Measurement of Productivity in Small-Series Production and Application of Lean Production Elements

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***Abstract* – The paper is oriented on the application of lean production and solving productivity in small-series production in the selected company. It introduces the essence of productivity in small-series production and the optimization of individual production facilities. The main task is to define wastage in the real state in the workplace and consequently increase productivity in production. The specific focus of the paper is on three types of products and workplace.**

***Keywords* – productivity, small series production, lean production elements, Fahrschemel**

1. Introduction

Small-series production is not focused on a large number of product types, but a large number of each type. Production is repeated in the so-called series (cars, machine tools, housing construction, etc.) on the same or different production facilities. The advantages include better application of specialization, periodicity and standardization of production processes.

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It is the most frequently applied type of production in business practice. It can take the form of small, medium and high series production [1], [7].

The aim of this paper will be to make changes in production processes and shorten production time in a small-series production company, which is partly due to the pressure of the external environment, but also due to the pressure from the inside of the company [2]. A very important part of this goal is mainly the assumption of development and consolidation of the company on the market. Achieving this goal involves strengthening the strengths and testing the new systems that are necessary to achieve and sustain the company's goals [4], [5].

2. Analysis of Productivity and Production Efficiency

The company's products are large-size weldments. The company's portfolio is divided into two main areas:

1. Cranes – container transhipment cranes, cranes for the service of electrolysis of non-ferrous metals – orders in this area are internally marked: 21xxx
2. Waterworks – area of structures used in the water sector – these contracts are internally marked: 22xxx

Production is realized only on specific order, production on stock is not usual. The production volume in the two areas mentioned above is approximately 2:1. With the project sponsor representatives were selected from both categories from orders planned for production based on the criterion of the number of pieces of the component and the repeated production of similar (identical) components in different orders. This paper deals with the improvement of processes in the welding workplace [4]. The criterion for evaluating the productivity of production at the welding workplace in this company is the sum of the productive hours worked per given order, resp. product type. The design concept of the products is also dependent on the customer's requirements, the design principles don not change, but parameters such as dimensions and weights are automatically dependent on the design proposals [3]. To simplify the monitoring of productivity at the welding workplace, hours / tons parameter is introduced in the company. This parameter represents hours worked on the product with respect to its weight. In the field of crane production, we chose a specific order with internal mark 21223. It is a contract where chassis and cats for 28 fully automatic gantry cranes are produced for the harbour of Tanger Medport (Fig. 1).

Each gantry crane chassis contains a component called Fahrschemel (Fig. 1). Because it is the most commonly produced component, company produces an average of 280 pieces per year (Fig. 2).

