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Improving the Productivity of Manufacturing Process Through the Analysis of Work Measurement Results

Case study

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TIIVISTELMÄ:

On kirjoitettu, että kehitys on tarpeen jokaiselle organisaatiolle, koska eri prosessien suorituskykytaso mitä todennäköisimmin laskee ajan myötä, ellei sitä aktiivisesti mitata, arvioida, paranneta ja ylläpidetä. Mikäli eri prosessien suorituskykytasoa ei aktiivisesti ylläpidetä, se johtaa kilpailukyvyn heikkenemiseen, sillä kilpailijat suurella todennäköisyydellä edelleen parantavat prosessiaan.

Tapaustutkimus on tehty suomalaiselle yritykselle, joka valmistaa tuotteita kansallisille ja kansainvälisille markkinoille. Tämän tapaustutkimuksen tarkoituksena on ensin määrittää valmistusprosessin yleisimmät esteet ja toiseksi selvittää, miten valmistusprosessia voidaan parantaa tuottavuuden lisäämiseksi.

Tässä tutkielmassa hyödynnettiin tapausyhtiössä vuoden 2021 aikana tehdyn aikatutkimuksen toissijaisia tietoja sekä työn mittausta koskevaa kirjallisuuskatsausta ja erilaisia menetelmiä, joilla pyritään tuottavuuden parantamiseen jatkuvalla laadun ja/tai prosessin kehittämismenetelmillä, kuten jatkuva parantaminen, Lean ja Six Sigma. Toissijaisen tutkimuksen tulokset ovat muokattu tapausyhtiön nimettömyyden vuoksi.

Aikatutkimuksen tulokset vahvistivat, mitä tapausyhtiössä oli havaittu. Valmistusprosessin viivästymiseen oli neljä pääasiallista syytä. Siksi opinnäytetyö vastaa sille annettuihin vaatimuksiin. Opinnäytetyö antaa pohjan jatkotutkimukselle saman tutkimuksen jatkumona tai rinnakkaisten toimintojen parissa, lisäksi opinnäytetyö kutsuu uusia lisätutkimuksia työn mittaamisen alalla.

AVAINSANAT: work measurement, manufacturing process, productivity, time study, work study, lean, six sigma, continuous improvement, aikatutkimus

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ABSTRACT:

It has been written that improvement is necessary for every organization since the performance level of different processes is likely to decrease over time unless it is actively measured, evaluated, improved and maintained. Lack of doing so, will lead to loss of competitiveness since the competitors are still likely to continue improving their processes.

This case study has been conducted for a Finnish company manufacturing products to national and international markets. The purpose of this case study is to first establish the most common hindrances in the manufacturing process, and secondly to find out how to improve the manufacturing process to increase productivity.

This thesis used secondary data from a time study conducted in the case company during 2021, as well as literature review on work measurement, and different methods which aim at productivity improvements through continuous improvement (CI) methods on quality and/or process, including Lean and Six Sigma. The results of the secondary data have been modified due to the anonymity of the case company.

The results of the time study proved what had been observed on the case company factory floor. There were established four main causes of delay in the manufacturing process. Therefore, the thesis answered the requirements given to it. The thesis gives basis for further study in the line or in linking operations, yet it also calls for further study in the field of work measurement.

KEYWORDS: work measurement, manufacturing process, productivity, time study, work study, lean, six sigma, continuous improvement, aikatutkimus

Contents

1 Introduction 8
1.1 Research question, objectives, and limitations 9
1.2 Structure of the thesis 10
2 Literature Review 11
2.1 Productivity and how to improve it 11
2.1.1 Continuous improvement 13
2.1.2 Lean manufacturing 14
2.1.3 Six Sigma 15
2.2 Work Study 16
2.2.1 What is work study 16
2.2.2 Work measurement methods 17
2.2.3 Non-value added work 19
2.2.4 Pace rating 19
2.2.5 Allowances 19
3 Research Method 20
3.1 Research approach 20
3.2 Data collection 20
3.3 Current State Analysis 20
3.3.1 Manufacturing process 21
3.3.2 Work measurement process 22
3.4 Reliability and validity 22
4 Results 23
4.1 Time study results 23
4.2 Timeline 26
4.3 Delays and allowances 27
5 Conclusions 34
5.1 Suggestions for improvement 35

5.2 Recommendation for future study 37

References 39

Figures

Figure 1. Six Sigma DMAIC-circle 15
Figure 2. Workstations involved the Product manufacturing process 21
Figure 3. Breakdown of working time by time type 24
Figure 4. Breakdown of working time by workstation 25
Figure 5. Total delays by category (percentage) 28
Figure 6. Total delays per category 29
Figure 7. Total allowances & non-value added by category (percentage) 31
Figure 8. Total allowances & non-value added by category 32
Figure 9. Total delays by category (minutes; percentage) 33

Tables

Table 1. Total assembly time split - actual 23
Table 2. Total assembly time split by workstation - actuals 24
Table 3. Timeline of the Product manufacturing 26
Table 4. Delay duration by category 28
Table 5. Total non-value added by category 30
Table 6. Allowances included in total non-value added by category 30

Abbreviations

CI	Continuous improvement
DMAIC	Define, Measure, Analyse, Improve, Control
MTM	Methods-Time Measurement
PDCA	Plan, Do, Check, Act
PMTS	Predetermined Motion Time Systems
TMU	Time Measurement Unit
TPS	Toyota production system
WM	Work Measurement

1 Introduction

When I think of production in any factory, I see it as the centre of the whole organization. It is the core that turns single components into something of value that the customers are willing to pay for. This is the simple world.

In more complex world companies also need to make profit – the more the better. There are different kinds of methods for increasing profits: sales prices could be increased, or on the other hand costs could be reduced. In production cost reduction means being more productive – doing more in less time.

There is also another point of view as Björn Andersen (2007) puts it in his book "Business process Improvement Toolbox". He sees that improvement is necessary for every organization since the performance level of different processes is likely to decrease after some time unless it is somehow actively maintained. If a company does not make any effort towards improving its processes, it will lose competitiveness, as competitors are still highly likely to improve their processes.

This thesis is conducted for a Finnish company manufacturing products to national and international markets. The need for this case study rises from the company's strategy. One of the company's strategic objectives is to create growth from its competitiveness. Almost anywhere one looks, while describing "competitiveness" word "productivity" is used. Productivity is believed to lead to growth, which in succession brings money and with that comes well-being organization (Cann, 2016).

As well as the strategic need, there are also day-to-day issues, which call for deeper analysis and ideas on how to improve productivity of the manufacturing process. As the sales department is requested to increase prices, the customers request shorter lead times. In the current circumstances, however, the production unit sees it is unable to commit to any shorter lead times.

To find out what could be done to increase productivity and to name the biggest obstacles hindering the manufacturing process, the company decided to conduct work measurement study.

