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LEAD TIME REDUCTION IN MANUFACTURING PROCESS OF TOOTHED PARTS

Abstract: *In manufacturing automotive industrial components, the reduction of machining time and operation spare time detected in the cutting operations can be realized by the modification of technological parameters. However, reduction in the total component manufacturing lead time can be realized to a great extent by re-organization of the production process to eliminate unnecessary waiting periods (e.g. storage, in-process storage, etc.). In our study the total lead times of two different types of components were analyzed by mapping the process in a detailed way. The rate of waiting time within the lead time was analyzed; the theoretical and the measured lead times were compared and the effect of operation sequence on lead time was analyzed. Using these calculations and also measurements the problematic operations were identified and suggestions for process improvement were made.*

Keywords: *operation time; manufacturing process; total lead time; analysis of the production process; standardization process.*

1. INTRODUCTION

One constant and cardinal issue of manufacturing is the continuous increase of productivity. The reasons behind this tendency are the continuous increase in consumption, the decrease in costs and competition among companies [1].

In all cases one significant issue is how much time is required to carry out order-based production, or the time needed for a single specified component manufacturing task. However, the question can be reversed: how much time consumed unnecessarily can be eliminated from a manufacturing process, i.e. is there unnecessary storage, material handling or waiting before starting the subsequent operation? These are called waste times [2, 3]. In Lean-focused manufacturing, which is currently typical in the automotive industry, each activity that creates no added value for the customers is called waste [4, 5]. In one of our former studies, analyses for the lead time of hard machining gears were carried out [6] in which the aim was the optimization of operation times.

Here, the analysis of the machining process of two components was performed. The process is a matured one and its operations are carried out with the latest manufacturing equipment and machine tools by perfectly-equipped workers. A lot size is between 60 and 300 components. In such cases 1 or 2 minutes per piece or even a one-second decrease in time consumption can make a difference [7].

Time consumption is one of the most important parameters of the manufacturing process. In this paper the component manufacturing lead time is analyzed. This parameter is influenced by many factors. However, it is essential because there is a strong relationship between it and the expenses, and hence the first cost of the product. When improving the manufacturing process one goal is the reduction of lead time [8].

One of the most significant components of production lead time is the operation time. Its value tends to gradually decrease. If merely the machining of case hardened components of a transmission system is analyzed, a remarkable change can be observed. Over the years the number of hardened surfaces and the tools and procedures (grinding, hard turning, joint procedure) applied for machining them have been modified. As a result of these changes the lead times have decreased remarkably. The aim of our study is to analyze if there are possibilities for further reduction of lead time from a process organization point of view after these significant developments.

Both the theoretical and actual (measured) values of lead time were determined and compared. Based on the rates of these values the operations in which the greatest differences were found were selected and possibilities for decreasing this ratio were determined.

The general definition of lead time is the period between receipt of the raw materials and the sale of the finished goods [4, 9, 10]. In practice the following three lead time categories are the most frequent: component manufacturing, production and total lead time (Fig. 1). Hereinafter only the manufacturing lead time is analyzed.

Manufacturing lead time is the period between the first manufacturing activity connected to a given order and the beginning of the sales process (finished goods storage is not included in this period). The start point of production lead time is the start of technical preparation. The start point of total lead time is the same and the end point is the end of sales operations.

There is a fourth category: series lead time. Within the manufacturing lead time it refers to one series (a given lot size, identical components). The series lead time is the period in which a production item (lot, series) is finished in a technological phase [12]. Manufacturing a product starts with the machining of the elementary items (components) and then these are connected to each other (assembly). A transmission system is built up from components and/or subassembly units. Joining these elements to get a functional, saleable product takes place in the assembly process. In this paper the lead time of manufacturing process is analyzed by mapping it for two different components.

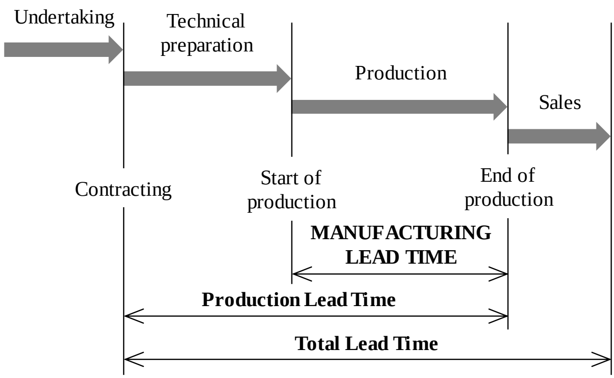

Figure 1 – Structure of the types of lead time [12]

Manufacturing of the analyzed components is characterized by mixed operation sequence (Fig. 2). In this case calculation of lead time ($T_{L,t}$) is the following [13]:

$$T_{L,t} = t_{op} + (n-1)\left(\sum t_h - \sum t_l\right), \quad (1)$$

where t_{op} is the sum of operation times necessary to finish a component; n is the lot size; t_h is a high operation time between two lower; t_l is a low operation time between two higher.

