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Cluster Analysis in Flexible Manufacturing Systems

Cluster analysis, as a technique which allows for comparison and grouping objects with similar features, can be a helpful tool to support flexible manufacturing systems. Such manufacturing systems are controlled by computers and are characterized by complex attributes and easiness to adapt to rapidly changing market demands.

Рассмотрен кластерный анализ как метод сопоставления и классификации объектов, обладающих общими характеристиками, применительно к гибким системам производства. Такие системы управляются компьютерами, имеют сложные свойства и легко адаптируются к быстро изменяющимся требованиям рынка.

K e y w o r d s: cluster analysis, manufacturing systems, production grouping.

Contemporary companies operate under conditions of increased changeability in business environment. Therefore, they must focus on flexibility in adaptation to changes, manifested in fast learning and ability to switch to new conditions, creativity and flexibility to innovation. An increase in efficiency of operation in business is a must, not an option. Difficulties which the companies encounter trigger continuous searching for new solutions for production management. The references focus on several definitions of clusters, whose concept derives from tendencies to gather similar objects in particular locations. Grouping of similar objects aims to produce the effect of synergy, due to their common features.

An analysis of production processes reveals existence, in some areas, of similarity in manufacturing methods for a number of products. Therefore, manufacturing of similar products can be combined in groups, called clusters. The process of cluster creation can be used at different levels of manufacturing in different companies or their groups, regions or even country. The cluster analysis allows for separation of the segments. It consists in determination of the relationships through diagnosis of relevance of parameters which describe them. The cluster analysis permits separation of the group of products with similar features, e.g. similar manufacturing technology, similar machines or required worker's

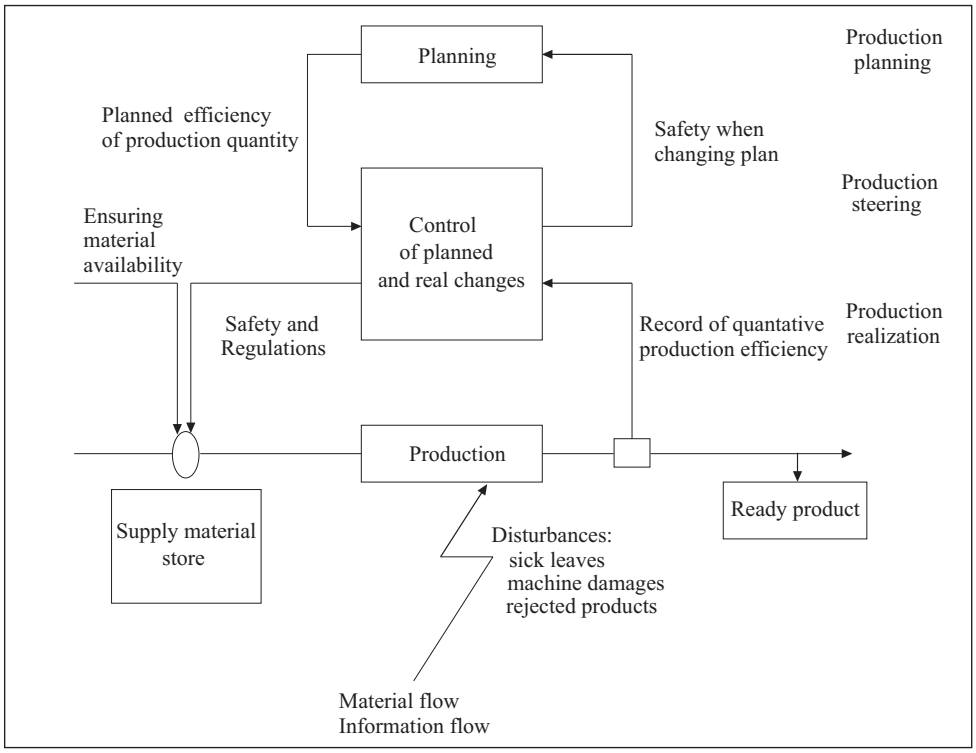

Fig. 1. Planning and steering of production [5]

qualifications. The cluster analysis assigns each feature a different importance and differentiation level.