In the coming chapters I shall talk more about what is meant by work measurement study, what kind of methods can be used to carrying it out. In 2011 EK-SAK Tuottavuusryhmä (Ahokas et al., 2011) defined work study, and how they see it in Finland. I shall base my viewpoint in this context.

Further in the thesis I shall elaborate on what kind of results were received from the work measurement conducted in the case company. After which, I shall analyse the secondary data and based on these findings I will suggest actions which could develop the process, and thus improve productivity.

1.1 Research question, objectives, and limitations

The case company has recognized that there is room for improvement in the manufacturing process' productivity. Some general ideas of the biggest manufacturing disturbances are in mind, yet they are unable to pinpoint the specific obstacles.

Therefore, two research questions were recognized. Firstly, what are the current main hindrances of productivity in the manufacturing process? And secondly, how to improve the manufacturing process to make it more productive?

The objective of this thesis is to find answers to above mentioned questions. My goal is to pinpoint the main hindrances, which have risen in the work measurement results as well as to give suggestions on what could be done in order to improve the manufacturing process for better productivity and thus reach shorter lead times.

It should be noted that this thesis is only limited to the surveyed production lines, therefore, the results will not be applicable even within other production lines within the same factory. I am to concentrate only in the manufacturing process and will not be covering possible hindrances in the linking operations, such as procurement or design engineering.

This thesis includes some classified information and therefore, the results have been modified due to the anonymity of the case company.

1.2 Structure of the thesis

This thesis begins with introduction to the researched topic. The first chapter introduces the research questions, what is the objective of this thesis as well as what are the limitations.

After the introduction the reader is introduced to the theoretical part of the thesis. I am to talk about what is productivity and what different kinds of productivity improvement methods there are. I shall talk in more detail about what is meant by work measurement and what kind of methods there are to conducting it. Background theory for the thesis has been gathered from various sources, such as academic articles and publications.

In the third chapter I will talk about the research method and describe the current state of the manufacturing process of the case company. In the fourth chapter I will go through the results of the work measurement study conducted at the case company and establish the most common hindrances in the productivity of the manufacturing process.

The final chapter, conclusions, will tie up the whole thesis. There I shall analyse the results and give some suggestions on what could be done to improve the productivity of the manufacturing process, as well as I shall give suggestions for possible future research.

2 Literature Review

Regardless of method, improvement program, or production philosophy applied to increasing productivity, it is important to know what factors affect productivity (Almström, 2013). First in this chapter I will talk about productivity and on high level about some of the methods for improving it. But as Muthiah and Huang (2006) say: “one cannot improve what one cannot measure”. Therefore, I will write in chapter 2.2 in more detail about work study and its methods.

2.1 Productivity and how to improve it

Productivity and how to increase it has been under researcher and investigation since the Industrial Revolution (Usubamatov, 2021; Grünberg, 2003). Muthiah and Huang (2006) write about increased competition creating a need for productivity improvement methods.

Almström (2013) introduces a productivity model, which highlights first three factors and then further develops the model with two more factors, which have an effect on improving productivity at the shopfloor level:

- improving working methods
- increasing performance
- increasing utilization
- improving product design, and
- reducing scrap

The equation 1 visualizes the expanded productivity model:

$$\text{Productivity} = M \times P \times U \times Q \times D \qquad (1)$$

In equation 1 method factor (M) is the ideal or intended productivity rate, which is the inverse of the ideal cycle time. Almström (2013) claims it is vital to use predetermined time systems, such as MTM, to determine the ideal cycle time. If other system is used, such as stopwatch method, the result will not be the ideal cycle time since the result is affected by performance (P) and utilization (U) factor. The performance factor advises the speed the work is carried out in relation to the ideal cycle time (below or above 100 %). The utilization (U) factor tells the time used performing the work in relation to the planned time (can be max 100 %). The quality (Q) factor is yield or 100 % minus the scrap rate, and the design (D) factor, which is the factor for improving the design to lower the manufacturing and assembly costs.

It has been researched (Almström et al. 2011; Almström 2013) that it is much easier to improve the method factor than the utilization factor. This is due to the fact that utilization factor is human affected, it is affiliated with company culture and the management style. The working methods are easier to change.

The shopfloor improvements are not the only ways of improving productivity. Almström (2013) writes about Taylor (1911), who was probably the first ones to also consider people's motivation and increasing it, as a method for productivity improvement. The Hawthorne studies by Elton Mayo and Fritz Roethlisberger from 1920s, found that the socio-technical factors influenced motivation and productivity increased. The studies claimed that the employees were motivated not only by pay, but also by sense of belonging. The productivity increased as the employee felt comradery and recognition. (Gitman, 2018)

Therefore, it is not only the improvements in the methods, but also improvements in the people's motivation that leads to improved productivity. There are several different kinds of methods, which aim at productivity improvements through continuous improvement (CI) methods on quality and/or process.

2.1.1 Continuous improvement

Giving employees the chance to develop their work does not only add to the engagement and greater motivation of the employees (Gitman, 2018; Thamizhmanii & Hasan, 2010), but it also creates competitive advantage for the organization. In Japan in the 1950s the idea of creating an organization culture where everyone could be able to improve the process, was developed.

The basic idea of CI is to create small continuous improvements in process and working methods, with as little money and risk as possible. Eventually these small improvements will lead to wholesome transformation in performance (Santos et al., 2006; Näslund, 2008, 275).

Plan-Do-Check-Act (PDCA)-cycle, also known as the Deming cycle, is perhaps one of the best-known ways of demonstrating CI (MCS, 2020):

- Plan – define the issues, analyse it, and create a plan. It is important to decide whether the issue is worth solving, who are affected by the issue, and how and who does the solution affect. It is also important to understand the root causes.
- Do – implement the plan and make any changes required to ensure it works. It is important to acquire any measured data that is available to help in decision-making later.
- Check – evaluate the results and identify opportunities for improvement. It is important to find answers on did the plan work, what worked and what still needs to be improved, what can be learned from this, and is this the right solution which will be carried on with.
- Act – make adjustments based on what is found in the previous step. It is important to pay attention to questions like what resources are needed to take the change through the organization, how to maintain the change, how to measure the impact of the change; and if the plan did not work, the cycle needs to start over again.

