https://doi.org/10.26552/com.C.2000.1.39-44

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METODOLÓGIA PRE NÁVRH SEGMENTÁCIE VÝROBY

A METHODOLOGY FOR CELLULAR MANUFACTURING DESIGN

Výhody, ktoré sa očakávajú od segmentácie výroby závisia prevažne od toho, ako efektívne boli realizované tri fázy jej návrhu. Ide o zoskupenie súčiastok a strojov, návrh jednotlivých výrobných buniek a spôsobu ich rozmiestnenia v dielni. Problematika bunkovej výroby vyvolala mnohé pokusy a aplikácie, ktoré vyústili do návrhu viacerých metód. Tento článok predstavuje novú technológiu pre návrh bunkovej výroby. Navrhnutá metodológia sa skladá z analýzy výroby, segmentácie výroby, špecifikácie jednotlivých buniek, kapacitného výpočtu, návrhu rozmiestnenia buniek, vytvorenia simulačného modelu a z procesu simulácie. V poslednej dobe je práve simulácia považobaná za užitočnú optimalizačnú techniku v tejto oblasti.

The realisation of benefits expected from cellular manufacturing largery depends on how effectively the three phases of design have been performed, namely part/machine grouping, developing the cell layout and cell system layout on the shop floor. This key question of cellular manufacturing has attracted numerous attempts in applying various design methods. This paper presents a new methodology for cellular manufacturing design. The proposal methodology is composed from products analysis, production segmentation, cells definition, cells capacity planning, cells layout design, building of simulation model and simulation process. Recently, simulation has been found to be a useful optimalization technique just in this area.

1. Introduction

The typical company makes thousands of different parts, in many different batch sizes, using a variety of different manufacturing operations, processes and technologies. It is beyond the capability of the human mind to comprehend and manipulate such vast amounts of detailed data. People still need to make decisions regarding how to run a manufacturing company and succeed in today's competitive environment on home and foreign markets. The pressures on management continue to escalate as global competition drives the need for producing a greater variety of high quality products, in smaller lot sizes and lower costs. These ongoing demands continuously increase the level of complexity present in a manufacturing environment. What is needed is both a strategy and a tool that can be used to achieve such a purpose.

The layout design of a manufacturing facility is one of the most important factors affecting product quality and cost. The manner in which the equipment is configurated on the shop floor affects material flow, manufacturing leadtimes, work in-process inventories, in-process quality and the manner in which work is scheduled, processed and controlled through production. Cellular manufacturing (manufacturing workcells) is a manufacturing system configuration by which these advantages may be achieved.

This paper presents a new methodology for cellular manufacturing design with utilization of simulation that recently has been found to be an useful optimalization technique in this area. Its structure and steps are shown in Figure 1.

2. Products analysis and data preparing

Products are built essentially from an assortment of produced and purchased parts, which for an assembly of complete parts are necessary. Information about products should be known before starting to design the manufacturing cell.

Products analysis is the first step for cellular manufacturing design. For example, to define a products spectrum, advantageous for cellular manufacturing, is possible by the ABC or P-Q analysis. The second step is the preparation of all needful data.

Input data for the proposal methodology are introduced in Figure 2, where the suggested structure of the data base is shown. It is advantageous for the input data to be saved into this data base.

Another way is the integration with a CAPP system that has similar parts data. In designing a manufacturing cell design is useful to use the already created database, because part families are already defined in the CAPP system according to the criteria specified by a company.

3. Cells formation

The first step of the production segmentation is the production flow analysis (PFA), that was presented by Burbridge [2]. Process plans are input data for PFA. Unsorted machine-part matrix is the result of PFA. Cluster analysis is the next step. The sorted (final) machine-part matrix is received by the cluster analysis.

