BACHELOR ASSIGNMENT

INCREASING UTILLIZATION BY USING AUTONOMOUS PRODUCTION AT A GEAR PRODUCTION COMPANY

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HANKAMP GEARS
Al meer dan 100 jaar in beweging

UNIVERSITY OF TWENTE.

i Research information

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ii Preface

Dear reader,

You are about to read my thesis report as a final assignment for my Bachelor's degree in Industrial Engineering and Management at the University of Twente. The assignment is conducted for Hankamp Gears. A gear production company in Enschede, the Netherlands.

I am grateful for the opportunity Hankamp Gears has given me. I learned a lot about the production of gears and automation. Since I spent a lot of time it was also a valuable working experience for me. I would like to thank the operators for taking the time to answer my questions. Next to that, I want to thank Pim for being my supervisor. I could always approach him with questions and the feedback to my report was very helpful.

Second, I also want to thank my first supervisor Marco Schutten. His feedback was very useful and during the meetings he gave input with which I could determine my next steps. Also, I would like to thank Dennis Prak, my second supervisor for his time and feedback.

Lastly I would like to thank my friends and family who motivated me during this assignment. Tips and experiences from other students helped while writing my thesis. Especially the meetings with my buddy Jeroen Assink.

Enjoy reading this thesis.

Monique Willems

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iii Management summary

This report explains the research conducted at Hankamp Gears, located in Enschede. Hankamp is a gear production company, which specializes in high-quality and tight tolerances, up to 0.001 mm. They produce orders with a batch size from 1 to 1,000 pieces and each order has its unique set of operations. Hankamp currently has to deal with higher customer demand without an increase in production capacity.

Because of the increase in demand without an easy opportunity to expand the capacity, the delivery times increase. In some cases Hankamp even has to say no to customers. The action problem they encounter is that machines at Hankamp are fully booked with orders for months. They are looking for ways to increase their utilization rates. One way they do this is by implementing autonomous production by using the loading systems of the machine and in some cases collaborative robots (cobots). Next to that, they are looking into the possibility of autonomous night production. When an operation process is stable, the machine operator can decide to run the machine autonomously during the night. In that case the operator sets up the machine in such a way it can run some hours during the night without anyone being present. However, for the operators, it is not clear when it would be beneficial. What are the technical requirements and are there extra cost related to autonomous night production? Or does it result in extra downtime of the machine during the day? Therefore, we select "no clear conditions when it is beneficial to run the machine during the night" as the core problem for this research.

Because of the limited time for the research, we decide to focus on the current bottleneck, the hobbing department. The department has 7 machines, which, in theory, can run autonomously during the night. Two of these machines are combined with a cobot. We specifically look at two out of the six different machines to answer the question. The composed main research question is:

Under what conditions is it beneficial to produce batches autonomously during the night so the capacity utilization is increased at the bottleneck department?

First we dive into the technical requirements. These have to be met, otherwise, autonomous night production is simply not possible:

- The correct tools have to be present to install the loading systems.
- It should not be the first time the order is produced.
- With the current machines and circumstances, the tolerance of the product has to be larger than 0.02 mm.
- The operation process should be stable and known.
- The operator should not have to measure a product after every N products given a batch size of X to see if the machine settings need to be adjusted.

Whether autonomous night production is beneficial depends on the following: the diameter of the product, batch size, cycle time, if the cobot is used and whether products can be stacked. Since it depends on so many parameters we draft a formula with which it is possible to calculate the extra production time Hankamp reaches by using autonomous night production. The formula is implemented in an Excel tool, which uses VBA code. This tool can be used for 3 out of 7 machines in the department: gvl, L382 and L282.

Next to that, for one machine (the k150hlc) we conclude that it is less fit for autonomous night production since it cannot run autonomously for a long period. It is only beneficial when the cycle time is larger than 4.5 minutes and between March and May 2022 that was the case only 7% of the time.

To use the Excel tool, the operator needs to go to a computer in the warehouse. To increase the usability we also create a decision tree which the operators can use to derive the answer whether night production is beneficial. The answer is less precise, but the decision tree can be printed and placed at the side of machines. Therefore operators do not have to go to the computer to get an answer. Next to that, the Excel calculation tool can be installed on the tablets that are used in the warehouse to access the ERP system. Operators might experience the use of the tool on the tablet as more user-friendly.

We construct a plan for Hankamp to implement autonomous night production; it uses the ADKAR theory. Literature indicates that ADKAR is beneficial in Hankamp's situation; it stands for each stage that is required for successful people change: awareness, desire, knowledge, ability and reinforcement.

The research results in the following recommendations:

- First, train the operators so everyone can install the cobot. At this moment there are some operators that cannot install it by themselves. Because of this, the cobot is not used to its full capacity.
- Next to that, Hankamp should use ERP scheduling so operators can select the next order they want to produce. In that situation, the operator has the ability to select an order which can make long production hours during the night at a beneficial time.
- Last, look into the possibilities to increase the loading capacity of the k150hlc. Because of the low loading capacity, autonomous night production is not indicated to be beneficial often. Hankamp is already looking into how to place an extra cobot at this machine. A problem is that at this point products are not always in the same position and therefore difficult to grab by a cobot. We recommend replacing the gravity loading system with another chain conveyor; in this way the finished products can be put back on a chain conveyor.

