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WASTE REDUCTION POSSIBILITIES IN A MANUFACTURING PROCESS

In this paper the manufacturing process of a high load-bearing capacity gear is introduced. These gears are built into truck and bus transmission systems and are machined at a high level of accuracy. The process has particular importance not only because the accuracy has to be ensured but because the machining of precision components requires relatively complicated processes. Here the process was described and quantified for a given component. The focus was on one-piece flow of components and its effect on decreasing lead time. On the basis of the analysis it was shown that one-piece flow can significantly decrease the lead time but the time spent with material handling increases, which results in a load on the operator or the material handling equipment. Therefore, multi-variable optimization is needed. The available results can be used for improvement of manufacturing processes of other component groups manufactured by similar technology.

Keywords: gear manufacturing, value stream mapping, waste reduction, production process improvement

1. INTRODUCTION

Development of machining procedures as production subprocesses can be defined in terms of improvement of material removal efficiency parameters, modernization of manufacturing equipment and reduction of preparation and finish times of manufacturing. Rationalization of preparation and finishing activities is very important in large-scale and mass production because the lead time of a whole series can be decreased significantly. That is why it has to be part of manufacturing process analysis. Toyota recognized this early and has developed its methodology for process rationalization over the past decades [1]. This was followed by the appearance and spread of the lean philosophy, which is one of the most notable manufacturing philosophies nowadays [2].

To determine the trends in the practical application of lean philosophy one study [3] analyzed 311 papers, finding that the lean philosophy was applied only in production planning and organization in the mid-1990s. The results showed that the rate of application in new areas has by 2015. In 2016 application for manufacturing process improvement was 40% of all reported applications. Further areas where interest in the application of the lean philosophy increased in organizational and work processes are for example healthcare [4, 5]; the building industry [6]; telecommunications [7]; environmental protection [8, 9]; maintenance [10]; product development [11] and energetics [12]. A significant part of the lean-focus papers that introduce practical cases suggest value stream mapping (VSM) for the analysis of processes. The elaboration of VSM was done by Rother and Shook [13].

VSM maps the material and information flows of a system and visualizes concretely the value-creating and the waste-creating process phases.

The value stream map describes processes using a relatively low number of illustrative symbols. It can be applied for the visualization of the current situation (current state VSM) and the desired situation (future state VSM) of the processes. The base conception of process improvement procedure is described in Figure 1. The advantages of preparing a VSM are: manufacturing planners can more easily gain an overview of the processes; the location and reason for the problems become easier to determine by the applied metrics; each process element can be measured separately and its effects on the lead time can be quantified. With VSM the areas needing improvement can be recognized more easily [14]. In this paper VSM is applied for modelling the analyzed gear manufacturing process.

Improvement of a manufacturing process, which is also analyzed in this study, starts always with breaking the process into sections and then mapping them. Here many manufacturing and logistics factors have to be considered (e.g. takt time, equipment efficiency, change-over time, work-in-process stock, etc.).

The results of this study focus on the times connected to the manufacturing process. Since the time parameters have several definitions [15], those used here are summarized below. These harmonize with the definitions applied in the plant producing gear wheels. Cycle time (C/T) is the time required for a component to be finished in a workstation (from the beginning of machining of one component to that of the next one). The work process (and within that the cycle time, too) can incorporate value creating and non-value creating time elements. Value creating time (VCT) is the time during which activities are performed whose result means value for the customers. In most cases one component is manufactured in several work stations and in one series several pieces have to be manufactured. The definition of lead time (L/T) connects to the manufacturing process (steps by which raw material becomes a finished good). Lead time is the time during which a batch or series is finished in all the work stations. The sum of cycle time and waiting time (W/T) of one component is the processing time (P/T). These time parameters are the most important initial points of process improvement projects.