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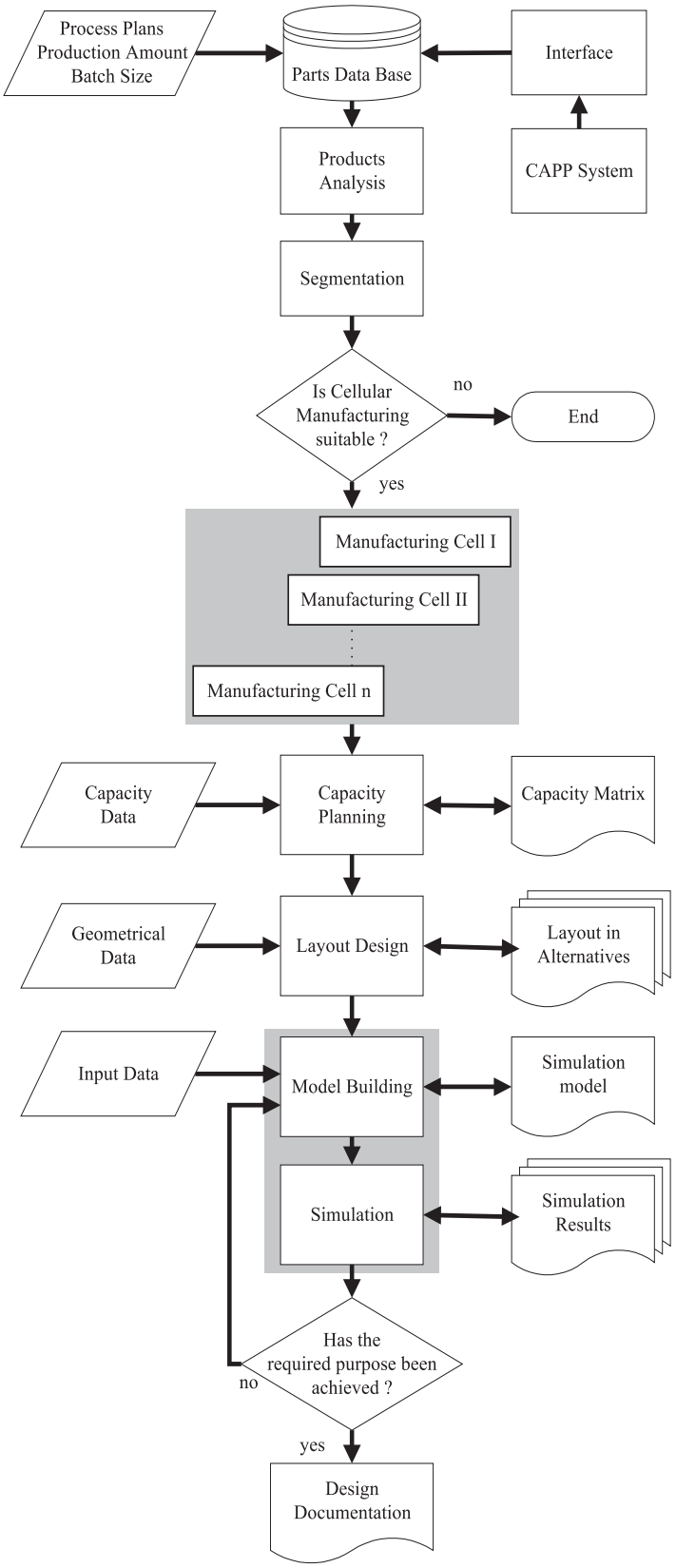

Figure 1: Sequence of manufacturing cells design

3.1. Initial machine-part matrix

The initial machine-part matrix $M\{p_{ij}\}$ (Figure 3) is created from the parts data base, where
i = number of parts
j = number of machines

$$pij = \begin{cases} 1 \text{ if part i visit machine } j \\ 0 \text{ otherwise} \end{cases}$$

	machine 1	machine 2	⋯
part 1	p_{11}	p_{12}	
part 2	p_{21}	p_{22}	
⋮			

Figure 3: Initial machine-part matrix

The initial matrix consists of all parts and machines which are required to be processed.

3.2. Cluster analysis

Arbitrary clustering algorithms can be used to solve the machine part grouping problem. Boe and Cheng [1] offer a detailed review of the existing algorithms. There are no clear guidelines for selecting a particular cell formation procedure given firm's goals, characterics, environment and its internal knowledge, skills and experiences.

Cell formation is neither an easy nor uniform process. The human factor is a key function for this process, because some machines and parts can not be partitioned into perfectly separate clusters. Consider the matrix in Figure 4. As part 5 requires processing on machines 1, 3 and 4, the matrix can not be perfectly partitioned. Part 5 is called an exceptional part. An intercellular move (or an exceptional element) is required for an exceptional part.

A bottleneck machine is defined in a similar fashion as is an exceptional part. The matrix in Figure 5 can not be perfectly decomposed because machine 5 processes parts belong to more than one cell.

Exceptional parts and bottleneck machines are the sources of intercellular moves. In order to obtain the maximum benefits of a cellular manufacturing system, intercellular moves must be reduced to the minimum. Therefore, a clustering algorithm should not only transform an incidence matrix to a matrix with a desirable structure but should also minimize the number of intercellular moves.