The processes of flow that occur in companies and their environment should follow in an efficient manner while their management, with its characteristic procedure, should aim to optimize them [1].

The management in business is currently a very complex process. It forms a consequence of the multiplicity of flows of goods (flow of materials, parts, semi-finished goods, finished products etc.) and accompanying information flows, interrelated with each other. For optimization of control of these flows on an operational scale, numerous decisions of a quantitative nature are made, e.g., which material to order, where, when and how much. A variety of information is also used, processed according to a complicated algorithms. These algorithms are incorporated in different computer software to support managers during decision-making processes [2]. It has become possible to facilitate operational management of different phases, supply, production or distribution of logistics processes in a company within one integral system. Logistics orientation can

thus be aimed at improvement in operational management through more efficient use of the resources. Logistics management also helps to change awareness of potential that results from proper flow of materials and information [3].

In consideration of the above-mentioned facts, one can conclude that during control of production flow, depending on the model of flow, the following solutions are employed. The internal control focuses on definition and control over performance of the core tasks in organizational units, maintaining the following priority: manufacturing quality, keeping the deadlines, shortening of production cycles, minimization of time for preparation and completion of the tasks [4]. Growing importance of the role of consumers (market) in manufacturing processes causes changes in previously used principle of 'manufacture a product and search for its consumer' into the new principle of 'find consumer and manufacture according to his expectations [4].

Production is a complex process and it is not limited to manufacturing only, but, as presented in Fig. 1, requires many supporting processes. Quantitative planning of production and then its real-time control, analysis of deviations and proper response are essential.

Interrelations and course of interactions demonstrate a level of complexity. During performance of manufacturing tasks, the deviations that appear both from independent or random reasons are taken into consideration. An overriding task is to ensure such organization of production that the effects are maximized.

The complexity of the process of production, interrelations between its components can be graphically represented by letter Y (Y model) [5]. As results from Fig. 2, both planning and manufacturing requires synchronization of many activities with each other. Relationships between all the elements of the process of planning and production and their interactions are shown in the presented figure. Upper part of Y letter encompasses phases of planning, in organizational and financial aspect as well as technical feasibility (design, manufacturing technologies, labour-intensity). The area of order execution, a lower part of Y letter, focuses on activities connected with control over product manufacturing, storage, transport, sales and checking its conformance to customer's requirements.

Great amount of information at each stage of the process requires employing computer techniques for their proper processing, control over progress, coordination of tasks and management.

Varied demand among customers, with a necessity to maintain production profitability, have caused a considerable rise in the amount of the processed information and common use of computer systems e.g. computer aided manufacturing (CAM), computer aided quality assurance (CAQ), computer aided design (CAD), computer aided engineering (CAE).

Changing market conditions bring increased pressure on production of a wide range of goods in small batches. Meeting market requirements and ensur-

