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Work-Cells Concept Development for High Mix Low Volume Market Conditions

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Abstract

Work-cells implementation enables enterprises to increase simultaneously the flexibility and productivity measures of a production process. An elaboration model permits focusing on the required outputs of the project and controlling of the implementation process. The developed work-cells concept is supported by a similarity analysis, production line balancing, as well as a production process simulation, and is followed by the analysis of the achieved results. The authors expect that this paper can be used by enterprises as a practical guide for work-cells implementation.

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Keywords: Work-cels; similarity analysis; production process; simulation

1. Introduction

1.1. Foreword

The goal of the current research was to increase simultaneously the flexibility and productivity of a production process in an electronic enterprise through reorganization of production lines. The current research was carried out by students, supervised by TUT researches and enterprise engineers within the frame of an applied research project. In fact, the enterprise demonstrated interest in new possibilities of achieving the formulated goal. TUT researchers were given an opportunity to apply the existing know-how in practice and the students acquired an internship experience, prior to master thesis topics selection. As all the project participants had clear project expectations, the

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current applied research project was organised in a win-win way.

1.2. Background

"Current market situation is characterised by globalisation, new product requirements, rapidly changing demands, and a continuous improvement of the existing technology for manufacturing activities" [1]. The authors have already disclosed this topic in previous research papers [2, 3]. In order to stay competitive in current market situation, the "manufacturing system must be able to yield different batch sizes from different product types, with the exact capacity and functionality in each case" [4]. Furthermore, the flexible manufacturing system enables to process a variety of different products simultaneously and to adjust the production quantities accordingly to the fluctuations in the customer's demand [5]. In addition, for the convenience in future the enterprises can automatize the manufacturing monitoring process [8, 9]. The Browne et al. [4] defined the several types of manufacturing flexibility, which other authors [5, 6] has developed further see Fig. 1. The particular enterprise manufacturing flexibility requirements depends on its customers' needs [7] and measured based on selected flexibility criteria's.

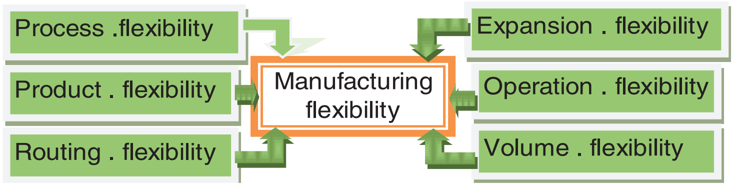


Fig. 1. Manufacturing flexibility types.

In other words, the manufacturing flexibility enables:

- The capability to produce different parts without time consuming setup;
- To measure how fast the enterprise manufacturing processes can be switched from one product to the next;
- Frequent changes in the production schedule and product design, as well as simultaneous handling of multiple products.

The final assembly line is a serial line, where all the workstations are arranged one after the other. It is a paced line, where the processed work pieces are transferred immediately to the next workstation. This type of a manufacturing system is not flexible, and it is hard to achieve a perfect line balance with a manual conveyor belt. In a real production line, the work pieces move from one station to another at different speeds, which depends on the operator skills and the amount of operations. If the previous operation cycle time is shorter than the consequent one, there are buffers between the workstations. There is no free space available for the buffers inside of the production line; however, the operators frequently take the products waiting in the line outside of the workstations. Such movements consume the workspace and make the operator's work inconvenient. In case of large buffers the production line should be moved to a distinct location with more free space, which is financially infeasible. Thus, it is reasonable to keep the line paced and avoid the operator's processing the next work piece before transferring the previous one to the next workstation. Cell production system explores from group technology (GT) [11, 12]. Dario Ikuo Miyake defines a cell production system as "a set of connected work stations in which a single worker or a small work team performs a horizontally broadened set of tasks within longer cycle times, and are empowered to undertake vertically enriched roles (multi-tasking)" [10]. The primary principle that guides a layout design in a cell production implementation is to make a cell as compact as possible by narrowing the distance between successive workstations. The main advantages are the minimization of material handling losses, the minimization of floor occupation, and avoidance of inventory between stations [13,14,15,16].

1.3. The objective of the current applied research project

The main idea of the current research was to develop an approach for increasing flexibility and productivity of enterprises. The objective of the present project was to suggest a work-cells structure for low volume and high mix production. Elaboration of the work-cells concept enabled the researchers to improve the flexibility of a production process. Moreover, the universality of a work-cell allowed a rapid changeover from one product to another. For this purpose the work-cells must be equipped with all necessary stationary tools at each workplace. It should increase amount of the tools and respectively the cost of the universal work-cell will increase too. Therefore, the research proposes an approach for regulating the number of work-cells for the manufacture of certain products and the number of universal cells for all type of products, accordingly to a long-time production plan.