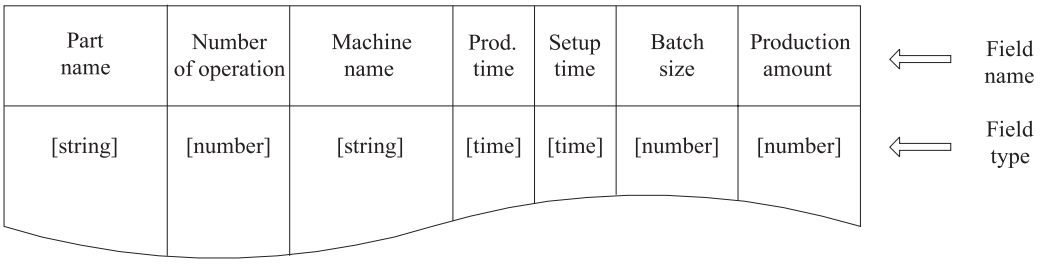

Figure 2: Data base structure of the process plans

	part 1	part 2	part 3	part 4	part 5
machine 1	1	1			1
machine 2	1	1			
machine 3			1	1	1
machine 4			1	1	1

Figure 4: Non-disjoint clusters due to an exceptional part

	part 1	part 2	part 3	part 4	part 5	part 6
machine 1	1	1				
machine 2	1	1				
machine 3			1		1	1
machine 4			1	1	1	1
machine 5	1	1	1		1	1

Figure 5: Non-disjoint clusters due to a bottleneck machine

4. Manufacturing cells definition

Several parts of families and machine groups can be identified by cluster analysis results, i.e. on the basis of the final machine-part matrix (Fig. 6). The criterion for parts formation is the similarity of routings in this case. On the basis of routhings similarity there is high probability that parts are similar in design or geometrical form (Kuric [5]).

Multiple solutions (alternatives) have to be generated for comparision at this step. Exceptional parts and bottleneck machines should also be addressed at this step. Further, if intercellular movement is large, a decision may be made whether to combine some or all bottleneck machines in one or more cells, each arranged as a job shop.

5. Capacity planning

The basic assumption in all present group formation methods is that a machine type within the group to which a component is assigned has sufficient capacity to process the component completely. If, in order to process all components assigned to a group, multiple units of machines are needed, then, they are required and allotted to the group. If a machine type is duplicated in two or more groups, each group gets sufficient capacity. Often a decision must be made whether it is more economical to duplicate a machine, and its associated processes, in two or more manufacturing cells, or to allow transport of the part between cells. Such transportation may utilize the excess capacity in one cell and thus avoid the need for an unit in another cell.

The capacity matrix (Figure 7) can be used as a basis for capacity planning that contains all needful data. The capacity matrix is the final machine-part matrix is completed by some data.

Capacity matrix elements are not the ones and zeros, as described above, but they represent a time defined as follows:

$$Tij = TPij + \frac{TSij}{BSi}$$

where: *i* - part number
j - machine number
TPij - processing time for a part i on the particular machine j
TSij - setup time for a part i on the particular machine j
BSi - batch size for a part i

