DESIGNING OF VIRTUAL CELL MANUFACTURING SYSTEM FOR SMALL ENTERPRISES

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SUMMARY
This paper presents designing virtual manufacturing cells methodology intended for practical use is small enterprises. Methodology is comprised of three steps which guides to comprehensive solution for creating virtual manufacturing cells, taking into account routing flexibility. In this paper assumptions of Group Technology and cluster analysis were used. By proper applying of described rules, planning process and controlling of intermittent manufacturing is improved which leads to increased flexibility.

Keywords: virtual cell manufacturing, group technology, cluster analysis

1. INTRODUCTION

Varied and changeable needs of customers compel companies to provide a flexible product offer. Manufacture a high variety of parts in small batch sizes at a competitive price, short deadlines and ability to ensure high quality are today a great challenge for enterprisers.
Especially small enterprises are in difficulty. Limited machinery and financial capabilities, and most of all, lack of production control tools makes it difficult for them to react quickly to changing demands of customers
The functioning of small enterprises shows that production system control in described conditions involves nothing more but applying experience and intuition (often in an improvised way) of people responsible for that system.
These findings became inspiration for devising a method of controlling intermittent and varied production in small companies. The reaction to the mentioned state of affairs is the presented below method for designing production cells. The proposed algorithms, intended to be programmed, are supposed to become an independent, simple and affordable system for controlling a varied and intermittent production.
In small enterprises, the key problem of controlling production characterized by high variability and changeability is how to (using scientifically justified methods excluding randomness) attribute making a particular operation on a particular object to a particular

machine tool. This problem appears when more than one machine tool being a part of a particular production system makes it possible to perform a specific technological operation with required quality (then we speak about functionally similar tools)

The method proposed in this article shows one possible solution to this question. The authors make use of the concept of **cell manufacturing** and **virtual cell manufacturing**. Cell manufacturing is defined as the set of technological devices realizing a production process of a particular parts family. Generating a production cell is the final effect of the applied method [4].

The word *virtual* refers only to the cell's boundaries which are envisaged. Technological devices constitute a material resource for a cell but are not a group of physical machine tools in a production hall as it happens in traditional production cells.

The necessity of such virtuality is because of the fact of quickly changing demand, which translates into manufacturing highly varied products in small batches, in dynamically changing production cells. These are the reasons for which the number of parts in a family gets outdated and the parts are replaced with new ones. Therefore, it would be difficult to imagine a constant reorganization of a production hall under production conditions. Thanks to resorting to virtual production cells such imagining is not necessary [6].

2. DESCRIPTION OF VIRTUAL CELL MANUFACTURING SYSTEM

The method assumes that designing virtual manufacturing cells is a complex process which consists of three stages (fig. 1). The first one, grouping, consists in joining company's technologically alike orders in families. The aim of the second stage is to determine which machine tools can be used for a particular operation considering their technological capabilities and scheduled workload. Finally, in the third stage, a production cell is set for a given parts family. This action will be described in detail further down the article. It should be highlighted that the first and second stages do not come in time one after another, but are realized simultaneously. Interrelations resulting from realizing first two stages are implemented in the final stage of the method.

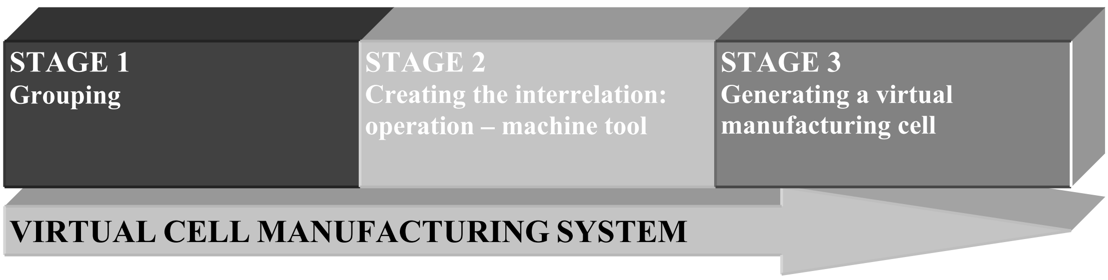

Figure 1. Stages of method for designing manufacturing cells Source: own study

3. REQUIREMENTS AND ASSUMPTIONS

The authors first defined a requirement that an algorithm used in the described method is to have a dynamic character. It is extremely important because of the character of varied and intermittent production. Solutions are generated online as continuously inflowing orders are the cause of constant changes of production conditions. That is why it is not possible to manufacture a parts family in a once and for all designed production cell. Therefore, the