Aside from recommendations to implement, we also recommend researching these areas further:

- The first option to further research is to improve the calculation of the Excel tool. The framework can be improved by researching the amount of time the machines stand still in the morning. Next to that also the usability can be evaluated. Now the results of the Excel tool have been used in a decision three but the usability of this tool can be evaluated.
- Following up on this research could indicate how to minimize the hours a machine stands still because there is no operator present. The machine does not stand still when it is producing or being setup for a next order.
- To use autonomous night production to its full potential, the work should also be scheduled for it. Further research can be used to investigate in what way the planning department can best schedule the work, also taking autonomous night production into account. When scheduling work, the planning department can then also use the Excel calculation tool to indicate to the others if night production is beneficial. If the technical conditions to produce autonomously are met this could be indicated in the ERP system by the operators. In this way the planner knows which products can be scheduled autonomously during the night.

Overall the research results in a framework that Hankamp can use to indicate when autonomous night production is beneficial. Some recommendations to use autonomous night can be implemented and others need further research.

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iv List of figures

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vi List of abbreviations

Abbreviation	Full name	First introduced
CNC	Computer Numeric Control	Page 10
BPMN	Business Process Modeling Notation	Page 16
ERP	Enterprise Resource Planning	Page 13
MPSM	Managerial Problem-Solving Method	Page 14
SMED	Single Minute Exchange of Dies	Page 28
TOC	Theory of Constraints	Page 27
VSM	Value Stream Mapping	Page 28

vii List of technical terms and Dutch translation

Term	Dutch translation	First introduced
Broaching	Brootsen	Page 20
Drilling	Boren	Page 20
Gear blank	Tandwiel schijf	Page 10
Grinding	Slijpen	Page 19
Hobbing	Vertanden	Page 1919
Honing	Honen	Page 20
Job traveler	Werkorder	Page 17
Laser engraving	Laser graveren	Page 20
Milling	Frezen	Page 10
Sawing	Zagen	Page 1919
Turning	Draaien	Page 10

1. Introduction

In this chapter, we first give an introduction about the company in Section 1.1 and the background of the problem in Section 1.2. After that, we discuss the stakeholders and show our problem cluster, see Sections 1.3 and 1.4. From this cluster, we select the action problem, Section 1.5, and the core problem, Section 1.6. Section 1.7 discribes the research design and 1.8 the research scope.

1.1. Company description

Figure 1: Example of a gear

Hankamp Gears is a gear production specialist in Enschede. It was founded in 1909 and its specialities are high-quality gears with tight tolerances, up to 0.0001 mm. Hankamp mainly produces for the energy, robotics, aircraft, pump and printing industry. Figure 1 shows an example of a gear produced by Hankamp. They focus on keeping the delivery time as short as possible with the highest flexibility. Batch sizes vary from 1 to around 1,000 products.

The company can be described as a job shop with over 55 machines, some with CNC. CNC stands for computer numeric control. It is a manufacturing system where computers operate the machine and. To produce a gear several operations are performed. It differs per gear how many operations are required; it can go from 2 up to 20. Figure 2 shows a flowchart with the operations for the production of an average gear. In most cases, the raw material is a round metal bar with a length of around 5 meters but sometimes the raw material is delivered in the form of gear blanks. Gear blanks are metal discs that can directly be processed by turning or milling. The order of the operations can differ depending on the type of gear. Before the final products get sent to the customer the tolerances are checked and the product is packed. Hankamp also performs more specific operations like honing, broaching, wire spark erosion or laser engraving.

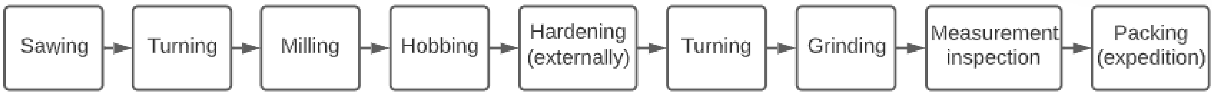


Figure 2: Flowchart of the production operations of an average gear at Hankamp

The management of the company and some machine operators work a day shift from 7:30 to 16:00. The other machine operators work in two shifts; a morning and an afternoon shift. The morning shift starts at 5:45 and ends at 14:00 and the afternoon shift starts at 13:45 and ends at 22:00. Normally Hankamp only produces from Monday to Friday and on Friday the afternoon shift ends at 18:00. A machine operator is responsible for 2 or 3 machines at the same time.