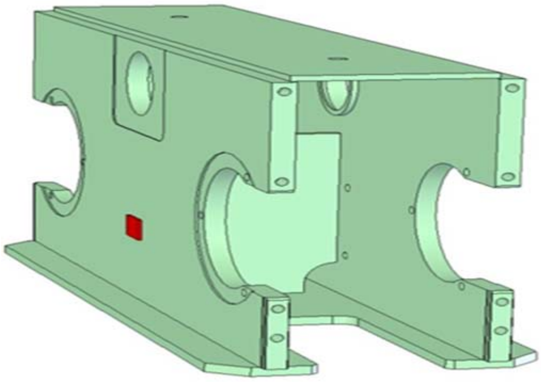

Figure 1. 3D view of component Fahrschemel

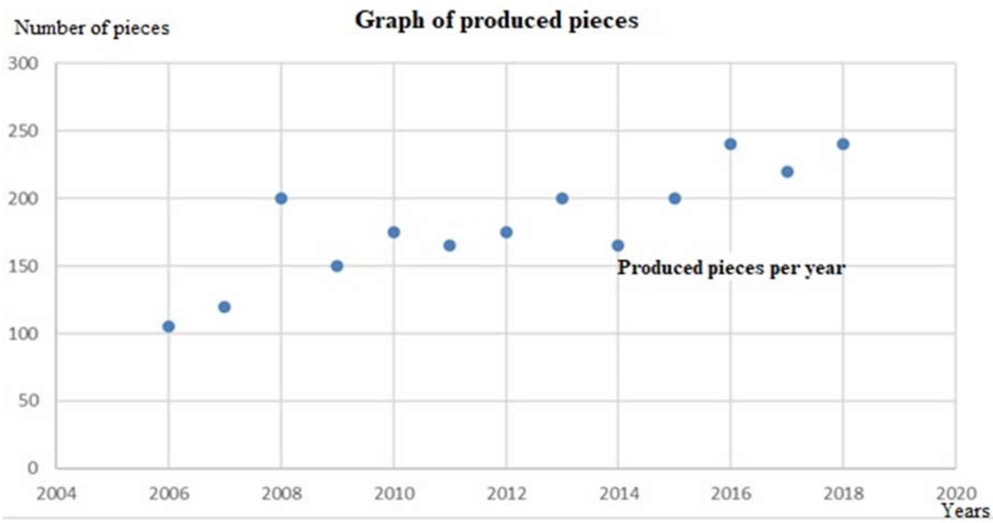

Figure 2. Number of Fahrschemel parts produced in years 2006-2018

By applying the repeated production criterion for similar (identical) components, a representative of the water sector was selected – the contract with the marking 22178. This is a contract where the company produced 4 pieces of Segment for the KW Hagneck hydroelectric power plant (Fig. 3). It is used to control the flow of water into the turbines.

Figure 3. Segment KW Hagneck

3. Measurement of Production Productivity

For the production of components for gantry cranes, the company produced 2550 pieces of Fahrschemel components from 2006 to 2018. The proportion of hours worked relative to the component weight is shown in Fig. 4. The large statistical variance of the monitored indicator is given by different weight and also by different number of pieces in the series, resp. in the contract. The values in Fig. 5 include hours made at all workplaces (assembly - stitching, welding, mechanical machining). Because of the fact that the planned production for 2018 was largely related to the component Fahrschemel with a weight of about 500 kg, the initial value can be considered as 23 hours/tone. Our goal is to make the production of Fahrschemel more efficient, and we set a 21hours/tone improvement target (5% increasing in productivity).

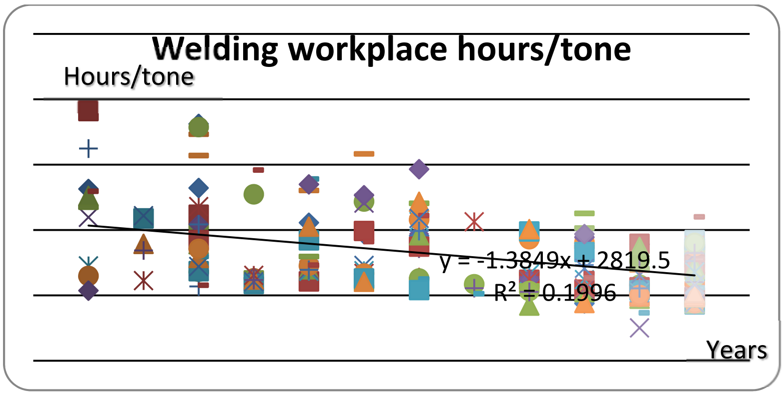

Figure 4. Share of hours worked to Fahrschemel weight

In the area of production of components for water management, from 2006 to 2018 company made 16 pieces of Segments for various waterworks.

The proportion of hours worked relative to the weight of the Segment is in Fig. 5.

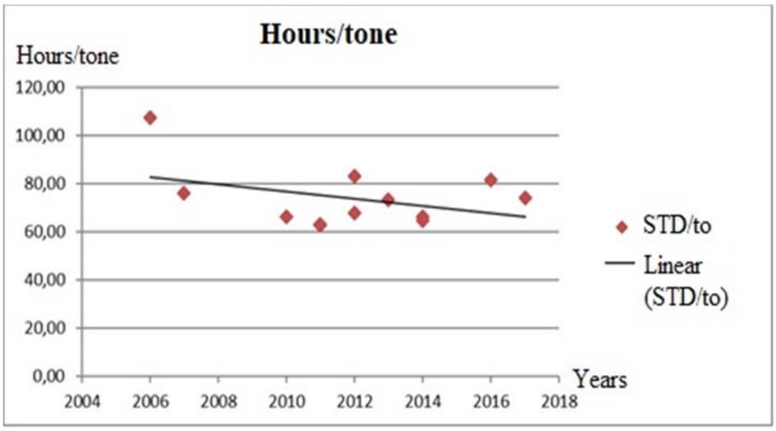

Figure 5. Share of hours worked to Segment weight

As a representative we chose the order 22178 – 2 segments. The previous two segments were produced in 2014, so the initial value of monitoring productivity of production is the value from 2014 - 68.02 hours/tone. Here we set a target of 64.62 hours/tone, which will be the increase in productivity of 5%.

