

THE USE OF LEAN MANUFACTURING TECHNIQUES – SMED ANALYSIS TO OPTIMIZATION OF THE PRODUCTION PROCESS

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ABSTRACT

Lean is a culture of real and continuous optimization. As a concept of continuous optimization in the midst of limited resources, it must be practiced continuously as a long-term organizational norm. This paper reveals why changeover time reduction is important in manufacturing industries and from the various tools and techniques available within Lean manufacturing describes mainly SMED (Single Minute Exchange of Dies) for changeover time reduction and its application in Shaft manufacturing industry. This paper also describes principles, benefits, procedures and practical application of SMED. Theoretical bases are verified in a practical part that describes the analysis and design optimization of non-productive time at changeover honing machine in a selected shaft manufacturing company. The output is the structural design of universal palettes and an evaluation of productivity due to optimization of operations of time honing gear shafts. The results achieved show considerable reduction in delay arising out of machine setting time, batch-setting time and demonstration delay.

Keywords: Lean manufacturing, SMED, changeover times.

INTRODUCTION

Lean Manufacturing is considered to be a waste reduction technique as suggested by many authors, but in practice lean manufacturing maximizes the value of the product through the minimization of waste [1]. Van Goubergen et al. [2] indicated three main reasons why set-up reduction initiatives can be appropriate for any company: to increase flexibility by conducting more changeovers and reducing lot size; to increase bottleneck capacities in order to maximize the line availability for production; and to minimize the cost, since production costs are related to equipment effectiveness.

According to Chiarini [3], the most important LM tools to eliminate the different kinds of waste in production are value stream map, cellu-

lar manufacturing, total productive maintenance and single minutes Exchange of dies (SMED). A great amount of literature has addressed the first four tools [4], while information on SMED is a bit scarce.

SMED is a tool developed by Shingo [1] as a proposal to reduce bottlenecks caused by stamping presses in Toyota. By the time SMED was developed, the machines were not working at full capacity and, thus, were not bringing the expected benefits. Nowadays, as Utulas [5] points out, SMED is one of many LM tools for waste reduction in production processes, since it offers a fast and efficient way to decrease changeover times.

Single Minute Exchange of Dies (SMED)/ One-Touch exchange of Die (OTED) is systematic of the reduction of changeover time by converting possible internal setting time

(Carry out during machine stoppage) to external time (performed while the equipment is running) and to simplify and streamline the remaining activity [1].

„Changeover times“ is defined as the period between the last good product from previous production order leaving the machine and the first good product coming out from the following production order [6,7]. Changeover time is defined as the time needed to set up a given production system to run a different product with all the requirements [8, 18], and they are a typical example of waste, since changeover is a non-added value activity that incurs hidden costs [2]. Therefore, because machines remain inactive during changeover times, this process must be reduced as much as possible [8].

SMED is a practical LM tool that helps maximize the product value by reducing setup time and improves setup processes and provides a setup time reduction of up to 90% with moderate investments. Setup operation is the preparation or post adjustment that is performed once before and once after each lot is processed [1].

Shingo [1] bases his method on categorizing all setup activities into internal and external ones. With internal activities being ones that can only be performed when the machine is shut down, and external being those that can be conducted during the normal operation of the machine while it is still running. SMED methodology is formed by four single stages [1]; a preliminary stage where the internal and external set-up conditions are not distinguished; the first stage were separating internal and external set-up takes place; the second stage where internal activities are converted to external ones; and finally the third stage focusing on streamlining all aspects of the set-up operation.

Based on time/video study Shingo [1] separated the changeover (C/O) time into internal and external set-up time. The activities performed by stopping the machine are called internal set-up time and on the other hand when the activities are performed without stopping the machine, these activity are called external set-up time. Yamazumi chart is used to analyze the internal (on-line activity) and external (off-line) set-up time. Based on these analysis possible internal set-up time are converted to external set-up and internal set-up times are streamlined by introducing multi operator working parallel during On-line activity and one touch set-up adjustments to convert the C/O time to single minutes.

