

Janusz MLECZKO<sup>1</sup>

## **DESIGN METHOD OF PRODUCTS' PROCESSES FOR GROUP TECHNOLOGY**

In contrast to the traditional manufacturing system, where the basic features are low product variety and mass production, recent manufacturing environment is characterized by shorter product life cycles, constantly diminishing batch sizes while the variety of product types and models continues to increase. In high-variety manufacturing, in spite of applying modern management techniques, setup time still plays an important part in the production cycle time. Product development teams use many methods and tools for design, test, and manufacture a new or improved product. Design for manufacturing methodologies are used to improve a product's manufacturability. For high-variety production the cumulative amount of setup time results from the number of changeovers. To shorten the production time and therefore cost the methods of group technology (GT) are used. This paper presents a method of increasing the manufacturability of elements produced in GT. The method was validated in the conditions of best practice production for high-variety production.

### **1. INTRODUCTION**

In contemporary markets customized products complicate the manufacturing processes significantly. The manufacturing systems have evolved over the past several decades in response to changing customer needs. In relation to customer requirements, the company changed the priorities in the strategy from price until the mid 1980s, quality until the early 1990s, flexibility until the mid 1990s, and agility or responsiveness thereafter [14].

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. Producing customized products at a low cost, which seemingly is a paradox, is the purpose of many enterprises. 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

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<sup>1</sup> University of Bielsko-Biała, Department of Industrial Engineering, ul. Willowa 2, 43-309 Bielsko-Biała, Poland  
phone: +4833827253, e-mail: jmleczko@ath.bielsko.pl

processing time and setup time. For high-variety production the cumulative amount of setup time results from the number of changeovers [2]. To shorten the production time and reduce costs the methods of group technology have been used for many years [16]. 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 [21].

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 shortly described. Then, an example to illustrate the problem is presented. Main part of the article consists of the method of calculation production costs in conditions of mass customization. Computational results are also discussed. The article concludes with some summary remarks.

## 2. PROBLEM BACKGROUND

Increase 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 ? How to manufacture the products ? How to shorten delivery time at the lowest cost?

The way of addressing these questions is concept of Mass Customization. The concept of Mass Customization (MC) producing customized goods at low costs received considerable attention in the research literature [8],[17],[24],[25],[27]. To implement product customization, many companies have changed their business models from make-to-stock to configure-to-order [29]. Configure-to-order (CTO) has been recognized as an ideal model that provides a right amount of product variety and a quick response time to customer orders [6],[29]. 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 of a customer order, order fulfilment starts from order processing [29].

Focusing on reducing the cost of offering product variety, Gupta and Krishnan [10] propose a methodology for designing product family-based assembly sequences.

Kusiak et al. discuss the design of assembly systems for modular products [15]. To shorten the production time and reduce costs for many years the methods of group technology are used [16].

The standard process planning and the group technology [13],[19],[22] are based on similarity. Both approaches to the process planning; the variant and the generative approaches are based on the similarity [3]. A key problem is to study the similarity

of products. Similarity of products allow use generative, variant or hybrid design method of routes.

The starting point for process planning was the concept of similarity. Mathematics knows similarity, coincidence, identity and equality of abscissas, triangles, sets, vectors.

Sets A and B are created from elements. Let's consider these sets for manufacturing process planning. Let the set A be the pattern (the standard), the set B the task to be solved:

- $A = \emptyset, B \neq \emptyset$  no pattern, full generative,
- $A \neq \emptyset, B \neq \emptyset, (A \cap B) = \emptyset$  no pattern, full generative,
- $A \neq \emptyset, B \neq \emptyset, (A \cap B) \neq \emptyset$  insufficient pattern, partly generative,
- $A \neq \emptyset, B \neq \emptyset, A \subset B$  insufficient pattern, partly generative,
- $A \neq \emptyset, B \neq \emptyset, A \equiv B$  identical sets, standard (paradigm),
- $A \neq \emptyset, B \neq \emptyset, A \supset B$  abundant pattern, variant access.

Other cases have no practical significance [3].