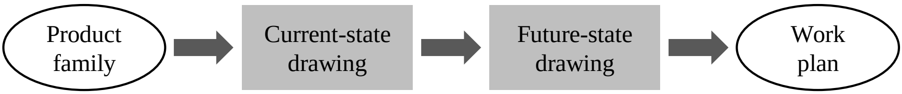

Figure 1 – General methodology of process improvement by VSM [16]

Process improvement can have more than one objective at the same time. Therefore the determination of the order of phases needing to be improved can be a difficult task. There are two main types of process improvement: process reengineering and continuous improvement. In the former case the basics of a process are redesigned at a given point of time and in the latter the rationalization is realized in incremental steps. In our study the latter was chosen because this strategy is preferred by most automotive industrial manufacturers.

The chosen component is a gear wheel. Its manufacturing process was mapped and its time efficiency was analyzed (lead time, cycle time). With the help of value stream mapping the manufacturing process of the component was analyzed.

2. PRODUCTION PROCESS OF GEARS

Highly stressed gear wheels like for example the ones built into transmission systems have to be able to transfer high torque, which is connected to the high rpm depending on the specified modification. These demand a high level of strength and high accuracy in order to decrease the acoustic effects of the final product (transmission). These types of components can be produced only by a sequence of relatively expensive technologies [17]. Beyond the planning and modernization of the technological process (tooling, machines, infrastructure, technological parameters, etc.), process improvement is aimed at the reduction of waste and of non-value-creating time (e.g. change-over time, inventory, etc.). Through this the production costs can be decreased and therefore the market price of the product can also be more competitive. The production process of a gear wheel that meets the requirements above can basically be divided into three parts: soft machining ensuring the primal shape (machining process done before heat treatment); heat treatment ensuring surface hardness and wear resistance, and hard machining procedures ensuring the final shape and accuracy. In the introduction of technological process the quality assurance phases (e.g. in-process measurement) are considered as part of the connecting machining phases and are not detailed in this paper. In an earlier study of ours the results of comparative analysis of hard machining procedures, the analysis of material removal efficiency and the possibilities of accuracy and surface quality improvement were introduced [18]. The technological process analyzed here is almost identical to that featured in the latest literature [19, 20]. The main operations of the manufacturing process can be seen in Figure 2, while the VSM of the process is shown in Figure 3.

The advantage of group production is that the efficiency of machines can be increased by considering the required machining times of the different components if several types of components are produced (with similar need for machining) whose surface combinations and machining times differ. In process production the layout of machines is adapted to the sequence of operations. The advantage of this is short material handling paths and hence a decrease in material handling time. The process analysis performed here adopts this approach.

Measurements were carried out to determine the time parameters: cycle times of technological operations and waiting times between the operations. In a given year several types of gear wheels are produced in a certain production line. If the line is occupied by another component, the gear wheel has wait. In this study the monthly average waiting time of the components produced in a plant was considered.

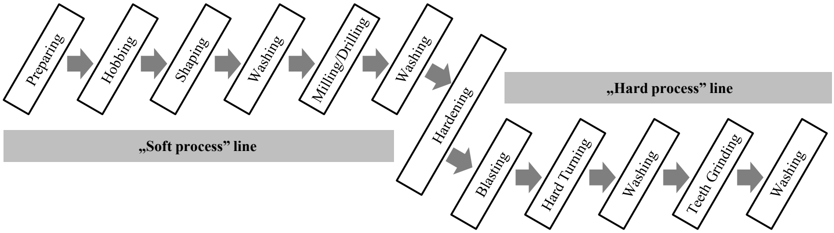

Figure 2 – General sequence of gear production process (Soft process line, hard process line)

