence of the above parameters on reducing changeover time also needs to be taken into account. The above parameters will constitute the basic criterion in the classification and the creation of groups. The criterion itself can assume static values but the assignment of the given task to the group will take a dynamic character dependent on the organizational features or resource constraints.

Apart from the choice of parameters, limitations should also be introduced in the division of the tasks into groups. The major limitation

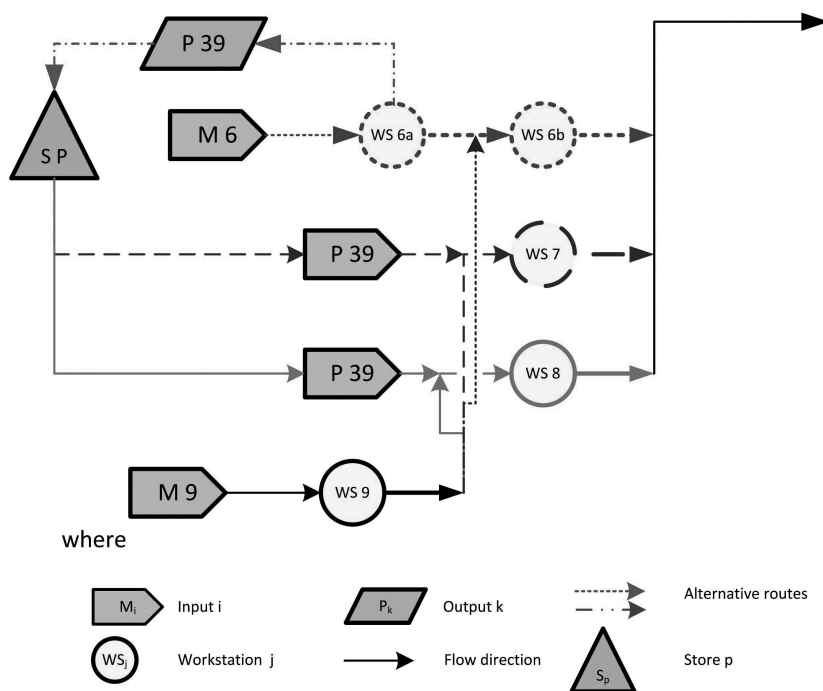


Fig. 2. Manufacturing process of shutter's components in alternative routes [18]

in the assignment of tasks to groups is the time criterion. Tasks with a distant planned performance deadline can be rejected from a group. In the above way a dynamic classifier is created according to task features at the level of the production process operation which causes, depending on the classification moment, the same element to be classified differently. In one case it can be assigned to a group and in the other it can be rejected. The above features have positive, negative or neutral influence. The features can be of the design (D), technological (T) or organizational (O) type.

6. Dynamic groups forming

Two types of groups were formed for roller shutters: boxes and curtains. A B2B (business to business) data system was used for the definition of the set of tasks for assignment purposes. After performing the scheduling function in the set of tasks, the planned terms were defined and recorded on the list. Tasks were narrowed to groups of machines having bottlenecks, groups for curtains and groups for boxes. The most interesting groups were formed by tasks in the first week on the list. In conditions of changeable operational production plans, the consideration of the subsequent weeks is pointless.

In order to increase the productivity of calculations, the task list has been narrowed to the first week. Classification into organizationally similar groups at the level of production process operations is a key classification for the whole method [15].

There are several possible classification scenarios [16]. For classification into organizationally similar groups the author applied following algorithm. After calculating the parameters for the two types of groups, the author applied pattern classifications.

At the specified manufacturing date t the assignment of the elements' set Id_{ix} to the set of groups Go_{ix} is a function dependent on parameters $P : \{Id_{ix} \in Go_{ix} : F(Po)\}$.

The cost of production is influenced by the organizational values of parameters $P_{21} \div P_{25}$. (labeled as Po). Parameters $P_{21} \div P_{25}$ play the role of assigning restrictions in accordance with the criterion of distance in cluster analysis.

7. Costs calculation

The following is a solution to the problem of the cost of production when using the dynamic method of grouping.

In conditions of small and unit batch production a calculation of the unit cost of each component in isolation from the grouping process which relies organizational conditions is a too far-reaching simplification. Cost analysis should take into consideration the possibility of grouping the item with others in organizationally similar groups.

