IMPACT OF THE CELLULAR PRODUCTION STRUCTURE ON THE ASSEMBLY OF REFRIGERATING EQUIPMENT

MICHLOWICZ Edward[1], SMOLIŃSKA Katarzyna[2]

[1,2]AGH University of Science and Technology, Cracow, Poland, EU

Abstract

The complex manufacture of refrigerating equipment most often uses the cellular structure. The problem in improving the material flow is a correct planning of processes in the individual cells. The final assembly line receives streams of materials from cells and streams of other components from buffer stores. The production task (finished refrigerating equipment) is affected significantly by cutting and bending processes of stainless steel parts. The paper presents the impact of these processes on the assembly of refrigerating equipment.

Keywords: Production system, work center, assembly

1. PREFACE

The problem discussed in the paper concerns the correct execution of a production task carried out in the *make-to-order* system. In contemporary production systems such problems are solved using a series of methods known as *lean toolbox* [1]. In addition to the classic literature references which propagate the use of *lean* methods in production systems [2, 3, 4, 5], there are other innovative approaches based on classic queuing theory [6]. In this paper, Altendorfer analyzes in detail the impact of inventory and process effectiveness on the lead time expected by the customer in single- and multistage production systems. Bhasin in [7] proposes a holistic approach to the *lean management* problems. The discussion on quality - *Lean Sigma* - is of interest in this paper. The implementation of *lean* methods to production companies, particularly of a medium size, is difficult, and does not always bring about the expected profits. Liker and Frank dampen the optimism presented in many papers [8], writing that the studies have shown that the implementation of *lean* methods achieves the intended results still only in two percent of cases. The reason is usually a poor understanding of the organizational factors that allow a successful implementation and follow-up. In the context of small and medium enterprises (SMEs) in Poland, the implementation of *lean* methods is even more complex due to the lack of knowledge being even more predominant than the lack of understanding. Hence, the authors argue that it is easier to convince the managers to use selected quantitative methods that do not make up a complicated system, but which can help to improve the basic productivity ratios [9]. Examples of logistics engineering methods that can be used are given in [10, 11].

2. PROBLEMS IN THE MANUFACTURE OF REFRIGERATION CABINETS

The analyzed company belongs to the SME segment, employing 300 staff and selling its products in more than 30 countries worldwide. The product range includes a few dozen display refrigerators and refrigeration cabinets which need more than 2000 various parts and components. Some of them are made in-house, and the others are bought from external suppliers. A particularly important company product range is the refrigeration cabinets used in medicine - mainly for storing blood, blood-based preparations, and plasma and cryoprecipitate. The ULUF range has a few varieties and the most complicated to manufacture is the ULUF 450.

The quality and is certified by the ISO 13485 standard (Medical devices. Quality management systems. Requirements for regulatory purposes) and the CE0434 mark (for equipment conforming with directive 93/42/EEC).

Figure 1 presents the manufacturing diagram of the refrigeration cabinets. The production process takes place in five production cells from which parts, components and subassemblies are sent to the main assembly line.