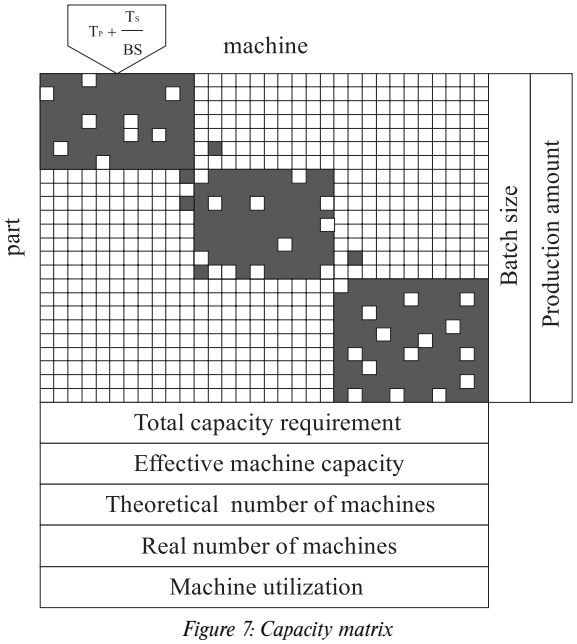

Figure 7: Capacity matrix

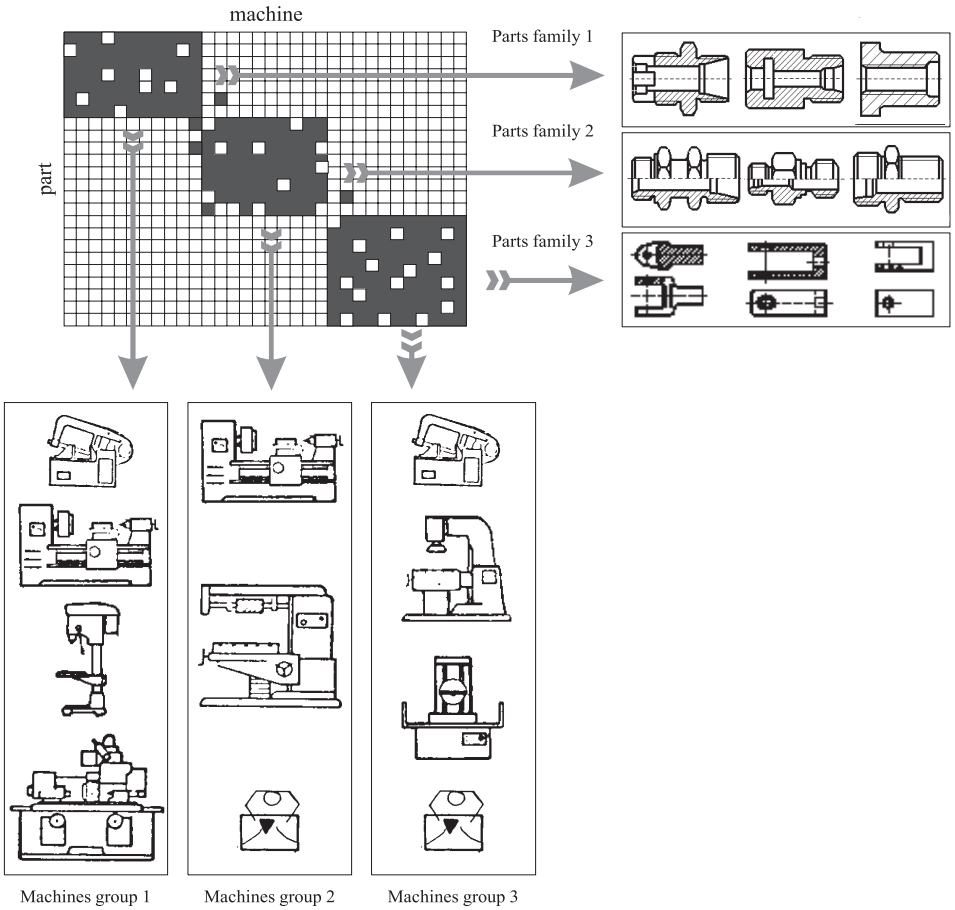

Figure 6: Schematic sequence of cell formation procedure

On the right side of the capacity matrix (columns - Batch size and Production amount) is data about batch sizes (BS) and production amount (PA) for particular parts.

On the bottom are data needed for capacity planning.

- Total machine requirement (TMR) represents a sum of times (in hours) for particular machine. TMR is defined as follows:

$$TMRj = \sum_{i=1}^{n} Tij * PA_i$$

- Into row Effective machine capacity (EMC) defines EMC for particular machine (in hours)
- Theoretical number of machines (TNM) is defined as follows:

$$TNMj = \frac{TRMj}{EMCj}$$

- Real machine capacity (RMC) represents TMC round up to interger.
- Machine utilization (MU) is defined as:

$$MUj = \frac{TNMj}{RNMj}$$

6. Cells layout design

Developing a GT cells layout is a lengthly and laborious task due to the multitude of design aspects and interrelated factors that have to be considered, and the decisions that have to be made. Therefore, it is important to organize this task through a framework for analysis. The following order steps are suggested as necessary in developing a GT cells layout.

1. *preparing layout data*
   The following data are needed for cell layout design:
   - process plans, cluster analysis results
   - areas of particular (manufacturing and handling facilities, working places, transport paths, etc.)
   - transport matrix (material flow matrix)
   - restrictions (shop dimensions, prohibited area, maximal loading of floor, etc.)

2. *developing cell layout*
   If the cell layout is not developed jointly with family and cell formation or the facility will not be organized as small job shops, the type of the layout for each cell has to be determined and a layout model developed, the layout is constructed. If

a family and cell formation was performed jointly with the cell layout, the latter may be revised at this step to account for factors which were not considered before.

3. *developing cell system layout*
Data on exact or approximate cell shape and areas, location of input/output points, as well as intercellular flow should be available at this stage and used to the developed cell system layout. Space restrictions may preclude using specific cell shapes and the latter may have to be treated as decision variables in the layout model. The type of cell layout should be not affected in this case (Hassan [3]). Further, if space restrictions prevent accommodating all the machines of a cell in the allocated space, some machines may have to be relocated to other cells.