presented method does not focus on designing but rather configuring production cells, which in other words is an online creation from elements constituted by machine tools.
Considering the addressee of this solution, i.e. small enterprises there is another requirement – to make the method affordable and easily implemented. This requirement stems from limited financial capabilities of small companies we talked about earlier. Therefore, tools used in given stages of the method should be as easy as possible in order not to generate additional costs of a solution.
Finally, what was highlighted in the introduction, it is necessary for the method of configuring production cells to allow for alternative ways. This requirement stems from the character of machinery often found in small enterprises, usually constituted by functionally alike machine tools.
The authors assumed that an enterprise has machinery which makes it possible to fulfill an order to the deadline imposed by a client.

4. REALIZATION

4.1. The method's first stage - grouping

The first stage of the method is grouping production orders. **The criteria for this grouping are technological similarity or constructional similarity**. According to these criteria families of parts are defined. The aim of such a grouping is creating a possibility to manufacture elements attributed to the same family with the use of same technological devices and equipment, i.e. within the same manufacturing cell.
From now on, it will be unthinkable to realize a single order. Rather than that a family of parts will be made. Obviously, in exceptional cases, when an order cannot be classified as an element falling for a particular family, a special, one-element family (with respect to variety) will be created.
In this stage of the method, the authors made use of the assumptions of **group technology (GT)**. The reasons for that behavior are connected with numerous benefits stemming from using GT. The application of it makes it possible to decrease seemingly the variability of manufactured products. Then, it is easier to control production. However, the greatest advantage of using GT is the possibility to produce small product lines in conditions similar to mass-production, which is especially favorable with respect to the effect of scale.
It is achieved through artificial increasing of a product batch. Grouping technologically alike parts makes it possible to shorten the preparation - finalization time, increase efficiency of machine usage, and enhance productivity and flexibility of a company. The benefits of grouping make it possible to substantially reduce cost of production per unit.
While seeking tools for grouping, the authors of the method decided to use **cluster analysis**. It is mostly because of the simplicity of this method as well as high effectiveness of grouping it offers. Cluster analysis combines different features of the production flow analysis method with methods applying probability coefficient.
The idea to group parts according to cluster analysis is as follows: the first step is describing an object with the help of its chosen characteristics which are important from the viewpoint of grouping.
The characteristics might include technological operations an object is subjected to, material it is made of, its mass, dimensions, etc. After attributing feature values to each object it can be identified with point P_i in n – dimensional space. Coordinates of this point can be presented by means of a vector which is determined by chosen features' values (p_1, p_2...p_n).
In such a defined space one can group data about parts through comparing distances between points representing them. The distance between points is expressed by the so called distance

classifier KO, i.e. Euclidean distance between two points in space. For a specific part $\mathbf{P_i}$ and part $\mathbf{P_{i+1}}$ compared by means of a distance classifier it is possible to determine similarity (or lack of it) occurring between analyzed parts:

$$\left| P_{i+1} - P_i \right| = \sqrt{[P_{i+1} - Pi]^T \, [P_{i+1} - P_i]}$$

Best effects of grouping are achieved with the method which sets a group representative, for which a frame technological process is designed. A frame technological process includes all operations performed within a cell. Around it the most similar elements are gathered.

It needs to be stressed that typical technological processes of group representatives are prepared by technologists and with respect to a programmed method constitute a data base of technological processes.

To sum up, the effect of the first stage is distinguishing parts families in the grouping process in order to create a frame technological process. In the next stages of the method, there is generated a best at a time *t* (i.e. online) set of machines and devices dedicated to realizing a production process of a product family.