4. Analysis and Measurement of Continuous Production Time

Because of the fact that the company is engaged in the production of large-size weldments, it is very important for the welding workplace to use the production area effective. Welding workplace has a production area of 1500 m². At first glance, it is sufficiently large, but already according to Fig. 6, it can be seen that according to the nature of production, this is a limiting factor in the entire production process. This is related to the continuous production time [9].

As the production time of these large-size weldments counts for hundreds of hours, company had decided to use the information system in the company (PsiPenta) as a source of information (production monitoring – control of the production time necessary for the production of the part). The substance of the information system is the monitoring; interconnection and organization of the whole company, and within this process working time is also achieved which is also used in the subsequent calculation of individual orders. From this information, system we can detect the time worked on the product [4].

Figure 6. Welding workplace

From the information system, we determine how many hours we need to produce the product and how long the product has been in the production process (in our case at the welding workplace).

$$Worked\ days = \frac{Hours}{working\ time * shifts * number\ of\ workers} \quad (1)$$

Moreover, if we multiply the number of weeks that the product spent at the welding workplace by 5 days, we will get a continuous production time.

$$Continous\ production\ time = Number\ of\ weeks * 5 \quad (2)$$

From these values, we can calculate the value added index (Vai), which expresses the ratio of the time during which the value added during the product production is added to the time that the continuous production time takes. The task is to reduce the continuous production time. In our case, we will also use the so-called modified index of value added, since the values for calculating the time, when to the product is added value, are taken from the information system and not by direct measurement of the process time in production.

The character of the production at the welding workplace does not allow direct measurement of time, because the time when to the product is added value is also spread over the times when the manipulation, preparation of the workplace, preparation of tools and others are in progress.

In order to monitor the continuous production time in the crane industry, we have selected the above-mentioned cat from the 21223 contract. To produce this cat is required the area of 80 m². Before the start of the project, it was planned to produce 2 cats simultaneously. Approximately 600 hours are required to produce cat 21180. These hours include hours for assembly – stitching, welding, and mechanical machining. Fig. 7 shows a cat consisting of different subgroups (subassemblies).

Company already had these subgroups made in advance. Therefore, we will follow the production of the cat from the stage of assembling the finished

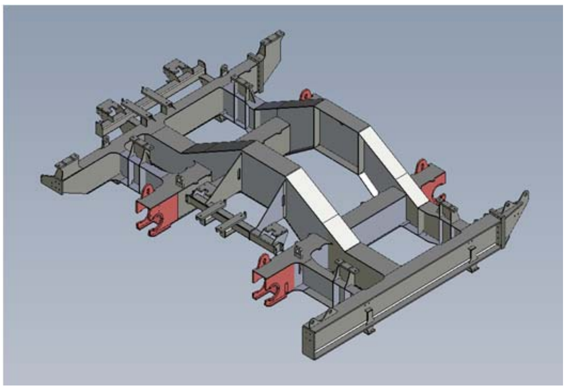

Figure 7. 3D view of a cat component

subgroups into a whole. The weight of the cat frame is 7.2 tons.

We evaluated the production of cats, which the company started to produce in 2017. In Tab. 1 are values obtained from the information system together with calculated values that will be used in the evaluation. The starting value will be the continuous production time (CPT) of 51 days (Vai – 60.78%). The goal is 31 days.

Table 1. Measured and calculated CPT values for selected cats since production began in 2017

Cat	1.	2.	3.	7.	8.
Hours worked in production	608.88	527.85	469.43	430.32	443.35
Hours worked in production converted to days	38.06	32.9	29.30	26.89	27.71
Number of weeks in production	7.6	6.6	5.7	5.4	5.5
Continuous production time per day	51	55	48	45	45
V_{ai}	74.5%	59.81%	61.04%	59.7%	61.5%

The order of the cats was selected in order, but we deliberately missed three pieces. We wanted to compare the sustainability of the measured values.