METHODOLOGY

Optimization means reducing the production process time as much as possible to increase production productivity [9, 19]. The main task is therefore to analyze the individual times of the operation of the production process, to find the time that most affects the length of the rebuilding and to find ways to reduce it. As these times are divided into production and non-productive, respectively. Productive and unproductive times, we focus mainly on non-productive production time.

As mentioned above, according to several authors [1, 2, 3, 8] SMED is a method for shortening the time of rebuilding production facilities. We minimize waiting times in a systematic process. For example workspace preparation, between the processing of two successive different types of production batches or products. For example, this method is about shortening the time for mold replacement, machine tool or production line rebuilding [9, 14].

The whole SMED method is based on a very thorough analysis of the redevelopment that we usually perform by direct observation at the workplace. Radically shortening conversion times from several hours to several minutes can be achieved, for example, in these ways:

- Classification and categorization of all redevelopment activities,
- Changing the organization of the reconstruction,
- Standardizing the conversion process,
- The training of each worker who performs the redevelopment,
- Special devices,
- Technical modifications of the machine [1].

This method is used in workplaces that are narrow where we often carry out rebuilding and the times required for rebuilding can result in significant losses of line capacity or machine capacity [10, 11, 19].

The condition for the application of small production batches are short conversion times, which ensure short **product lead times**. Large production batches result in long lead times and high production progress. Reducing conversion times is a major factor in reducing doses [12]. Fig. 1 presents the expected improvement on changeover time depending on the different focus that can be adopted during the SMED implementation. If focus is only on methodology, results can be poor. In contrast, by combining design

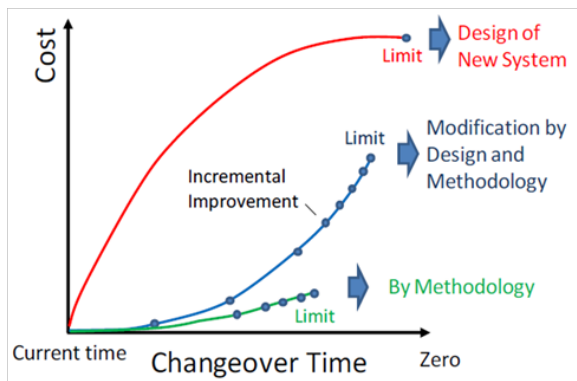


Fig. 1. Limits and costs of changeover improvement strategies [9]

modifications and methodology improvements, the outcomes can be acceptable with moderate investment [12, 18].

A long time for rebuilding also creates problems such as increased waiting times for processing or consuming critical capacities with regard to dose waiting [9].

The optimization project was implemented in a selected engineering company focusing on the production of gears. The SMED analysis tool was used to solve the optimization of the times that entered the production process of honing. SMED analyzes individual redevelopment times that represent the unproductive time of honing selected toothed shafts. Among the factors that directly affect the production process of honing in terms of productivity features [13]:

- input raw material - untreated shaft,
- machine technical options - machining parameters,
- tool - honing wheel (depends on the hardness of the disc).

Among the factors that indirectly influence the process of honing in terms of productivity features [2, 20]:

- reconstruction - derivative change,
- dose size - frequent reorganization of derivative changes,
- operator - experience,
- technical condition of the machine - malfunction.

After the set up of an SMED team, a video recording of the machine's manufacturing process (from the H3 shaft to the H2 shaft) was made, based on which the individual operations of the redevelopment were analyzed and included in the individual categories and the specified times of the individual operations.

The basic categories of redevelopment operations are: Clamping, Cleaning, Control panel, Dressing, Loading/material, Measuring, Honing Head, Automation, Setting/Adjustment, Teaching, Try out, Waiting, Walking, Searching.