Design for manufacturing methodologies are used to improve a product's manufacturability. There are exist a variety of manufacturability guidelines (for example [1],[4],[5],[23],[28]). Researchers have developed various approaches for evaluating designs, including direct (rule-based) and indirect (plan-based) methods. Three important issues dominate the discussion about design for manufacturing (DFM) also called design for manufacturability [12]:

- a) Can the manufacturing process feasibly fabricate the specified product design?
- b) How much time does the manufacturing operation require?
- c) How much does the operation cost?

DFM compares a product's manufacturing requirements to existing manufacturing capabilities and measures the processing time and cost [11]. DFM approaches can be used during the conceptual design and the detailed design steps. Generally, DFM approaches focus on the individual manufacturing operations. For example, Anderson [1], Bralla [4], use DFM for reducing the unit manufacturing cost of many products.

### 3. PROBLEM FORMULATION

The main problem is determining design of elements so that the similarity allow the use in a wide range the group technology (GT). This is especially important in unit and small batch production. And to be precise rules for a dynamic grouping in the organizationally similar groups.

To solve this problem finding an answer to the following questions is necessary:

- a) Changing of what the workstation parameters affect the changeover?
- b) Is it possible the design of manufacturing process so that apply this processing parameters, which occur most often?
- c) How profitable is the use of variants of the manufacturing process in condition of unit and small batch manufacturing ?

To illustrate the above problem a simple example is given.

#### 4. ILLUSTRATIVE EXAMPLE

The example in this paper is the production of product families on laser cutter. As a result of CAM software elements are arranged in an optimum way to the sheet so as to obtain a minimum waste (see Fig. 1).

In conditions of mass customization a component demand will typically be equal to the number of demand this item in one unit of the product. Is the count of the element has an effect on costs? Are the components produced on a laser cutter able to manufacture ?

The use of unification in the form of shorten the list of type and the thickness of the material used increases manufacturability because it reduce costs. As is typical for this type of production it will not result in the production of one unit. Cost reduction is mainly due to the use of group technology. So the technological will be those elements that will have a greater tendency to create groups.

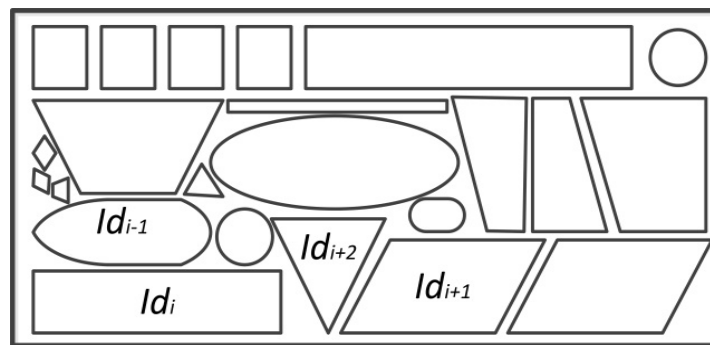


Fig. 1. Result of an arrangement by CAM software

The unification of sheet metal thicknesses and grades of materials narrow the list of raw material, increase manufacturability and reduce costs. This is due to the possibility of applying GT in actual organizational conditions. So the technological will be those elements that will have a greater tendency to grouping. If the company use unification when increase the manufacturability of manufactured elements. But is this the only way ? If in the process of designing a new product use elements produced from the same thickness and grade of material then despite the lack of unification we obtain the similar effect in the global. In the case of laser cutting elements would be manufactured in one organizationally similar group. There is not always possible to design the process in that way, but knowledge of this dependence on one hand offer significant diversification of product on the other hand preserve the cost minimization criterion.

#### 5. SOLUTION METHOD

The following is a solution to the problem of cost of production in a condition of usage dynamic method of grouping.

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

Manufacturing elements with GT usage the processing time and cost are depended on the counts of the groups. On cost of manufacturing in conditions of mass customization the key role have the setup time.