The research results were applied for the production process reorganization in one electronic enterprise in Estonia. The authors intended to share the received practical experience with other researchers and enterprises that were interested in similar projects implementation.

2. Framework for work-cells concept elaboration for high mix production

A framework was elaborated to define the sequence of steps, which enterprises should perform in order to increase the flexibility of a production process. The implementation steps were divided into two main stages:

1. Data analysis stage, which consists of the following steps: the definition of the main parameters of a new manufacturing system, data collection, grouping and processes simulation;
2. Reorganisation elaboration stage, which consists of the following steps: calculation and development of a work-cells structure and their layout, work-cells replenishment and product flow layouts, calculation of needed investments.

The authors defined the input and output parameters required for the work-cells, as depicted in Fig. 2.

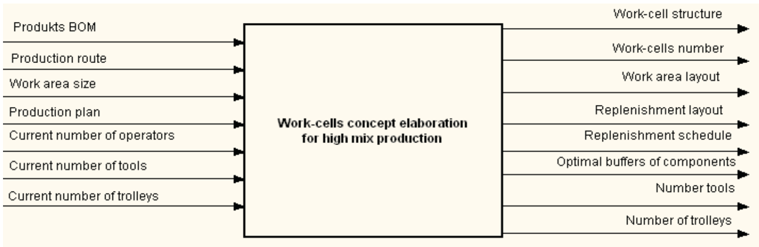


Fig. 2. Main input-output parameters for framework elaboration.

The tasks of defined implementation stages are introduced in Fig. 3.

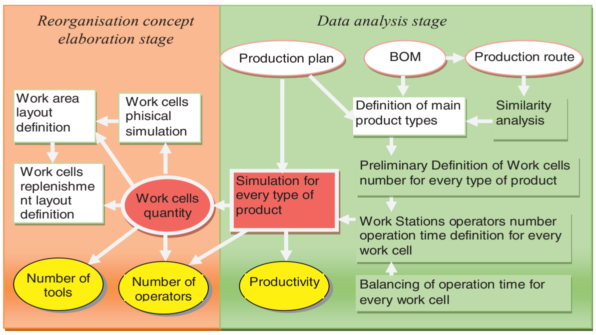


Fig. 3. Framework of the project implementation.

3. Data analysis stage

A data analysis stage is the first step of the developed framework, which the authors used for data preparation and analysis.

3.1. Route based similarity analysis

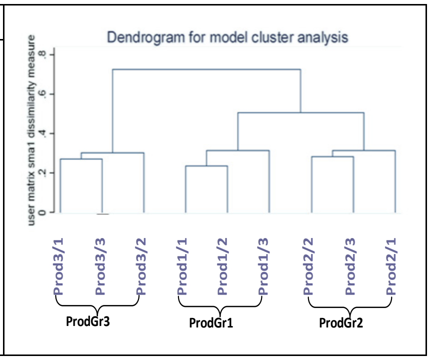
Routings of items are required for definition of the groups of machines based on a similarity analysis. Askin & Standridge have formulated the basic concept of the similarity analysis [17]:

- Identify items that are made with the same processes / the same equipment
- Include those items into a part family
- Group into a cell in order to minimize material handling

Each product's route represents a unidirectional flow, which could not be changed. The similarity coefficient is used in order to define the similarities among different products [18, 19]. The route-based similarity coefficient is calculated in order to compare different products. The similarity coefficient is the ratio in which the total number of machines required divides the number of common machines. In the current applied research project the similarity analysis showed, that the enterprise should divide the products into three groups: ProdGr1, ProdGr2, ProdGr3 (see Fig. 4). Moreover, the product groups ProdGr1 and ProdGr2 had more common operations, or they were more interchangeable.

	Prod1/1	Prod1/2	Prod1/3	Prod2/1	Prod2/2	Prod2/3	Prod3/1
Prod1/1	1						
Prod1/2	0.728	1					
Prod1/3	0.687	0.780	1				
Prod2/1	0.293	0.255	0.263	1			
Prod2/2	0.271	0.247	0.251	0.763	1		
Prod2/3	0.269	0.258	0.275	0.698	0.672	1	
Prod3/1	0.289	0.281	0.262	0.512	0.485	0.467	1
Prod3/2	0.300	0.282	0.294	0.479	0.458	0.528	0.680
Prod3/3	0.312	0.266	0.265	0.536	0.494	0.479	0.715

a)



b)

Fig. 4. Assessment of product similarity by components: a) similarity matrix, b) matrix dendrogram.