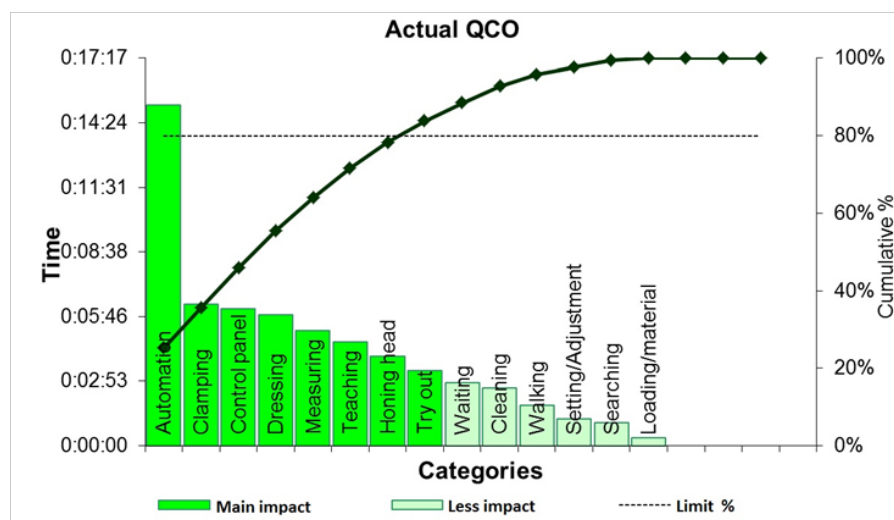
SMED analysis results showed that the average rebuilding consists of 94 operations and its total average time is 1 hour and 19 seconds, representing a non-productive time to be reduced. Selected parts of SMED rebuilding analysis is presented in Figure 2. After merging the opera-

0:25:00					
	73	<u>the position of the portal loader</u>	I	0:00:27	<u>Control panel</u>
0:25:27					
	74	<u>Replacement of the gripper feeder</u>	I	0:00:56	<u>Automation</u>
0:26:23					
	75	<u>Walking to the pallets</u>	I	0:00:12	<u>Walking</u>
0:26:35					
	76	<u>Palletizing, Exchange pallets</u>	I	0:06:52	<u>Automation</u>
0:33:27					
	77	<u>Loading the pallet</u>	E	0:00:08	<u>Loading/material</u>
0:33:35					
	78	<u>Loading pieces on pallets</u>	I	0:00:13	<u>Loading/material</u>
0:33:48					
	79	<u>Mask replacement</u>	I	0:00:53	<u>Automation</u>
0:34:41					
	80	<u>Walking to the machine</u>	I	0:00:18	<u>Walking</u>
0:34:50					

Fig. 2. Selected part of table with SMED rebuilding analysis

Table 1. Operations from the automation category

Elapsed time	Rebuilding observation			Subsequent analysis	
	number	description of operations	I/E	duration	Category
0:00:05 0:18:15	65	Rollchecker Exchange	I	0:00:29	Automation
0:18:44	66	Replacement of the grippers on the revolver and closing of the door	I	0:01:52	Automation
0:20:51	68	Remove the dressing tool from the machine	I	0:00:09	Automation
0:21:00	69	Securing the dressing tool in a box	E	0:00:20	Automation
0:21:20	70	Securing the dressing tool head in a box	E	0:00:30	Automation
0:21:50	71	Exchange of the grippers	I	0:02:04	Automation
0:23:54	72	Establish and clampe the dressing tool	I	0:01:06	Automation
0:25:27	74	Exchange the grippers on the feeder	I	0:00:56	Automation
0:26:35	76	Remove pallets, exchange pallets	I	0:06:52	Automation
0:33:48	79	Mask exchange	I	0:00:53	Automation
		Total time		0:15:11	

**Fig. 3.** Pareto graph

tions of each category into a separate table, the total times of these categories were then identified and the pareto graph created. Table 1 shows an operation from the automation category.

After adding the total time of the individual categories, a Pareto graph was drawn up (Fig. 3), which identified that the automation category had the greatest impact on the length of machine rebuilding and hence the productivity of the toothed shaft production.

In order to reduce the total time of this category, and thus reduce the total unproductive time in the gearing process, it was necessary to determine which operation is the longest and can be adjusted so that the total time drops to the lowest possible value. An analysis of all operations in the automation category has shown that operation with order

number 76 - „remove pallets, pallet exchange“ takes the longest, even from all the operations of the whole reconstruction. This operation time is 6 minutes 52 seconds.