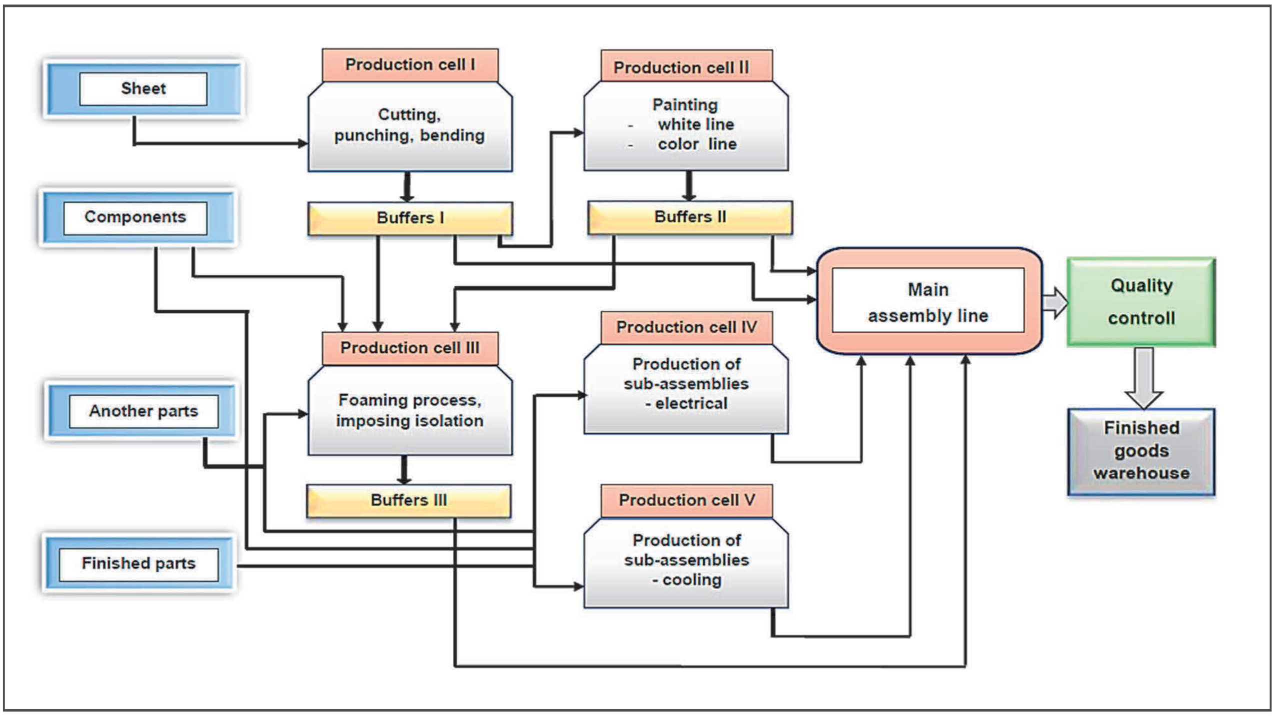

Figure 1 Production system diagram

Cell I is used for the operations of cutting, punching and bending of steel (stainless, galvanized and painted) parts. Welding, pressure welding and deburring operations are also carried out there. The manufactured subassemblies are sent to the buffer.

Cell II is used for painting operations of the metal parts (the majority of the parts are painted white, some are painted in other colors, some are not painted).

Cells III, IV and V are typical component-focused cells, and the processes include insulating some spaces with polyurethane foam (III), preparation and assembly of electrical subassemblies (IV) and refrigerating subassemblies (V).

There are buffers in some cells for storing the components needed in subsequent operations. The finished product - a refrigeration cabinet - is made on the assembly line. The current production pace of the cabinet is about 30 hours, and the final assembly takes about 3.5 hours. After assembly the cabinet goes to quality control and is then tested for several hours.

The production of the refrigeration cabinets is only according to "make-to-order" principle and causes specific difficulties in keeping to the deadlines. These difficulties include:

- the customer having a large influence on the customization. As a result the products are little repeated, and with low volume there are problems with supply of individual components (e.g. there is demand for 80 different compressors),
- the production of parts in technology and component-focused cells,

- highly-skilled operators are required in the component-focused cells (a lot of manual operations), and as a result the exchangeability of operators is practically impossible,
- production in cell I (the technology cell) is carried out together with other job orders, hence it often starts earlier than required for the final assembly, and as a result WIP grows excessively due to collecting many job orders to start the punching and bending (i.a. economically profitable series to start modern numerically controlled machines).

As many different job orders are performed in each cell (other refrigeration cabinets and also display refrigerators and open merchandisers), the planning of the processes in the individual cells and for individual machines is difficult and complex. An example of a hypothetical schedule of realizable various processes during the manufacture of a refrigeration cabinet is shown in **Figure 2** (the average duration of the production task is 36 hours).