2.1.2 Lean manufacturing

The roots of lean manufacturing lie in the early nineteenth century, when Henry Ford started using mass production in his works. After that the Japanese took the method further, and after the World War II the Toyota production system (TPS) i.e., lean manufacturing was developed by Taiichi Ohno. (Bhuiyan & Baghel, 2010, 763)

Lean process consists of five aspects (Näslund, 2008, 274):

- Value – defining the value in the given process
- Value stream – Identifying the value stream of steps in the process that add value
- Flow – no interruption between the activities in the process. All non-value adding activities should be removed or at least minimized
- Pull – nothing to be made unless the next activity/customer needs it
- Perfection – going through the steps in the process continuously for the process to excel

Lean manufacturing aims at removing waste, "muda", from production. Waste is seen as something that the customer will not pay for, i.e., which does not add value to the product. The target is to add value to the customer, shortening of lead times, and minimizing process costs. Taiichi Ohno identified seven types of waste, which can be found in any process:

- Transportation – unnecessary movement
- Inventory – parts laying in stock or finished products waiting delivery
- Motion – excess movement of people
- Waiting – unnecessary waiting between the different manufacturing steps
- Over-processing – excess working on goods
- Over-production – production of unnecessary products
- Defects – defects in the product

To these seven wastes identified by Ohno, Womack and Jones (2003) talked about eighth and ninth waste: goods and services, which do not meet the customer needs and underutilization of people. (Womack & Jones, 2003)

2.1.3 Six Sigma

The roots of Six Sigma are in the 1980s at the Motorola factory, where it was created for increasing productivity and for helping in removing operational waste. Where Lean manufacturing seeks to reduce waste in a process, Six Sigma aims at reducing variation in a process i.e., a more stable and predictable process. (Bhuiyan & Baghel, 2010, 763)

Six Sigma uses the process of Define, Measure, Analyse, Improve, and Control (DMAIC) to tackle the process variation and to minimize waste. DMAIC-cycle begins with defining the issue needing to be tackled. It is then measured, and those results are analysed to give a precise view of the matter. Improvements are applied, and then controlled for the best and sustainable remedy. DMAIC is a continuous process, a cycle that repeats itself repeatedly (Figure 1).

Figure 1. Six Sigma DMAIC-circle

2.2 Work Study

2.2.1 What is work study

Work study is a term used for systematic methods and techniques, such as work measurement, which are used to examine human work. Work study aims at systematic investigation of all aspects affecting efficiency and economy of the investigated issue in order to improve the matter. (ILO, 1979, 29)

Work study aims to look at work from three different aspects: economic, technical, and employee aspect.

- The economic aspect aims at finding out the economic impacts on work – what work adds value, causes delays and extra cost; it aims to find out the bottlenecks in the process; what work is repetitive, takes time and requires extra material movement.
- The technical aspect aims to find out possibilities to adopt new tools, techniques, and technologies in the process.
- The employee aspect considers the ergonomics and safety of the process, for example, are there working stages that require repetition, are monotonic, or otherwise hazardous for health and safety. (Ahokas, et al., 2011, 6)

There are four parts to work study: method studies, work standardization, work guidance, and work measurement (WM).

- Method study is systematic development of an economic, profitable, and safe working method for a certain job. All elements of the job cycle are evaluated including the materials, machinery etc. It is important that also the layout, ergonomics, and other working conditions are taken into consideration while developing the working methods.
- Work standardization makes sure that once an effective way of carrying out a job is found, all employees will start using it. Ahokas et al. (2011, 6) point out, that development does not stop, even though a standardized way of working has

been found. Development should still be carried out, for example, through the methods of continuous improvement. Work instructions, job descriptions, and standardizing elements of the job can help in standardizing the whole work cycle.

- Work guidance makes sure the employees know the safest, most effective ways of working, and that they can use the standardized working methods.
- Work measurement (WM) is recording a certain task and how much time carrying out the task takes. There are different methods to carrying out WM. These will be elaborated on in the following chapter 2.2.2. (Ahokas, et al., 2011, 6)

The results of work study can be utilized in different uses (Byrne, n.d.):

- pricing of the products
- capacity/resource analysis
- production control
- sales offers
- wage negotiations
- benchmarking

In Finland the Act on Co-operation within Undertakings 16 § (L30.12.2021/1333) stipulates, that when the employer is about to make some changes for example in the working methods or working conditions, it is obliged to discuss the issue with the employee representative (Finlex, 2021). Therefore, it is mandatory to advise the employees about the upcoming work study.

2.2.2 Work measurement methods

There are different methods to conducting work measurement. Which method to use, is determined based on the purpose of the work measurement. The difference between observation and time studies vs. PMTS is that when conducting observation and time studies the observer must be physically there, whereas PMTS uses estimates.

2.2.2.1 Observation study

Observation study implies the observer physically observes and writes down how many actions of predetermined type there are during a certain time range. After the study it can be established how the total work time is divided. (Ahokas et al., 2011, 24)

2.2.2.2 Time study

Time study is used to setting the standard time for carrying out a specific work. For the time study to be accurate the operator (person carrying out the work) and the observer (time study engineer) must be fully qualified to do the work. The work to be carried out together with the working conditions must be clearly defined. The standard time is established by the observer timing the specific operations needed in completing the work and at the same time s/he rates the pace of work. (Whitmore, n.d.)

As the observer times the work, s/he records the time usually in centiminutes (0,01 min). Rating is used to adjust the actual times to standard times. This is done, since the working speed differs depending on the person doing the work. (Whitmore, n.d.) Since the reason is to time the time needed to complete the work, and not the operator’s working speed, rating is needed.

2.2.2.3 Predetermined motion time systems (PMTS)

The roots of PMTS lay in the 1920s, when the method was first introduced by F. Gilbreth. Gilbreth analysed work into basic actions, which were timed and put in a table. In the coming years Gilbreth’s method was revised and came more known Work-Factor and Methods-Time Measurement (MTM). These systems consider all basic actions, such as walking, kneeling, reaching, sitting down, inspecting, eye focus, calculating etc. (Whitmore, n.d.)

The basic idea of PMTS is to break a work into its basic actions, times for these actions are looked up from a table depending on which system is being used e.g., MTM or Work-Factor. In MTM the unit being used is time measurement unit (TMU), one hour is 100 000 TMU. The times are adjusted based on moved distance as well as the difficulty of the required action.

2.2.3 Non-value added work

In completing a work there is also work to be considered, which does not complete the work, yet taking care of these tasks is necessary to complete the work. It also includes time used for personal needs and recovery from fatigue. This is called non-value added work and it is measured as minutes per work day. (Ahokas et al., 2011, 11)

2.2.4 Pace rating

To tackle the fact that some people work faster than others, pace rating is used in work measurement. The pace rate is valued as 100 (pace rate = 1,0), which means the person is working at normal pace. If the person was working slower than normal, pace rate is 90 (pace rate = 0,9), and if working faster than normal then pace rate is 110 (pace rate = 1,1). Pace rate is determined by the work measurement engineer, therefore her/his skills are vital. (Ahokas et al., 2011, 16)

2.2.5 Allowances

There is extra time allowed for different conditions, which is taken into consideration when drafting the time measurement. These allowances are for example relaxation allowance for recovering from the workload (fatigue), personal needs, adverse environmental conditions, and some others, which are concerned with machine operations. (Whitmore, n.d.)