We need the area of 277 m² to produce a Segment and we need approximately 3300 hours to produce it [6]. From Tab. 2 shows the monitored and calculated indicators for the continuous production time.

Table 2. Measured and calculated CPT values for two Segments produced in 2014

Segment	1.	2.
Hours worked in production	3349.1	3502.8
Hours worked in production converted to days	69.77	72.97
Number of weeks in production	30	34
Continuous production time per day	150	170
V_{ai}	46.51%	42.93%

The starting value will be the continuous production time of 150 days (Vai – 46.51%). The goal in the company is to reach 140 days. From Tab. 2 follows that the second Segment spent 4 weeks longer in production than the first Segment.This is because of the fact that the subgroups were produced for both Segments at once. It is a large-sized welded component with a length of 15 meters and a weight of 55 tons. The difficulty of production this welded component is shown in Fig. 8.

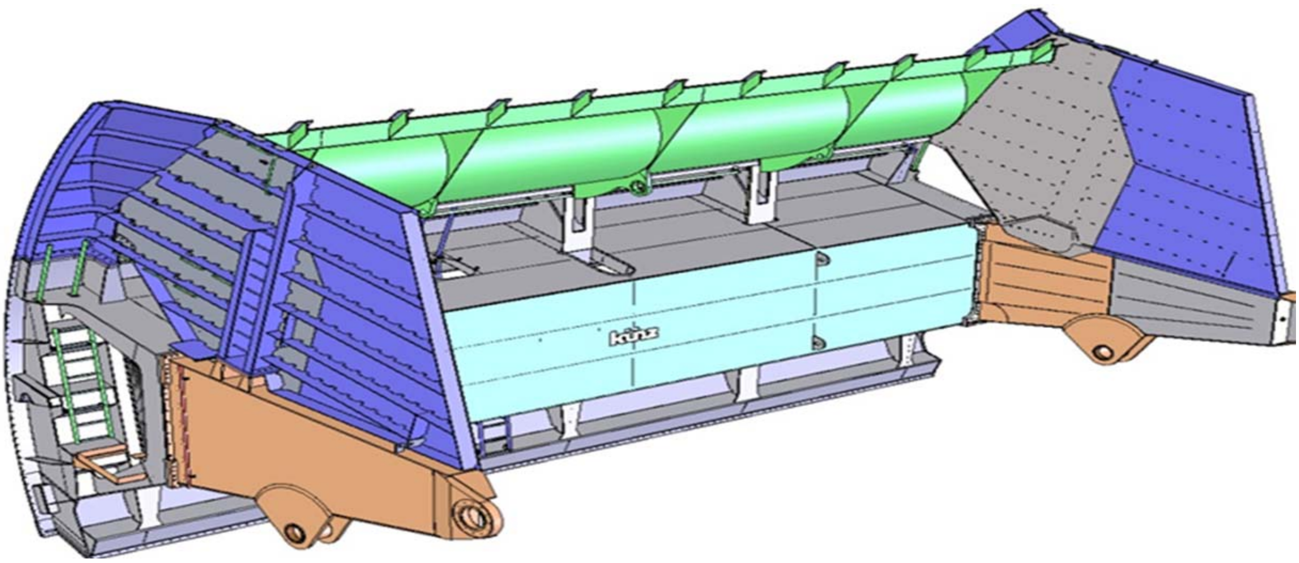

Figure 8. 3D view of Segment component

From the above mentioned data and information it is possible to summarize the project goals defined in the company, which are summarized in Tab. 3.

Table 3. Defined goals

Project goals	Metric	Baseline	Current	Goal
Reduction of continuous production time 21223 Laufkatze	Day	38	27	28
Reduction of continuous production time 22244 Segment	Day	X	X	X
Reduction of continuous production time 21223 PFW	Day	X	60	50
Increase productivity in production of 21223 Laufkatze	Hours/tone	82.19	59.79	59.17
Increase productivity in production of 22244 Segment	Hours/tone	X	Stopped	Stopped
Increase productivity in production of 2123 PFW	Hours/tone	FS=25; SCHW=70	FS=22; SCHW=70	FS=21; SCHW=66.5
Hefting productivity	Hours/piece	X	FS=3,5	FS=3,15
Welding productivity	Hours/piece	X	FS=3,625	FS=3,285

Legend to Tab. 3: Chassis parts for portal – PFW: FS-Fahrschemel, SCHW-Schwinge

The goals of reducing CPT 22244 and increasing productivity in the production of 22244 were not be met, because the production deadline for this contract was postponed to the end of 2018 when work on the project began. This change is due to the customer's request for a later delivery date.