When manufacturing elements with GT usage, the processing time and cost depended on the amounts of the groups. When manufacturing in conditions of mass customization, setup time has the key role. Reducing the setup time has a significant impact on the unit cost of production. Currently, a lot of methods of calculating the costs of production are used. In each of the methods the most important are the direct costs [13, 22].

The cost of i^{th} product consists of two factors:

$$K_i = Kb_i + Ku_i \quad (2)$$

where – means direct costs and Ku_i – indirect costs of i^{th} product .

Direct costs Kb_i can be divided into costs associated with the material, cooperation and the costs associated with the process. Processing costs are the sum of labor costs and cost of workstations.

$$Kb_i = Kmb_i + Kkb_i + Kprb_i \quad (3)$$

$$Kb_i = Kmb_i + Kkb_i + Kstb_i + Kprb_i \quad (4)$$

where:

Kmb_i – direct material costs of i -th product,

Kkb_i – cooperation costs of i -th product,

$Kprb_i$ – processing costs of i -th product,

Kpb_i – labour costs of i -th product,

$Kstb_i$ – workstations costs of i -th product.

For the analyzed case a simplification was assumed: a constant value of the cost of cooperation and constant value of direct labor costs:

$$Kkb_i \cong const \quad (5)$$

$$Kpb_i \cong const \quad (6)$$

The component $Kstb_i$ is the sum of the costs of each operation of the manufacturing process (o):

$$Kstb_i = \sum_{o=1}^o Kstb_i^o \quad (7)$$

Unit cost of single operation $Kstb_i^o$ results from the number of performed elements. It consists of two components:

$$Kstb_i^o = Ksetup_{Id_i} + Kwork_{Id_i} \quad (8)$$

Component of direct cost associated with the changeover time $Ksetup_i$ is related to the production batch size. The larger the batch size, the smaller the share of the cost associated with the changeover is attributable to unit cost. Hence, in the case of unit production the share of a cost component associated with the changeover is relevant. If a company uses GT then it can reduce that cost.

The workstation costs will be associated not with production batch size but rather with organizationally similar group size created dynamically at the level of each operation of manufacturing process.

$$Kstb_i^o = \frac{Ksetup_{O_k}}{n} + Kwork_i \quad (9)$$

where:

n – number of elements in the group O_k ,

$Ksetup_{O_k}$ – setup time of O_k group.

This formula can be used to evaluate the cost of production in the conditions of grouping. Dynamic grouping reduces the cost of production due to simple mathematical formulas. In all cases, however, the scale of the impact of grouping on costs is not known. Also the dependency of the organizational parameters on the costs is searched for.

$$K_{Stb_i} = fO_k(P_1^a, \dots, P_x^a, \dots, P_X^a) \quad (10)$$

where:

$fO_k(P_1^a, \dots, P_x^a, \dots, P_X^a)$, is a function of costs for the group O_k dependent on the parameters $P_1^a, \dots, P_x^a, \dots, P_X^a$. Some of the parameters concerned organizational factors (eg, resource availability, delivery time, the release operation, the priority of the order).

8. Verification of the method

To confirm this thesis and to determine the cost of the product with the organizational grouping verification, testing in the selected company A was done. The test object was the production system described in section II. The study analyzes the organizationally similar groups created formed in 2011. The main parameter influencing the changeover of the line is type of profile and color of the curtain. Wider case study was presented in [17].

Although the same manufacturing process parameter P7 affects the costs.

The problem is to calculate the cost of the product and its components manufactured with the use of grouping. In this case, and many other similar systems, the production takes place in alternative manufacturing routes.

In the first variant of production takes place entirely on the rollforming line. Changeover time is long at 2 hours. Waste material is approximately 12 m of tape needed to start the line. The values of direct costs in the first variant:

$${}^I K_{b_i} = {}^I K_{mb_i} + {}^I K_{Stb_i} \quad (11)$$

where:

${}^I K_{mb_i}$ – material costs for i -th element in the first variant,

${}^I K_{Stb_i}$ – workstation costs for i -th element in the first variant,

$${}^I K_{mb_i} = (s_i * l_i + d_w) * c_i \quad (12)$$

where:

s_i – the width of the i -th - element (curtain),

l_i – number of blades in curtain,

d_w – length of the tape resulting from the start of line,

c_i – price of raw material (1 m of tape),

$${}^I K_{Stb_i} = [(s_i * l_i + d_w) * t_m + Fsetup_m] * k_m \quad (13)$$

where:

t_m – efficiency of rollforming and assembly line (m) in [m/h].