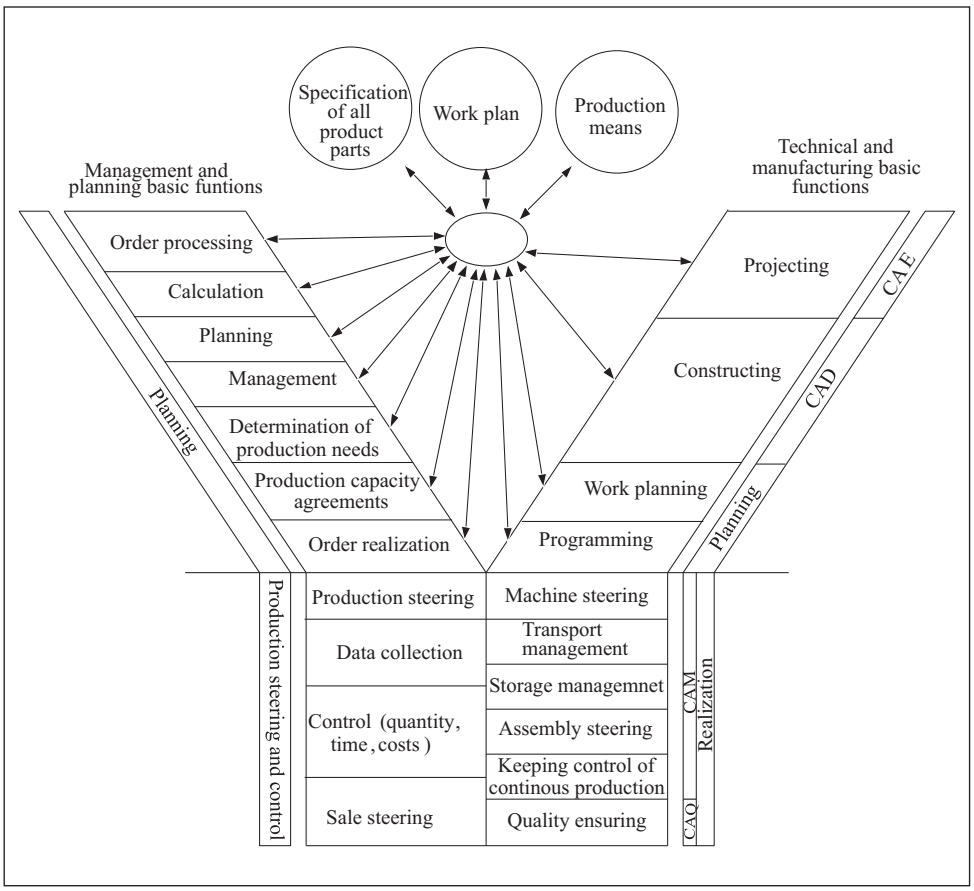

Fig. 2. Interrelations of production planning and management [5]

ing high efficiency of company's operation is possible through application of flexible manufacturing systems (FMS).

Flexible Manufacturing Systems. A characteristic feature of FMS is the operator exclusion from a machine operated by them and giving the machine some autonomy and possibility of multifunctional processing of a variety of elements. Flexible manufacturing systems are those with manufacturing equipment controlled by the computers and characterized by a versatility and easiness of retooling; they can manufacture any product within a particular class of items technologically similar however showing varied constructional features.

Main forms of flexible organization of production include [6]:

flexible manufacturing module, equipped in the machine tool controlled by computers, buffer of semi-finished goods and parts and tool or pallet changer (e. g. robot);

flexible manufacturing cell, which comprises several production modules connected with a type of products or technological process, integrated by means of transport, storage and common computer control;

flexible manufacturing line, equipped in a group of special-purpose machines deployed in a particular order – each operation within the set can be performed on one machine which can be adapted to frequent and rapid retooling;

flexible manufacturing network, comprising several interrelated modules, cells and lines (usually at the level of production department), enabling total realization of the particular range of products.

Flexibility, being a fundamental feature of FMS, might be defined as a property that expresses system's ability to adapt to changing production conditions and to exchange functions of defective components of the system by its other components.

Most of authors emphasize the following types of flexibility [6]:

flexibility of machines, determining system susceptibility to changes in production for a set of product types;

product-line flexibility, which denotes ability to fast and economical switching to production of a new type of goods;

production-size flexibility, which is an ability of the system to ensure profitable production at different quantities of the manufactured goods;

technological process flexibility, which means an ability to manufacture a particular set of product types by means of different methods and using varied materials;

technological routing flexibility, being an ability of the system to easy and modular extension and development according to the needs;

operation order flexibility, i.e. ability to change the order of some operations for each type of product;

stuff flexibility, i.e. ability to perform a manufacturing process with variable number of operators;

production flexibility, defined as ability to efficient response to disturbances, typically in three forms: technological, performance-related and structural.

Flexibility of the production system can be reached by means of a variety of methods, through formation of the range of products, constructional and technological solutions, selection of equipment and control system, particularly through employing of highly qualified stuff. Production flexibility and its differentiation is usually connected with a multiplicity of product batches of smaller size. The methods of connecting of small batches of goods into bigger ones include the use of product grouping technologies.

Group technology (GT) consists in determination of the typical process for a set of technologically similar products. Aggregation of products in families, manu-

factured in production cells organized for the purpose, allowed for considerable shortening of time required for preparation and completion of production tasks as well as other important benefits, e.g. bigger autonomy in the group of workers. In GT the processed products are grouped into subsets in such a way that the creation of a set of machines for each of the subsets, being — in a specific range — autonomic production group (forming actually a flexible manufacturing system), is possible [7].

