# HIGH-VARIETY PRODUCTS MANUFACTURING BASED ON DYNAMIC CLASSIFICATION

**Janusz Mleczko**

S u m m a r y

According to the 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. This paper presents high-variety products manufacturing based on dynamic classification. 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. In high-variety production, in spite of applying modern techniques, setup time still plays an important part in the production cycle time. The problem is not single change over time, but is in the quantity of changeovers required. This observation inspired the author to prepare a method of setup time reduction through the appropriate arrangement of tasks in the operational production plan. The appropriate arrangement of tasks means considering the similarity of parts from the point of view of operations carried out. The similarity of parts facilitates setup time reduction, which translates into smaller lot sizes, reduced in-process inventories, shorter lead time and higher throughput. The method was validated in the conditions of best practice production for unit and small batch production.

**Key words:** dynamic classification, operational production plan, group technology, unit and small batch production, high-variety production, product family

**Wytwarzanie wyrobów wielowariantowych na podstawie klasyfikacji dynamicznej**

S t r e s z c z e n i e

Wymagania współczesnego rynku przedsiębiorstwa determinują wytwarzanie wielowariantowych wyrobów dostosowanych do potrzeb użytkownika. W produkcji wielowariantowych produktów, pomimo zastosowania nowoczesnych metod zmniejszania czasu przezbrojenia, nadal odgrywa on znaczną rolę w cyklu produkcji. Problem dotyczy nie czasu pojedynczego przezbrojenia, ale liczby przezbrojeń. Stąd opracowano metodę skrócenia czasu przezbrojenia poprzez sekwencjonowanie zadań na poziomie operacyjnego planu produkcji. Zaproponowana metoda zakłada ustalenie podobieństwa zadań ze względu na wykonywaną operację przy użyciu wielostopniowej i dynamicznej klasyfikacji. Uwzględniono cechy konstrukcyjne, technologiczne oraz zmienne cechy organizacyjne wytwarzania. Metodę sprawdzono w praktyce produkcyjnej małych i średnich przedsiębiorstw.

**Słowa kluczowe:** dynamiczna klasyfikacja, operacyjny plan produkcji, technologia grupowa, produkcja małoseryjna i jednostkowa, produkcja wielowariantowa, rodziny wyrobów

Address: Janusz MLECZKO, PhD. Eng., University of Bielsko-Biała, Department of Industrial Engineering, 43-309 Bielsko-Biala, 2 Willowa St., e-mail: jmleczko@ath.bielsko.pl

## 1. Introduction

It is a widely accepted practice to utilize product diversity and process variation to develop product families in which a set of similar variants share M differentiates within common structures. 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 changes in many paradigms, including customer expectations.

Customers have become more demanding and want products that can meet their specific individual requirements [1-3]. Thus customization is turning out to be essential to maintaining competitive advantage in many industries. Producing customized products at a low cost, which seemingly is a paradox, is the purpose of many enterprises [4]. 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. Despite using modern management techniques (e.g. SMED Single Minute Exchange of Die technique) in the conditions of unit production in SMEs, total setup time is significant.

For high-variety production, the cumulative amount of the setup time results from the number of changeovers. In the examined companies of the SMEs sector the relationship between setup time and processing time is still high and ranges over a few to several per cent of the processing time.

The above research inspired the author to prepare a method of setup time 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. The paper is structured as follows: first, the studied problem is concisely described. Then, an example is provided to illustrate the problem. The main part of the article consists of assumptions of dynamic classification and clustering. The article concludes with some summary remarks.

## 2. Problem background

Manufacturing based classification began to evolve in the 1940s. It is based on the idea that products do not have to look the same to be similar. Although they may appear to be different, they can be manufactured in the same way. It

becomes possible to develop a classification system that groups products according to their manufacturing characteristics [5-6]. Analyzing literature, it is possible to find a lot of methods of recognizing product similarities. The most important are: classification and grouping. Classification is a statistical science term and can be defined as a procedure in which individual items are placed into groups based on quantitative information on one or more characteristics inherent to the items (referred to as traits, variables, characters, etc) and based on a training set of previously labeled items [7-8].