$Fsetup_m$ – changeover time of m line,

k_m – workstation costs per hour of m line.

The cost of the i -th element manufactured with grouping in the first variant:

$${}^I K_{b_i} = \left(s_i * l_i + \frac{d_w}{n_e} \right) * c_i + [(s_i * l_i + d_w) * t_m + \frac{Fsetup_m}{n_e}] * k_m \quad (14)$$

where:

n_e – number of elements manufactured within organizational similar group Oe .

In the second variant semi-product is manufactured on the rollforming line. The semi-product is the 6 m profile. The changeover time of line and waste material for the semi-product production is the same as in the first variant. The difference is that they can produce a larger number of semi-products and then use it in the subsequent process. The problem is the semi-product waste in cutting. Depending on the width of the curtain, waste ranges from 5 to even 15%. The values of direct costs in the second variant:

$${}^{II} K_{b_i} = {}^{II} K_{mb_i} + {}^{II} K_{Stb_i} \quad (15)$$

where:

${}^{II} K_{mb_i}$ – material costs for i -th element in the second variant,

${}^{II} K_{Stb_i}$ – workstation costs for i -th element in the second variant,

$${}^{II} K_{mb_i} = (s_i * l_i + d_w) * c_i * d_i \quad (16)$$

where:

d_i – waste factor connected with the production from semi-products.

For the second variant assumed $\frac{d_w}{n} \cong 0$, where n – count of semi-products manufactured without changeovers of rollforming line.

$${}^{II} K_{Stb_i} = [(s_i * l_i + d_w) * t_m + Fsetup_m] * k_m + ({}^{II} t a_i + Fsetup_a) * k_a \quad (17)$$

where:

t_m – efficiency of rollforming line (m) [m/h] (without assembly) (in this case assumed $t_m > t_m'$),

$t a_i$ – cutting and assembly time,

k_a – workstation costs of cutting and assembly workstations (a) (per hour),

$Fsetup_a$ – setup time of cutting and assembly workstations (a) (in this case assumed $Fsetup_a \approx 0$),

k_m – workstation costs per hour of m line (in this case assumed $k_m \approx k_m'$),

When calculating the cost of changeovers with grouping for the manufacturing of semi-products assumed $Fsetup_m / n = 0$.

$${}^{II} K_{b_i} = s_i * l_i * c_i * d_i + [(s_i * l_i + d_w) * t_m] * k_m + ({}^{II} t a_i) * k_a \quad (18)$$

The calculations of costs for all values of the parameter P7 at five days aggregation for dynamic grouping were done. The selected results of calculation of direct cost (per 1 m² of the shutter) manufactured in both variants are listed in Table 1.

The direct cost of production for selected samples has a different. It shows the various possibilities for producing with organizational grouping. There is quite a big difference in the production of components due to the value of the parameter P7. In all cases the value of parameter P7 #-CD has a higher production cost than the value of the parameter P7#BI. In case P7#CD it is more cost effective to use the second variant, in the case of P7#BI it is the reverse.

For values of the parameter P7#-BR there were significant differences between the cost of production in each week of the year.

There were cases when the production of variant II was preferable. For values of the parameter P7#-BR there were significant differences between the cost of producing in each week of the year. Despite the relatively frequent execution and a tendency to group different "a priori" the conclusion is that it is more advantageous in variant I than II.

There were cases when the production of variant II was preferable (see Figure 3).

The author also determined the maximum and minimum values of the manufacturing costs for each option value of product family. Wider case study was presented in [18]. The calculation results are applicable to the calculation of the discount on the stage of confirming orders.

9. Conclusions

The contemporary customer requirements, determine the production systems. Strategies for small and medium-sized

enterprises are increasingly being directed towards the production of products with many options. Currently, production systems must be prepared to produce product families in the shortest possible production cycle and at low cost.

For this type of production method of costs calculating the focus should be on the analysis of the cost of the grouping at the stage of preparing the organization of production. The use of grouping leads to a reduction of changeover time and thus reduces costs.