5. Evaluation of Model Products Production and Proposal of Lean Production Elements Application

This phase of the project was solved with the project team in the company. The consultants to the selected representatives were also invited locksmiths, who were responsible for production, respectively quality and dimensions of selected products.

5.1. Proposal and Selection of Suitable Solutions in the Field of Crane Production

In terms of production nature in the company is Fahrschemel a smaller part, which takes about 12 to 15 hours. The production process can be easily and in detail described [12]. For a detailed description of the Fahrschemel production process and evaluation of individual production processes, we used a matrix of causes and consequences Tab. 4.

Table 4. Matrix of causes and consequences: description of the production process

Outputs of the FS production process (according to customer criteria)						
Processes in FS production	Geometry	Weld quality / visual aspect	Productivity	Production costs		Order of priorities
Criterion Weight, Relevance (1-10)	10	10	8	5	Priority	
Straightening the sidewalls	6	0	4	1	97	7.
Sidewalls clamping	1	0	1	2	28	8.
Preworking of sidewalls	10	0	2	4	136	6.
Assembly – stitching	10	8	8	6	274	1.
Welding	6	10	8	8	264	4.
Straightening	6	2	8	8	184	5.
Clamping before final machining	10	4	10	10	270	2.
Final mechanical machining	10	4	10	10	270	3.

For each process, we have determined the criteria (geometry, weld quality, productivity and production costs), based on which we then select the process we will improve. Tab. 4 also clarifies, which processes in the production of Fahrschemel are the most important in terms of desired product properties, i.e. priority. Out of the first four most important processes, we have selected 3 to deal with. We chose:

1. Assembly – stitching,
2. Clamping before final machining,
3. Welding.

Even though the final mechanical machining gained a higher priority than welding, we excluded it from the selection because of the costs. As this process is proven, change of this process would already require a large investment in tools. In order to increase Fahrschemel's productivity, in the company were managed 3 sub-projects for the 3 selected production processes:

1. Assembly – stitching → optimizing the workplace for Fahrschemel assembly with regard to Occupational safety and health (OSH), ergonomics and regulations in the workplace, which should bring more efficiency of the operation.
2. Clamping before final machining → design, production of the fixture preparation for the final mechanical machining of Fahrschemel so that this clamping can be done outside the work desk on the fixture preparation, which should save machine time, respectively to release capacity for other products.
3. Welding → usage of a robotic workstation for Fahrschemel welding with regard to OSH, and the regulations in the workplace, which should make the operation more efficient.

In Fig. 9 is Pareto analysis of the effects of individual production processes on the required properties of Fahrschemel.

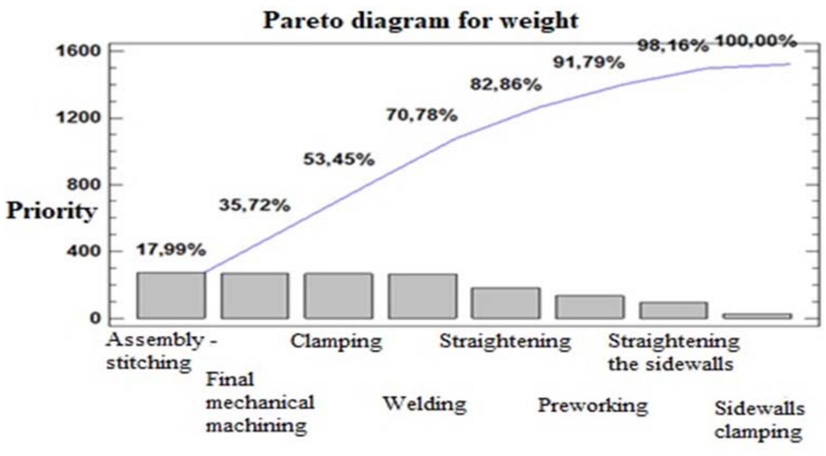

Figure 9. Pareto analysis of the effects of individual production processes on the required properties of Fahrschemel

To reduce the continuous production time of the cat 21223, it is important to describe the production process in a similar way to the Fahrschemel. To describe the production of the cat we used scheme (Fig. 10), which in detail describes the production process of the cat.