3 Research Method

3.1 Research approach

This thesis is a case study, and I will be using inductive approach. I am trying to establish some larger themes from smaller occurrences, which have been found in the source data. Since I am also trying to establish how things ought to be in future, it can be said that the research question is normative.

3.2 Data collection

In this thesis I will be using secondary data. There was an external time study engineer (later referred to as the timer) called in to record a project aiming to manufacture a Product for an international client during the summer and autumn of 2021. The data includes timed periods as well as written explanations of what has been happening at which point of the data collection period.

Some of the data used in the thesis comes from observing the workstations myself, and thus previously gathered information of the working methods and processes of the case company.

3.3 Current State Analysis

The aim of the research was to improve the productivity of the manufacturing process. The research began by establishing the current state of the manufacturing process via work measurement study. First, the manufacturing process will be described and then the work measurement process will follow.

3.3.1 Manufacturing process

There are five different workstations involved in the manufacturing of the Product (Figure 2). Workstation 3, Assembly C, was timed during summer and the rest of the workstations during autumn, when the product itself was manufactured.

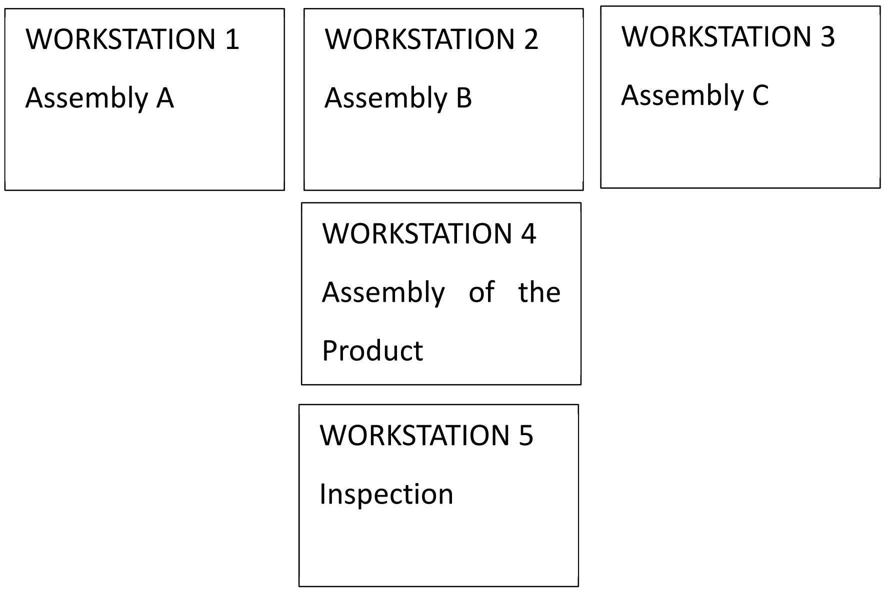

Figure 2. Workstations involved the Product manufacturing process

The estimated (planned) working hours were 25 h in total. These hours are divided so that assembly of the Assembly B will take four hours, assembly of the Assembly C takes five hours, and the Assembly A, assembly of the Product and inspections take 16 hours altogether.

Limitations to the manufacturing process are brought by limited resources – there are only certain operators that have the knowledge of the parts to be manufactured. Therefore, even though concurrent assembly is possible between workstations 1, 2, and 3, the final assembly cannot start before the assembler at Workstation 1 is ready to continue to the Workstation 4.

At the time of the time study, the factory did not use time tickets per job to record the hours. Therefore, the actual working hours were estimated at the time the job was completed. If there were delays during the manufacturing process, for example due to quality issues, these were not visible anywhere. Also, the material handling, collecting parts from the warehouse, were included in the manufacturing hours.

3.3.2 Work measurement process

There were two separate occasions, when the timer was called in to conduct time study. During the summer of 2021 he came to time the assembly process of Assembly C. The second time the timer came in at the beginning of autumn of 2021, when the manufacturing of the Product began. Since the factory wanted to find out what is the standard time for manufacturing the Product, the chosen study method was time study, more precisely stopwatch method. The observed workstation operators have obtained more than 10 years of working experience in the line of the study.

3.4 Reliability and validity

The data used for the thesis, was gathered by a trained and experienced time study engineer, who observed operators with a working experience of over 10 years each. As per the timer's experience, the timed results demonstrated what he views as typical assembly workstations. The timed results were also in accordance with the planned (estimated) manufacturing hours.

However, it should be taken into consideration that in Finland the calculation methods and handling the results of the time study differ from international methods, for example in the way how pace rate and allowances are treated (Ahokas et al., 2011, 22).

4 Results

As was established in chapter 3.1.1 Manufacturing process, the planned working hours for the Product were 25 h altogether. The hours were divided between the different workstations accordingly: Assembly B four hours, Assembly C five hours, and Assembly A, assembly of the Product and inspections take 16 hours.

4.1 Time study results

The time study results show actual manufacturing hours for the Product were some 30 h in total (Table 1). However, if a calendar timeline was drawn, manufacturing of the Product took two weeks and a day, which totals some 88 h (11 working days * 8 h/work-day). The timeline will be discussed in the following chapter 4.2.

Assembly time split - actual		min	h	% tot.	% of working time
Jal	Value added work	87,0	1,4	42,24 %	51,73 %
Hä	Delay	42,3	0,7	20,55 %	25,16 %
Apu	Non-value added work	38,8	0,6	18,87 %	23,11 %
ELP	Allowances (coffee break & fatigue) (lunch not processed)	37,8	0,6	18,34 %	
		205,9	**3,4**		

Table 1. Total assembly time split - actual

The Table 1 above depicts the time split between the different time types. It was measured that the total value added work time was 1,4 h. There were 0,7 h of delays of various kinds. Non-value added work took 0,6 h, and allowances, which includes coffee breaks and fatigue, yet not lunch break, some 0,6 h.

Figure 3 demonstrates the time types in a form of a pie chart, which shows that the total value added time is 42 % of the total manufacturing time, delays, non-value added work, and allowances take all about 20 %. Ahokas et al. (2011, 13) claim that typically the value adding processing time is less than half of the whole working day.

