Algorithm for workcells design

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Abstract. The paper presents a methodology for the design of the manufacturing cells, covering all the necessary steps, from the analysis of the customers' needs, to part families for group technologies, process engineering, control procedures, production rate, production planning (push or pull workflow), supply in the manufacturing cell, workcell configuration, work standardisation. The necessary tools through each stage are presented. Also, there are presented links to major company systems. For each design stage, deliverables are specified. this design approach is not linear. At each stage it is possible (and indicated) to go back and analyse the previously established parameters. The methodology is a complex one, and in a wider space the detailed parameters will be presented in extenso.

1 Introduction

A workcell is a manufacturing system built in order to obtain high quality products, in a productive way, at the lowest possible cost. The equipment involved in the manufacturing process are placed next to each other, to minimize the transport of both work-pieces, products and people. Workcells simplify the flow of materials, management and even accounting systems.

The concept of organizing manufacturing cells was developed by the Toyota Manufacturing System. It still represents the basis for organizing Lean Manufacturing systems, but also the most modern ones, such as Digital Factory and Smart Manufacturing.

Apparently, manufacturing workcells seem to be simple systems. Behind this apparent simplicity there are complex technical, logistical, informational and human systems. The elements of the aforementioned systems interact with each other, so that the production flow can work as continuously as possible, without wastes, able to be adjusted and improved. The aim is to keep the level of the seven losses, defined by Toyota, to a minimum. It is also intended that the size of the production batches to be small.

Designing a workcell is a complex engineering issue that must take into account several information from different departments.
Also, the design has to go through some logical steps. At each step, new parameters of the workcell are established, starting from the analysis of the information known at that time, taking into account the imposed requirements and the technical limitations. Designers must have a deep knowledge of the elements of a workcell, the interactions between them, as well

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as the physical and information flows that go through the manufacturing cell. Last but not least, the necessary labour force, their level of training as well as the operators needs must be taken into account. Designing a manufacturing cell is a complex effort, involving both specialists from the production department, but also from other departments: marketing, production planning, logistics, human resources, etc.

This paper aims to present a design algorithm of the manufacturing cells, which highlights both the design steps, design tools, company systems that provide information and support, and the results needed to be established at each design stage.

2 Workcell design – state of the art

Work cells are the basic structures of manufacturing processes, which is why it aroused the interest of specialists.

Alfieri [1] proposes the analysis of the company as a "Systems of System" (SoS). This approach is currently used in the context of complex military or government initiatives. The author raises the issue of describing an enterprise as a system consisting of subsystems corresponding to the main aspects of manufacturing systems (resources, quality management systems, production planning and control procedures, etc.) and the relationships between them. The idea is generous but remains at the stage of a philosophical approach.

Benkamoun [2] develops a systematic design process for manufacturing systems.

Cochran [3] describes a framework for the design and implementation of production systems. This framework allows setting and communicating objectives and design solutions from the highest level to the lowest level of a manufacturing enterprise. The same author [4] presents a case study of manufacturing cells design that combine new and existing machines, showing the difficulties that may arise in such situations. Just changing the arrangement of the machines in the cells could offer some benefits, but these benefits were offset by a high level of investment required. The simulations showed long-term effects. It is difficult to design a feasible manufacturing cell just by rearranging existing equipment.

Caggiano [5] presents a case study of a manufacturing cell design in a digital manufacturing system. An existing manufacturing cell for turbine blades for aircraft engines is improved by automating and robotizing the deburring station.

De Carlo [6] presents a case study about the relocation of a manufacturing cell. Three methods of analysis are used: empirical, a method that uses a diagram of the relationships between activities, and a complex method of Lean Manufacturing analysis. The most effective proved to be the last.

Duda [7] exemplified the design of a car manufacturing cell on the principle of axiomatic design. A breakdown of the design steps is used. This example demonstrates the impact that low-level design decisions can have on high-level system objectives and the need for a systematic approach in the design of the production system.

El Maraghy [8] develops aspects of assembly cell design. Different models of assembly cells organization are presented. The characteristics of the intelligent manufacturing systems as well as the Internet of Things are highlighted. These modern structures allow the connection improvement between the physical and the digital world. In such systems good decisions can be made smart, in a faster way.

Lešková [9] presents a case study of an assembly cell design. The characteristics of the assembly workstations with a modular structure, made of aluminium profiles, are underlined. Nine principles of manufacturing cell design are discussed: continuous flow; simplicity; work organization; clear presentation of the work pieces; reconfigurability; the quality of products; maintainability; easily access and ergonomics.