1.2. Background of the problem

Hankamp Gears currently has to deal with higher customer demand without an increase in production capacity. They encounter a backlog throughout the production. Some customers order their products well in advance; so this production is already scheduled. The backlog combined with the planned production results in certain machines being fully booked for months. This is a problem because Hankamp either has to decline incoming orders or their delivery time will increase. In practice, Hankamp chooses to let their delivery times increase. One reason for the machines being fully booked is lack of capacity. In March 2022 a new machine is delivered to improve this, but the expectation of the management is that it will not solve all capacity problems. It is possible to increase the capacity by introducing a night shift from 22:00 to 6:00. However, the management does not want this because they already have trouble finding enough capable employees to fill two shifts a day.

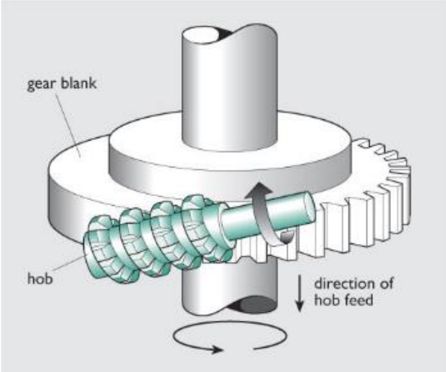


Figure 3: Illustration of the hobbing operation

By talking to the management and employees we conclude that the gear hobbing department is the bottleneck department. Figure 3 illustrates the hobbing process, a cutting tool named a hob rotates at a certain angle to cut out the material. At the same time, the gear blank rotates so the cutting process forms equal teeth (Thorat, 2017).

Hankamp has several machines that have the ability to run automatically without any supervision. This can be used during the day, so the machine operator can perform other tasks or the machine can run without any employee present during the night. At some departments within Hankamp, machines already run production autonomously during the night, so-called lights-out manufacturing. A machine works autonomously when it can perform operations without an employee. This hardly ever happens at the hobbing department. The decision to run autonomously or not is made by the machine operators. One possible explanation is that there are no batches specifically planned to run during the night. The management would like to increase the automatic night production. Ideally, small batches run during the day and larger batches during the night. When the batches are really small, the number varies per machine, but less than 20 on average; the operator changes the gear blanks by hand instead of the automatic loading systems. The management thinks this will reduce the idle time of the machines.

It is not always beneficial or possible to run a machine autonomously. The setup of the machine needs to be changed to run autonomously. This takes time, but when succeeded the machine operator can perform other work on a different machine. Therefore, it is only beneficial to set up the machine when the batch size and production time are large enough. On top of that, in some cases, automatic production is simply not possible. For example, for some products, manual quality checks have to be performed regularly. In case the measurements deviate, the machine settings need to be changed.

Most of the machines are planned for 63 hours per week. This is less than the amount of time there are machine operators present (76 hours) since an operator is responsible for multiple machines at the same time and sometimes a machine breaks down. If proven that the efficiency is higher, the number of planned hours can be increased. The production schedule is focused on the 10 largest customers. For these customers, Hankamp tries to meet all the promised delivery times. Other customers have less priority when it comes to their orders. When scheduling the orders an estimation is made of the cycle time and the setup time per machine. This is done based on experience or previous similar orders. The cycle time is the time it takes to perform one process on one gear blank. The setup time is the time it takes to install the machine and raw materials before production. We provide more information about the setup in Section 2.3.1. Sometimes orders take longer than planned because these estimates turn out to be inaccurate.

To conclude, Hankamp encounters different kinds of problems. To further analyse the problems we look into the stakeholders and make a problem cluster.

1.3. Stakeholders

The internal stakeholders are the management and the machine operators. The management of Hankamp would like to implement automatic night production to increase capacity utilization. The machine operators are important stakeholders because they perform the tasks at the machine. They perform the setup and production of the gears; so they have the best knowledge about the practical implications of implementing night production.

The external stakeholders, the customers, are the least involved. The performance of the production process influences the delivery time and quality. The increase in capacity utilization can reduce the current delivery times. A potential risk is a decrease in quality. The batches are produced without any supervision and can result in lower quality. When the gears are not within the tolerances it reduces customer satisfaction when unnoticed or it increases the quality costs. Quality costs are costs encountered because quality is insufficient for sale (Bragg, 2021).

1.4. Problem cluster

Figure 4 shows a problem cluster of the problems encountered at the hobbing department at Hankamp. This is a useful tool to map all connections between encountered problems (Heerkens & van Winden, 2017). We discuss the problem cluster in general; for a more elaborate explanation of every process in the cluster see Appendix A. All problems lead to one main problem that Hankamp encounters daily, which is that the machines are fully booked for months. The left side of the problem cluster describes the problems encountered because of the planning. For the production schedule, the planner makes an estimation of the setup and cycle times based on experience. These estimations are not very precise and therefore result in a production that takes longer than expected. Another reason for the main problem is that their current capacity cannot cope with the increased demand. A third reason is that the capacity utilization is low in the department. It is low because several machines can run autonomously during the night but Hankamp is not able to make use of this. The right side of the cluster explains when it is not beneficial to use autonomous production. Machine operators decide to produce autonomously or not. The part in the middle of the cluster explains problems machine operators encounter which makes them decide not to produce autonomously.