3.2. Number of work-cells definition for every product type

The high mix production work-cell concept implies that each cell must produce a product starting from the first operation until the last one. The work-cells organization is "a complex of activities that contribute to technologically rational and economical manufacturing of the product" [20].

Initially, in the current research project three assembly lines produced all products. The authors performed all the calculations and simulation models based on the sample weekly production plan for 9 weeks. The production process for every product family was analyzed separately. The total planned weekly production volume was used for the analysis of the simulation results. Three different variants of work-cells were defined based on the analysis of 9 weeks production plan, see Table 1. Such a separation enabled the authors to define the number of work-cells, oriented toward a specific product with the changeover possibility. The researches have considered the MIN amount of work-cells for the definition orientation.

Table 1. Production plan for every group of product.

Product groups	week 1	Week 2	Week 3	week 4	week 5	week 6	week 7	week 8	week 9
ProdGr1	2800	2800	2700	2600	2600	1800	1800	1800	1800
ProdGr2	1400	1550	1750	1750	1750	1475	1475	1475	1475
ProdGr3	3100	3200	3300	3300	3300	4000	4000	4100	4100
Total weekly volume	7300	7550	7750	7650	7650	7275	7275	7375	7375
Volume variations	Variant 1		Variant 2			Variant 3			

In the course of the project's implementation the required number of work-cells was calculated based on the total weekly volume for each product family and equation (1) was used for calculating the preliminary resource requirements R:

$$R = \sqrt{(week\_amount)^2 + (production\_cycle\_time)^2} \tag{1}$$

Based on the resource calculation required for the production plan fulfilment, we defined the number of work-cells for every type of a product per week. The research group has obtained the common number of work-cells by summarising the work-cells requirements for all product families, see Table 2. The MIN amount of the needed work-cells was considered in order to define the required number of work-cells for every product family and the MAX amount was used for the universal work-cells number calculation. The results of the calculations given in Table 2 were checked by using the process simulation. In current case, one work-cell is related to the product ProdGr1, one work-cell for product ProdGr2, and three work-cells for product ProdGr3. The authors have decided that one additional work-cell must be universal and may be switched to several products as needed. The results from Table 2 state that a universal work-cell must work as ProdGr3 or ProdGr1. The exact proportion of time, utilised by each product in the universal cell can be defined based on the simulation results.

Table 2. Work-cells definition.

Calculated work-cells number	Variant 1		Variant 2			Variant 3				MIN	MAX
for ProdGr1	2,3	2,2	2,1	2,05	2,05	1,5	1,5	1,5	1	1	2
for ProdGr2	1,15	1,25	1,35	1,35	1,35	1,2	1,2	1	1	1	1
for ProdGr3	2,5	2,5	2,55	2,58	2,58	3,3	3,3	3,5	4	3	4
Total calculated work-cells number	5,95	5,95	6	5,98	5,98	6	6	6	6		
Defined work-cells number	6	6	6	6	6	6	6	6	6		

3.3. Balancing of operation time

While analyzing the production line and the possibilities for cells formation, the main criteria is the operation times. Fig 5 introduces how "a small work team performs a horizontally broadened set of tasks" [10]. The existing production lines tact times are in good balance. While composing new operation times for work-cells, the goal is to keep the line as balanced as possible. The authors have defined the number of workplaces in a work-cell based on the simulation results.

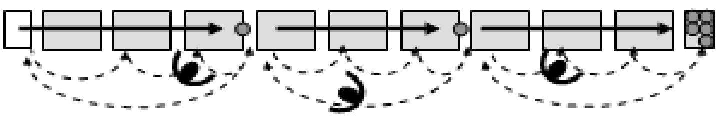


Fig. 5. Operations combination for work-cells.

4. Reorganization concept elaboration stage

4.1. Requirements and limitation for work-cells structure development in current research project

The main requirements to work-cell elaboration:

- To enhance production flexibility, it is necessary to enable high mix production in future;
- To increase the flexibility of labor usage in the labor shortage case;
- To decrease the frequency of changing one product to another by increasing the amount of work cells;
- To improve the flexibility of repair;
- To decrease non-value added time (better replenishment, decreased walking distance between repair and production, decreased setup time for tools replenishment);
- The sequence of operations for assembling the products (workflow) should remain.

Space limitation:

- Dimensions of current factory space;
- Dimensions of workbenches and equipment;
- Space for materials is limited.

Resources limitation:

- Number of workers;
- Number of workbenches in a cell;
- Equipment amount (also testers, cranes, lifts, etc.).