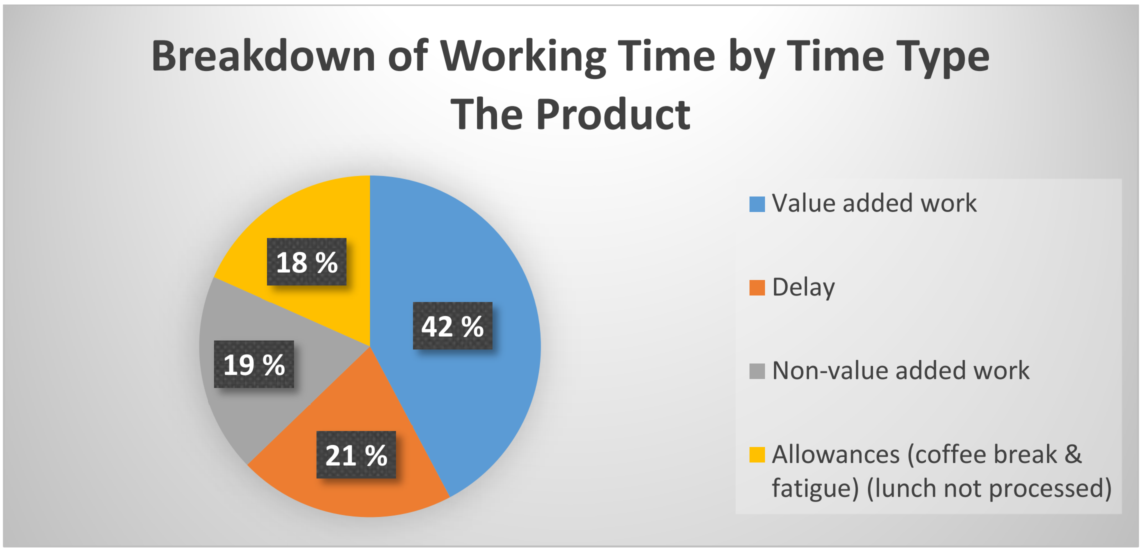

Figure 3. Breakdown of working time by time type

Next, we can see how the manufacturing times were divided between the different workstations (Table 2). In the table the actual time is the clocked time. T-time (h) has been calculated as

T = (actual time x pace rate) x rate of non-value added work (2)

Part	Actual (h)	Delays (h)	T-time (h)
Workstation 1 - Assembly A	9,40	3,35	9,13
Workstation 2 - Assembly B	2,86	1,45	2,49
Workstation 3 - Assembly C	5,16	0,77	5,47
Workstation 4 - The Product	7,83	3,46	7,50
Workstation 5 - Inspection	4,51	1,98	4,38
Total	**29,75**	**11,01**	**28,98**

Table 2. Total assembly time split by workstation - actuals

As can be seen from the Table 2 above most of the total manufacturing time 9,4 h goes at the workstation 1 – Assembly A. Some 7,83 h is taken at the workstation 4 – final assembly of the Product. The assembly of Assembly C at workstation 3 and the inspections at workstation 5 take some 4,5 h each and workstation 2, Assembly B takes some 2,5 h.

Table 2 also shows how much delays were encountered at the each of the workstations. These values, however, are not the norm, but timed during this certain manufacturing process. Workstation 4 – final assembly faced the most delays, 3,46 h. Workstation 1 – Assembly A 3,35 h, and the rest of the workstations had less than two hours of delays. The delays will be further elaborated on in chapter 4.3.

Figure 4 below demonstrates the breakdown of working time by workstation in a pie chart. Workstation 1 took some 32 % of the total manufacturing time, workstation 4 took 26 %. Workstations 3 and 4 took some 15 %, and workstation 2 took 10 %.

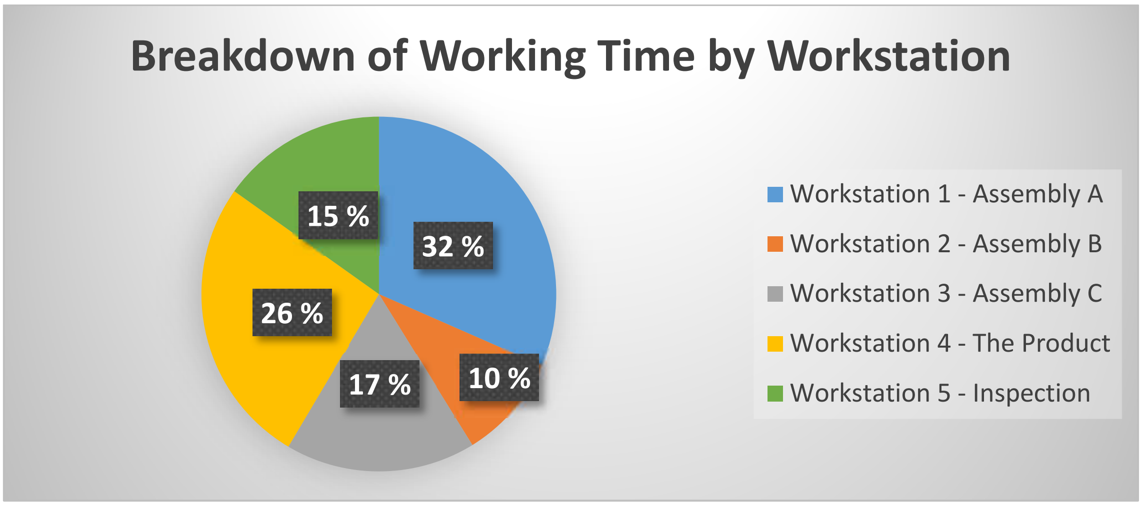

Figure 4. Breakdown of working time by workstation

4.2 Timeline

When the manufacturing process of the Product is drawn on to a timeline, it can be seen that the manufacturing process took some 88 h (11 working days * 8 h/workday) (Table 3).

		Date	Main job	Workstation
1	Mon	6.9.2021	Assembly A	Workstation 1
	Tue	7.9.2021	Assembly A & Assembly B	Workstation 1 & 2
	Wed	8.9.2021	Downtime - Quality of the part in Assembly A	
	Thu	9.9.2021	Assembly of the Product	Workstation 4
	Fri	10.9.2021	Finalizing Assembly A, mid inspection	Workstation 1 & 5
	Sat	11.9.2021	Weekend	
	Sun	12.9.2021	Weekend	
2	Mon	13.9.2021	Downtime - knowhow	
	Tue	14.9.2021	Assembly of the Product	Workstation 4
	Wed	15.9.2021	Final assembly - The product waiting for a part, *otherwise ready*	Workstation 4
	Thu	16.9.2021	Downtime - Quality of the part	
	Fri	17.9.2021	Downtime - Quality of the part	
	Sat	18.9.2021	Weekend	
	Sun	19.9.2021	Weekend	
3	Mon	20.9.2021	Final inspection - The Product ready	Workstation 5

Table 3. Timeline of the Product manufacturing

Table 3 depicts the timeline of the whole manufacturing process of the Product. As can be seen from the table, already during the first days of the manufacturing there were some hindrances in the process – missing material and quality of the material.

During the days there was downtime in the manufacturing again. In the middle of the process there was lack of knowhow, since the assembly of this kind of product requires special kind of knowledge, and the operator was not available. At the end of the process another quality issue with material was detected.