Complete time of task  $Id_i$  on machine  $j$  -  $\mathcal{F}_{Id_{ij}}$

$$\mathcal{F}_{Id_{ij}} = \mathcal{F}setup_{Id_{ij}} + \mathcal{F}work_{Id_{ij}} \quad (1)$$

where:

$\mathcal{F}work_{Id_{ij}}$  - process time of task  $Id_i$  on  $j$  machine,

$\mathcal{F}setup_{Id_{ij}}$  - setup time of task  $Id_i$  on  $j$  machine.

$\mathcal{F}_{Id_{ij}}$ -complete time of task  $Id_i$  on  $j$  machine,

If the tasks have not been arranged and the organizationally similar groups have not been created then total duration time on  $j$  machine:

$$\mathcal{F}_j = \sum_{i=1}^n \mathcal{F}_{Id_{ij}} \quad (2)$$

In the case of creating groups: If  $\mathcal{F}_{GO_k}$  means the total duration time of group  $O_k$  and  $O_k: \{Id_i, Id_{i+1}, \dots, Id_n\}$  then finally task duration time is:

$$\mathcal{F}_{O_k} < \sum_{i=1}^n \mathcal{F}_{Id_i} \quad (3)$$

and will be calculated by the following formula

$$\mathcal{F}_{O_k} \cong fsetup_{O_k}(P_1^a, \dots, P_x^a, \dots, P_X^a) + \sum_{i=1}^n \mathcal{F}work_{Id_i} \quad (4)$$

where:  $fsetup_{O_k}(P_1^a, \dots, P_x^a, \dots, P_X^a)$ , is a function of the recalculation of setup times for the group  $O_k$ , dependent on the set of parameters  $P^a = \{P_1^a, \dots, P_x^a, \dots, P_X^a\}$  of the machines  $m^a$ .

In case of accepting of the largest time of setup from all tasks as the setup for the group

$$fsetup_{O_k}(P_1^a, \dots, P_x^a, \dots, P_X^a) = \max_{1 \leq i \leq n} \mathcal{F}setup_{Id_i} \quad (5)$$

then

$$\mathcal{F}_{O_k} \cong \max_{1 \leq i \leq n} \mathcal{F}setup_{Id_i} * \zeta_m + \sum_{i=1}^n \mathcal{F}work_{Id_i} \quad (6)$$

where:  $\zeta_m$  is a factor to increase the setup time, taken deterministic from knowledge base for each machine  $m^a$ .

The more the multiplicity of organizational groups (n) to the greater number of produced elements can be disposed of setup time and thus the complete time is decreased.

Complete time of task  $Id_i$  on machine  $m^a$  -  $\mathcal{F}_{Id_i}$

$$\mathcal{F}_{Id_i} = \frac{f_{setupOk}(P_1^a, \dots, P_x^a, \dots, P_X^a)}{n} + \mathcal{F}_{work}_{Id_i} \quad (7)$$

or simplify:

$$\mathcal{F}_{Id_{ij}} = \frac{\max_{1 \leq i \leq n} \mathcal{F}_{setup}_{Id_i} * \zeta_m}{n} + \mathcal{F}_{work}_{Id_{ij}} \quad (8)$$

To increase manufacturability Author checked the parameters of the highest frequency impact on the changeover times.

To confirm this thesis and to determine the manufacturability of the product with the organizational grouping verification by testing in the selected company A was done. The object was a manufacturing system producing elements in conditions of unit and small batch. The study analyses the organizational similar groups created formed from 2007 to 2011. The company has a manufacturing system consisting of several dozen workstations performing mainly processing by modern, CNC controlled, machine park. Bottleneck has a tendency to move [18]. In the studied system bottleneck was often placed on the milling and laser cutter machines performing sheets processing. Data were taken from real processes collected in databases of ERP system.