Optimizing operations - analysis of the current situation

In order to optimize the aforementioned process of machine rebuilding of the selected operation or shortening of time, it was necessary to modify the preparations so that they do not have to be replaced and replaced at each conversion to individual types of gears. A toothed shaft is mounted on the assembly jig, which is then moved over the belt into the honing machine. At present, a different type of assembly jig is used

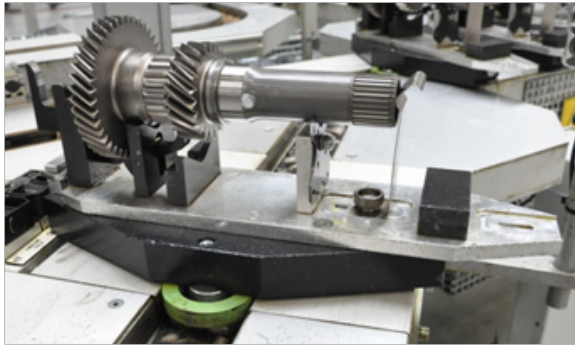


Fig. 4. Toothed shaft mounted on the pallet

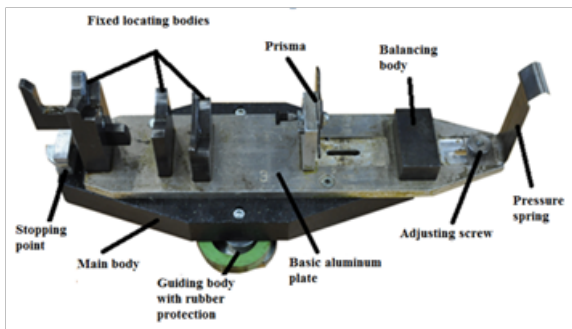


Fig. 5. Selected old pallet type

for each type of toothed shaft (5 types), resulting in increased conversion time. The goal of the optimization was to design a universal assembly jig for all 5 types of toothed shaft, replacing the current types (examples on Fig. 4 and Fig. 5).

The starting conditions for the solution, design of the universal palette

The task of the new assembly jig is to ensure that it is not necessary to exchange the prepara-