Manufacturing technology for these parts is similar, which allows for, in a sense, a 'forced' rise in the size of batches. A reduction of unit costs for products is reached, maintaining production flexibility. A fundamental condition is, however, to determine such technologically similar groups of products. Technological processes have been developed for each product and a part of them might have been previously manufactured; thus some technological processes can be restored from the database. On the basis of such processes a matrix of technological processes will be found with consideration of the method of grouping, which helps to obtain the groups of products that show technological similarity. Group technology allows for combination of batches of individual products into the technologically similar groups, which can be manufactured together due to the same technological operations [7].

All the parts that appear within a particular group will be manufactured with the same technological operations, using the same methods and by means of the same fixing jigs and tools. Thus they will have similar core manufacturing process. In such cases it is reasonable to employ a cell-based form of organization i.e. cells focused on a manufactured item or particular technology.

Grouping of parts requires not only solving the problems of technological similarity, but also providing of technological equipment for manufacturing cells, which ensures product manufacturing efficiency within the group, ensuring timely execution of orders at minimal costs [8]. Due to this reason, optimization of product grouping should be performed.

The diagram of use of computer technology for grouping and optimization of production is presented in Fig. 3.

The grouping and optimization encompasses an analysis of technological similarity of the products, equipment in production cells and their manufacturing capacities. In grouping process calculation of distance classifier KO of representative and analyzed part is essential. When KO value is suitable then partial classification is possible. An assessment of opportunities of manufacturing of a given product in each group requires, as it follows from the figure above, a multilateral analysis.

An analysis of technological processes of manufacturing and assembly and the similarities is an important element in product grouping. The cluster analysis can be a helpful tool for each classification, including classification of machine parts according to similarity of technological processes.