Machine-part grouping problems were also considered in many publications [9-12]. This issue is referred to as “part family & machine cell formation”, “machine part grouping”, or “group technology manufacturing”. The problem arises when dividing a group of machines into subsets and assigning operations to these subsets in order to optimize a production organization quality criterion. Although the problem generally concerned the improvement of industrial engineering, the purpose of the optimization was situated elsewhere. This criterion reflects the “density” of operation within the established machine groups and the “sparseness” of operations outside of these groups. Additional aspects that complicate the formulation of solution to the general problem are: timing, costs, sequencing of operations, the possibility of duplication and the cost of machines, as well as various limitations on the groups.

The concepts of high-variety manufacturing are described in literature by [13-14], amongst others. Some scholars focused on the optimization of data preparation and the modeling of product structure (e.g. [15-17]). They linked the product configuration process to the process through which the customer’s needs are translated into the information needed for tendering and manufacturing (typically product cost, bill of materials (BOM), production cycle, etc.). The attention management literature recently devoted to the issue of product configuration is also related to the importance of software applications. The concept of Mass Customization (MC), producing customized goods for a mass market, has received considerable attention in research literature [18-19]. The fundamental modes of operation for mass customization were given in [20-22]. A risk and limit of mass customization is known as ‘‘mass confusion”, which is a metaphor for the burden of the consumer resulting from attractive but probably overloaded options [13, 23]. More and more often, small and medium-sized enterprises (SME) are using software to increase the functionality of their products and offerings. Variability management by software is becoming an interesting topic for SME with expanding portfolios and increasingly complex product structures.

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 [24]. The product family is composed of possible configuration solutions $P = \{P_1, P_2, ..., P_n\}$ with AND

relation. Each solution $P_i \big| \forall i \in [1, N]$ could be derived by adjusting the configurable modules, $M = \{M_1, M_2, ..., M_n\}$. Each configurable module $M_i \big| \forall i \in [1, K]$ may possess several available module instances $M_k^* = \{CA_{k1}, CA_{k2}, ..., CA_{kL_k}\}$ 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 performances, 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.

A dynamic development of Flexible Manufacturing Systems (FMS), which started in the 1980s, was aimed at cutting the cost of manufacturing various products, particularly given the context of customers' constantly growing demands. A constant tendency to lower the number of manufactured products while at the same time increase their variety led, in conventional systems, to a dramatic increase of setup time in the total work time [25]. Only technologically advanced means of manufacturing with modern methods of process control allows the reduction of the changeover times and thereby reduces production costs and the delivery time of products to customers.

## 3. Problem formulation

A large number of SMEs have decided to introduce an ERP class system although they have recognized that the introduction process is difficult and expensive. However, an alternative solution cannot be easily found [26, 2]. In the majority of companies the introduced ERP systems were not fulfilling expectations in the area of operational production control. Companies need efficient tools and methods of process control which could work in an “on line” mode.

An efficient production system realizes “make to order” manufacturing of configurable products. Due to the fact that the system resources are not wholly used, it is possible to accept additional orders. Prior to commencing the realization of these orders one should answer the following questions:

- Do the resources possessed make it possible to complete the orders on time without exceeding the limitations?
- If the demand for resources exceeds availability, is it possible to increase the availability of resources (improve the bottleneck)?
- Which variant of the routing process is the optimum?

In other words, one should find an answer to the following questions:

- How to distribute production orders among alternative routes?

• What resources should be allocated to jobs to complete the orders on time and without exceeding constraints?

Such a formulation of the problem serves to emphasize its decision-making nature. So, a feasible variant of a given work order schedule, following both the customer's requirements and the manufacturing system capabilities, is sought.

To solve this basic problem, different computer methods are used. Some concern virtual enterprises [27] or Digital Factories [28-29]. The author used the method of dynamic classification. This method can be developed as a potential source of supply for Digital Factory.

## 4. Solution method

### 4.1. Overview of the 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.

For example, for the varnishing line, the major influence on the changeover time is the colour of the varnish. Regardless of shape (which does have an influence on the processing time), if there are elements painted the same colour in the same set of tasks then the line will not need to be rearmed. Using the standard construction classifier in this case – where the subject of classification is an element and not the operation – can have unwanted effects. The groups would be created for elements of the same kind. When designing the production process we do not know in what sequence the elements will be made and as a result we assign the full setup time in the base. While if we arranged the tasks properly we could lower the setup times to a greater extent. Setup times cannot be lowered to zero but let us assume that we are able to assess the lowering of setup times for the remaining elements which constitute such a prepared group.