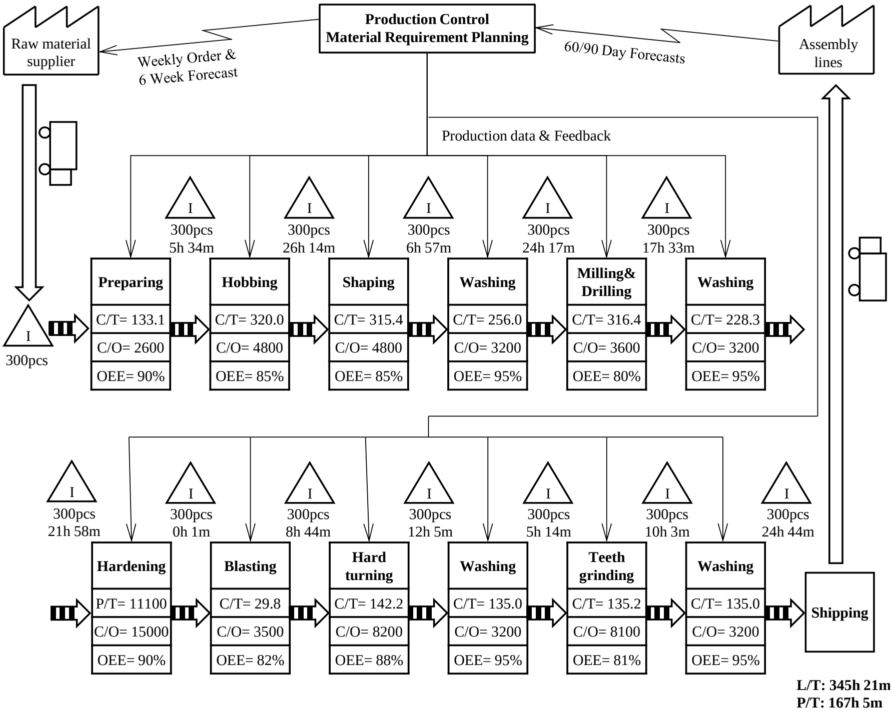

Figure 3 – Current state VSM of the process (C/T, P/T, C/O are indicated in sec) (In case of hardening, the processing time of the series is indicated)

The result of the analysis is that – performing measurements for a series of 300 components – the lead time of the series (cycle times and waiting times of all the 300 pieces) is 345h 21min. The processing time (which incorporates the C/T and W/T) of one component is 167h 5min. The processing time of 300pcs is 182h (including the machining steps and other operations such as washing or hardening). Considering only the processing time as value-creating time, the rate of VCT is 52.7% within lead time that contains no changeover; the operation sequencing is serial. Work stations and machines are not always available at the time specified by the operation sequence. Waiting times between operations are unrealistically long in several cases (e.g. waiting before hardening). In many cases these waiting times include the times when there is no work performed (e.g. at night) or the production of another component is prioritized (e.g. application of pull principle) and the given batch may be produced only many days later. These findings provide us with a clearer picture about the lead time.

3. PROCESS IMPROVEMENT POSSIBILITIES

The lean philosophy focuses on process improvement offers several possibilities depending on what technological operation are involved in the process. In the analyzed process the goal is lead time reduction. According to the literature, the most widely applied solutions are:

- Reduction of cycle time of operations [21].
  - Optimization of technological data.
  - Reduction of manipulation time of tool and workpiece (machine modernization).
- Reduction of in-process waiting times [22, 23].
  - Optimization of flow units of workpieces (e.g. one-piece flow).
  - Implementation of operation sequencing that meets the production needs of the plant.
  - Reduction of cycle times of some operations in order to balance production time (levelling)
  - Allowing in-process buffers (owing to a slower preceding operation the subsequent one can be continuous; supermarket calculation is needed)
- Reduction of change-over time [14, 23]
  - Modernization of production equipment.
  - Automation of production equipment.
  - Ensuring the availability of equipment necessary for change-over with change-over stock.
- Combination of operations [23, 24]
  - Application of machine tools that combine more than one machining procedure.

In the process improvement suggestion we calculated the reduction in lead time gained by the application of one-piece flow. A great extent of the reserves of value creation possibilities are already utilized in the material removal process (manufacturing factories have focused mainly on this in process improvement). This is the reason why the reduction possibilities of non-value-creating times in phases apart from the machining phases were analyzed in this study. Decreasing the machining time can result in lower time savings than the reorganization or rationalization of the whole production process can produce.