Various companies [10… 14] present their own perspectives resulted from the experiences gained in the design of manufacturing cells.

Analysing the literature in the field of manufacturing cell design, it is found that there are papers that analyse the general flows of the company without providing algorithms for the design of workcells, other papers present case studies for designing workcells for different industrial flows, and there are also few of them which analyse partial aspects of the workcell design without addressing the complex flows of the company.

This paper presents the algorithm for designing a manufacturing cell, regardless of the industry in which it operates. All the elements that make up the manufacturing cell are taken into account, as well as the physical and information flows that run through it.

3 Algorithm for manufacturing cell design

The algorithm starts from the market requirements, on the basis of which the product families are established. A manufacturing cell will be designed for each product family. Product families, respectively related group technologies can be established by: intuitive grouping (simple parts / mixed processes), production flow analysis with the use of matrices for sorting parts (products with medium complexity / mixed processes) or by coding and classification (high complexity products / mixed processes).

The next step is process engineering. The tact time is computed, based on the requirements of the customers and our available time.

A database is created with all the information regarding the technological flow (operations, equipment, durations - operation cycle times, worker cycle times, equipment cycle times, set-up times, waiting times), presented as well structured as possible (tables). The required number of equipment, workers and process efficiency are computed. On the basis of this information, a preliminary balancing of the workers activities can be made and the preliminary size of the production batch can be established.

The methods of intermediate and final control, and the implementation of the "Total Quality Management System" are establish next.

At this point, the flow characteristics of the work pieces, passing through the manufacturing cell, must be determined. We start from the production rate, establish the number of parts in a container, the maximum number of containers needed at a time in the manufacturing cell and in the adjacent inter-operational stocks (supermarket). Now it is important to establish production type (push or pull). If the pushed flow is chosen, the required documents are set. If the pull stream is chosen, the number of cards ready to start production is determined to be placed on the Kanban board.

The next step connects the production flow with the logistics system and determines how the manufacturing cell is supplied.

Once this information is known, it is possible to proceed to the detailed design of the manufacturing cell. Many works refer only to this stage.

Finally, it is necessary to standardize the work in the manufacturing cell. The employee incentive system must also be developed and disseminated in order to achieve continuous improvement.

Table 1 shows the main steps of a workcell design.

The design process of the manufacturing cell is not linear. At each stage you can return to a previous one, in order to make corrections and improvements.

If some activities use robot or corobots, the design steps of the cell remain the same. In addition, the concrete aspects related to the parameters of robots and corobots will be analysed.

Table 1. Algorithm for work cell design.

	Task	Working tools	Enterprise system	What is obtained
1	**Part families (ordered by the customers) for group technologies**			
1a	Establish the estimated volume of products that will be ordered by the customers in the next period	Analysis of the orders from previous, analogous periods; Forecasts of the customers' demand.	Marketing system Planning system Logistic system IT system	The number of products (from each category) required to be produced in the unit of time
1b	Group technologies; Parts with similar shapes, that can be produced on the same machines (which have similar production routes) are grouped.	Intuitive grouping; Production flow analysis with the use of matrices for sorting parts; Coding and classification;	Production system Planning system IT system	The number of manufacturing cells and the range of parts that are manufactured in each workcell
2	**Process engineering**			
2a	Takt time	Computing formula	Marketing system Logistic system Planning system Production system	Takt time [s]
2b	Analyse the technological processes	Analysis of existing technologies; Measurements.	Production system	Tables with all the parameters that characterize the production process
2c	Compute of the required number of equipment;	Computing formula	Production system	Necessary equipment

2d	Compute the required number of workers	Computing formula	Production system	Number of workers required in a manufacturing cell
2e	Process efficiency	Computing formula	Production system	Subunit value; in the case of a small value, process optimizations are sought and the number of workers is reduced; Resume the process from point 2b
2f	Preliminary balancing of production	Balance the operators' activity (heuristic analysis)	Production system	Standardized Work Combination Table (preliminary)
2g	Preliminary size of production batches	Heuristic determination based on previous experience, volume of ordered goods, size of parts, etc.	Production system Planning system Logistic system IT system	The aim is to make batches as small as possible (even one-piece flow)
3	**Control procedures**			
3a	How to perform the intermediate control	Team personnel are trained in manufacturing control techniques; Implementation of poka yoke devices	Production system TQM system	Elaboration and completion of documents
3b	How to perform the final control;	Integration of capability and maturity models	Production system TQM system	Elaboration and completion of documents
4	**Production rate, production planning (push or pull workflow)**			
4a	Estimate the production rate	Calculations, based on demand and production capacity	Production system Planning system Logistic system IT system	Production rate
4b	Number of pieces in a container	Calculations based on production rate, parts dimensions; Heuristic	Production system Planning system Logistic system	Number of pieces in a container