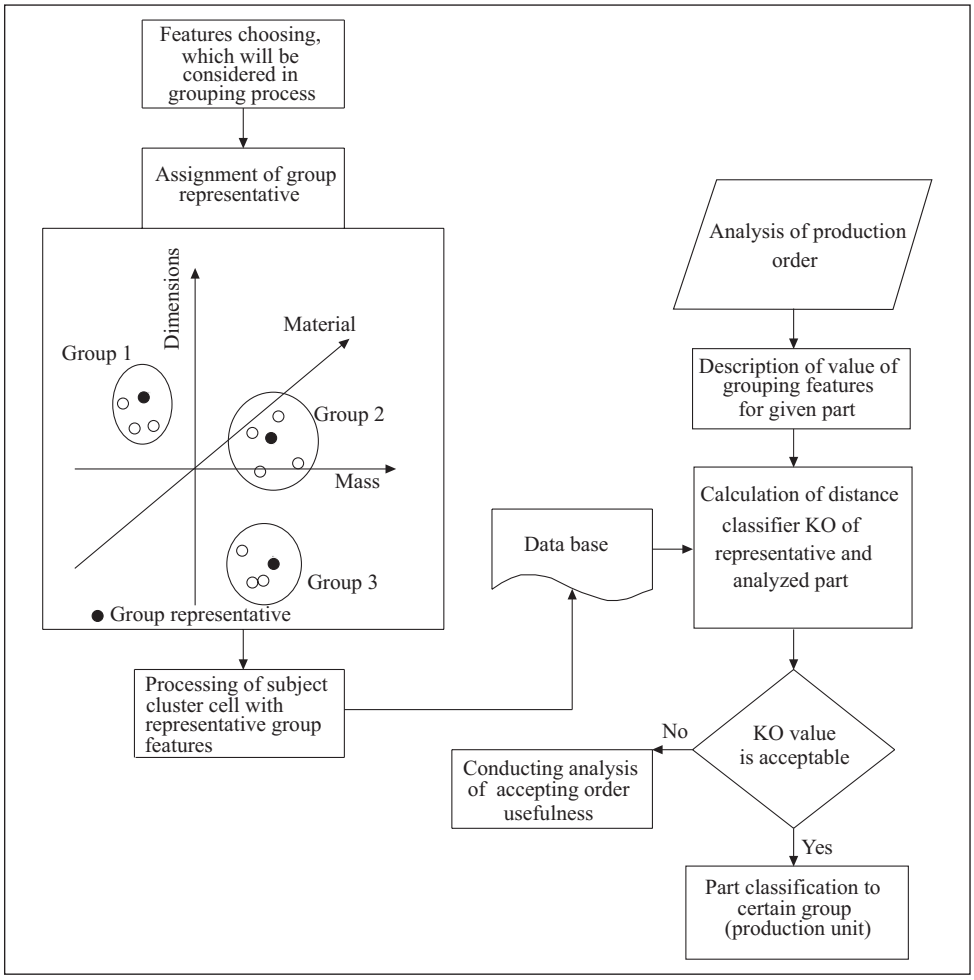

Fig. 3. Grouping scheme [8]

Cluster analysis. The cluster analysis can be numbered among scientific mathematical methods and it is a part of multidimensional analysis domain. Through application of the methods of mathematical statistics, it allows for separation of some groups (clusters) for a particular assemblage of elements, while the groups differ considerably from each other. The groups are created from the most proximate (most similar in their properties) elements, represented by the points in n-dimensional space. This method permits grouping of elements whose properties are similar within a group but different from the elements outside the group. The cluster analysis, as a method of grouping, allows for assessment of similarity of particular products.

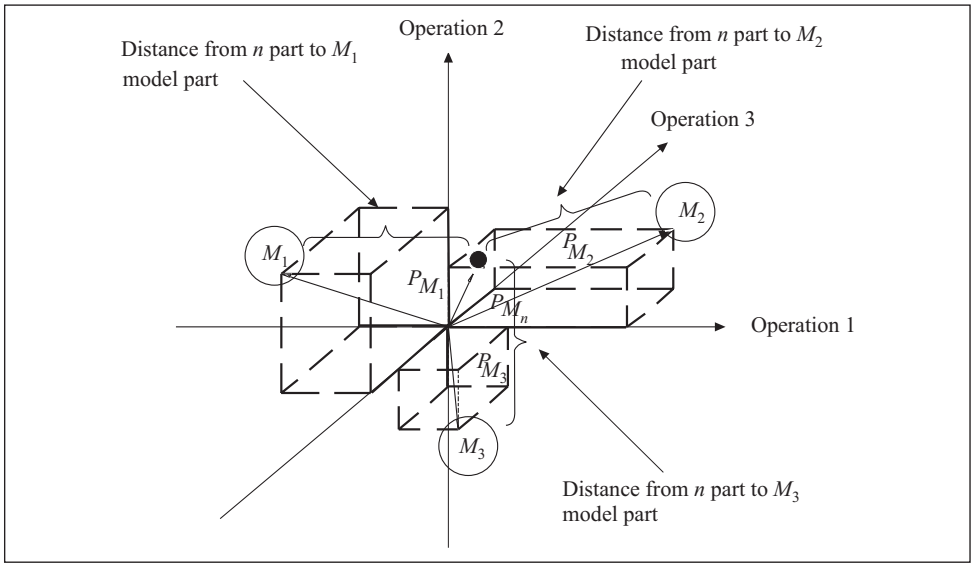

Fig. 4. Scheme of cluster analysis for model parts [9]

The cluster analysis is the method that allows for comparison of particular objects (in the analysed case this means manufactured products $i = 1, ..., n$) by comparison of the features typical of these objects (in the analysed case this means operations of technological process for the product, marked with x_{ij}, where i is the number of products and j being a number of a particular technological operation $j = 1, ..., m$). As a consequence of these assumptions, each technological process can be interpreted as a point in n-dimensional space or a vector $\mathbf{P}_n = (x_{n1}, x_{n2}, \ldots, x_{nm})$, whose components denote operations of technological process [9].

The design of the products technologically similar to each other by means of the cluster analysis can be realized in two ways:

determination of the 'model' products $M_1, ..., M_n$, for which a particular technological process and manufacturing system organization are developed; these parts become representatives of a given group of technologically similar group;

analysis of the properties of technological processes by means of 'with each other' method and grouping of the products that show the highest technological similarity.