Assignment into the groups is not limited. The basic limitation is the demanded production time. The group cannot consist of too many elements because while performing the tasks for the whole group we perform them faster than is needed and we absorb the resources. Although we shorten work consumption, we lengthen the unit production time. We are searching for an optimum in a multi-criterion optimization of the cycle length, work consumption and production costs. In fact, the process of classification itself has a dynamic character which depends on organizational conditions. Creating such groups in a manual way would not be useful either, which is why it requires IT support. This method could even be identified as a semi-automatic one.

Taking into account the above assumptions, a heuristic method of arranging was created. Assignment to a similar element group is based on the criterion of similarity at the level of the production process operation (Fig. 1.).

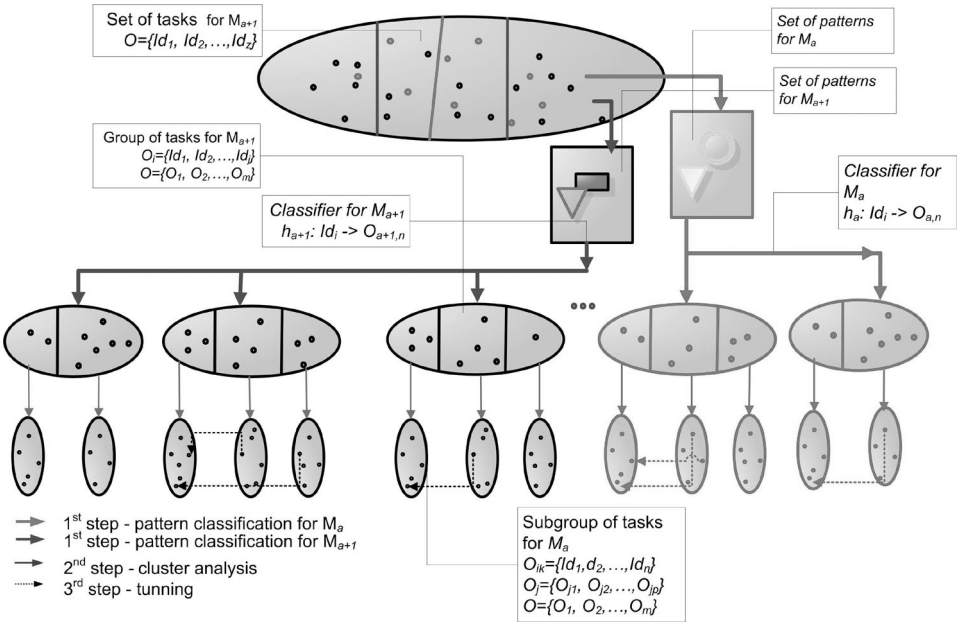


Fig. 1. Dynamic classification

The criteria are rather static but the given element – and in fact the task of the production process operation – can dynamically belong to different groups in different operations of the production process. Due to organizational limitations, the element can belong to different groups fulfilling even the same statistical similarity criteria. This can be verified by tests in real conditions. Operations of creating and modifying subgroups based on the results of earlier phases of grouping also prove the dynamic character of the presented solution.

### 4.2. Illustrative Example

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. For roller shutters, the parameters for configuration are shown in Table 1.

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

60-70 m/min. Unfortunately, the changeover time of the line is 2 hours. Until now, shutter manufacturing was based on profiles supplied in 6m sections. The profile was then cut to length according to individual customer requirements.

Table 1. Basic parameters for configuration and influence of features on the tasks arrangement process

| Node | Parameter | Possible values of parameters | Amount of values | Comments | Group type | Kind/Influence |
|---|---|---|---|---|---|---|
| 1 | PA System P1 | {39, 41, 45, 52} | 4 | System determines the width of the profile. | PAN/SKR | D +++ |
| 2 | Width dimension P2 | From 300 to 3800. | about 3500 | Maximum roller width depends on the PA system. For example, for PA = 39 is equal to 2800 and for PA = 41 is equal to 3800. | PAN/SKR | D ++ |
| 3 | Colour of profile P7 | {brown, dark brown, blue,….}, full range of RAL | About 12 or 1000 | Parameter values depend on the supplier of profiles. It is possible also to paint profiles to the any RAL colour | PAN | D +++ |
| 4 | Colour of box P8 | {brown, dark brown, blue,….}, full range of RAL | About 12 or 1000 | Parameter values depend on the supplier of profiles. It is possible also to paint profiles to the any RAL colour | SKR P8 | D +++ |
| 5 | Kind of box P9 | {130,150, 180,..} | 4 | Parameter values depend on the supplier of boxes. | SKR | D +++ |
| X | P20 | <0;10> | ∞ | Priority of superior order Parameters from P20 to P23 are limitations of the assignment to the group. P 20 is suggesting not to arrange elements into groups with divergent priorities of orders. | PAN/SKR | O --,--- |
| X | P21 | <0;168> | ∞ | Date of delivery The due date scheduled in the plan will be a basic parameter dividing organizationally similar groups. | PAN/SKR | O --,--- |
| X | P22 | {T,F} | 2 | Release the operation (the previous operation was performed and material is available) | PAN/SKR | O,T -- |
| X | P23 | <0;10> | ∞ | Delaying task in the production plan | PAN/SKR | O --- |

