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Modification of the Cellular Structure with Increased Production in the Make-To-Order System

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The customer market is becoming more and more demanding. Customers want to have influence on the final shape, form, functionality and characteristics of the product. As a result, entrepreneurs are forced to abandon the Make-to-Stock system in favour of the MTO (Make-to-Order) concept, with the purpose of not only meeting the customers' needs, but also, for example, reducing the costs by manufacturing exactly the number of products which is currently demanded on the market. The article describes an example of a production task performed in the cellular structure. The customer required a substantial and abrupt increase (by 65%) of the production task. In order to tackle the problem, logistics engineering and lean manufacturing methods were applied. Having regard to the Industry 4.0 perspective, a concept of automated work cells was presented in order to minimise the role of the operator.

Keywords: cellular manufacturing, MTO methods, logistics engineering, lean.

1. INTRODUCTION

Nowadays, in order to be competitive, there is still (but to a lesser extent than in previous years) a striving for the reduction of costs related to execution of the production process. Given the fact that the customer market is becoming more and more demanding, it is obvious that the striving has to take into account actions that are consistent with the customer's needs, for example when concerning the Order Fulfilment Cycle Time, but especially in the scope of adjusting product features to the customer's expectations. The manufacturing of selected products in the MTO (Make-to-Order) system may be decisive in a company's survival on a very competitive market (e.g. the automotive sector) or opening up new markets [1]. Assuming that one of the logistic goals of the company is to reduce the time of execution of the production process (lead time), which in the make-to-order system results in reduced order processing time, efforts should be made to eliminate unnecessary transport, downtime and general wastes in the production process, as well as to ensure a continuous flow of the product through the production cells [2].

The type and form of production organisation also impose some restrictions regarding the selection of the proper production structure [3]. Non-rhythmic production can take both a pipeline and non-pipeline form, and may be realised in group layouts, functional layouts or production lines.

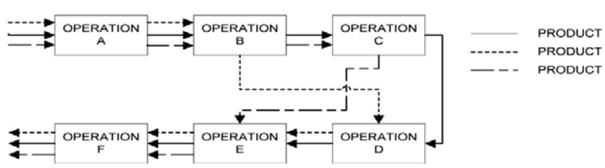

Fig. 1. Flow in the group layout.

However, the striving for continuous flow of material forces the application of the group layout [4].Regardless of whether the production is executed in work cells or on the production line, the machines should be positioned according to the performed technological operations. The sample flow of material in the group layout is presented graphically in Fig. 1.

The group layout assumes that machines and equipment used in the production process are deployed in accordance with subsequent phases of the technological process, or they form cells, i.e.

specially selected groups of work stations intended for a specific group of products. The application of these solutions allows for a significant reduction and ordering of the company's internal transport. This is due to the possibility to develop a line which is ordered in accordance with the manufacturing technology of a given product or a work cell [5]. However, in the event of failure, the likelihood of disrupting the production process is high.

In pipelined structures, each machine or device is assigned to perform a single, specific technological operation, thus cost-effectiveness of specialisation and process automation is possible [6]. The lines are used in manufacturing of larger batches. In the production of atypical products, cellular structures are more often applied. Work cells are divided according to the general division of the production structures. Machine cells, that is groups of technological devices selected according to their intended use, and production cells, prepared to manufacture a specific class/group of products, are applied. The second group may also include the cells where the assembly processes are performed.

2. CHARACTERISTICS OF THE PRODUCTION PROCESS

The object of this study is the final assembly line (FAL) of the air conditioning system of a passenger car. The manufactured component is a heat exchanger (a condenser in this case). The analysed production process consists of three stages. The final assembly line constitutes the third stage and comprises several cells. The manufacturing process is executed in the MTO (Make-to-Order) system and is of a mass-production character. The description of the operations at the individual stages is presented in Figure 2.

STAGE 1 - a machine called a stacker (used for stacking) is used in the assembly process. The core is assembled from pipes, fins and manifolds. These elements are placed into a soldering frame in order to stabilise them during the soldering process. The cores are transported to the station of loading the furnace on carts holding 16 pieces each.