This formula can be used for calculating the theoretical lead time of the production of the analyzed components.

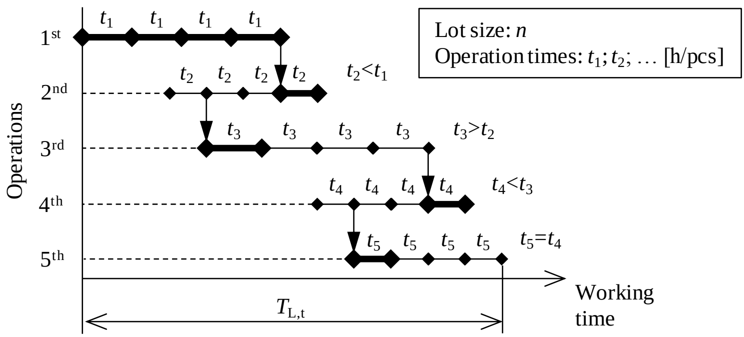

Figure 2 – Calculation of lead time in case of mixed operation sequences [13]

2. METHODS

The analyzed components are parts of two transmission systems (a countershaft and a gear wheel). In the analyzed series the number of countershafts is 60 and the number of gears is 216. The current values of the operation times were available in the SAP ERP system used in the plant where the components are produced. Theywere used for determining the lead time. Conditions and limitations of the study:

- No possibilities were looked for to decrease operation times of machining by technology improvement.
- The reasons for waiting were not analyzed (e.g. machining another component or series on the subsequent workstation).
- In the hardening operation other components are being hardened at the same time. When determining the operation time, the specific time of the analyzed component was not calculated (hardening time divided by the number of components); rather, the current operation time was considered.
- Operation times were not defined by the theoretical (calculated) values, hence no comparison of calculated and measured values was carried out.

3. RESULTS AND DISCUSSION

In Table 1 and 2 the operations of the components are summarized in order of occurrence. In Figs. 3 and 4 the sums of operation times of the components machined in one series are demonstrated (series operation time).

Table 1 – Operations and main activities in manufacturing the countershaft

Sign	Description	Sign	Description
1	Preparation	9	Media removal
2	Gear cutting	10	Washing
3	Deburring	11	Straightening
4	Tooth cutting	12	Cylindrical grinding
5	Tooth chamfering, deburring	13	Tooth grinding
6	Washing	14	Washing
7	Case hardening	15	Quality check
8	Shot peening	16	Final check

In case of the countershaft the operation time of cylindrical grinding can be considered as an outlier. In case of the gear a significant outlier is the operation time value of the 3rd operation (washing) and the 9th (case hardening). The reason for these was that not the operation times (of the whole lot) were recorded in the system but rather another time that included extra waiting. This can be considered as incorrect data recording.

Table 2 – Operations and main activities in manufacturing the gear wheel

Sign	Description	Sign	Description
1	Preparation	9	Case hardening
2	Tooth milling, chamfering	10	Shot peening
3	Washing	11	Media removal
4	Final check	12	Hard turning
5	Preparation	13	Tooth grinding
6	Washing	14	Washing
7	Laser welding	15	In-process quality check
8	In-process quality check	16	Final check

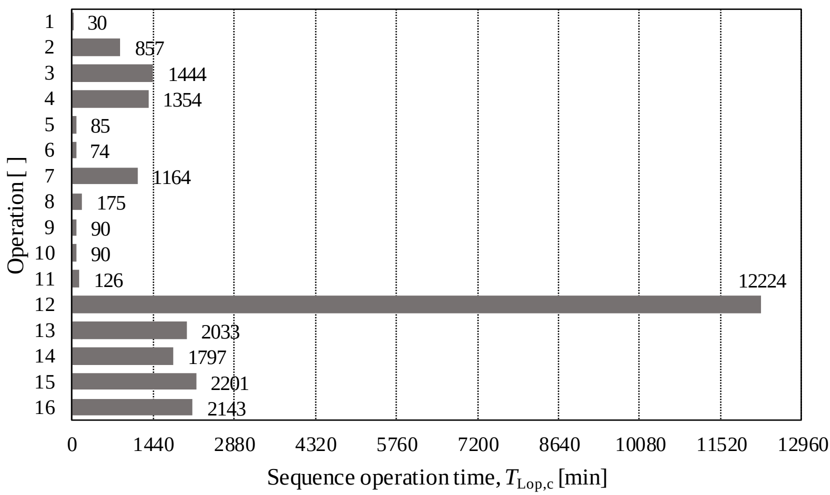

Figure 3 – Series operation times for the countershaft series

Using the technological documentation available at the plant, the theoretical operation times of the series ($T_{op,t}$) were analyzed and then were compared to the values ($T_{op,c}$) obtained from the SAP ERP system. The rates of these values are summarized in Tables 3 and 4 for each operation.