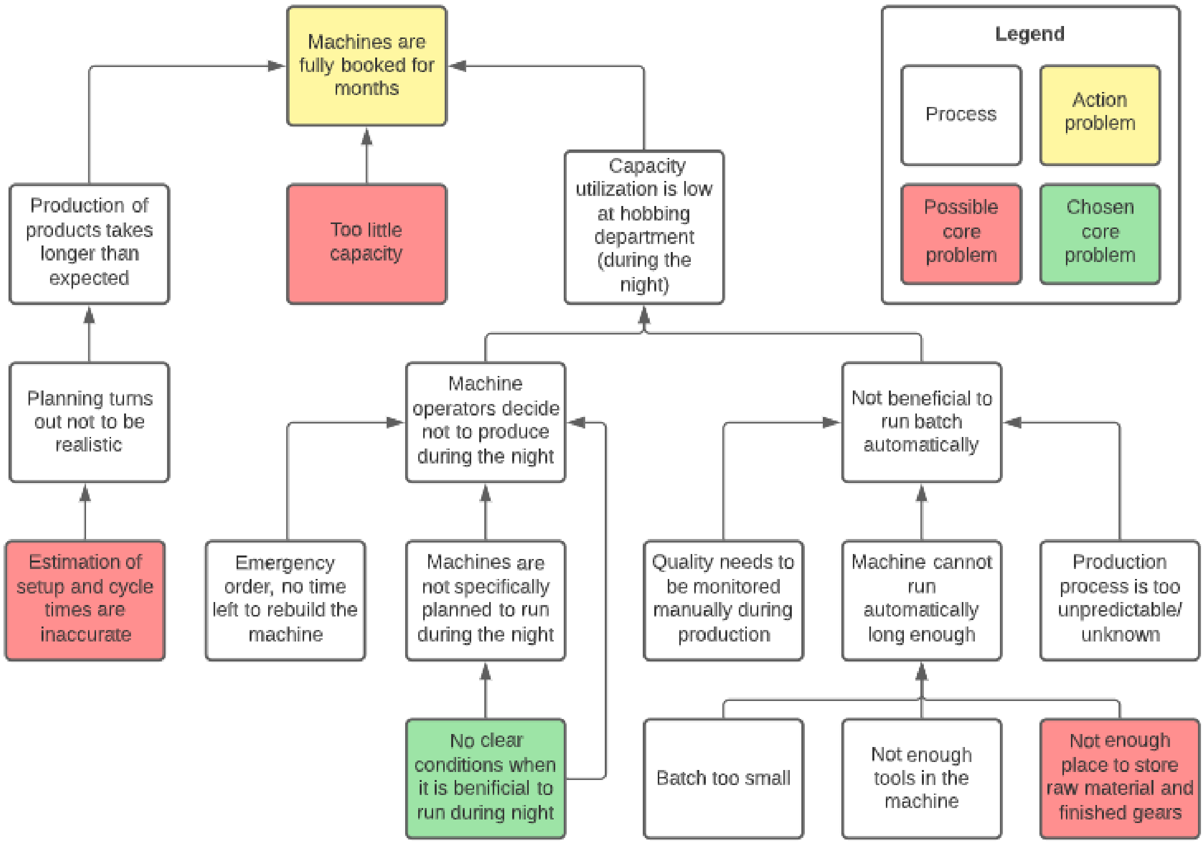


Figure 4: Problem cluster Hankamp Gears

1.5. Action problem

The action problem is that machines at Hankamp are fully booked with orders for months, not only at the gear hobbing department. Due to time constraints, we focus on the bottleneck, the gear hobbing department. The Enterprise Resource Planning (ERP) software (Epicor) used at the Hankamp registers the week up until the machine is fully booked. A machine is fully booked in a week when it is booked with 63 hours of work. So until which week Hankamp has to wait to schedule new production if every week is booked with 63 hours. Figure 5 shows a bar chart with the machines of the hobbing department and the number of weeks the machine is booked. The X-axis shows the codes of the machines at the hobbing department that have the functionality to run autonomously. The data is manually extracted from the ERP system; therefore the data extractions do not have regular periods between them. Between the first two bars is 20 days, between the next 8 days and the rest 7 days. For the K150hlc we see quite a drop in the number of weeks between March 31th and April 14th. At that time the new machine was delivered, the L282. Because of that, work was moved from the k150hlc and L382 to the new machine.