During the process, the first days' quality issue with material was tackled, and the operator was able to finalize the Assembly A. The operator then continued to finalize the

Product but detected that the previous attempt at fixing the quality issue with the material had been in vain. The Product was otherwise ready at this point, but new material was ordered now.

The coming days of manufacturing went in waiting for the new material. At the end of manufacturing process new material arrived, which was a good fit, and the Product could be finalized. Final inspection was conducted, and the Product was ready to be packed for delivery.

To recap, there were 25 h estimated for manufacturing, 30 h were timed, yet the calendar timeline depicts 88 h total manufacturing hours.

4.3 Delays and allowances

The results revealed that there are different kinds of hindrances in the manufacturing process. The delays were divided into seven different categories (Table 4) based on what kind of issue was at hand.

Design-category was related with design, such as designer using wrong material or there was a mistake in the drawings. Flow of information -category was awarded to delays concerning issues with SAP not functioning correctly or instructions not found as should. Material missing -category was concerned with issues related to material not being on time or it was not ordered. Operator mistake -category was concerned with issues, where the assembler had caused the delay himself. Other-category was given to any other kind of delay than what was already categorised. Quality of the parts -category concerned quality issues, for example where the operator had to fix material for it to fit, and warehouse-category was a delay caused by the warehouse, for example it had collected the wrong parts by mistake, or the parts were not found in the named storage location.

Category	Sum / Duration/min
Design	8,85
Flow of information	6,37
Material missing	20,27
Operator mistake	21,37
Other	5,37
Quality of the parts	24,39
Warehouse	13,40
Total	**100,01**

Table 4. Delay duration by category

Looking at the results in the above Table 4, it can be seen that the most delays were caused by the quality of the parts, some 24 minutes, operator mistakes some 21 minutes, missing material some 20 minutes, warehouse some 13 minutes, design almost nine minutes, and flow of information and other about six minutes each.

Figure 5 shows the total delays by category as a percentage.

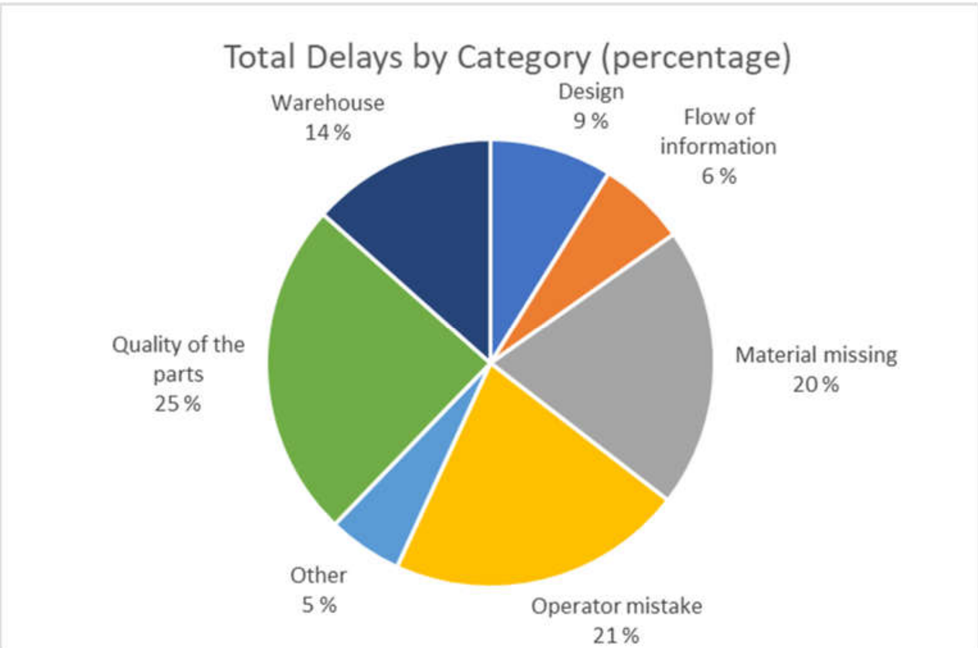

Figure 5. Total delays by category (percentage)

Figure 5 above depicts that quality of the parts caused 25 % of all delays, operator mistakes 21 %, missing material some 20 %, warehouse 14 %, and design, flow of information and other less than 10 %.

Figure 6 below depicts the total delays by category as a histogram.

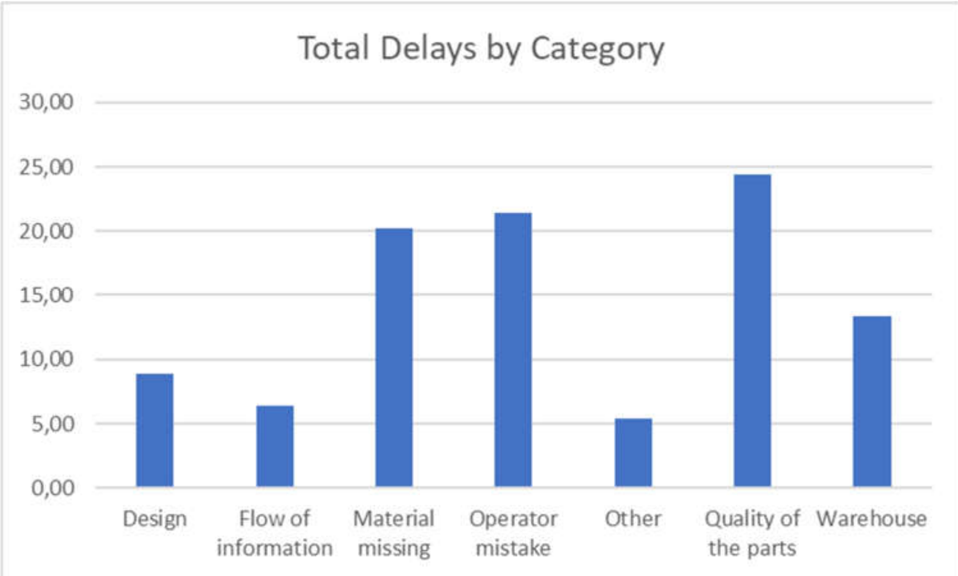

Figure 6. Total delays per category

The non-value added tasks were divided into six different categories (Table 5). Helping others -category concerned the operator helping his co-worker on a task. Information flow -category was related to tasks such as finishing work in SAP or reading the drawings. Meetings-category included weekly meetings and work-related discussions with management. Other-category was given to any other kind of delay than what was already categorised. Tidying up -category concerned cleaning the workstation whether switching between the tasks or after the workday was finished, and tools-category concerned all tools-related such as collecting and returning the needed tools or forklift.

Category	Sum / Duration/min
Helping others	14,27
Information flow	15,39
Meetings	19,07
Other	5,55
Tidying up	15,03
Tools	21,18
Total	**90,48**

Table 5. Total non-value added by category

The results show in Table 5 above, that most of the non-value added work was done with tools. Collecting the tools and returning them to where they belonged took 21 minutes from the total product manufacturing hours. Meetings took 19 minutes. Information flow, tidying up, and helping others took some 15 minutes, and other almost six minutes.