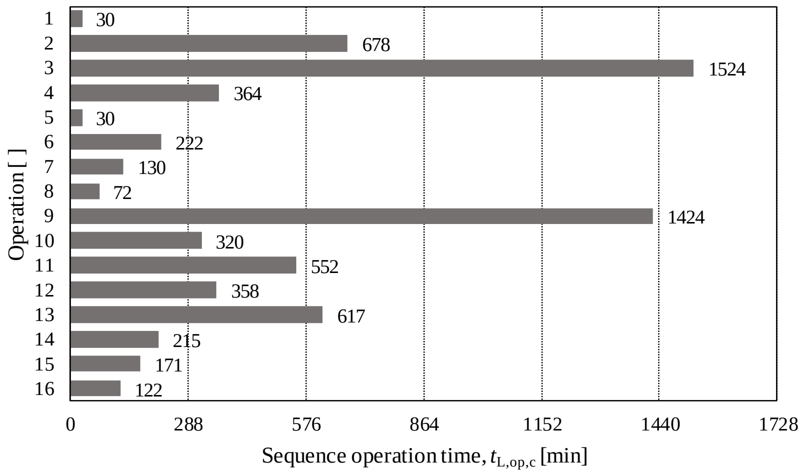

Figure 4 – Series operation times for the gear series

Table 3 – Rates of current and theoretical series operation times – countershaft

Operation	$T_{op,t}/T_{op,c}$	Evaluation	Operation	$T_{op,t}/T_{op,c}$	Evaluation	Operation	$T_{op,t}/T_{op,c}$	Evaluation	Operation	$T_{op,t}/T_{op,c}$	Evaluation
1	1.00	☆	5	0.89	☆	9	1.00	☆	13	3.53	✓
2	3.15	✓	6	2.96	✓	10	0.90	☆	14	52.76	✕
3	17.61	✕	7	10.39	✕	11	0.76	☆	15	64.74	✕
4	2.57	✓	8	3.43	✓	12	31.54	✕	16	119.06	✕

Legend: ☆ - favorable (0-1.2); ✓ - realistic (1.21-4); ✕ - unfavorable (>4.1)

The times for deburring, case hardening, grinding, washing after tooth grinding and the two last quality check operations are considered unfavorable compared to the theoretical values (10-120-fold values) for the shaft.

In the case of the gear wheel the washing, the final check, the case hardening and the shot peening operations are unfavorable based on the calculated indicator. Process activities besides machining operations were also analyzed.

Table 4 – Rates of current and theoretical series operation times – gear wheel

Operation	$T_{op,t}/T_{op,c}$	Evaluation	Operation	$T_{op,t}/T_{op,c}$	Evaluation	Operation	$T_{op,t}/T_{op,c}$	Evaluation	Operation	$T_{op,t}/T_{op,c}$	Evaluation
1	1.00	☆	5	1.00	☆	9	30.96	✕	13	2.07	✓
2	1.31	✓	6	3.00	✓	10	5.71	✕	14	8.60	✕
3	84.67	✕	7	1.00	☆	11	2.56	✓	15	1.58	✓
4	5.60	✕	8	2.88	✓	12	1.02	☆	16	1.88	✓

Legend: ☆ - favorable (0-1.2); ✓ - realistic (1.21-4); ✕ - unfavorable (>4.1)

The thread diagrams of the activities of the production are demonstrated in Figs. 5 and 6 for the two components. A thread diagram highlights which activities of the process can be considered as value-creating and which not. The points of the intermittent line in the first column (machining and other main operations) indicate the value-creating operations and the remaining points are for the non-value-creating activities such as logistics, quality checks or waiting. The quality check and the logistics operations cannot be eliminated; however, their durations or their frequency can be reduced by process reorganization. Waiting is a phase that should be eliminated.

The rate of value-creating activities (16) is 0.36 within the number of all activities for both the shaft and the gear. Rates of waiting times were also analyzed within the lead time and are summarized in Table 5. It can be seen that the rate of waiting in the case of the countershaft is 17% and in the case of the gear it is almost 80%. Both values can be considered as high. Beyond this, the total value of waiting (T_w) itself is quite high: 61 hours of waiting in the production process of 60 shafts.