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 did not allow for waste-free production. It's possible only on the rollforming line with cutting to length according to individual customer requirements. The above line is CNC controlled and the controlling data are transmitted automatically by the manufacturing execution system (MES). The process can be implemented by alternative routes (Fig. 2.).

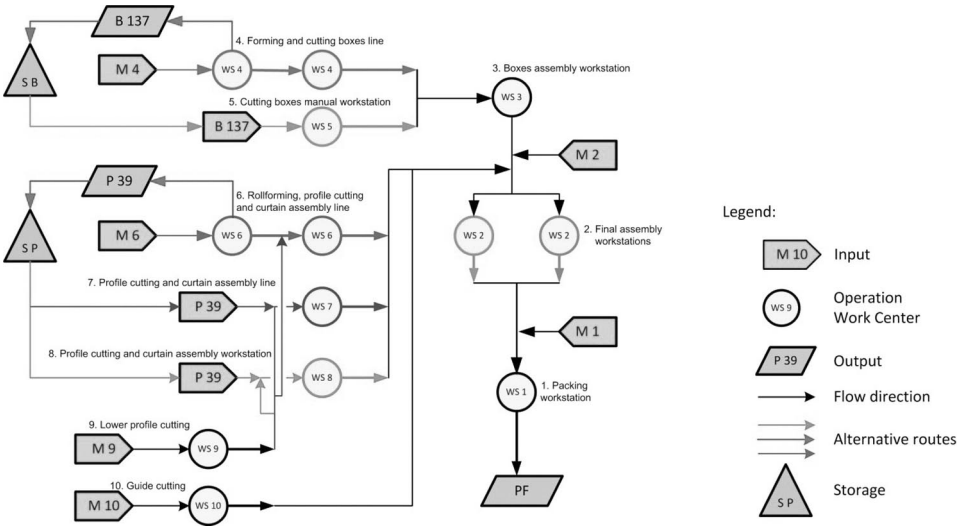


Fig. 2. Alternative routes for roller shutter family

### 4.3. Defining parameters of tasks having influence on changeover time

In this step, position groups were divided into homogenous types by those parameters which have an influence on changeover time. For each element of the set of machines $M_X = \{m_1, m_2, \dots m_n\}$ a choice was made of those parameters which have an influence on changeover times and they were assigned to $m_1$:$\{p_{11}, p_{12}, ..., p_{1k}\}$, $m_2$:$\{p_{21}, p_{22}, ..., p_{2l}\}$, …, $m_n$:$\{p_{n1}, p_{n2}, ..., p_{nm}\}$. The assignment of parameters will be insufficient; the influence of the above parameters on reducing changeover times also need 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 will be 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.

In order to define the influence of features on the tasks arrangement process, a matrix of assignment to organizationally similar groups was created for each of these types. In order to do that for each of these groups the dependence on features, as well as the kind of influence for this type of connection, was defined. Influence means assignment to the organizational group and the method of calculation of changeover time.

### 4.4. Dynamic groups forming

Two types of groups were formed for roller shutters: boxes and curtains. (Fig. 3.). For the definition of the set of tasks for assignment purposes a "business to business" (B2B) data system was used. 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 (PAN and SKR).

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. There are several possible classification scenarios. After calculating the parameters for the two types of groups, the author applied pattern classifications. The problem of pattern classification can be stated in a formula as follows: given training data $\{(x_1, y_1), ..., (x_n, y_n)\}$, produce a classifier $h$: $X \rightarrow Y$ that maps any object $x \in X$ to its true classification label $y \in Y$. Sets $O_1, O_2, ..., O_m$ where $O_i = \{Id_1, Id_2, ..., Id_z\}$ has a separate character and $O_i \subseteq O$, $\bigcup_i O_i = O$ for $\left|\forall i,k \in Id\right.$ condition $O_i \cap O_k = \varnothing$ is satisfied. The assignment of elements' set $Id_i$ to the set of groups $O_k$ is a function dependent on parameters P:$\{Id_i \in O_k{:}F(p)\}$.