## 6. DEFINING PARAMETERS OF TASKS HAVING INFLUENCE ON CHANGEOVERS TIME

For the manufacture product families dynamic grouping method was used. In this method [20], 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

$$P^1 = \{P_1^1, \dots, P_x^1, \dots, P_X^1\}, \dots, P^a = \{P_1^a, \dots, P_x^a, \dots, P_X^a\}, \dots, P^A = \{P_1^A, \dots, P_x^A, \dots, P_X^A\}. \quad (9)$$

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 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, that the same element is 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 design (D), technological (T) or organizational (O) type. In order to define the influence of features on the tasks arrangement process, a matrix of assignment to organizationally similar groups is created for each of these types. In order to do that for each of these groups the dependence of features as well as the kind of influence for this type of connection is defined. Influence means assignment to the organizational group and the methods of calculation of changeover time and manufacturability.

## 7. DETERMINATION OF THE PARAMETERS INFLUENCE TO CREATE ORGANIZATIONALLY SIMILAR GROUPS

According to (9), the set of parameters (P) describing the operation of the manufacturing process is equal:

$$P^a = \{p_x^a\}_{x=1,\dots,X} \quad (10)$$

Every parameter  $p_x^a$  belonging to the set  $P^a$  is described by:

$$p_x^a = (vl_x^a, im_x^a) \quad (11)$$

where:

$vl_x^a$  – means value of the  $x$  parameter for  $M^a$  workstation,

$im_x^a$  – means impact of the  $x$  parameter on changeover time for workstation  $M^a$ ,

$$vl_x^a \in VL_x^a \quad (12)$$

where:

$VL_x^a$  - set of parameter values  $x$  for  $M^a$  workstation.

For the laser cutter sheet changing has significant impact on changeover time.

The pattern for classification was created on the basis of P2 parameter values (P2 means the same raw materials). In the studied system, the analysis of created groups for P2 parameter were done. The data are categorized in descending order of the parameter P2 which occurs most frequently. Number of groups formed for the most "popular"

parameters were varied during manufacture. The above research shows the most "popular" P2 values for the raw material. Analysed elements were produced over the past 5 years. The most natural direction of increasing manufacturability is the standardization of raw materials. For the customized production it is not always possible. It is also important to answer the question about the profitability of standardization.

If we know list of raw materials from which products are most often manufactured, is it possible to change the manufacturing process in that way to use materials which have tendency for grouping ?

If the answer to that question is yes, how to measure the profitability of this process. To solve the problem of increasing the manufacturability the author proposes to create indicators based on the concept of "throughput accounting" (TA).

Theory of Constraints (TOC) defines three simple measures of efficiency [7],[9]:

Throughput (T) - the rate at which the system generates money through sales.

Investments (I) - all the money spent by the system for the purchase of what is going to sell.

Operating Expenses (OE) - all the money spent by the system to replace the investment in processing.

Throughput can also be expressed per unit product ( $T_u$ ) by the following formula:

$$T_u = P - TVC \quad (13)$$

where:

P - is a unit price of the product,

TVC - is a totally variable cost of the product, (in most cases mean raw materials).

Total throughput for the product during the period of time is:

$$TT_p = T_u * q \quad (14)$$

where:

q- is the quantity of product p sold during the specified period.

Factor determining the profitability of the product  $\xi$  is equal:

$$\xi = \frac{T_u}{CCR} \quad (15)$$

where:

CCR – means working time of bottleneck.

The higher throughput and less time spent on bottleneck the more profitable is the production of product. Extending the use of this measure for the production of components it can be stated that this ratio can evaluate the profitability of production elements. In conditions of unit and small batch production, it is essential to reduce the time changeovers. Reducing the CCR were done by dynamic grouping. But is it possible to influence the throughput ? Assuming that the selling price is fixed and at the start of production it is difficult to change it, there remains only the issue of TVC - totally variable costs.



Considering equations (8) and (14):

$$\xi = \frac{P-TVC}{CCR} = \frac{P-TVC}{\mathcal{F}Id_i} = \frac{P-TVC}{\frac{fsetupO_k(P_1^a, \dots, P_X^a, \dots, P_X^a)}{n} + \mathcal{F}workId_i} \quad (16)$$

Throughput Accounting (TA), as one of the few methods of cost calculation, takes into account the processing time on the bottleneck. Therefore, in conditions of production suited to customer needs, where delivery time is a particularly important parameter TA could find the right application.