			IT system	
4c	Estimate the number of required containers	Calculations Heuristic	Production system Planning system Logistic system	The maximum number of containers required at a time in the manufacturing cell and in the inter-operational stocks (supermarkets)
4d	Production scheduling	Specific methods of analysis and production planning	Production system Planning system	For the push flows (documents); For the pull flows (cards ready to start production, placed on the Kanban board).
5	**Supply in the manufacturing cell**			
5a	Establish how parts and information move. Design the withdrawal Kanban and eventually production Kanban	Analysis and development of these systems	Production system Planning system Logistic system IT system	Number of cards; Algorithms for moving parts and information; Card locations.
5b	Establish the size of the supermarket stocks (in front and behind the manufacturing cell)	Calculations Heuristic analysis	Production system Logistic system	Number of containers in each supermarket stock for each type of product; The area for each supermarket stock.
6	**Workcell configuration**			
6a	Determine (calculates) the space occupied by each workstation, inter-operational storage and supermarket stocks	Draw the shadows left on the floor by each machine tool (workstation), or equipment, or stock Try to minimise the production system cell	Production system	Sketches

6b	Identify constraints or affinities	Heuristic Diagrams that analyse the connections between stations	Production system	Tables, diagrams specifying the level of connection between workstations
6c	Set the cell configuration	U shape, or L type, or oval, or linear, etc. Follow the preservation of the logical sequence of the work phases through discussion with the workers; Try the simplest configuration that ensures, low maintenance, easy reconfiguration, minimal costs; The cell must be kept in motion, with minimal effort, small space	Production system	Manufacturing cell location plan
6d	Analyse the phases of each operation and handling	Timing	Production system HR system	Documents describing the phases of each operation, durations
6e	Ergonomic analysis of operators' work	Filming Timings Analysis	Production system HR system	Documents with proposals for improvement
6f	Establishes the activity for each operator;	Techniques for balancing the operators' work	Production system	Standardized Work Combination Table - preliminary
6g	Design specific devices	Try to design modular devices that allow adjustments, small changes Make sure that the elements ensure positioning, rotation, processing; Use universal fastening systems that can be used for different sizes; Large components must be easily moved; Minimize any movement that does not add value.	Design department Supply department Production system	General drawings Devices

6h	Establish locations for storing tools, devices	Design of storage areas and do appropriate coding; Organize easy access to tools, consumables, equipment, components.	Design department Production system Supply department	Tools and devices location
6i	Visual management	Place open signals to improve communication between team members and for fast, real-time visual management. Use Andon lights and dashboards to signal line status	Production system Supply department	Signalling
7	**Standardization**			
7a	Make and sign documents	Establish standard working procedures; Include testing, quality control, inspection, packaging procedures in the job description to minimize reprocessing; Give workers the right to stop the line in the case of non-conformities.	Production system	Process capacity sheet; Standardized Work Chart; Standardized Work Combination Table.
7b	Staff motivation	The flexible design of the cells must be scalable and encourage continuous change and improvement	Production system	Employee stimulation system

4 Conclusions

Although, at present, most production systems are based on manufacturing cells, the literature has not been presented a concise but complex algorithm for their design. The present paper aims to achieve this. The main stages of designing workcells are presented. These are: part families for group technologies, process engineering, control procedures, production rate, production planning (push or pull workflow), supply in the manufacturing cell, workcell configuration, work standardisation.

At each stage are specified the main systems (departments) of the company that provide information for design.

Also, the concrete products that are obtained after each stage are specified. It should be noted that this design approach is not linear. At each stage it is possible (and indicated) to go back and analyse the previously established parameters. The limited space of the paper did not allow the detailing of the tools used in each stage. This is desirable to be done in a larger space, where concrete examples can be presented.

The algorithm is also suitable for the design of robotic, agile and SMART cells. Specific adaptations can be easily made on the red thread shown.

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