Set $O$ was divided into as many classes as there were labels $y_i \in \{1, 2, ..., g\}$ created, where the label is a unique value of a parameter having a strong influence on setup time. In the case of the roller shutter two kinds of group appeared. One of them is defined by the forming of curtains and the other by the forming of boxes. For groups of curtains, the strong influence on setup time has P1 and P7 parameters (see Table 1). Number of created groups is equal to the

unique and not empty value of cartesian set P1 and P7. For groups of boxes the strong influence on setup time have P1, P8 and P9 parameters (see Table 1). The number of created groups is equal to the unique, and not empty, value of the cartesian set P1 and P7. For groups of boxes, the strong influence on setup time has P1, P8 and P9 parameters (see Table 1). The number of created groups is equal to the unique, and not empty, value of cartesian set P1, P8 and P9.

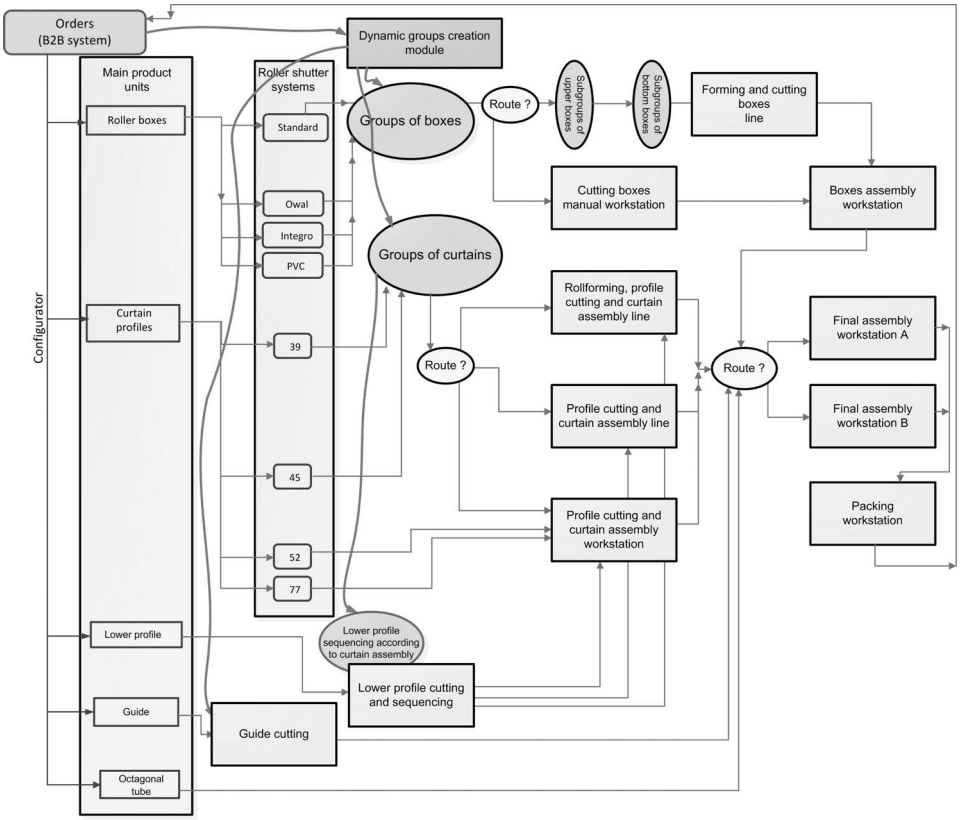


Fig. 3. Material flow for roller shutters family

### 4.5. Subgroups forming

Subgroups were formed on the basis of cluster analysis. Partition clustering algorithms require a large number of computations of distance or similarity measures amongst data records and cluster centers, which can be very time consuming for large data bases. Moreover, partition clustering algorithms generally require the number of clusters as an input parameter. However, the number of clusters is usually an unknown priori, so the algorithm must be

executed many times, for a different number of clusters. The algorithm uses a validation index to define the optimal number of clusters. In the case of forming organizationally similar groups calculating the amount of groups is possible.