STAGE 2 - the soldering process takes place in the soldering furnace. The furnaces are pass-through and with a conveyor inside. At the furnace entry station, operators equip the manifold with a bottle and place carts with cores in docks, from where a cobot (collaborative robot) draws the cores. After soldering, the core may be removed from the soldering frame. The soldering frames go back to the assembly station where they are re-used. The soldered condensers are placed on ladder carts used to transport them to the final assembly cell.

STAGE 3- the final assembly takes place in cells presented in Figure 3. The most important element of final assembly is a helium machine (HM). Peripheral stations are set up by the helium machine (BM - machine for equipping the bottle, WM - machine for welding the bottom, CD - control devices). Depending on the product's reference number, the final assembly is a set of operations aiming at equipping the condenser with peripherals and conducting a tightness test.

1. Equipping the bottle with a dehumidifier, filter and bottom (BM station)
2. Welding of the bottle bottom (WM station)
3. Tightness test (helium machine - HM)
4. Geometry check of the condenser and check of components – CD

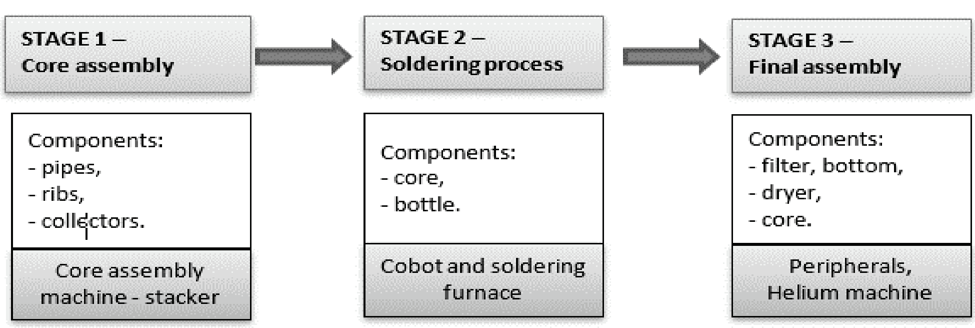

Fig. 2. Production stages of the condenser.

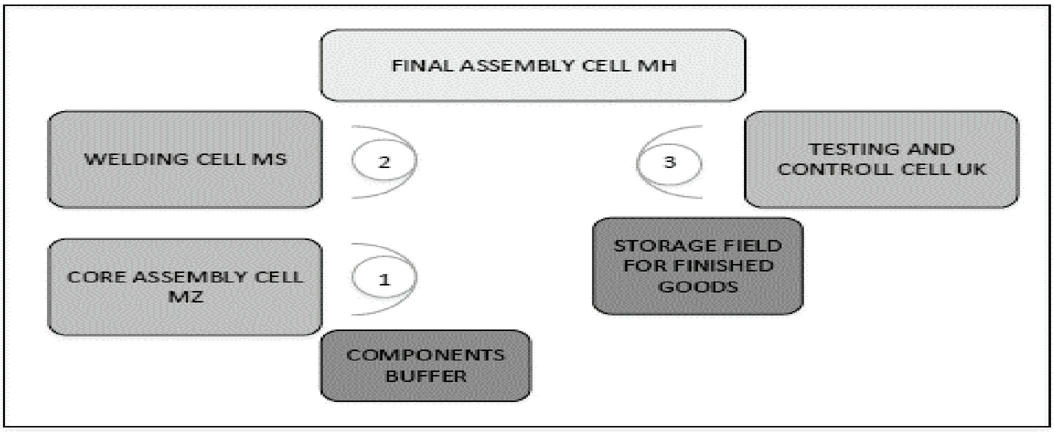

Fig. 3. Final assembly cell diagram (FAL).

2.1. PROBLEM SOURCE

Due to the planned abrupt increase in the number of exchangers ordered by the customer (from 450,000 pcs/year to 742,000 pcs/year, that is by 65%), there is a problem with the execution of the new orders.