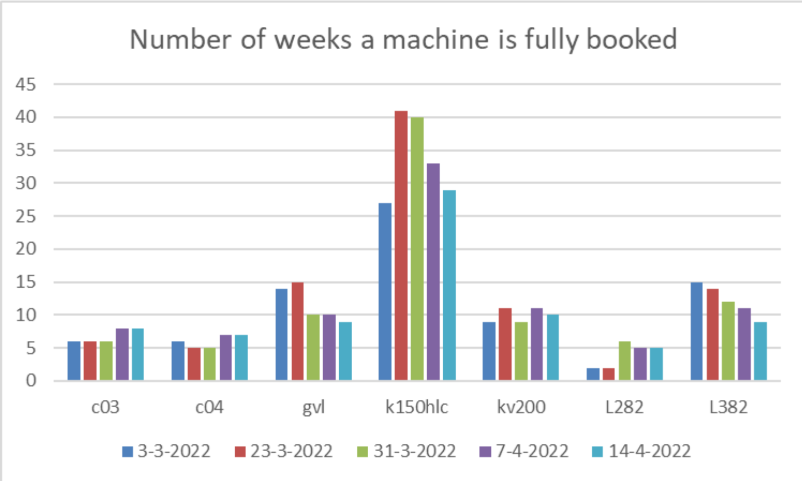


Figure 5: Number of weeks a machine is fully booked

1.6. Core problem

As indicated in the problem cluster with the red, there are several possible core problems identified. We choose the core problem based on the rule of thumb (Heerkens & Van Winden, 2017). The core problem should not have a cause and must be able to be influenced. All possible core problems in the problem cluster, see the red boxes in 1.4Figure 2, match these requirements. The last step of the rule of thumb is to pick the most important problem to tackle first. This is the problem that has "the most effect relative to efforts and cost" (Heerkens & van Winden, 2017).

We have chosen the problem to tackle by elimination. Two possible core problems can only be resolved by high cost, too little capacity and not enough place to store raw materials and finished products. Hankamp has to buy a new machine or cobot. Cobot is an abbreviation for a collaborative robot, the robot collaborates with a human. At this moment there are two cobots used by two machines in the department. These cobots are in the form of robot arms that load material on the machines. Besides that, the company ordered a new machine that is delivered in March 2022. Therefore we do not choose one of these two problems as the core problem. Estimation of the cycle times could be improved but Hankamp has many new unique orders. For the new order it is very difficult to estimate the setup and cycle time. Therefore it would be difficult to improve the estimations. Only one problem remains, namely there are no clear conditions when it is beneficial to run the machine during the night. The company knows that the machines have the capabilities; at other departments automatic production during the night is already implemented.

1.7. Research design

This research is performed according to the Managerial Problem-Solving Method, further referred to as MPSM (Heerkens & van Winden, 2017). The MPSM exists of 7 steps, see Figure 6. We divided the research into 5 phases and each phase is a chapter in the report.

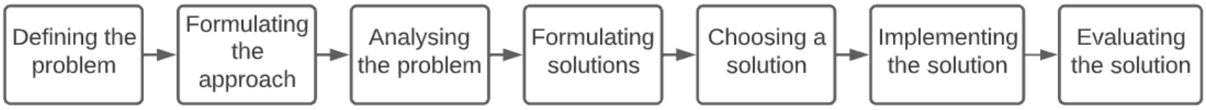


Figure 6: The 7 steps of the MPSM

The goal of the research is to increase the utilization of the capacity during the night at the gear hobbing department of Hankamp Gears and by that reduce the number of weeks a machine is fully booked. The main research question is the following:

Under what conditions is it beneficial to produce batches autonomously during the night so the capacity utilization is increased at the bottleneck department?

1.7.1. Phase 1: Current situation

To find out more about why the problem occurs we analyse the current situation. First, we try to gain insight into the general production process, after that we look more closely into the automatic production process.

1. What is the current production process at Hankamp Gears?
    a. What is the production process for a gear?
    b. What is the setup process for automatic production?
    c. How is the production planned?

These sub-questions are solved by interviewing machine operators and managers at the company. Not only at the gear hobbing department, but also operators from other departments are interviewed, which already use night production. For sub-questions a and b specifically, observations at the production floor are made. With the gathered information we make a process model. A process model is a visualisation of a process, different methods exist. A knowledge problem in this phase is; what is the best option for visualisation of the process? Based on the literature we choose the best option, and briefly motivate the choice.

1.7.2. Phase 2: Theoretical framework

The systematic literature review has to indicate how to improve the production process according to existing theories, like Lean management. Apart from that, we want to know more about the implementation of automation. These are two knowledge problems. Therefore, we construct the following two research questions.

2. What are relevant techniques for process improvement to increase capacity utilization?
3. What are relevant theories about the implementation of automation in production?

We solve these knowledge problems by reviewing existing literature.

1.7.3. Phase 3: Finding the solution

To implement autonomous production during the night it is first important to know when it exactly it is beneficial. To do so we answer the following question:

4. Which conditions should be met to make autonomous production of gears during the night at the gear hobbing department beneficial?

We answer this question by again interviewing machine operators and the management and analyse ERP data.

1.7.4. Phase 4: Implementing the solution

The next step is to implement autonomous night production when indicated that it is beneficial. Due to the short time, we advise on the implementation of autonomous night production.

5. How can Hankamp implement night production at the bottleneck department when indicated that it is beneficial?

To answer this question we use the theory from answering question 3 and the results from question 4. Besides that, we interview employees about their views on working with autonomous night production.