At this stage of classification a subdivision of groups based on subgroups is shown.

The sets $O_{ix}$ were formed: $\left|\forall i \in \{1, 2, ..., m\}\right.$ $O_i = \{O_{i1}, O_{i2}, ..., O_{ip}\}$ where $O_{ix} = \{Id_{x1}, Id_{x2}, ..., Id_{xz}\}$. Groups have separate characters: $O_{ix} \subseteq O_i$, $O_i \subseteq O$, and $\bigcup_{ix} O_{ix} = O_i$, $\bigcup_i O_i = O$, where $\left|\forall i,k \in Id\right.$ conditions are satisfied: $O_i \cap O_k = \varnothing$, $\left|\forall i,k \in Id\right.$ $O_{ix} \cap O_{kx}$.

The assignment of the elements' set $Id_i$ to the set of groups $O_{ixk}$ is a function dependent on parameters P:$\{Id_{ix} \in O_{ix} : F(p)\}$. At this stage of classification, organizational parameters: P20, P21, P22, P23 played an important role.

Clustering aims to find useful groups of objects (clusters), where usefulness is defined by the goals of the data analysis. The decision about the amount of clusters is undertaken based on the following two assumptions: the machine works in a one shift system and the working day consists of 8 hours. The parameter P21 is a feature which strongly influences the formation of the groups. The following heuristic formula is used for the initial K for creating the clusters.

If $\max\left(\mathrm{P21}(Id_i)\right) - \min\left(\mathrm{P21}(Id_i)\right) > 1$ then new clusters are formed.

Assuming, that for every group:

$$\forall i \in \{1,2,...m\}\ K_i = \mathrm{int}\left(\max\left(\mathrm{P21}(Id_i)\right) - \min\left(\mathrm{P21}(Id_i)\right)\right) \tag{1}$$

where the amount of clusters is indicating $K_i$ we receive the required initial amount of clusters.

### 4.6. Final grouping

The first two stages consisted of creating groups and subgroups. Classification took place according to the similarity of the technological parameters P1-P19. The grouping (e.g. in the case of the curtain of the roller cutter – the index of cartesian set P1×P7) was strongly influenced by preserving organizational limitations (P20- P23). The next phase of forming groups was the final grouping.

The final grouping took place based on the results of the first two phases. Additional conditions for the moving of elements between subgroups were taken into consideration. It wasn't possible to carry out the above task in step 2 because of the organizational nature of the parameters which limited grouping. In this phase, we moved tasks within neighboring subgroups, verifying the

results of the grouping with additional limitations. All groups where these subgroups appeared at the front of the queues were then analyzed, i.e. a decision was made as to which tasks should be completed first.

Subgroups which were in the previous phase were marked with initial numbers $O_{k1}$, $O_{(k+1),1}$. The final grouping was calculated according to the formula:

$$\forall_k \, \mathrm{V}_i \, Id_i \in O_{k,2} : \begin{cases} if \;\; f(Pa) is \; true \; then \; Id_i \in O_{k,1} \\ if \;\; f(Pa) is \;\; false \; then \; Id_i \in O_{k,2} \end{cases} \tag{2}$$

This is not necessary for all workstations to apply the 3rd stage. Furthermore, a lack of underlying data in the classical structure of an ERP package can cause additional problems for the classification. Often in order to complete this stage the dataset for parameters must be extended in order for the above analysis to apply. As a result of a calculation of the above phase even entire clusters can disappear. Subgroups can be assimilated by preceding index subgroups.

The example of applying the 3rd stage concerns the formation of boxes for roller shutters. The research of grouping is connected with manufacturing from full metal tapes. For the same value of the parameter P7, more than one day of rescheduled tasks is required. This kind of action optimizes the waste of material as well as lowering the time of rearming.

### 4.7. Control of manufacturing

Control of manufacturing is based on a dedicated MES class system. (Fig. 4.). The control system is based on jobs being provided to the workstations as a "virtual card” (electronic task list). Virtual job cards are prepared by the module ZA. Module ZA uses a dynamic classification of the tasks in the operational production plan. On workstations which aren't equipped with CNC machines the confirmation of tasks and the validation process takes place on the touch panel. On the other workstations the tasks on the job cards are automatically transferred to the machine as a control data stream. Data transfer is prepared by the “configuration engine”. Data for the configuration engine are obtained directly from the B2B portal.

Examples of tasks performed by the employee on the rollforming workstation are given below.