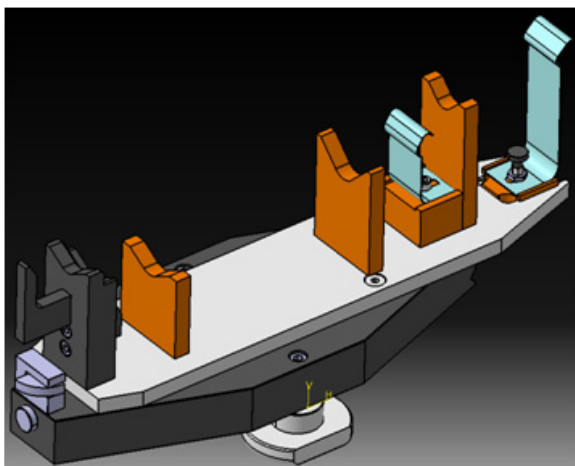


Fig. 6. 3D model of universal pallet for

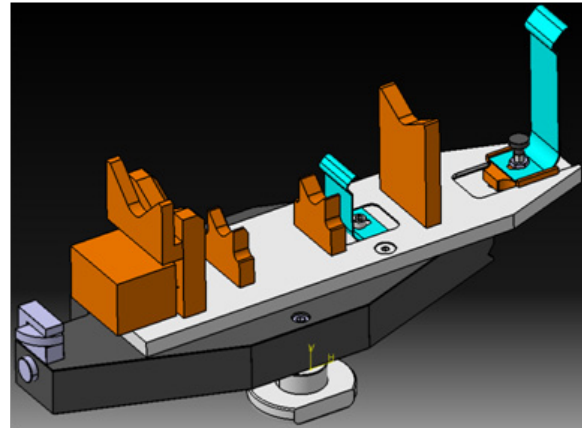


Fig. 7. 3D model of universal pallet for shaft shaft H1, H2, H3, H4, H5

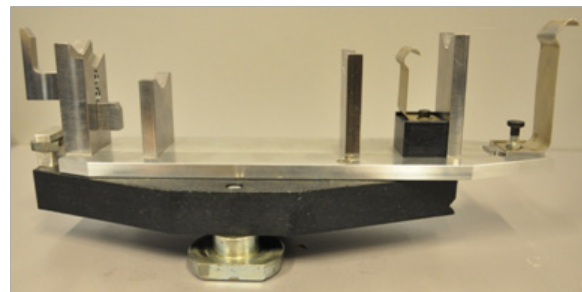


Fig. 8. Universal palette for shafts H1, H2

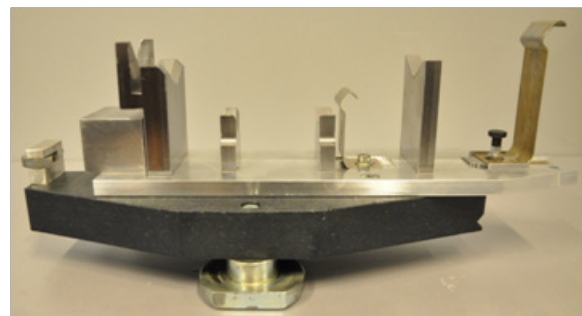


Fig. 9. Universal palette for shafts H3, H4, H5

tion in any machine rebuilding, and this has led to a reduction in unproductive time while eliminating the disadvantages of current pallets. Since the production process of honing takes place on four machines, two universal devices have been designed because of the very complex construction of only one. First - for input shafts marked H1 and H2, second - output shafts H3, H4 and H5 reverse gear. The CAD system with support for 3D modeling was used to create the design, namely the Catia V5 program with Part design modules, Assembly design, and Drafting.

Table 2a. Preview of JPH Analysis for the 9th Week

Reason/day	Monday			Tuesday			Wednesday			Thursday		
Work shift	A	B	C	A	B	C	A	B	C	A	B	C
CHO large-number	2	0	0	2	3	2	0	0	0	0	1	1
CHO large-time	2	0	0	2.5	4	2.5	0	0	0	0	1.15	1.25
CHO small-number	1	1	1	0	0	0	2	2	0	1	0	1
CHO small-time	0.7	0.75	0.75	0	0	0	1.6	3.5	0	0.5	0	0.75
CHO total-number	3	1	1	2	3	2	2	2	0	1	1	2
CHO total-time	2.7	0.75	0.75	2.5	4	2.5	1.6	3.5	0	0.5	1.15	2
Maintenance	1	0	0	0	0	0	2	2	4	1	7.5	3
Adjustment	4	1.5	1.25	3.5	1.25	4	2.5	1.5	3.75	1	3	2.5
Profiling	0	0	0.5	0	0	1	0	0	0	0	1	0
Clamps/Runout	0.25	1	0.75	0.5	1	1.25	1	0.5	0.25	1	0.5	0
Rework	0	0	0	0	0	0	0	0	0	0	0	0
Sercos	0	0	0	0	1	0	0	3	0.5	0	0	0
Maintenance assistance. tests	0	1.5	0	0	0	0	0	0.5	0	0	0	0
Cleaning the centrifuge	0.5	0.25	0.25	0	0.25	1.25	0	0.25	0.25	0.25	0.25	0.25
Unfulfilled cycle time	0	0	0	0	0	0	0	0	0	0	0	0
Waiting for parts	0	4	0	3.5	2	1	5	0	0	1	0.75	2
Without operator	0	0	7.5	0	0	4	0	0	4.5	6.5	0	4
Planned shutdown	1	0	0	0.5	0	0	2	0	0	0	0	0
Losses (hours)	9.45	9	11	10.5	9.5	14	14.1	11.25	13.25	11.25	14.15	13.75
Losses of machines (hours)	8.45	5	3.5	6.5	7.5	9	7.1	11.25	8.75	3.75	13.4	7.75
Extra hours		7.5			7.5			7.5			7.5	
Effectiveness	58.0%	60.0%	51.1%	53.3%	57.8%	37.8%	37.3%	50.0%	41.1%	50.0%	37.1%	38.9%
Machine effectiveness	62.4%	77.8%	84.4%	71.1%	66.7%	60.0%	68.4%	50.0%	61.1%	83.3%	40.4%	65.6%
Number of machines	A	B	C	Number of days			Working time			Number of shifts		
	3	2	3	5	5	5	112.5	105	112.5	352.5	15	