1.7.5. Phase 5: Conclusion

Lastly we evaluate answer the main research question. The question is answered based on the knowledge received by answering the five sub-questions. We discuss the possible difficulties and restrictions of the solution in the discussion section. Next, we give recommendations to Hankamp and suggestions for further research.

1.8. Research scope

For this research, we focus on the bottleneck at Hankamp Gears, the hobbing department. Within this department, the research focuses on the implementation of automatic production during the night. Every step of the setup process to let a machine run autonomously is not described in detail. The focus is on the duration of the global tasks and possible difficulties in the process. Besides that, the research focuses on beneficial batch sizes and advises on how to adapt the planning to the new situation when implemented.

2. Current situation

This chapter describes the current situation of the production process at Hankamp. The goal is to answer the following research questions.

1. What is the current production process at Hankamp Gears?
    a. What is the production process for a gear?
    b. What is the setup process for autonomous production?
    c. How is the production planned?

Section 2.1 describes the general production process at Hankamp. Besides a textual description, we visualise the general process and motivate which visualisation method to use. Section 2.2 explains the production of a gear by its most applied operations and a short description of the other operations performed. In Section 2.3 we dive into the bottleneck, the hobbing department. The section describes the setup process in detail, through textual description and visualisation. Section 2.4 explains how Hankamp schedules its production. Lastly, Section 2.5 includes a short summarizing answer to the research question and its sub-questions.

2.1. General process

Hankamp can be described as a job shop manufacturing facility. All products produced are requested by customers. Hankamp does not have any standard orders; it makes what the customer wants. Most products are produced make to order (MTO), but for some customers gears are kept in stock; this is called make to stock (MTS). The batch sizes vary from 1 to 1000 pieces. When more products are ordered they produce multiple batches of at max 1000. The diameters of the gears vary from 20 to 600 mm and Hankamp also sells shafts with gear teeth. Next to that, Hankamp produces gears out of various metals and plastics.

After an order is confirmed, a job traveler is made, which is a physical document that contains a technical drawing, measurement reports and all the operations that have to be performed with all necessary information. Each product can have up to 20 different operations and all are shown on the job traveler. The job traveler travels through the factory with the material. Every time an operation is finished, the operator notes the number of products, signs off the job traveler and updates the ERP system.

2.1.1. Selection for visualisation method

To explain the process within the company we use visualisation, in this case, a process map. There are three main stages in process mapping (da Silva et al., 2019). First, identify the goal of the process map, readers and expected results. Next, collect the data for the process map through interviews and observations. Lastly, transfer the data into visualisation.

To get a good overview of the situation we provide a general view of the entire process and a more detailed view of the processes at the hobbing department, especially regarding the setup of the machines. We have selected Business Process Modeling Notation (BPMN) as the visualisation tool. BPMN shows each activity and decision made in a process. The goal is that the analysis of the current situation leads to possible problems regarding the implementation of autonomous night production. We think the visualisation should therefore focus on the performed activities. In the next paragraph, we explain how BPMN works in more detail.

There are 3 different levels of process modelling: process mapping, process description and process model. BPMN supports all levels (White & Miers, 2008). A process map shows a process at the highest level. It has few details and shows the activities and main decision. A more detailed version is a process description; this also includes the people involved, data and information flows. The third level contains the most detail, a process model. This model has enough details to enable direct importation into other data system tools. We model at the process description level since it is our goal to understand the process and find possible problems in autonomous production.

2.1.2. BPMN model of the general production process

Figure 7 shows at a high level the end-to-end production process at Hankamp. Each BPMN model has one or multiple start and end events, see the green and red circles in Figure 7. The rectangles display an activity described by text. A gateway shows when the process diverges (splits) or converges (merges). Sequence flows connect the process elements like activities, gateways and events. Appendix C explains BPMN in more detail and contains a legend for the elements (Table 5). It shows four different departments: the sales, planning, purchasing and production departments. When a customer orders a product, the sales department creates a job traveler. After that, the planning department schedules the order and the purchasing department makes sure the raw material is ordered if necessary. After the raw material is delivered, the actual production of the gear can start. On the shop floor, the machine operator collects the raw material and tools to set up the machine. The operator collects all necessary information about the tools and operation from the job traveler. When the machine has finished the operation on the gear blanks, the operator brings the semi-finished products to the next department. This process on the shop floor repeats itself until all operations described on the job traveler are performed. We do not describe the heat treatment that happens externally in Figure 7 for the simplicity of the model. In principle it is a similar process; only the hardening company needs to collect the material perform the operation and deliver it back to Hankamp. After all operations are completed, the material is sent to the expedition. Here employees pack the gear and send it to the customer.