Operational / technical constraints:

- The flows of materials and finished goods should not cross over;
- Sequence of operations for assembling the products (different workbenches, components, tools and testing programs must be used for different products);
- Replenishment paths complexity will increase;
- Too many components on one workbench can influence ergonomics.

4.2. Structure of Work Cells

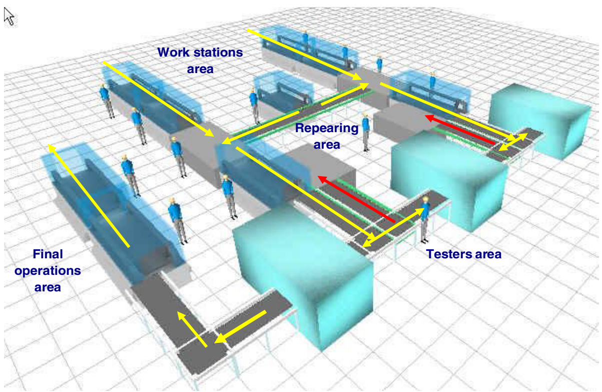


Fig. 6. Work-Cell presentation in Enterprise Dynamics.

Based on the balanced operation time and simulation results the configuration of work cell was elaborated, see Fig. 6.

4.3. Work-cells equipment

Tools description is one of the inputs to conceptual framework for the layout change in addition to the problems, shortcomings, bottlenecks, constraints and the main ideas standing behind clustering the assembly line. The authors have completed the analysis of the stationary tools number for work-cells based on certain products required for a universal work-cell; see Fig. 7. The concept developers discovered that minimizing of the universal work-cells quantity significantly reduces the amount of the equipment, needed for a production plan implementation.

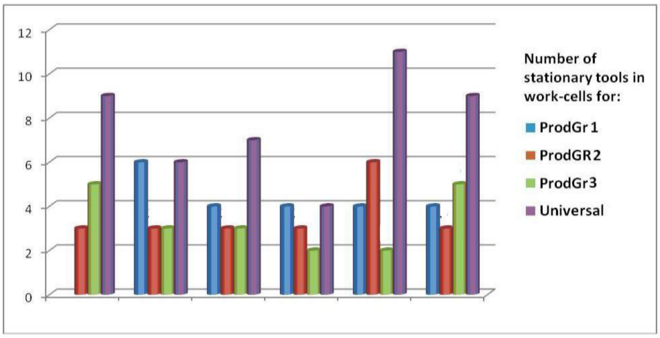


Fig. 7. Number of stationary tools by work places for several type of product.

In order to fit the required work-cells into the available production space, in the current research project the reduction of workstation numbers was essential for a cellular manufacturing layout definition. The analysis was performed in order to verify if the big variance and dissimilarity of tools would constrain the process of their clustering. It was concluded that the tools will not limit work-cells concept realisation in reconstruction of the assembly line, where mostly manual labour operators are used and not much space for equipment is needed at workplaces (such as automated screwdrivers). The conclusion was made that the tools would not disable to cluster the layout due to the fact that there was no big difference between hand tools used in the manufacturing process and the stationary tools were not used. The attachment of the latter to workbenches takes more time and their replacement is more time consuming in case of switching to a different product. The hand tools, used in the current applied research project, were small, not attached to the workbenches and thus easily movable and consumed less space. Taking into consideration the ergonomics, the research groups has defined that an average technologist should use 7 – 8 stationary tools per workstation.

4.4. Material replenishment in work-cells

As the location of the work-cells was symmetric with respect to the testing area (see Fig.8), the material replenishment of the work-cells and the finished product transportation were carried out from the external sides overall layout. In order to define the materials replenishment in the work-cells, it was necessary to define the amount of trolleys, pallet places, and containers for the elaborated work-cells layout. The research group suggested increasing the amount of rack shelves in order to fit all needed boxes with small components. The fitting of some different components on the trolleys together enabled us to decrease the number of trolleys needed. However, due to the increased amount of trolleys the new layout has increased the travelling distance and time of transport worker, delivering trolleys with big mechanic components from a warehouse.

4.5. *Work cells analysis and common layout elaboration*

The authors have recommended using the simulation of the process for a work-cells analysis. Every type of a product must be analysed separately. The main criteria of a simulation model are:

- A weekly plan must be fulfilled;
- All operators must be max loaded;
- Queues must not arise.