Table 2b. Preview of JPH Analysis for the 9th Week

Friday			Saturday	Sunday	Total							
A	B	C			A		B		C		Total	
0	2	1	1	0	4		6		4		15	
0	5	1.75	1.5	0	4.5		10.15		5.5		21.65	
1	0	0	0	0	5		3		2		10	
1	0	0	0	0	3.8		4.25		1.5		9.55	
1	2	1	1	0	9		9		6		25	
1	5	1.75	1.5	0	8.3		14.4		7		31.2	
0	0	2	0.5	0	4	3.56%	9.5	9.05%	9	8.00%	23	6.52%
2	1.5	1	1	0	13	11.56%	8.75	8.33%	12.5	11.11%	35.25	10.00%
0	0	0	0	0	0	0.00%	1	0.95%	1.5	1.33%	2.5	0.71%
1	0.5	0	0.5	0	3.75	3.33%	3.5	3.33%	2.25	2.00%	10	2.84%
0	0	0	0	0	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0	0	0	0	0	0	0.00%	4	3.81%	0.5	0.44%	4.5	1.28%
0	0	0	0	0	0	0.00%	2	1.90%	0	0.00%	2	0.57%
0.25	0.25	0.25	0.25	0	1	0.89%	1.25	1.19%	1.25	1.11%	3.75	1.06%
0	0	0	1	0	0	0.00%	0	0.00%	0	0.00%	1	0.28%
0	0	1.5	0	0	9.5	8.44%	6.75	6.43%	4.5	4.00%	20.75	5.89%
8.5	0	7.5	2	0	15	13.33%	0	0.00%	27.5	24.44%	44.5	12.62%
0	0	0	0	0	3.5	3.11%	0	0.00%	0	0.00%	3.5	0.99%
12.75	7.25	14	6.75	0	58.05	51.6%	51.6	48.7%	66	58.7%	181.95	51.6%
4.25	7.25	5	3.25	0	30.05	26.7%	26.7	42.3%	34	30.2%	113.2	32.1%
			22.5		0		30		0		52.5	
43.3%	51.7%	37.8%	70.0%	100.0%	48.4%		51.3%		41.3%		52.4%	
81.1%	51.7%	77.8%	85.6%	100.0%	73.3%		57.3%		69.8%		70.4%	
Number of machines		Average time of a large CHO (min)					86.6		60		90%	
3		Average time of small CHO (min)					57.3		42			

The creation of 3D models of universal pallets was based on the requirements and dimensions of the individual shafts [15, 16, 17]. Fig. 6 and Fig. 7 illustrate the 3D models of the proposed universal pallets. Changes to the current type of pallets:

- the prisms have been replaced by fixed locating bodies on which the shaft is stored,
- a T-shaped groove has been formed in the base plate for displacing the compression spring on the body to provide a fixed position by means of a spring piston,
- creating new shapes of fixed stands.

After modeling all the components and creating in the Catia program, the individual pallet components were then manufactured with appropriate technologies and completed into prototypes (Fig. 8 and Fig. 9).

RESULTS AND DISCUSSION

From the results of the SMED analysis, the longest time to rebuild the honing machine is that of changing the assembly jig. By modifying or creating new universal pallet, a total of 6.87 minutes was saved on one rebuild. The time of one rebuild has therefore decreased from an average of 1.01 hours to 0.89 hours, which is a time optimization of 11.9%.

Observed JPH (Job per Hour) analysis over the 9-week period revealed the following:

- the average number of conversions per week: 18.
- average weekly rebuilding time: 1.01 hours x

18 = 18.18 hours.

- weekly rebuilding time after optimizing its time: 18.18 hours – (18x6.87 min) = 16.12 hours.
- weekly saving time after optimizing of rebuilding time: 18.18 hours – 16.12 hours = 2.06 hours.