The previous duration of the production cycle (production line's pace) was SCT about 53 seconds, and the maximum output of the line in the 3-shift production was about 40,000 pcs of exchangers/month. The simplest solution to execute monthly orders of 65,000 pieces would be to launch a new, second final assembly line. After conducting an initial analysis, it was decided that such a solution was non-viable at that time.

Therefore, it was proposed to leverage the opportunities by two groups of methods:

- logistics and production engineering methods,
- methods from the lean production area.

The task of improving the continuity of the flow can be presented in several stages [7]. In the first stage, accurate identification of the processes related to manufacturing and logistics is necessary. After the identification and agreeing the current aims for improving production efficiency, appropriate methods and tools for achieving these aims should be selected.

Therefore, the initial activities involve two stages:

Stage I - process identification - activities: 1 – 2 – 3 – 4

1. Selecting a process to be analysed.
2. Preparing a detailed flow chart of the technological process.
3. Collecting details of the process, for example orders, deliveries, stocks etc.
4. Determining the basic parameters and quantities describing the process and carrying out the necessary time study of duration of operations.

Stage II - Selection of improvement methods and tools (e.g. VSM, TPM) - activities: 5 - 6

5. Description of the losses and wastes during the process (for example 7 muda, 6 big losses).
6. Tool selection.

Figure 4 presents the first two stages of the algorithm which serves to improve productivity of the production system.

Subsequent steps necessary to achieve the required improvement of operation (efficiency) and continuous flow of materials depend on the selected method (tool).

The last two stages (N - number of stages) of

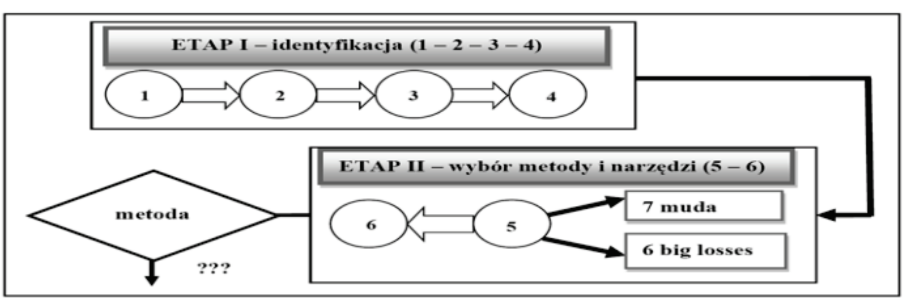

Fig. 4. Algorithm - choosing the method of improvement.

introducing changes to the production process are:

Stage N-1 - introducing changes - actions:

- preparation of agreements and dates of the possible changes,,

Stage N – the analysis of effects and improvement - actions:

- the analysis of effects of the introduced changes,,
- persistent implementation of Kaizen rules!

3. PROCESS ANALYSIS AND TESTING

According to the presented algorithm of procedure, it is necessary to identify the problems in the process of final assembly of the condenser.

3.1. IDENTIFICATION OF PROBLEMS AND WASTES IN A CELL (MUDA)

As a result of analyses, three main groups of problems were identified:

1. A large quantity of micro-downtimes, especially at the welding station (WM) (Table 1),

Table 1. Analysis of downtimes in the welding cell (WM) (during a single shift).

Pos.	Cause of downtime	Total downtime [sec/shift]
1	No carts	0
2	No boxes / packages	3
3	No racks	5
4	Planned line maintenance	11
5	Technological tests	11
6	Change of welding wire	48
7	Planned line maintenance	84
8	Shortage of components	106
9	5S activities during a shift	120
10	Change of ribbon in printer	300
11	Poka-Yoke control	391
12	1 Level line maintenance	444
13	First article acceptance	540
14	Failures / Adjustments	910
Total - per one shift		2,973 (49.55 min)

2. The 'bottleneck' of the final assembly line (FAL) is the welding cell (WM) (Fig. 5),
3. Incorrect balancing of the number of operators in the cells of the FAL line.