The main tasks of the employee are transferring data to the machine and the registration of executed tasks based on the list of tasks prepared by the dynamic classification module. After line changeover, an employee presses the button on the machine’s touch panel and sends data (a file or data stream based on the

machine manufacturer's specification). The registration of the performance is carried out on the touch panel screen, after the assembly of the curtain.

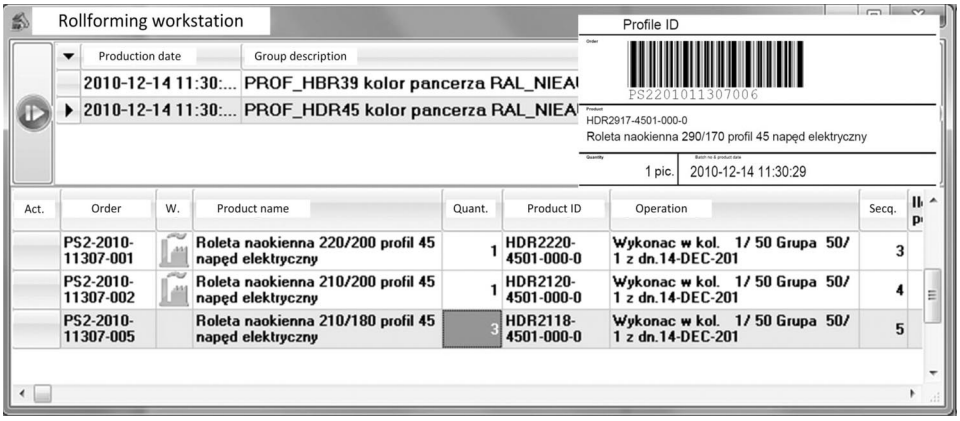


Fig. 4. The registration performance and print labels screen

After the machine has completed the curtain, either the employee confirms the execution by pressing the button on the touch screen or the machine (in two-way communication) returns the information about the execution which is confirmed by the employee (with the aim of controlling incompatibility in the process). The next task is to print a label with the order number relating to the curtain (Fig. 4). The label is then stuck to the curtain. After registration, the performance status of the order is marked out. Equipping the line with the marking device is an alternative solution. In this case a bar code is printed directly on to the curtain (without a label).

## 5. Conclusions

The method which has been introduced in this paper gives more scope to the profitability of IT projects in the future. This approach seems to be an excellent tool for a decision making model for SMEs. In consequence, this method can be an alternative for expensive and difficult to implement scheduling methods. Constraint-based scheduling with dynamic classification are efficient tools for solving real-life scheduling problem in an “on line” mode.

The method is effective when the following conditions are met:

- preparation of the knowledge base with special attention to the availability of data from the point of view of features having influence on changeovers times and task parameter data bases,

- principles of dynamic creation of organizationally similar groups,
- cyclical (daily) classifications of tasks into organizationally similar groups,
- process support with the use of IT software.

The data from ERP systems and additional software applications allow the automatic creation of groups in real production systems in SMEs. The current global business environment requires high flexibility from the designers of advanced manufacturing systems. The organizational criteria of dynamic classification can be a powerful tool for the production of configurable products. Constraint-based product family design and assembly technology has great meaning in product development. It can support product engineering analysis, save new product storage space, and support transportation analysis. Dynamic classification can be an indispensable tool for supporting the production of roller shutters.

Using the method of obtaining data from ERP or B2B systems as a source data for a digital factory can cause higher practical use of simulation tools in the digital factory. Simulation tools used for this purpose enable designers to develop manufacturing systems which will be able to work effectively during the whole life cycle [29].