Productivity evaluation

Weekly production of toothed shafts produced on 3 machines at 18 changeover operations:

- 76,4 ks/hour x 3machines x (18x8 hours) = 33 004 pcs.
- Annual output at 100% machine efficiency:
- 33004 pcs x 46 weeks = 1 518 184 pcs/year.

Increase the productivity of toothed shaft production after optimizing the weekly rebuilding time:

- 76.4 pcs/hour x 2.06 hours ÷ 157 pcs.
- Annual production after increased production productivity:
- (33004 pcs + 157 pcs) x 46 weeks = 1 525 406 pcs/year.

By optimizing of time rebuilding honing machine was increased annual productivity gear shafts about 7222 units produced, an increase of 0.48%.

Taking account of the machine efficiency

The efficiency of the machine influences the overall productivity of production and should therefore be taken into account when determining it. The following factors influence the efficiency of the machine: maintenance, adjustment outside of rebuilding, profiling, splinters / throwing, rework, sercos, maintenance assistance, tests, centrifuge cleaning, unfulfilled cycle time, part wait, no operator, scheduled outage.

From the JPH analysis, the average machine efficiency was 70%.

Table 3. Productivity of toothed shaft manufacturing

Type of toothed shaft	pcs/hour
Input shaft H1	73
Input shaft H2	72
Output shaft H3	75
Output shaft H4	73
Reverse shaft H5	89
Average number	76.4

Table 4. Comparison of productivity before and after optimization of time rebuilding

	Before optimization	After optimization	Difference
Average rebuilding time per week	18.18 hours	16.12 hours	2.06 hours
Weekly production (100% effectiveness)	33 004 pcs	33 161 pcs	157 pcs
Annual production (100% effectiveness)	1 518 184 pcs	1 525 406 pcs	7222 pcs
Annual production (70% effectiveness)	1 062 729 pcs	1 067 784 pcs	5055 pcs

The annual output of the production toothed shafts after optimization with respect to the efficiency of the machine:

- $7222 \text{ pcs/year} \times 70\% \doteq 5055 \text{ pcs/year}$.

CONCLUSIONS

Single Minute Exchange of Dies is systematic reduction of changeover time by converting possible internal setting time to external time and to simplify and streamline the remaining activity [18,21].

The paper was dedicated to optimizing the timing of the shaft manufacturing operations in the selected company. The goal was to optimize the unproductive time of honing these shafts, thereby increasing production productivity.

Based on an analysis of the production process, it was found that productivity is most affected by non-productive activities that generate non-productive times. These are activities that are linked to the rebuilding of the honing machine. The unproductive time arises during the rebuilding of these machines to manufacturing of another type of shaft, so the analysis was aimed at optimizing the times of rebuilding.

For the analysis of the rebuilding the SMED tool was used, where every single operation was recorded by video. The rebuilding consists of a total of 94 operations and takes 1 hour and 19 seconds. Individual operations were categorized into 14 categories, showing that the automation category had the greatest impact on conversion.

There was selected operation no. 76 - pallet pallets, pallet exchange, which has the longest time not only in its category, but in all the operations of the entire rebuilding, lasting 6 minutes 52 seconds. This operation is best suited for optimization, due to the fact that all other operations are necessary and unchangeable. The optimization of this operation consisted in the construction design of new universal pallets, which need not be exchanged, whereas so far for each type of shaft used a different type of preparation. This saves the entire time of this operation, bringing the optimization of the time of this operation to 11.9%.

After implementing changes in production, overall production of the shafts increased. Productivity evaluation and analysis was performed by monitoring the production process during a 9 week period, where the data were recorded and recorded in the JPH analysis, which showed that

the average weekly rebuilding were 18 and thus 18.18 weekly unproductive.

Thanks to new universal pallets, this time is reduced by 2.06 hours. For this time it is possible to produce 157 pieces more. Annual production increases by 0.48%, which is 7222 units by 100% machine efficiency. But since the efficiency of machines is 70%, the overall increase in shafts' productivity is 5055 units more than before.

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