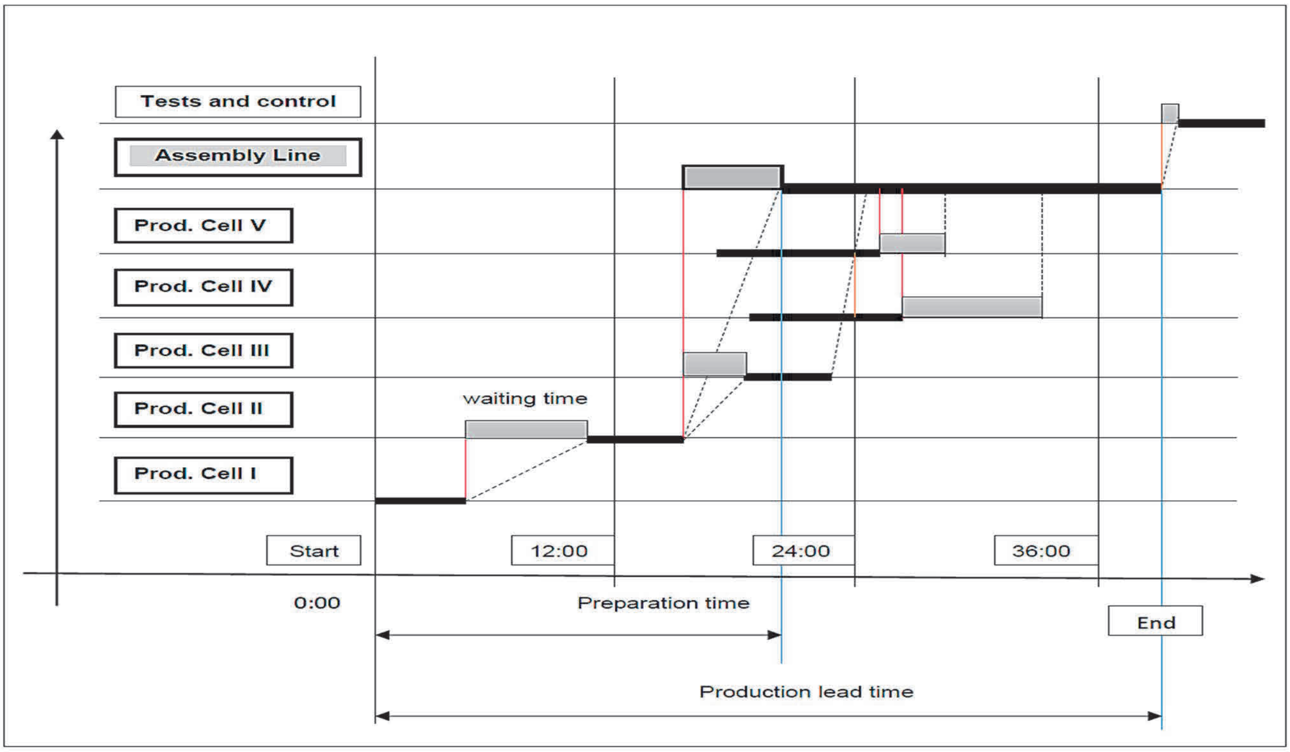

Figure 2 Example of the production task schedule

The studies have allowed identification of stoppages of which the most important are:

- stoppages due to delayed delivery of purchased parts,
- stoppages due to poor quality of supplies,
- stoppages due to the absence of correlation between production schedules in cells with the assembly schedule; this type of delays generates the biggest costs for the company because the ‘delays’ occur at the final stage, i.e. the assembly of a finished product.

The other delays are due to quality defects at various manufacturing stages, most often paint coat defects.

There is an overproduction at each stage in the company so the impact of these defects on delayed deliveries to customers is minor. The occurrences listed above present some problems which have to be minimized as they generate *muda*.

3. PROPOSALS TO SOLVE THE PROBLEMS

The most important difficulties relating to the performance of the z_i job order include:

- determining the earliest and latest time to start individual operations for each process;
- ensuring an adequate high quality (required by the customer) of parts and components made in the manufacturing cells (usually there are no spare parts, so a non-conformity results in delaying subsequent operations);
- ensuring an adequate information flow between the manufacture in cells and the needs of the final assembly;
- coordination of material flows and limiting the buffer storage of prematurely manufactured parts to an absolute minimum.

Thus, the following task was formulated in order to improve the production system:

$$T_{zi}^{UL} = \sum_{i=1}^{m} \tau_{ic}^{UL} \quad \rightarrow min \qquad (1)$$

where: τ_{ic}^{UL} - the duration of operation in cell *ic,*

z_i - the number of the performed production task for ULUF cabinet (UL),

i - the number of the manufacturing cell called *c,*

The duration of individual processes (acc. to **Figure 1**) - simplified notation:

- for cell I (cutting, punching and bending);

The duration of the task of cutting, punching and bending of all the parts necessary to make the UL cabinet is the sum of the times of necessary operations (bending is not performed on some parts):

$$\tau_{I}^{UL} = \sum_{1}^{M} t_{ip} + \sum_{1}^{N} t_{jb} \qquad (2)$$

where: M - the number of punched parts, N - the number of bent parts.

- for cell II (painting);

The duration of the painting process is the sum of the times of all operations of painting white and other colors (not all the parts are painted):

$$\tau_{II}^{UL} = \sum_{1}^{P} t_{iw} + \sum_{1}^{R} t_{jc} \qquad (3)$$

where: P - the number of parts painted white, N - the number of parts painted other colors.

- for cell III (foam insulating);

The duration of the foam insulating process of the *z* set of parts is the sum of times for preparation of the moulds, filling the moulds and seasoning (cooling):

$$\tau_{III}^{UL} = \sum_{1}^{K} t_{zp} + \sum_{1}^{K} t_{zf} + \sum_{1}^{K} t_{zs} \qquad (4)$$

where: K - the number of mould sets necessary to perform the task.