The production process was also analyzed based on the operation sequence. The production of the shaft and the gear is characterized by the mixed operation sequence. This includes parallel operations too, which means that the lead time is shortened.

#	Sign						Description	#	Sign						Description
	A	B	C	D	E	F			A	B	C	D	E	F	
1	•						Preparation (1)	23						•	Waiting
2					•		Storage	24	•						Media removal(9)
3				•			Conveyance	25			•				Material handling
4						•	Waiting	26	•						Bore washing (10)
5	•						Gear cutting (2)	27			•				Material handling
6			•				Material handling	28						•	Waiting
7	•						Deburring (3)	29	•						Straightening (11)
8			•				Material handling	30				•			Conveyance
9	•						Gear cutting (4)	31						•	Waiting
10			•				Material handling	32					•		Storage
11						•	Waiting	33				•			Conveyance
12	•						Chamfering, debur. (5)	34	•						Cyl. grinding (12)
13				•			Conveyance	35			•				Material handling
14	•						Washing (6)	36	•						Tooth grinding (13)
15				•			Conveyance	37			•				Material handling
16					•		Storage	38	•						Washing (14)
17				•			Conveyance	39			•				Material handling
18						•	Waiting	40		•					Quality check (15)
19	•						Hardening (7)	41			•				Material handling
20			•				Material handling	42		•					Final check (16)
21	•						Shot peening (8)	43				•			Conveyance
22				•			Conveyance	44					•		Storage

Legend: A – Machining and other main operations; B – Quality check;
C – Material handling; D – Conveyance; E – Storage; F - Waiting

Figure 5 – Thread diagram - countershaft

Table 5 – Rate of waiting time within lead time

	Shaft	Gear
Waiting time, T_w [h]	61	165
Lead time, $T_{L,c}$ [h]	367	209
$T_w/T_{L,c}$ [%]	16.75	78.81

#	Sign A	Sign B	Sign C	Sign D	Sign E	Sign F	Description	#	Sign A	Sign B	Sign C	Sign D	Sign E	Sign F	Description
1	●						Preparation (1)	23						●	Waiting
2					●		Storage	24				●			Conveyance
3						●	Waiting	25	●						Hardening (9)
4			●				Material handling	26				●			Conveyance
5	●						T. mill., chamf. (2)	27	●						Shot peening (10)
6				●			Conveyance	28			●				Material handling
7	●						Waiting (3)	29	●						Media removal (11)
8				●			Conveyance	30			●				Conveyance
9		●					Final check (4)	31						●	Waiting
10				●			Conveyance	32	●						Hard turn, grind. (12)
11						●	Waiting	33				●			Conveyance
12	●						Preparation (5)	34						●	Waiting
13					●		Storage	35	●						Tooth grinding (13)
14				●			Conveyance	36				●			Conveyance
15						●	Waiting	37						●	Waiting
16	●						Washing (6)	38	●						Washing (14)
17				●			Conveyance	39				●			Conveyance
18	●						Laser welding (7)	40		●					Quality check (15)
19				●			Conveyance	41			●				Material handling
20		●					Quality check (8)	42		●					Final check (16)
21				●			Conveyance	43				●			Conveyance
22					●		Storage	44					●		Storage

Legend: A – Machining and other main operations; B – Quality check;
C – Material handling; D – Conveyance; E – Storage; F - Waiting

Figure 6 – Thread diagram – gear wheel

The criteria of good operation sequence is [13]: $T_{L,c} << \Sigma T_w$

If the criterion is met, the time efficiency is considered to be good.

The comparison for the two components is included in Table 6. For the countershaft the time efficiency is good but in case of the gear wheel it is not.

Table 6 – Comparison of summarized operation times (total machining process) and lead times of the components

Part	$T_{L,c}$ [h]	t_{op} [h]	Time efficiency
Shaft (60)	367<	431	favorable
Gear (216)	209>	114	unfavorable

Both the comparison of lead and operation times and comparison of lead and waiting times indicates that the production process of the gear is less efficient than that of the countershaft. At the same time the rate of waiting time within the lead time is relatively high in the case of the countershaft.