The introduction of a method of cost calculation allows a comprehensive assessment of the impact of the option parameters of our products and their components manufactured in production adjusted to customer needs (mass customization). The method can provide a basis to implement the appropriate values of the matrix of discounts depending on the selected options of the product and the counts of elements produced with organizationally similar grouping. Without adequate supporting information systems to carry out the calculation of cost of the stages, the order acceptance does not seem practicable.

It is also possible using simplified methods in the practice of business processes carried out in the „on line” mode with B2B tools. The use of Pareto optimization (see Figure 4), where the search is the minimum cost and processing time, while complying with the constraints of the date of delivery to the customer, should, from the one hand, fulfill the requirements for the efficiency of calculations, and on the other hand, have sufficient accuracy from the perspective of business process.

The study showed the possibility of reducing production costs both theoretically and achieved in practice. Both studies and practice have shown the usability of the proposed manufacturing solutions.

Week	Value P7	$I K_{mbi}$	$I K_{stbi}$	$I K_{bi}$	$II K_{mbi}$	$II K_{stbi}$	$II K_{bi}$
3	#-CD	67,97	31,18	99,15	72,24	28,09	100,33
12	#-CD	72,10	50,39	122,48	72,24	38,53	110,78
...	#-CD						
42	#-CD	70,39	42,70	113,08	72,24	25,80	98,04
2	#-BI	64,53	13,25	77,78	72,24	32,98	105,23
3	#-BI	63,26	6,18	69,45	72,24	26,15	98,39
...	#-BI						
51	#-BI	64,88	15,19	80,08	72,24	24,54	96,78
2	#-BR	83,79	94,57	178,36	72,24	19,52	91,77
3	#-BR	64,11	10,93	75,04	72,24	21,70	93,94
4	#-BR	65,84	20,28	86,12	72,24	21,64	93,88
5	#-BR	69,29	37,59	106,88	72,24	17,07	89,31
6	#-BR	66,46	23,51	89,96	72,24	19,18	91,42
..							
18	#-BR	63,56	7,84	71,39	72,24	22,83	95,07
22	#-BR	62,95	4,39	67,34	72,24	42,40	114,64
...	#-BR						
51	#-BR	63,94	9,98	73,92	72,24	172,26	244,50