The conducted analyses indicate that failures and adjustments were the main waste. They contributed to the loss of almost 15 min/shift. Having regard to the line's pace SCT = 53s, wastes per shift can be calculated:

$$\frac{900\ s}{53\ s/piece} = 16{,}98\ pcs$$

Assuming 340 working days/year and 3 shifts, we get the quantity of non-manufactured exchangers per annum:

$$16{,}98\ pcs * 3 * 340 = \mathbf{17320} pcs\ \text{/year}$$

The conducted time studies of all the operations indicated that the 'bottleneck' of the final assembly line (FAL) is the welding cell (WM). The measurements (Fig.5) indicate that the WM station has the longest cycle time (SCT) (61.9 s).

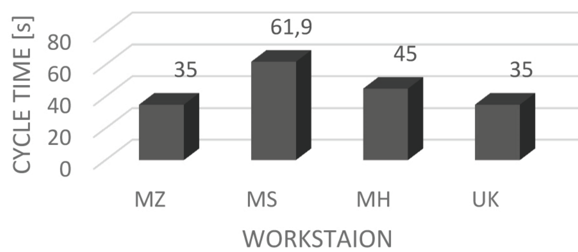

Fig. 5. Analysis of cycle times in individual FAL cells.

Improper balancing of operators' work was another detected problem.

For a measurable description of the operators' work and quality problems on the line, an indicator of work pace called KOSU was used:

$$KOSU = \frac{(availabletime\ -\ planneddowntime) * numberofoperators}{numberofgooditems}$$

It was assumed that concerning the FAL line, the target value of KOSU indicator should reach 110 The chart in Figure 6 shows that for over a year KOSU had exceeded the value, thus indicating that the line had been operated by too many operators or that the cycle time had been too long. The changes introduced in a later period resulted in achieving the desired indicator value (subsequent months of the following year).

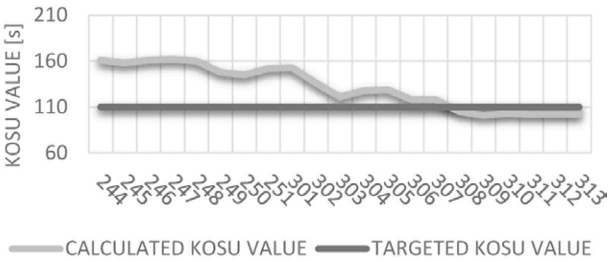

Fig. 6. KOSU indicator during the first year of production and after the changes.

3.2. ACTIVITIES RELATED TO IMPROVEMENT OF INDICATORS

In order to ensure continuity of supply to the customer in the case of larger orders, it is necessary to introduce changes to the production system which would ensure achieving the cycle time (SCT) of about 30 seconds. Figure 7 shows the chart of planned orders and achieved outputs (before and after the changes).

impossible to indicate the defective item. Addressing this problem requires further changes to the system and will be the subject of further research.

Modification of the helium machine made it possible to achieve the cycle time (SCT) of both the helium machine and the entire cell at 33 s/piece.

Table 2 presents the results of improved output achieved through the modifications introduced to the final assembly line (FAL). The achieved output increase by **~65%** also results in securing the continuity of product supply to the customer.

Apart from the improved output, both modifications also generated some minor financial savings.

Explanations to the table:

OEM - for assembly in the car factory

OES - for sale as a replacement part.