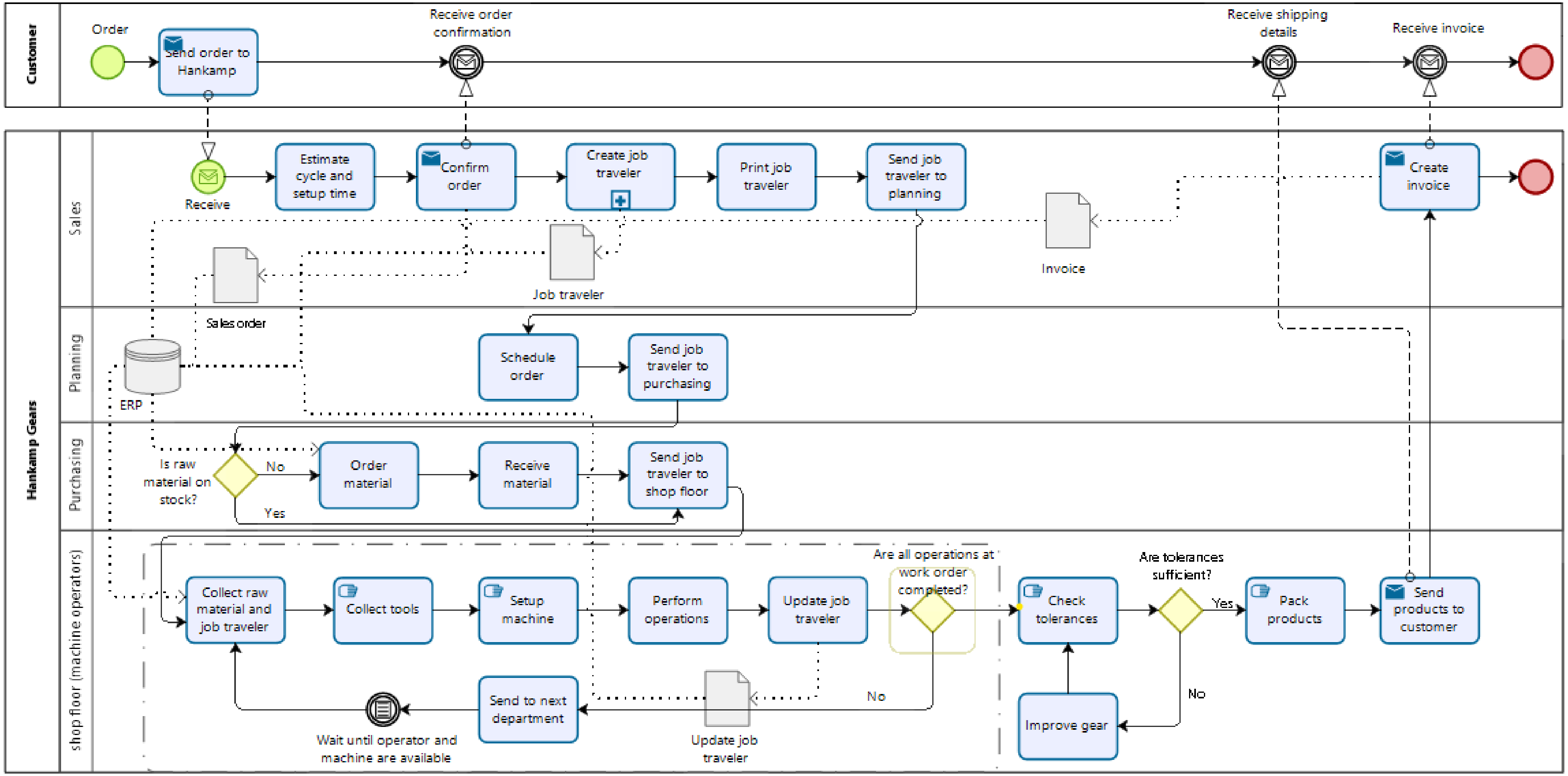


Figure 7:BPMN model end-to-end process at Hankamp Gears

2.2. Operations performed

Hankamp performs the following operations for their customers: sawing, milling, turning, hobbing, grinding, honing, broaching, wire spark erosion and laser engraving. The gears can also undergo heat treatment, but this happens externally. Hankamp uses one company for this and they pick up and deliver products daily. In this section, we explain the general processes Hankamp uses to produce a gear, starting with the raw material and finishing with a gear. We use the same process as shown in Section 1.1, see Figure 8. Table 1 explains the operations in more detail. It is important to keep in mind that the operations performed and the order of the operations vary per order. After that, we include a table with the other operations Hankamp performs with a short explanation.

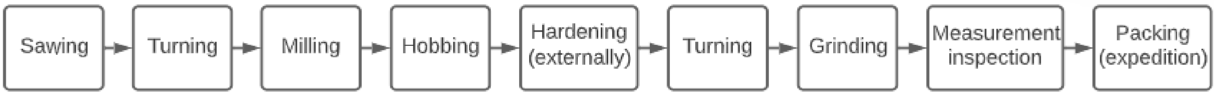


Figure 8: Production process of an average gear at Hankamp

The raw materials are either long shafts or gear blanks. Most of the raw materials used are shafts. The following figures show the production process from raw material to end product. Figure 10 shows the gear blank from Figure 11 transformed after turning and milling. This is one operation performed with a CNC machine, so both turning and milling. This machine has the capability to perform multiple machine operations in one because they can contain multiple tools and can change them without human interference. The machine has built-in storage where it can select a new tool. When all operations are completed, the product is packed at the expedition and sent to the customer. Hankamp performs more operations than discussed in this example.