Tab. 1. Direct cost of manufacturing in the variants I, II

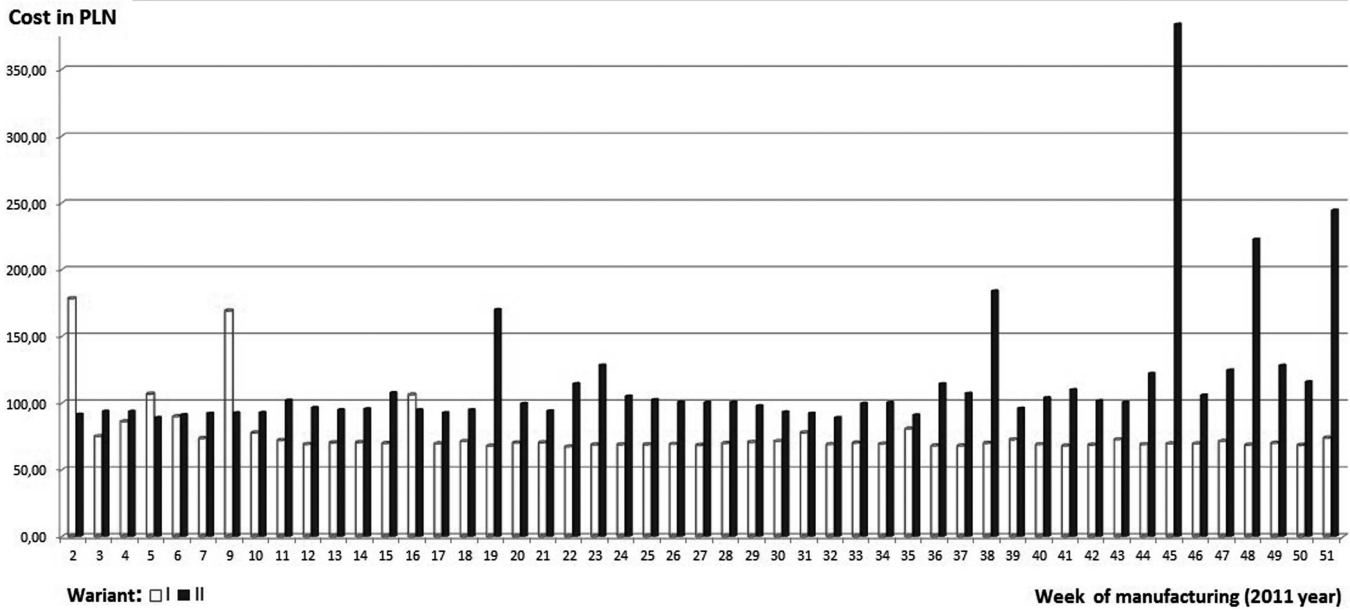


Fig. 3. The value of cost for elements with P7#-BR the variants in 2011

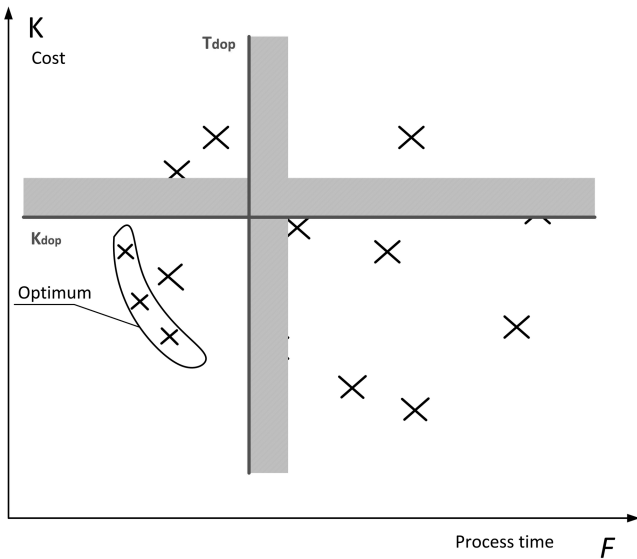


Fig. 4. Pareto optimum

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Key words:

group technology, mass customization, costs, product family.

Abstract:

According to requirements of the market a great number of small companies are forced to offer a wide variety of products and to frequently respond to the market with customized solutions. High-variety production like mass customization is facing the challenge of effective variety management, which needs to deal with numerous variants of both product and process in order to accommodate diverse customer requirements. Large product portfolios allow customers to select products closely matching their needs, but it results in a larger costs. In the production of mass customization a very important issue is changeovers times. In spite of applying modern management techniques, setup time still plays an important part in the production cycle time. To shorten the production time, and therefore lower the cost, the methods of group technology (GT) are used. This paper presents a method of cost calculation taking into account manufacturing in organizational similar groups. The main purpose of this method is to identify the range of costs of elements produced in GT. The method was validated in conditions of high-variety production.

UWARUNKOWANIA KOSZTOWE WYTWARZANIA WYROBÓW DOSTOSOWANYCH DO POTRZEB KLIENTA**Słowa kluczowe:**

technologia grupowa, masowa kastomizacja, koszty, rodziny wyrobów.

Streszczenie:

Zgodnie z wymaganiami współczesnego rynku duża liczba małych przedsiębiorstw jest zmuszona do oferowania szerokiej gamy wyrobów i często oferuje rozwiązania dopasowane do potrzeb klienta.

Wysoka różnorodność wyrobów (masowa kastomizacja) stoi przed wyzwaniem skutecznego zarządzania wytwarzaniem wielowariantowej oferty produktów dopasowanej do potrzeb klienta w oparciu o wariantowe procesy wytwarzania. Duże portfolio produktów pozwala ściśle dopasować wyrób do potrzeb odbiorcy, ale jednocześnie prowadzi do podwyższenia kosztów realizacji zamówień. W warunkach produkcji dopasowanej do potrzeb klienta bardzo ważnym zagadnieniem są czasy przebrojeń. Pomimo stosowania nowoczesnego parku maszynowego, ze względu na ich ilość, czasy przebrojeń nadal odgrywają ważną rolę.

Poniższy artykuł przedstawia metody kalkulacji kosztów wytwarzania z uwzględnieniem dynamicznego grupowania w grupy organizacyjnie podobne. Głównym celem prezentowanej metody jest określenie zakresu kosztów produkowanych elementów w ramach GT. Metoda została zweryfikowana badaniami w warunkach produkcji wyrobów o wielu opcjach wykonania.

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