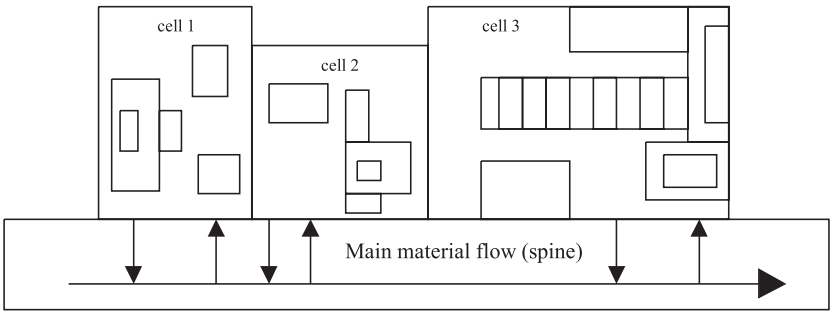

Figure 8: Topkins system layout

4. Examining the location of bottleneck machines
Bottleneck machines may have not been properly assigned to cells at the family and cell formation stage and thus their location should be examined after constructing the cell layout and revised when a relocation improves the movement cost.

7. Modeling

Modeling is the transformation (realization) of an existing or abstract system into an experimental model. The modern object-oriented simulation systems offer to user different pre-defined objects (object library) for model building. These objects can be divided into several categories (Figure 9).

From this reason, before a model building it must be clear which objects the particular simulation system offers and how they are characterized (properties).

The following elements are usually modeled in a simulation model:
- products,
- machines,
- stores (warehouses),
- operators,
- transport facilities.

7.1. Input data

Generally, data which are required for the cell modeling may be divided into the following categories:
1. *Data which describe a structure of manufacturing cell:*
   - type number of produced parts,
   - process plans,
   - type and number of machines,
   - type and number of transport and handling facilities.
2. *Data which describe the manufacturing cell:*
   - type and number of machines in cell,

BASIC OBJECTS							
Material flow objects				Information flow objects			
movable		immovable		movable		immovable	
active	passive	active	passive	active	passive	active	passive
- Transporter	- Cointainer - Entity	- SingleProc - Buffer - Sorter - Line - Source - Drain - Local Control	- Track - Warehouse		- Attributes	- Trigger - Generator - Time sequence	- Tables - SQL interface - File interface

Figure 9: Basis objects of simulation systems

- type and number of parts produced,
- number of operators,
- model of worktime,
- control strategy.

3. *Data which describe the process in cell:*
   Manufacturing process is characterized by:
   - batch size and manufacturing plan,
   - processing time (including the setup time) of part types (batches) on particular machines,
   - machine failures, time period, (machines statistics),
   - machine capacity,
   - manufacture priority,
   - process of a batch between particular machines.
4. *Data, which define manufacturing costs in the cell:*
   - machine utilization,
   - inventory, resources.

8. Simulation

When the simulation model is created, it is possible to begin the simulation process.

Simulation data have to be processed and verified. Correct output data are achieved only by correct input data. The total consistency a real system and the simulation model is not in principle possible, the idealized model can not represent all restrictions. For this reason simulation goals and a level of strictness of a simulation model must be defined before modeling. The model validation follows after a first simulation run and results analysis. In case of need the particular system parameters are changed or the simulation model is edited and the next simulation run follows. Simulation results (statistics tables, charts, etc.) must be compared and interpreted into a legible and clear form by an simulation expert. These statistical results have to be processed into a final documentation.

The following questions may be answered by simulation:

I. Performance Measures
   - Machine utilization
   - Production rate
   - Utilization of an operator or robot
   - Utilization of a bottleneck station

II. Decision Variables
   - The number and types of machines in the work cells
   - The batch size of a particular part type
   - Sequencing of part types within the cell
   - Material handling priorities within the cell

III. Questions to be Answered
   - How many of each type of machines are required to balance production?
   - What is the best cell design for maximizing throughput?
   - What is the utilization of the bottleneck machine given by a particular sequence of orders?
   - What is the optimum sequencing of part types through the cell that mini-mizes setup?

The most optimal variant, as chosen by the simulation, resulted in the last step. In case of need, the particular changes may be made (to change a manufacturing facilities location, number, etc.) and finaly the complete documentation is designed.

9. Conclusion

This paper presents an integrated approach to the particular phases of the design of cellular manufacturing. This approach can be used for the transformation of an existing structure into cellular structure, thus for a new project on “green meadow“.

It has created a practical solution of the proposal approach. This solution is implemented into the simulation system SiMPLE++ (SiMulation in Production, Logistics and Engineering), as an application template for cellular manufacturing design.

Reviewed by: J. Matuszek, J. Košturiak

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