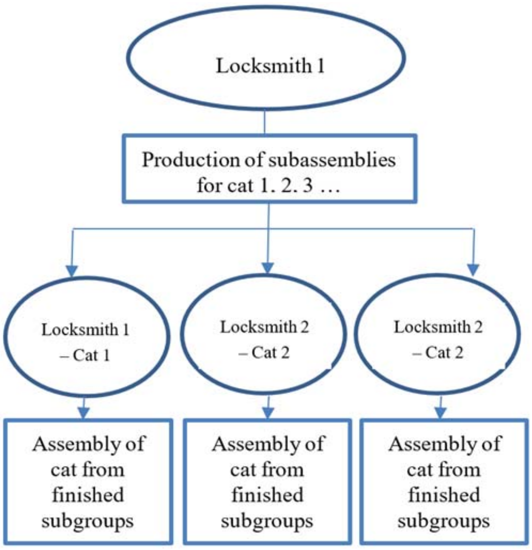

Figure 10. Distribution of working groups for cats' production

An important impulse was the threat of overloading a production capacity to the production area. This would result in an increase of the hours necessary for handling, respectively transfer unfinished and finished production. From Fig. 10 results we have are that 3 cats 21223 are put into production at the same time. As the initial operation of "subgroup production" takes about 40 hours, we estimate shortening of CPT by 1 week as well as the better usage of the work area at the welding shop. Before the start of production 22244 order, part of the project team met with the locksmiths responsible for the production of the two previous 2014 segments. Based on a detailed analysis of the component, we have identified the possibilities of cost savings and shortening of CPT based on design changes of purchased components. Drawings of purchased components had large manufacturing tolerances and shape adjustments (relief for weld edges), which had to be worked on a horizontal boring machine, eventually firing and grinding by locksmiths [11].

As an example, we can use Fig. 11, where the milling of the weld edge took 6 hours. Burning in this case was not possible from a technological point of view.

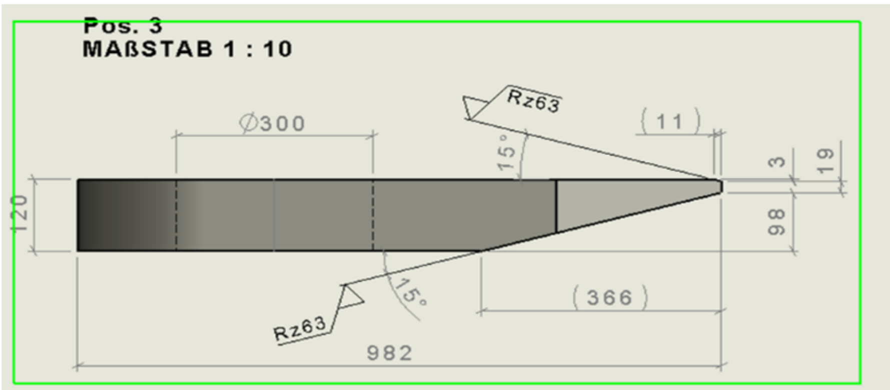

Figure 11. View of weld edge preparation for weld

5.2. Implementation of the Solution and Introduction Into Production in the Production of Fahrschemel

We decided to use ergonomic workplace analysis for sub-project assembly – stitching. From the photograph of the original workplace (Fig. 12) intended for the assembly – stitching operation of Fahrschemel, it is clear that the locksmith has a small handling space around the preparation for assembly. Semi-finished products are located far from the workplace (necessity to use a bridge crane for handling with semi-finished products), which leads to manual handling of loads and frequent bending. We identified the most serious problems:

1. Small storage space for semi-finished products, the solution is to relocate the stand drill, which gives us the possibility of increasing productivity in the handling area.
2. Frequent bending when handling semi-finished products, carrying in hands, long distances. The

solution is to zoom in the storage space of semi-finished products, to use a cantilever crane when handling loads over 5 kg, which will increase safety at work and achieve better and faster handling of semi-finished products.

Figure 12. Original workplace of assembly and stitching of Fahrschemel

The state after adjusting the workplace for the assembly – stitching operation of the Fahrschemel is shown in Fig. 13.