## References

[1] B. SKOŁUD: Operational management. Production in small and medium enterprises. Wydawnictwo Politechniki Śląskiej, Gliwice 2006.
[2] J. MATUSZEK: Methods and techniques in the management of production engineering. Wydawnictwo ATH w Bielsku-Białej, Bielsko-Biała 2007.
[3] J. MATUSZEK, J. KOŠTURIAK, M. GREGOR, J. CHAL, J. KRIŠT'AK: Lean company. Wydawnictwo ATH w Bielsku-Białej, Bielsko-Biała 2003.
[4] A. KUMAR, S. GATTOUFI, A. REISMAN: Mass customization research: trends, directions, diffusion intensity, and taxonomic frameworks. *Int. Journal Flexibly Manufacturing Systems*, **19**(2007), 637-665.
[5] A. HOUTZEEL: Group technology. Maynard's industrial engineering handbook. 5th edition. McGraw-Hill, Ohio 2001.
[6] D. BEN-ARIEH: Analysis of a distributed group technology methodology. *Computers Industry Engineering*, **35**(1998), 69-72.
[7] B. EVERITT: Cluster analysis. 3rd edition. Arnold, London 1993.
[8] P. TAN, M. STEINBACH, V. KUMAR: Introduction to data mining. Addison-Wesley 2006.
[9] B. ADENSO-DIAZ, S. LOZANO, I. EGUIA: Part-machine grouping using weighted similarity coefficients. *Computers & Industrial Engineering*, **48**(2005), 553-570.
[10] G. JEON, M. BROERING, H.R. LEEP, H.R. PARSAEI, J.P. WONG: Part family formation based on alternative routes during machine failure. *Computers Industry Engineering*, **35**(1998), 73-76.

[11] U. R. KULKARNI, Y.M. KIANG: Dynamic grouping of parts in flexible manufacturing systems – A self-organizing neutral networks approach. *European Journal of Operational Research*, **84**(1995), 192-212.
[12] J.W. OWSIŃSKI: Machine-part grouping and cluster analysis: similarities, distances and grouping criteria. *Bulletin of the Polish Academy of Science, Technical Sciences*, **57**(2009)3, 217-228.
[13] C. HUFFMAN, B. KAHN: Variety for sale: Mass customization or mass confusion. *Journal of Retailing*, **74**(1998), 491-513.
[14] C. BOZARTH, C. M. MCDERMOTT: Configurations in manufacturing strategy. A review and directions for future research. *Journal of Operations Management*, **16**(1998), 427-439.
[15] J. LAMOTHE, K.M. HADJ-HAMOU: An optimization model for selecting a product family and designing its supply chain. *European Journal of Operational Research*, **169**(2006), 1030-1047.
[16] M. SINNEMA, S. DEELSTRA: Classifying variability modeling techniques. *Information and Software Technology*, **49**(2007), 717-739.
[17] F. ELGH: Supporting management and maintenance of manufacturing knowledge in design automation systems. *Advanced Engineering Informatics*, **22**(2008), 445-456.
[18] G. DA SILVEIRA, D. BORENSTEIN, F. S. FOGLIATTO: Mass customization: Literature review and research directions. *Int. Journal Production Economics*, **72**(2001), 1-13.
[19] R. DURAY: Mass customization origins: mass or custom manufacturing? *Inter. Journal of Operations & Production Management*, **3**(2005), 314-328.
[20] B. J. PINE: Mass customization production and services. *Planning Review*, (1993)7-8, 6-55.
[21] B. MACCARTHY, P.G. BRABAZON, J. BRAMHAM: Fundamental modes of operation for mass customization. *Int. Journal Production Economics*, **85**(2003), 289-304.
[22] F. SALVADOR, P. B. DE HOLEN, F. PILER: Cracking the code of mass customization. *MITSloan Management Review*, **50**(2009)3, 71-79.
[23] P. ZIPKIN: The limits of mass customization. *MIT Sloan Management Review*, (2001), 81-87.
[24] J. JIAO, M. M. TSENG, Q. MA, Y. ZOU: Generic bill of materials and operations for high-variety production management. *Concurrent Engineering: Research and Application*, **8**(2000)4, 297-322.
[25] A. JARDZIOCH: Problems of control of workpiece flow in a flexible manufacturing system. *Advances in Manufacturing Science and Technology*, **32**(2008)1, 29-43.
[26] F. R. JACOBS, E. BENDOLY: Enterprise resource planning Developments and directions for operations management research. *European Journal of Operat. Research*, **146**(2003), 233-240.
[27] Z. BANASZAK, B. SKOŁUD, M. ZAREMBA: Computer supported production flow prototyping for virtual enterprises. *Journal of Intelligent Manufacturing*, **14**(2003)1, 83-106.

[28] M. GREGOR, Š. MEDVECKÝ, B. MIČIETA, J. MATUSZEK, A. HRČEKOWA: Digital factory. Ústav konkurencieschopnosti a inovácií. Žilinská Univerzita, Žilina 2006. (In Slovak).
[29] M. GREGOR, P. ŠKORIK: Simulation and emulation of manufacturing systems behavior. *Management and Production Engineering Review*, **1**(2010)2, 11-21.

*Received in January 2011*