- for cell IV (assembly of electrical subassemblies);

The duration of electrical parts assembly is the sum of the times of all necessary operations (e.g., soldering) to prepare the subassemblies for the final assembly:

$$\tau_{IV}^{UL} = \sum_{i=1}^{ME} \tau_{ic}^{UL} \quad (5)$$

where: ME - the number of required operations for electrical subassemblies.

- for cell V (assembly of refrigerating subassemblies);

The duration of refrigerating parts assembly (e.g. the evaporator) is the sum of the times of all the necessary operations to prepare the subassemblies for the final assembly:

$$\tau_{V}^{UL} = \sum_{i=1}^{MC} \tau_{ic}^{UL} \quad (6)$$

where: MC - the number of required operations for the refrigerating subassemblies.

- for the final assembly line;

The duration of final assembly is the sum of the times of all operations necessary to make a given type of refrigeration cabinet (casing, evaporators, compressor, shelves, castors, electrical wiring, control systems, etc.):

$$\tau_{MA}^{UL} = \sum_{i=1}^{MA} \tau_{ic}^{UL} \quad (7)$$

where: MA - the number of operations for a given type of ULUF cabinet.

In order to verify the system operation, the system model was developed (acc. to **Figure 1**), and implemented in the WITNESS simulation software. The model structure is presented in **Figure 3**.

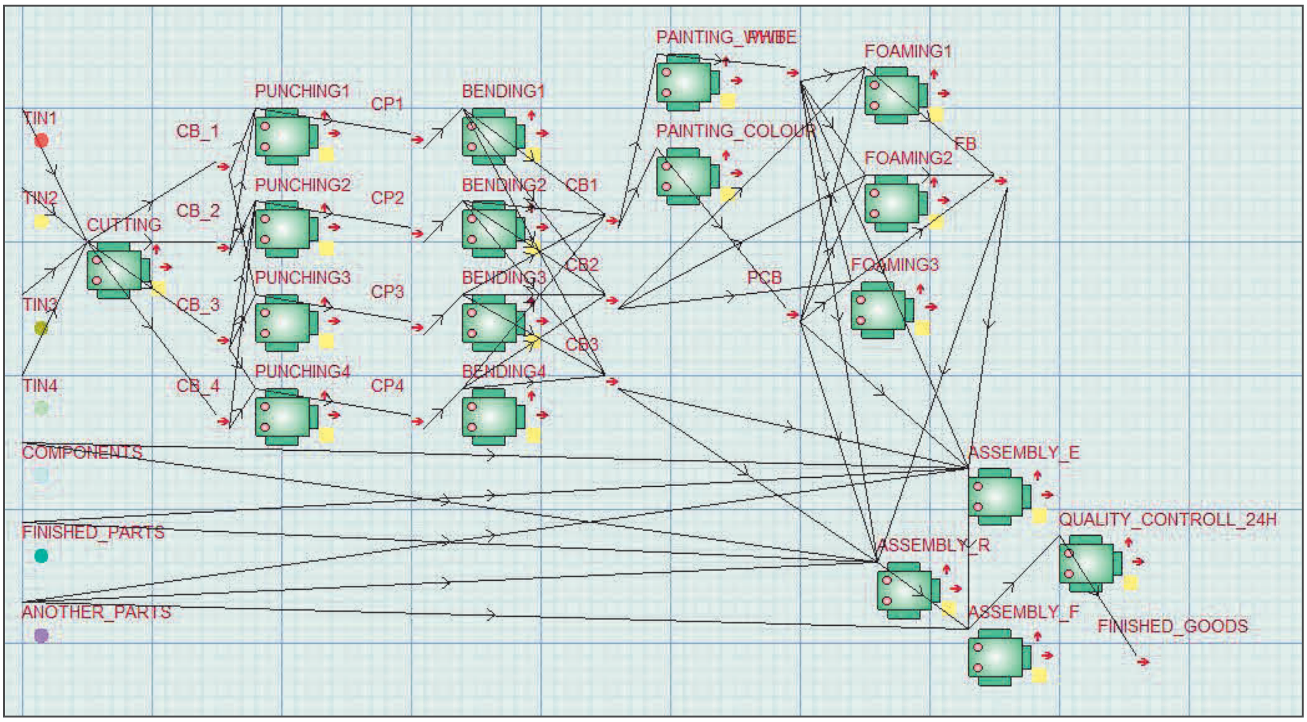

Figure 3 System model implemented in the WITNESS simulation software

Figure 4 presents a simplified VSM (Value Stream Mapping) for as-is state which represents basic information and material flows, manufacturing operations, and storage and warehousing processes.