The locksmith, who is responsible for the workplace and the operation, was actively involved in this sub-project. We have moved the stand drill and installed it at the band saw. We have thus taken advantage of the fact that the operator on the band saw in the meantime, when the band saw divides the material in automatic mode, so it can operate the stand drill. This contribution will not be further discussed in this paper.

Figure 13. Situation after workspace adjustment

The welding operation of the Fahrschemel component has so far been carried out on a positioner (Fig. 14), which has been designed for this purpose. The disadvantage was the manipulation of the crane when clamping into the positioner and the zero usability for other weldments. The main requirement of this sub-project was the semi-automation of the workplace, elimination of the manipulation with the crane, the associated downtimes, stoppages due to the waiting for the crane and also the manipulation itself [4], [7].

Figure 14. Original positioner for Fahrschemel welding

With this investment, company used a welding workplace – IGM robot (Fig. 15), which is already used by the company for welding other products. Another advantage is that the second piece of Fahrschemel can be clamped on the robot without affecting anything else.

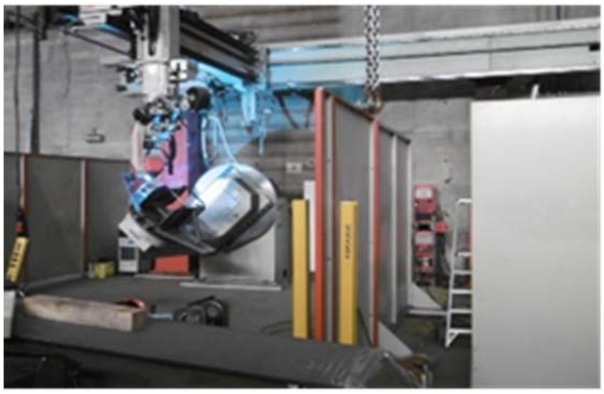

Figure 15. Semi-automatic welding workplace

After the completion of the order 21180, the company prepared the area to launch the project 21223 (cats). At this place (Fig. 16) production of subgroups for 1, 2 and 3 cats by one locksmith was started.

Figure 16. Locksmith's workplace for assembly the cat 21223

We have consulted with the design department all proposed changes that were not included in the drawings for purchase. These changes were subsequently reflected in the drawings for the new order 22244 KW Kirchbichl, where the company produced 3 pieces of Segments for the customer until autumn 2018.

6. Evaluation of Goals Achievement and Quantification of Benefits

The evaluation of the project goals fulfilment is summarized in Tab. 5. The achievement of the individual target values shows that not all goals have been met as expected, but the individual deviations are so small that we can say that the goals of reducing CPT and increasing productivity in Segment production have been met.

Table 5. Evaluation of goals

Project goals	Metric	Baseline	Current	Goal	Average achieved value
Reduction of continuous production time 21223 Laufkatze	Day	38	27	31	87
Reduction of continuous production time 22244 Segment	Day	0	150	140	Production date postponed
Increase productivity in production of 21223 Laufkatze	Hours/tone	100	95	90	95
Increase productivity in production of 22244 Segment	Hours/tone	68.02	0	64.619	Production date postponed
Hefting productivity	Hours/piece	FS=3.9	FS=3.5	FS=3.15	FS=3,5
Welding productivity	Hours/piece	0	FS=3.625	FS=3.285	FS=1,9

The evaluation of the project goals in terms of monitored values showed that some of them were successful, and some of them were not fulfilled but for objective reasons that the company could not influence.

7. Conclusion

It is logical that companies are under constant pressure to optimize and improve their processes [9], [10]. Using lean production concepts and tools, we have tried to prove that wastage can also be avoided in small-series production and processes that are not entirely standard can be optimized [8].

The main contribution of this article is the development of knowledge of decreasing the continuous production time and time for small-series production. It is also important to detect and realize weaknesses and then determine the response to eliminate them. Strengthening the strengths, testing the new systems that are necessary to achieve and maintain the company's goals outside the company - customer-oriented and in the company – understand and identify with the company's direction across the entire spectrum of employees is a matter of course. This contribution is neither quantified nor analyzed in this paper, because of the feedback which is expected from the market environment and directly from customers.

The objectives of the project in terms of monitored values were partially met and some of them were not met for objective reasons. The evaluation of the project in terms of quantification of realized savings proved as very positive.

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