4. RESULTS AND DISCUSSION

The process analyzed here (see Figure 2) works in a push system and the workpieces spend a relatively large amount of time waiting between two operations. A suitable layout of the machines for the production process and establishing a material forwarding system (continuous forwarding) makes the one-piece forwarding an option. The analysis focused on how much the lead time is in a plant (existing manufacturing practice) where the pieces of a series are forwarded one by one. Beyond that, changes in the value-creating time proportion of the lead time were analyzed if one-piece flow is applied. One-piece flow can be an objective according to lean practice because it allows continuous production without waiting loss if the cycle times of the operations are identical. If not, the manner of operation sequencing determines the total time of waiting and the number of interruptions. In the case of looped operational sequencing the lead times were calculated by different numbers of forwarded workpieces. This sequencing method ensures that the machine tools and the workstations can work without interruption. The lead time is calculated by Eq.(1) [21].

$$L/T = t_i + (n-1)\cdot(t_l - t_s), \quad (1)$$

where t_i is the sum of operation cycle times; n is the number of components produced in one series; t_l is the sum of cycle times of operations that are preceded and followed by shorter operations; t_s is the sum of cycle times of operations that are preceded and followed by longer operations.

Considering the cycle times indicated in the value stream map (Figure 3) and application of looped operation sequencing, if the whole series of 300 pieces is forwarded between the workstations, the lead time of the series is 182.01h (this is a special case: serial operation sequencing). In the case of one-piece flow this value is 47.31h. The material handling times of the operator are summarized in Table 1.

The lead time can be reduced by 83% compared to the original one (345h 21min) when one-piece flow is applied. The rates of value-creating time within the lead time increase significantly (average 98% from the original 52.7%) because the production is nearly continuous. We analyzed how much time an operator spends on material handling. This provides useful information about the workload of the operator. This time changes as shown in the graph of Figure 4 (W/T). It can be observed that decreasing the stream lot leads to a significant increase in the material handling (manual forwarding to the next workstation) time of the operator for small (1 to 15 pc) stream lots. Similarly, in the case of automatic workpiece forwarding (e.g. by conveyor belt or robot) the forwarding times can decrease but one has to consider the procurement and operating costs of these equipment too as extra costs. The forwarding times are summarized in table 1.

Table 1 – Times of workpiece forwarding

Operation	Time of workpiece forwarding [sec]	Operation	Time of workpiece forwarding [sec]
Preparing	12	Hardening	30
Hobbing	12	Blasting	12
Shaping	12	Hard turning	12
Washing	12	Washing	12
Milling&Drilling	12	Teeth grinding	12
Washing	30	Washing	60

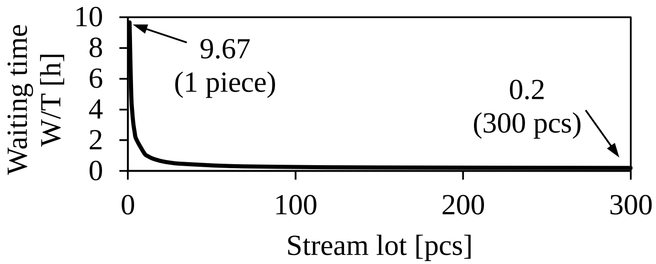

Figure 4 – Times of workpiece forwarding between operations (W/T – waiting time) with changes in the size of stream lots

In the case of one-piece flow the time spent on material handling by the operator increases to the extent that the sum of these times (all workstations in the whole process) reaches 28% of the lead time of the series.

5. SUMMARY

In this paper the lead time of the production process of a typical gear wheel was analyzed. The process was modelled by a value stream map, which reveals various improvement possibilities that are not mentioned in this study. Lead time was calculated by the cycle times of the operations and the waiting times measured between the operations. Looped operation sequencing was suggested in order to operate the machine tools without interruption. It was shown that the total time of in-process waiting decreases significantly. It was also shown that if the stream lot is lower, the forwarding time of workpieces increases significantly with small stream lots. Although there can be several goals of process improvement (beyond lead time and forwarding time reduction, for example the workload of operators, moved weights; cost), they are recommended to be considered simultaneously owing to their interactions. As was shown here, by the application of one-piece flow the lead time can be significantly decreased but the operator time of forwarding within L/T increases greatly.

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