Here, for example for laser cutter production, the essence of the approach to improve manufacturability of the product with the use of the proposed measure was explained. To improve manufacturability, there are two possibility of changing parameters: changing the grade sheet and changing the thickness of the designed element.

The increase the cost of the proposed element can be compensated by reduction of manufacturing time. Let's imagine the designing an optimal static condition without taking into account the grouping.

The analyzed element can be made of either material S1 or S2. Material S1 costs 12.35PLN per 1kg, S2 10.45PLN per 1kg. Price achieved from the sale of element is 15PLN. Changeover time is 0.15 hours. The processing time is 0.12 hours. Number of elements is one. The consumption of raw material for one item is 1kg. According to the proposed methodology ratio was calculated for both variants:

$$\xi_{s1} = \frac{P-TVC}{\mathcal{F}Id_i} = \frac{15-12,35}{0,15+0,12} \cong 9.81 \text{ PLN/h}$$

$$\xi_{s2} = \frac{P-TVC}{\mathcal{F}Id_i} = \frac{15-10,45}{0,15+0,12} \cong 16.85 \text{ PLN/h}$$

System in case of S1 generates 9.81PLN/hour in the case of S2 - 16.85PLN/hour. The simple dependence shows that the variant S2 is better.

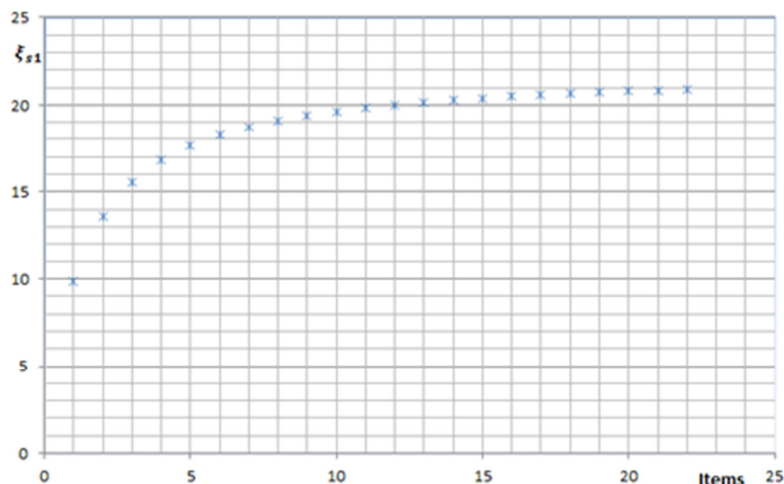


Fig. 2.  $\xi_{s1}$  coefficient

Is S2, in all conditions of the manufacturing process, more advantageous variant ? Assume that S1 is a material occurring relatively frequently in the manufacturing process. The element is produced within the organizationally similar groups, and number of the items in this group is 5. Then

$$\xi_{s1} = \frac{P - TVC}{\frac{f_{setup} O_k (P_1^a, \dots, P_x^a, \dots, P_x^a)}{n} + F_{work} Id_i} = \frac{15 - 12,35}{\frac{0,15}{5} + 0,02} \cong 17,6 \text{ PLN/h}$$

and S1 variant is advantageous.

The Fig. 2 shows the dependence of  $\xi_{s1}$  coefficient from the number of items in the group. Above the amount of 5 items the variant S1 is more profitable. The Fig. 3 shows the dependence of  $\xi_{s2}$  coefficient from the number of items in the group.

Second possibility of element's design is manufacture from greater than required thickness. Let it be a raw materials S3. When thickness increases the raw material consumption should be greater and equal 1.15kg. Price for 1kg of material S3 is 10.45PLN. Laser cutting time is also greater and equals 0.16h. The  $\xi_{s2}$  value without grouping is:

$$\xi_{s3} = \frac{P - TVC}{F_{Id_i}} = \frac{15 - 10,45 * 1,15}{0,15 + 0,16} \cong 9,62 \text{ PLN/h}$$

The maximum throughput value in S3 variant, using grouping, is just over 18.5PLN/hour. But not always designer allow to use this variant.