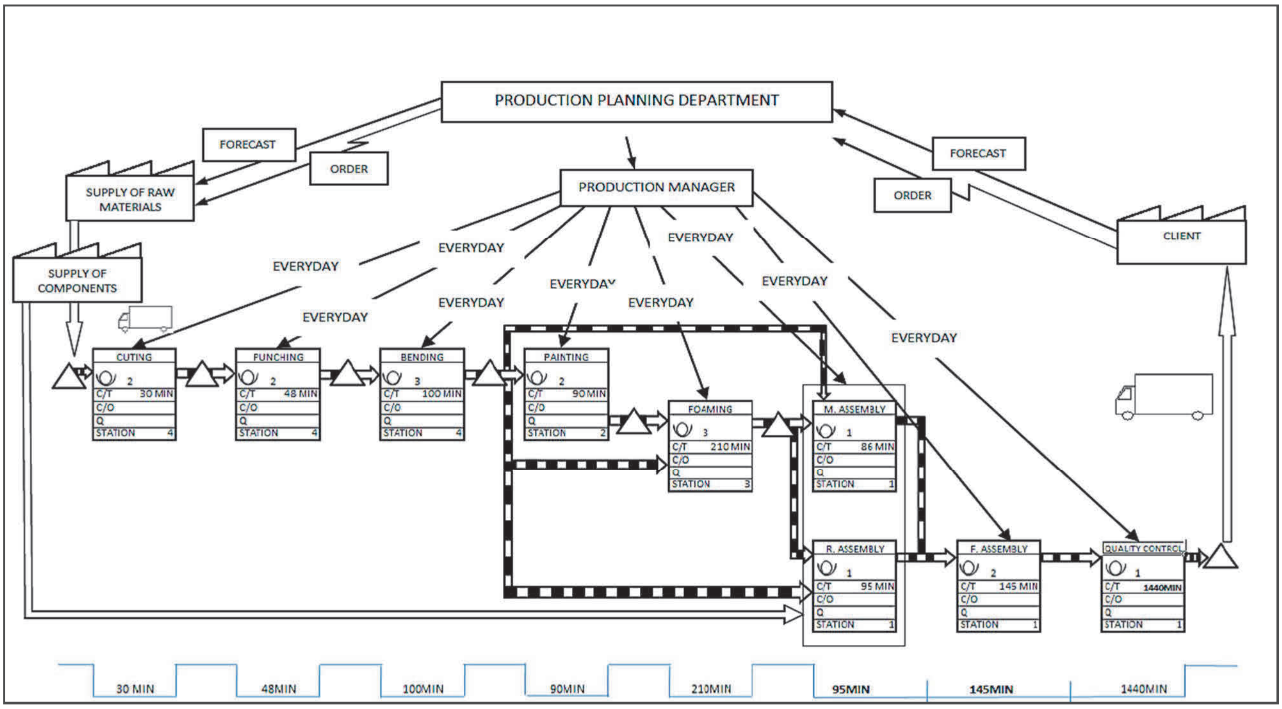

Figure 4 Simplified Value Stream Mapping - VSM

The following steps must be taken in order to reduce the task lead time:

Step 1. For each cell:

1) Standardize the workstations:
   - implement 5S rules;
   - keep the time of operations (on workstations, including all activities performed by the operator);
   - keep time of retooling (possibly use the SMED method to cut the retooling time).
2) Prepare time schedules for each cell.
3) Apply the graph-analytical method - develop the network of occurrences and activities in individual cells (CPM or PERT).

Step 2. Define the value stream and visualize it as a VSM:

1) For as-is state.
2) Propose changes and build the future state map.

4. SUMMARY

Production in SMEs can be carried out according to one of the basic principles: *make-to-order* or *make-to-stock*. Make-to-order, particularly when the customer has a lot of leeway to customize a typical product, is a difficult and complex task. In the case of complicated devices it is often necessary to order ready-made subassemblies and parts from external suppliers. The most important thing for the cellular structure (preferred in this case) is to make correct production time schedules for cells so that on the line assembly takes place without stoppages. In addition to a correct correlation of the assembly time schedule with the production time schedules, it is necessary to ensure adequate external supplies.

The solution of these problems requires using the *lean production* methods (5S, spaghetti diagrams, Yamazumi charts, identification of 7 muda, VSM, and quantitative methods offered by logistics engineering (ABC classification of materials, XYZ, Pareto charts, CPM, and PERT).

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