There are, however, also allowances such as breaks allocated to the workday (Table 6). The national collective agreements in technology industry do not allocate certain minutes for example for coffee breaks but instructs that employee can have refreshments at the most convenient time workday wise (Teollisuusliitto, 2022, 79).

Category	Sum / Duration/min
Allowances	75,67
Helping others	14,27
Information flow	15,39
Meetings	19,07
Other	5,55
Tidying up	15,03
Tools	21,18
Total	**166,15**

Table 6. Allowances included in total non-value added by category

Table 6 above depicts how the total minutes rise as the allowances are added to the non-value added work categories. As table 5 showed the total minutes by non-value added work by category were some 90 minutes, only the allowances are almost as much with about 76 minutes.

Figure 7 below shows the total allowances and non-value added work by category as a percentage.

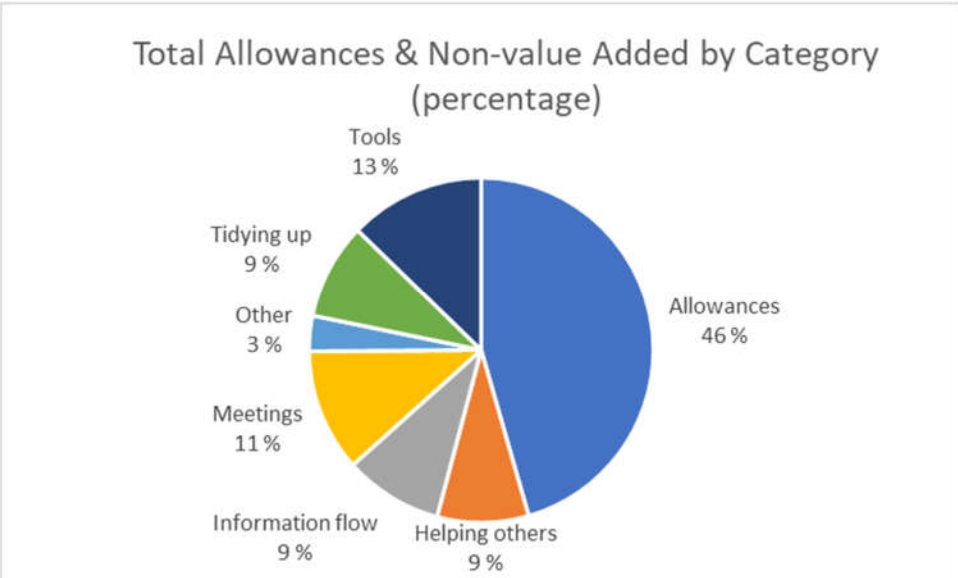

Figure 7. Total allowances & non-value added by category (percentage)

As can be seen from the above Figure 7, allowances take 46 % of total allowances and non-value added work. Tools and meetings take around 12 %, tidying up, information flow, and helping others 9 %, and other 3 %.

The histogram below (Figure 8) demonstrates the total allowances and non-value added work by category.

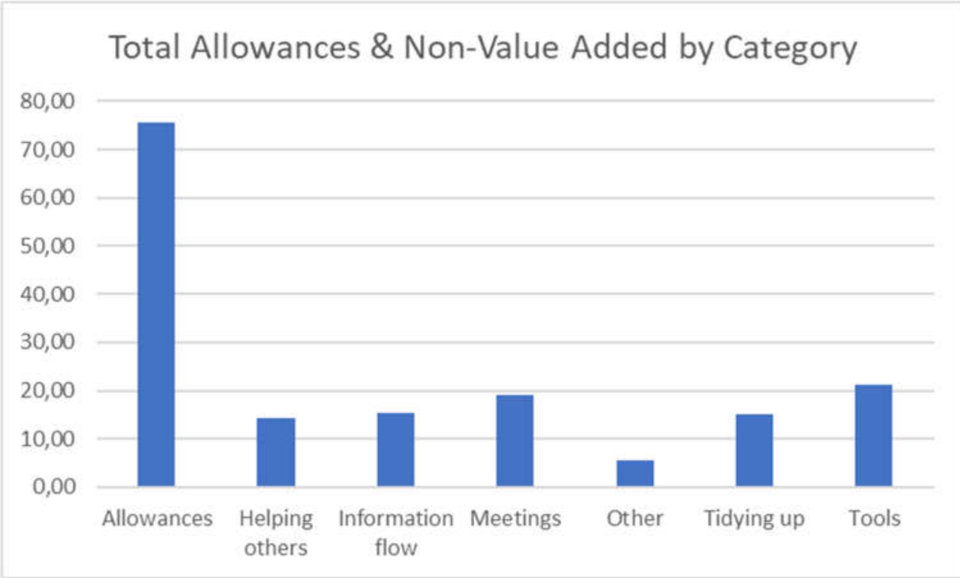

Figure 8. Total allowances & non-value added by category

Figure 9 below demonstrates all delays amended with extra allowances. Extra allowances -category has been calculated from the time study results. All allowance-category results have been viewed from the time study and a 15-minute coffee break considered as a normal coffee break. All that goes beyond 15 minutes, personal cell phone calls etc. have been considered as extra allowance.

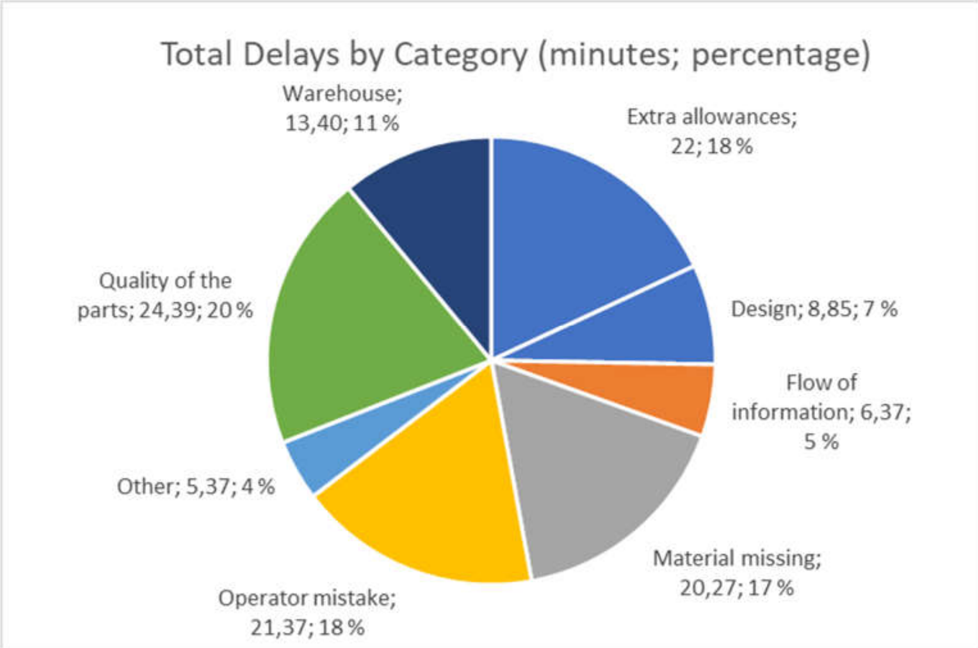

Figure 9. Total delays by category (minutes; percentage)

Figure 9 above depicts 20 % of total delay in manufacturing is caused by quality of the parts. Extra allowances, operator mistakes in manufacturing, and missing material cause about 18 % of delay. Warehouse causes some 11 % of the delay, and design, flow of information, and other cause less than 7 % of delay.