The authors have used the simulation time that was one week minus the time required for a products changeover. A common workshop simulation model is introduced in Fig. 8. The results of the simulation confirmed that the authors had properly defined the number of work-cells for the current production as follows: one for ProdGr1, one for ProdGr2, three for Prodgr3, and one universal. After that, it was important to calculate the time distribution for several products in a universal work-cell. It was done by a processes simulation and the following simulation results were received:
Variant 1 - Universal work-cell must be used for ProdGr1.
Variant 2 - Universal work-cell must be used 0.5 of week time for ProdGr1and 0.5 of week time for ProdGr3.
Variant 3 - Universal work-cell must be used 0.8 of week time for ProdGr1and 0.2 of week time for ProdGr3.

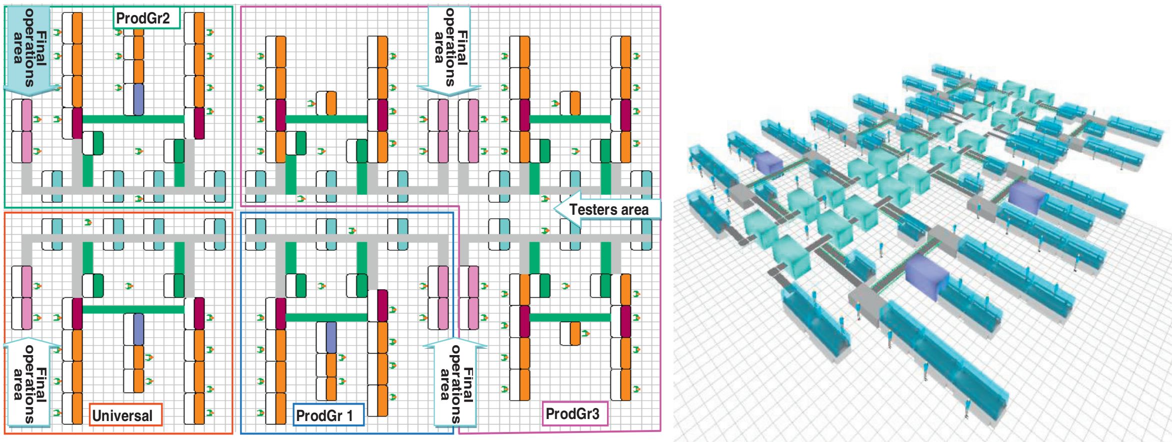


Fig. 8. Simulation model for work-cell concept.

We performed the analysis of productivity based on a sample weekly production plan and considered a number of variants. The variants differ in the usage of the universal work-cell. The simulation results of all the variants showed that the productivity exceeded the sample production plan up to 10% (see Table 3).

Table 3. Productivity analysis based on simulation.

Products	**Variant 1**		**Variant 2**			**Variant 3**			
Total weekly plan	7300	7550	7750	7650	7650	7275	7275	7375	7375
Simulation results	8045		8002			8052			
Productivity increasing: pieces	745	495	252	352	352	777	777	677	677
percentage	10,20%	6,55%	3,25%	4,21%	4,21%	10,86%	10,86%	9,17%	9,17%

5. Analysis of work-cells conception

Plusses of Work-Cells concept:

- Agility increased – it is possible to produce up to six different products simultaneously.
- The production planning process has become more straightforward as no changeovers are needed; flexibility of production planning was increased.
- The new layout has added the possibility to operate only a half of the work-cell in case of small orders.
- The universal work-cell enabled a rapid changing over to any product manufacturing.
- The pallets were moving inside of a work- cell.
- Work in small groups increased the self-organization within the work-cell.

Minuses of Work-Cells concept:

- The labour skills requirements increased (more operations done at one working place);
- Complexity of materials supply has increased;
- Ergonomics suffered to some degree because workbenches could get overstaffed;
- Number of employees increased;
- Number of tools increased;
- Number of additional equipment (lifts, trolleys, rack shelves) increased;
- Many rotations of modules decreased the speed of production or increased the stress for workers;
- It was necessary to combine the working instructions.

Conclusion

Flexibility and productivity simultaneous increase is the essential tool, which enables to raise the competiveness of a company in the high mix low volume market conditions. The current research paper introduced a concept for work-cells implementation, which consists of a data analysis and a number of elaboration stages. The data analysis stage is supported by a similarity analysis, followed by a work-cells definition for every product type and balancing of workstations. The work-cells elaboration process is supported by the simulation software.

The practical implementation of the proposed approach of using the work-cells in accordance with a long-term production plan and focusing of the most of work-cells on a certain product allowed reducing the number of stationary tools almost twice. The simulation allowed to define a more optimal time distribution for universal work-cells. At this stage the analysis of tools, suggestion of a new factory layout and the redesign of the replenishment process were performed.

Acknowledgements

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