It is possible to get the effect of cost reduction due to the possibility of group technologies, in particular the dynamic grouping.

But is grouping always possible ? The problem is that there is no certainty. Solving of this problem is collecting of three variants of the process. Choice the appropriate variant is possible at the stage of organizational preparing of production, especially by the operator or CAM software. The more options we have the better database capabilities are. It

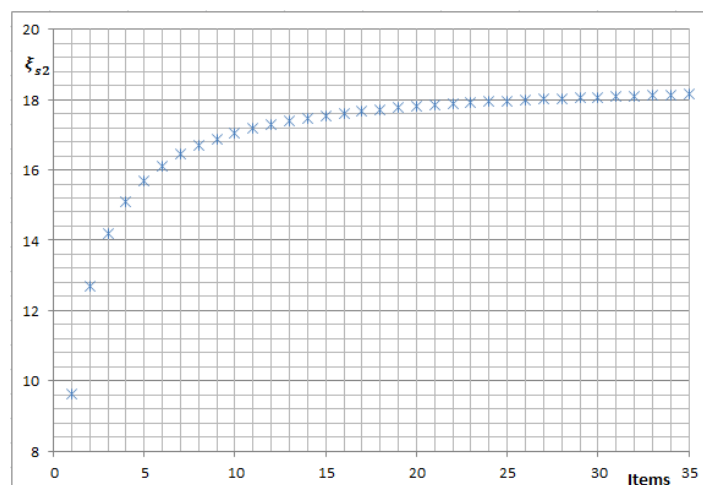


Fig. 3.  $\xi_{s2}$  coefficient

sounds as the paradox but in conditions of mass customization, product and the elements manufacturability can be increased by creating alternative variants of process routes. Preparing alternative variants increase the labour intensity of organizational preparing the production but it is compensated, according to the TOC, by increasing throughput.

The next question concerns the limit of the grouping, precisely the conditions of profitable adding elements to the group organizationally similar when a variant of the process is not optimal in static conditions.

Limit should be calculated for the element factor  $\xi$ . If the condition is satisfied

$$\xi_X > \xi_{stat} \quad (17)$$

then grouping is profitable.

where:

$\xi_X$  – means the coefficient value calculated at adding to the group X.

$\xi_{stat}$  – means the coefficient value calculated at the optimum variant without grouping.

Adding the elements to the group benefit from increasing throughput of the other elements of the group and thus the whole system. This require further study in a specific production system.

## 8. CONCLUSIONS

The contemporary customer requirements, determine the production systems. Strategies for small and medium-sized enterprises are more and more often directed towards the manufacturing variant products. Currently, production systems must be prepared to produce product families in the shortest possible production cycle and low cost. The mass customization is realized in the system of unit and small batch production in Make-To-Order mode (MTO). For this kind of production of the definition of manufacturability of products and their components should focus on the tendency to reduce the changeovers time. Therefore, easy and inexpensive to manufacture are the products that have a tendency for grouping. Introduced methodology and set of measures can comprehensively evaluate manufacturability of products and their components, and determine the direction of their increase. It may be a basis for modification of existing designs and technologies. The study showed the possibilities of production costs reduction in both theoretical and achieved in real manufacturing systems. Dynamic grouping is not based on the structure of the manufacturing processes but on the parameters of the operation. These preliminary studies were based on historical data, allowed evaluate manufacturability of products from the perspective of the earlier production orders. Another area of research would provide a tool to evaluate manufacturability at the design stage. The designer should analyse manufacturability from the perspective of grouping.

The above calculations without the IT support are impossible. The attached examples show the possibilities of improving the manufacturability of elements produced in the laser cutter. The main direction leads to the creating alternative manufacturing processes, where

the key is the possibility of use sheet metal with higher requirements. Despite the higher cost of materials, the use of dynamic grouping reduces its negative impact.

Calculation of the cost by the algorithms based on the TOC allow find the limit of profitability changes. Both studies and practice, show usability of the proposed manufacturing solutions.

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