4. RECOMMENDATIONS FOR PROCESS IMPROVEMENT

There is a need for a more thorough analysis of the revealed problems of the processes in order to reduce or eliminate them. Based on the current analysis the following tasks can be designated:

- Rates of waiting times within the lead times are relatively high (countershaft production: 16.75%, gear production: 78.81%). The reasons for these waiting times have to be identified and analyzed. Then process improvement steps have to be designated.
- Based on the differences between the current manufacturing lead time and the summarized operation time, the production of the countershaft can be considered favorable, while the production of the gear wheel can be considered unfavorable in the plant practice. In the latter case the reasons are the long waiting times and the relatively long operation times (compared to the planned ones). This (for the gear) partly confirms the statement made in the previous point.
- The rates of current and theoretical series operation times are different in some cases: the measured values of 6 operations (or main activities) in the countershaft production and 5 in the gear wheel production can be considered as unfavorable compared to the theoretical values. Based on these results, an in-depth analysis of the unfavorable operations is suggested. The reasons for the differences have to be discovered and organizational steps have to be taken to eliminate them.
- The rate of current and series operation times for the countershaft in operations is 65 times higher than calculated theoretical values, and at the final quality check is 65-120 times higher. The efficiency of these activities has to be studied and process improvement steps have to be introduced.
- Series operation time rates are unfavorable for the washing activity in several cases (5 activities). Analysis and process improvement are also needed in these activities.

In the analyzed process the following methods are suggested. These fit the practice of the plant: cause-effect analysis (e.g. failure tree, 5W1H), Pareto analysis, and value analysis. The improvement consists mainly of organization methods and rationalization steps.

Most of the washing operations are not efficient. The reason for that is the lack of capacity and the overload of resources. Increasing the capacities and reorganization would lead to improvement of washing activities.

On the basis of our estimations the waiting time can be reduced by 25% for the shaft and 40% for the gear.

4. SUMMARY

The production process of two typical components (a shaft and a gear wheel) were studied. Our aim was the analysis of the lead time components. Steps for improving the production process, are suggested to help in the reduction of lead time. In case of the analyszed components the rates of waiting time within the processes were relatively high, which resulted not from technological problems but from organizational shortcomings. The lean production organization system and toolset is applied in the analyzed plant, so we endeavored to build these into our analyses and consider them in recommendations. The next step in both the research and the process rationalization in the plant is the designation of process phases whose improvement is urgent (this can be established after ranking the problems). Next, improvement steps have to be determined and process standardization can be recommended. Analysis of the production process of other similar components may result in a clearer overview about process efficiency. At the same time, results revealed that there are periods in the production process which could be eliminated not by technological improvements but by process organization solutions.

This study introduced a method that can serve as a best practice for the plant to eliminate waste. In summary, it can be stated that the sensitivity of the method is acceptable because the method explores waste using a complex approach and is capable of making waste in the production process more visible.

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ЗНИЖЕННЯ ЧАСУ ПРОЦЕСУ ВИГОТОВЛЕННЯ ЗУБЧАСТИХ ЧАСТИН

Анотація. *При виготовленні автомобільних компонентів зменшення часу обробки і вільного часу, що виявляється в операціях різання, може бути реалізовано шляхом зміни технологічних параметрів. Проте, скорочення загального часу виробництва компонентів може бути досягнуто в значній мірі шляхом реорганізації виробничого процесу для усунення непотрібних періодів очікування (наприклад, зберігання, зберігання в процесі і т.д.). У цьому дослідженні загальний час виконання двох різних типів компонентів були проаналізовані шляхом докладного картування процесу. Система автомобільної трансмісії складається з компонентів або складальних одиниць. Об'єднання цих елементів для отримання функціонального товарного продукту відбувається в процесі складання. У цій статті час виконання виробничого процесу аналізується шляхом зіставлення його для двох різних компонентів. Аналізовані компоненти є частинами двох систем трансмісії (проміжний вал і шестерня). Поточні значення часу роботи були доступні в системі SAP ERP, використовуваної на заводі, де виробляються компоненти і були використані для визначення часу виконання замовлення. Теоретичний і виміряний час виконання замовлення порівнювався і аналізувався для виявлення впливу послідовності операцій на час виконання замовлення. За допомогою цих розрахунків, а також вимірювань були виявлені проблемні операції і внесені пропозиції щодо поліпшення процесу. У разі аналізованих компонентів показники часу очікування всередині процесів були відносно високими, що пояснювалося технологічними проблемами, а організаційними недоліками. Наступним кроком як у дослідженнях, так і в раціоналізації процесу на заводі є визначення фаз процесу, поліпшення яких є невідкладним (це можна встановити після ранжирування проблем). Потім необхідно визначити етапи поліпшення і рекомендувати стандартизацію процесу. Аналіз процесу виробництва інших аналогічних компонентів може дати більш чітке уявлення про ефективність процесу.*

Ключові слова: *зменшення часу обробки; виробничий процес; послідовність операцій; аналіз процесу виробництва; стандартизація процесу.*