5 Conclusions

This thesis was conducted as a case study for a Finnish company functioning in national and international markets. The company had a strategic need, but also day-to-day issues, which called for deeper analysis and ideas on how to improve productivity of the manufacturing process. To find out what could be done to increase productivity and to name the biggest obstacles hindering the manufacturing process, the company had decided to conduct work measurement study. There was an external, experienced time study engineer to come in and conduct the time study.

The results showed that the lead time for Product manufacturing was as had been planned with planned manufacturing hours of some 25 h, and actual, timed hours were 30 h. The results looked positive. However, the manufacturing had to be stopped several times in between due to different kinds of delays, and therefore finishing production took some two weeks. This makes the words of Ahokas et al. (2011, 21) resonate. They imply that decreasing lead times does not only come from increasing the working pace, but from removing different kinds of waiting times.

The time study results revealed a total of 78 minutes of delays, when the extra allowances were added the total delays increased to 100 minutes. The four largest categories to cause delay in the manufacturing process were quality of the parts (24 minutes/20 %), extra allowances (22 minutes/18 %), operator mistake (21 minutes/18 %) and missing material (20 minutes/17 %). These results are backed with empirical observations, and therefore, were not a surprise.

The aim of the thesis was to answer two research questions. Firstly, what were the current main hindrances of productivity in the manufacturing process? And secondly, how the manufacturing process could be improved to make it more productive? The first research question I have been able to answer, by establishing the four biggest causes of delays. The second research question will be answered in chapter 5.1.

The theoretical part of the thesis consisted of literature on work measurement and time studies. The topics of Lean, Six Sigma, and continuous improvement methods were investigated through journals, publications, and other sources. These topics were to provide insight on how the productivity of manufacturing process could be increased.

Reading different kinds of articles and journals as background information for this thesis, it has only strengthened my vision of how people from all operations and levels need to be included in the process. For a factory to function efficiently it requires the efforts from all operations. Seldomly productivity is increased only by improving a part of a process. Making changes in one place tends to have an effect somewhere else too.

It should be noted that the results introduced in this thesis cannot be taken to draw larger conclusions and applied to other companies. The time study results give a picture of the measured workstations, and for example the measured delays are from that time.

5.1 Suggestions for improvement

It is only after the standardization of the working methods that systematic development of a job can begin (Ahokas et al., 2011, 6), and through that productivity can be increased. However, as Näslund (2008, 278) writes, maybe one of the reasons behind unsuccessful change and operational performance improvement is that companies lack the systematic way of using the change methods.

As was established in the previous chapters, the four categories to cause the most delay in the manufacturing process were quality of the parts (24 minutes/20 %), extra allowances (22 minutes/18 %), operator mistake (21 minutes/18 %) and missing material (20 minutes/17 %).

Quality of the parts is the biggest hindrance in the manufacturing process, which causes delay in the process. The delay with the quality of the parts comes from several kinds of issues, yet most of the delays found in the time study were of supplier mistakes, such as holes missing or being too small, the supplier had not finished the parts, or the part was not according to the drawing.

If the critical points of parts, for example holes, could be identified and marked in the drawings, an income inspection would solve the issue of the parts not being as ordered. The supplier should add the drawing with the delivery, and the warehouse personnel would know which drawing has been used. The income inspection would not, however, solve the issue of parts not fitting together, since the fitting together is done at the time of production.

The second largest cause of delay in the manufacturing process was extra allowances. A 15-minute break in the morning and in the afternoon is the commonly accepted duration of a break, yet there is a habit of having some 15 minutes extra for revival in addition to personal cell phone usage etc. Perhaps the only way of getting the break times in order again is merely talking it out and sticking to the times from the management side also.

The time study showed operator mistakes to be the third largest hindrance to the process. There were several longer delays, which were caused by the operators' own mistakes. In the current situation the operators face tremendous pressure at times. The tight schedules with perhaps late start to the production-phase require quick decisions and sometimes autopilot-mode, and to some extent some of them being "one of a kind", as there are no other operators for all tasks, who can take the place when someone for example falls sick. These are situations, which are likely to cause mistakes and oblivion.

To ease the feelings of pressure, and possibilities for mistakes and oblivion, careful documentation should be in use. Also, cross training the operators would disperse more knowledge between the operators, and eventually there would be more trained personnel. Haste in the production-phase is caused by different reasons, mainly due to quality of the parts, and missing material and information. If these points could be eased, there could be less pressure on the operators to finish production hastily.

Missing material was the fourth largest hindrance in the manufacturing process. In this case it was a matter of supplier not being able to produce the part, since there were old drawings and tools to be used. This kind of case is not unusual, since many of the designs use older drawings and tools, and thus the suppliers have trouble delivering the order on time. Lack of purchase order follow-up is an issue. If there was systematic purchase order follow-up in place, many of the missing material issues would be tackled in advance as production could be rescheduled to some extent.

5.2 Recommendation for future study

The research showed that the manufacturing process is productive, as long as there are components to make of and of good quality. Since this thesis did not take into consideration any related processes, such as design, purchasing, or quality, further study would be needed to find out what are the main hindrances there and what would help these processes to work more productively in cases where time is of essence.

Another interesting topic related to this research would be finding out, if and how the suggested development ideas were taken to action, and did these actions have any impact on productivity of the manufacturing process. The full effect of the new actions can only be found out after they have been standardised and have become the normal way of doing. A new work study would have to be conducted, and the results to be compared.

On larger scale I found it rather difficult to find information on time studies and how to interpret the results. Ahokas et al. (2011) have done a terrific job at drafting a small-scale manual on work study and on its different uses, yet I would have enjoyed reading about what the results normally look like in different kinds of manufacturing companies. Especially interesting would be “before and after” -type of time measurement study, which could give ideas for companies on what kind of changes could make a difference. But naturally, which changes work for a company does not necessarily work for the other.

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