Interpretation of both cases is presented in Fig. 4 and 5.

A comparison of a process for the analysed product with the model product processes is carried out through determination of distance product classifier. It is the basis to assign a product to a technological group which is represented by the model product. Similarly, in the next case of product grouping, a value of distance classifier between each process is determined, however, the process for the

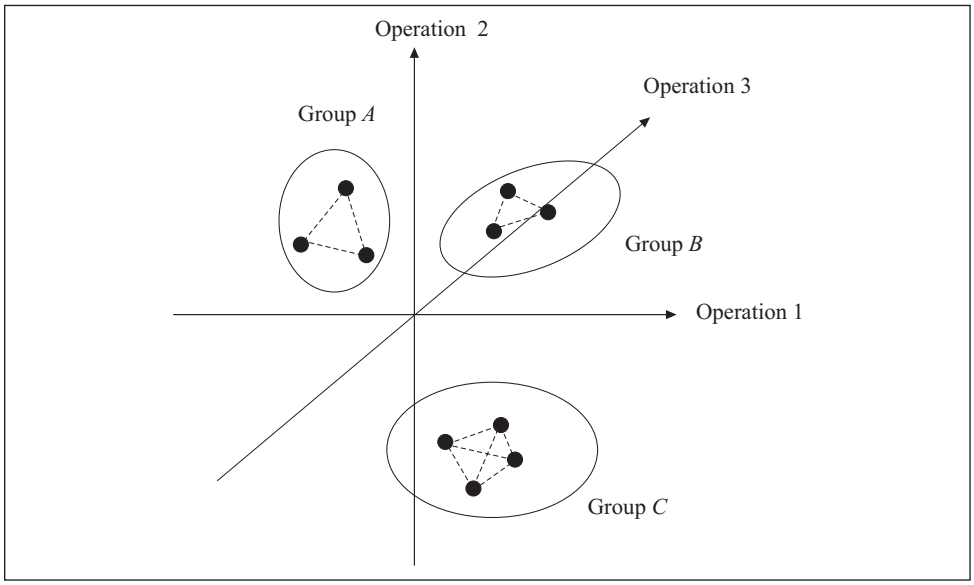

Fig. 5. Scheme of cluster analysis for grouped parts [9]

model product is not created. The products with the smallest value of distance classifier are grouped together. The distance classifier is determined as Euclidean distance between two points, both of which represent the technological process of a particular product:

$$[P_{i+1} - P_i] = \sqrt{[P_{i+1} - P_i]^T [P_{i+1} - P_i]}. \quad (1)$$

In the case of development of a model product, a number of groups of products technologically similar were actually assumed since a representative (i. e. model product) was determined for each of them. In the latter case of application of cluster analysis, the number of groups is not even initially determined. The procedure of grouping is conducted by successive creation of technologically similar product groups (cluster analysis employs a concept of a tree or a cluster of similarities).

Manufacturing process, particularly in the case of flexible manufacturing, should be developed in variants. Preparation of different variants of the manufacturing process, depending on the situation, should allow for [9]:

selection of the variant that ensures minimal costs of the process with deadlines acceptable for the customers;

selection of the variant that ensures minimal deadline for the order execution with costs acceptable for the customers;

preparation of an alternative manufacturing technology to be realized in the case of overload in the workstation assigned for the technology, its breakdown or other reasons. An immediate decision on changes in technological process should be made in such emergencies, however, these changes cannot affect the quality of the manufactured product.

Summary. The cluster analysis can be a useful tool for grouping in manufacturing of goods. It combines the features that allow for analysis of flow of production and similarities in each group within the production organization. Development of manufacturing technologies and IT allows for the use of leading-edge tools and methods for FMS. Market expectations and assurance of high efficiency of company's existence is possible through application of FMS.

Розглянуто кластерний аналіз як метод зіставлення і класифікації об'єктів із загальними характеристиками стосовно до гнучких систем виробництва. Такі системи керовані комп'ютерами, мають складні властивості та легко адаптуються до швидко змінюваних потреб ринку.

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