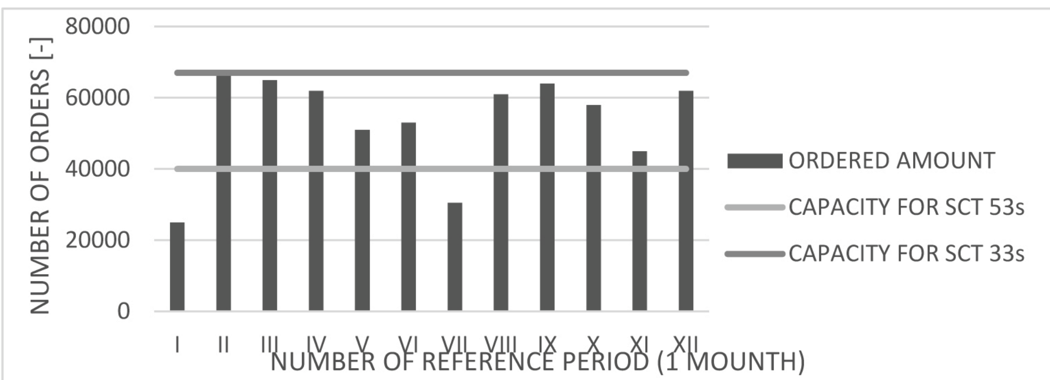

Fig. 7. Comparison of orders with regard to line output.

The following changes were introduced as part of the activities aimed at improving the output:

1. Modification of the chamber of the automatic welder (WM).

The modification involved changing the trajectory of the welding torch of the welding robot and fixing the condenser so that two pieces of the condenser could be inserted and welded at the same time without the need to open the chamber. This contributed to achieving the cycle time (SCT) of 62 s per two pieces, resulting in SCT = 31 s.

2. Modification of the helium plate in the chamber of the helium machine (HM).

The change was similar as in the case of the automatic welder (WM). The helium plate in the chamber of the helium machine was modified so that 2 condensers at a time could be loaded for the test. However, this concept poses a substantial problem when lack of tightness in one of the tested condensers is detected; in the proposed system it is

Table 2. Comparison of the results of improved output after the modifications.

Product	Clients market	SCT before [s]	$Production_{53}$ [pieces/year]	SCT after [s]	$Production_{33}$ [pieces/year]
AC01	OEM	53	210,000	33	350,000
AC01	OES	53	15,000	33	21,000
AC03	OEM	53	210,000	33	350,000
AC03	OES	53	15,000	33	21,000
TOTAL		53	450,000	33	742,000

3.3. PROPOSED FUTURE INITIATIVES

The next step in improving productivity in the final assembly cell should be Total Process Automation. Concepts for the implementation of a robot which serves all the stations, excluding the final inspection station, were developed. The critical point is a complicated operating algorithm in the case of a helium machine with a double helium plate. The concepts of an automated final assembly cell assume a closed cage with an industrial robot installed in the centre of the cell with the same layout of the machines as before, or a suspended robot which moves along a running rail. In both solutions the operator is isolated from all the automatic stations. The possible concept is presented in Figure 8.

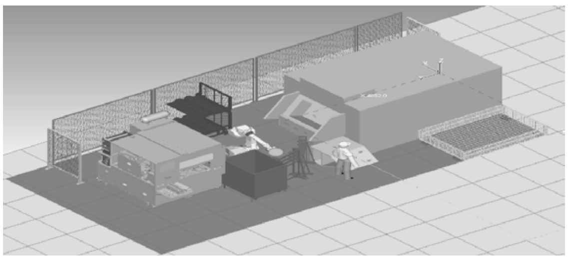

Fig. 8. Concept of an automated final assembly cell.

4. CONCLUSIONS

The study concerned improving output of the final assembly line of a product manufactured in several stages. The final assembly is the last stage of manufacturing. The line comprises several production cells with a group layout. The objective was to modify the processes in such a way as to enable an abrupt increase of production by about 65%. The construction of a second production line was ruled out. In order to tackle the problem, logistics engineering and lean manufacturing methods were proposed.

Until recently, methods from the area of logistics engineering and lean manufacturing have been treated - especially by smaller companies - as redundant and of little use. The study proves that an implementation which utilises lean manufacturing as well as constant development of the Kaizen philosophy may lead to improved productivity in production plants. It becomes clear that most of the changes in the analysed process are of an organisational nature and require extensive expertise on applied technologies and processes.

Process modifications allowed for avoiding investment in a second line of machines and involving other available production cells. This is of high significance due to the fact that the company producing the exchangers (condensers) supplies them to many car manufacturers and has to ensure continuity of supplies to each of them.

Having regard to the Industry 4.0 perspective, the concept of a fully automated final assembly cell was proposed.

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