4.2. The method's second stage – creating the interrelation: operation – machine tool

In this stage of the method comes the description of a production system. Machine tools possessed by an enterprise are characterized by the following data: technical capabilities of a device, minimum and maximum size of a machined part, technological standards, accuracy of a performed operation, and machine tool efficiency. This data as provided by producers of devices and equipment is not difficult to get.

It is important because of practical functionality of a proposed solution. In a programmed version of the method, information describing available machinery is entered and recorded in the data base of machine tools characteristics.

Once a production system is described, one can process the information further, confronting it with requirements for a typical technological process of a parts family. In the first stage of the verification operation – machine tool a typical process of setting a parts family representative is compared with technological capabilities and accuracy of a performed operation. The result of such an action is the matrix operation – machine tool from which stem alternative ways of a parts family production process (table 1).

Table 1. Alternative ways of a typical technological process of a parts family

operation \ machine	1	2	3	4	5	6	7	8	9	10	11	12	13	…
10	**1**		**1**								**1**			
20		**1**	**1**										**1**	
30					**1**				**1**					
40	**1**						**1**				**1**	**1**		
50				**1**				**1**	**1**					
60		**1**				**1**						**1**		
70			**1**		**1**					**1**				
….														

In the second stage of the verification a scheduled workload of machine tools is accounted for. In order to estimate labor consumption and production forces needed to perform a given operation one has to multiply the size of a parts family by technological standards of performing operations on alternative machine tools (duration of performing an operation). The data concerning the number of parts is taken from the stage 1.

By comparing a calculated labor consumption of an operation with a scheduled workload of machine tools we obtain a matrix of operations which at a given **moment** (i.e. online) can be performed by machine tools (table 2). The gray rectangle in the matrix (table 2) found in the crossing of fields *operation – machine* means that a machine tool at a time *t* does **not have vacant** production capabilities and hence cannot be used at this particular moment for realizing a process of making a family of technologically alike parts.

Table 2. The matrix of alternative ways ***at the moment*** *(online) of a production process of a parts family with marked excluded technological devices.*

machine / operation	1	2	3	4	5	6	7	8	9	10	11	12	13	…
10	1		**1**								**1**			
20		**1**	1										1	
30					1				**1**					
40	1						**1**				1	**1**		
50				**1**				1	**1**					
60		1				**1**						1		
70			**1**		**1**					1				
….														

4.3. Stage 3 of the method – Generating a virtual manufacturing cell

The last stage of the method is based on the two previous stages of it. Its immediate effect is determining a production cell – **a virtual manufacturing cell**.

Virtual manufacturing cell is characterized by important virtue, i.e. for particular family of parts, in particular production process could be processed on a different set of functionally alike devices. The same family of parts in time *t* and time *t + 1* could be manufactured with the use a different set of functionally alike machine tools.

Thanks to using production cells of envisaged boundaries it is possible to divide production resources between families of parts. The effect of this is a better utilization of machinery.

Coming back to the description of the final stage of the method, the algorithm included in it allows making scientifically justified conclusions about the best (in particular conditions and time) attribution of a specific device (which is functionally similar) to a specific, typical technological process.

The input data at this stage is the matrix generated in the previous stages of the method (table 2). As far as operations 10, 40, 50, and 70 are concerned, varianting of technological devices is possible. For instance, the operation 70 can be made on machine tools 3 and 5. The choice is made on the basis of the results from comparing machines efficiency with the number of parts in a group. In order to maximize the usage of machine tools, a rule was set as follows: families of technologically alike parts with a high volume are more favorably made on more efficient machine tools. The classification of a family as having many or few parts is made by experienced experts. It is impossible to introduce the standard classification of families into small, medium, or large with respect to the number of parts they include. This is because such a classification would largely depend on specifics of an enterprise and industry where it functions. At this stage it is justified to expect that used tools will make it possible for a system to "learn" the environment it functions in.

5. CONCLUSIONS

The presented method for designing virtual manufacturing cells is very complex and consists of three stages. The proposed method, intended to be programmed, are supposed to become an independent, simple and affordable, for small enterprises, **system for controlling a varied and intermittent production**.

It can be made mostly thanks to improving flexibility and usage of universal machinery.

At present, the authors are searching for the tools enabling practical realization of stages 2 and 3. The results of these works will be presented in the next paperwork of the authors.

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