Figure 12: Raw material shafts

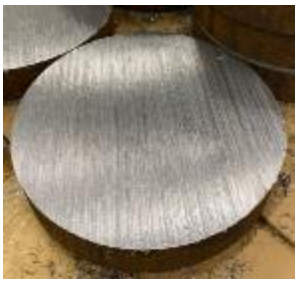


Figure 11: Gear blank

Figure 10: Gear blank after turning and milling

Figure 9: Gear after heat treatment

Operation	Explanation	Picture (when relevant)
Sawing	The raw material shafts are sawn into gear blanks.	
Turning	The workpiece rotates at a high speed and a tool pushes against the workpiece to cut off material.	
Milling	Mils the centric hole in the gear blank.	
Hobbing	A cutting tool named a hob rotates at a certain angle to cut out material. At the same time, the gear blank rotates so the cutting process forms equal teeth.	
Hardening	This is a heat treatment which makes the gear stronger.	
Grinding	A tool with many small cutting edges rotates over a surface or gear tooth. The goal is to create a nice even surface and to remove scratches and stains.	

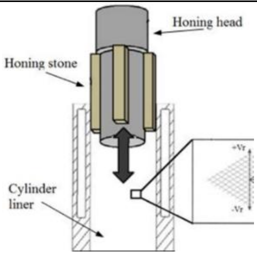
Honing	Honing is like grinding also a method to smoothen the surface but it is less aggressive and removes only little material from the workpiece. Instead of the outside of the gear, it is used to hone the interior cylinder holes. Figure 13 shows a schematic view of the process. The honing head removes material by moving vertically while rotating.	 *Figure 13: Schematic view of honing process*
Broaching	When broaching, a linear tool with teeth makes linear movement while the workpiece is set. It is often used to make a keyway like in the red circle in Figure 14.	 *Figure 14: Gear with broaching keyway*
Wire spark erosion	An operation where a wire using electrical discharges (sparks) removes material from a workpiece. This process is also known as electrical discharge machining (EDM). This method is beneficial in case it regards a complex shape or metal with high hardness.	
Laser engraving	Utilizing a laser, text can be engraved into the gear. This could be used for a batch number or company brand.	
Drilling	Some gears also have extra holes apart from the one in the middle, see Figure 15. This operation can be performed before or after the hobbing. When executed after hobbing it is possible to locate the holes to the hobbing teeth.	 *Figure 15: Gear with milling holes*

Table 1: Explanation of other operations performed at Hankamp

2.3. Hobbing department

The focus of this research lies in the hobbing department. There are 9 machines in this department. 7 machines can run autonomous, Table 2 shows the codes of these machines and the loading method. A ring loader is a circular belt on which the products are stored. A belt loader is a conveyer belt on which the products are stored. Not every ring or belt loader has the same capacity or suits the same product diameters only the method is similar. Appendix B shows images of theses 7 machines and there loading systems. 7 machine operators work in the department: 1 support operator, 4 operators and 2 technical specialists. The support operator is responsible for loading raw material on and finished products off the machine. The operators also load the machine but can also set up a machine for production. The technical specialists lead the team of operators and have the most knowledge about the setup process. Operators can approach them when they are uncertain about the setup. Each workday has 2 shifts and in every shift, there is one technical specialist and 1 or 2 operators.

Resource group no	Automatic loading
c03	Ring loader
c04	Ring loader
gvl	Cobot + ring loader
k150hlc	Belt loader
kv200	Belt loader
L282	Cobot + ring loader
L382	Ring loader

Table 2: Autonomous machines at the hobbing department

2.3.1. Machine setup for production

Figure 16: Example of automatic ring loader

Appendix B indicates which machines can produce autonomously and shows a picture of every machine. In total there are 7 and one is more fit for autonomous production than the other. The machines can produce multiple products without a human intervening because they have automatic loading. This is often in the form of a ring loader or a loading belt; Figure 16 shows an example of a ring loader, it has the form of circular track. The workpieces stored on a ring loader are picked up by the machine and after the operation is done they are put back on the ring loader. In some cases, the products can be stacked. A belt loader uses a conveyor belt system of which the products are taken. In the next paragraphs, we discuss the setup process.

An operator can decide to load the machine in 3 different ways: manual, automatic and autonomous.

1. Manual. The operator changes the workpiece after one operation is performed. Manual loading happens more often than the other loading methods when the batch is smaller than 20 pieces, or when the workpieces are large, more than 400mm. For the larger workpieces, the cycle time is longer compared to a small workpiece. Because there is often a larger contact surface to hob and the depth of the tooth is often also larger.
2. Automatic. With this loading method the products are loaded automatically by using a ring or belt loader. For some products, it is required to check the quality of the workpieces because the tolerances are tight. When humidity or temperature changes, the results of the same operation can be different. Therefore there is a risk that the product does not fit the tolerances. By changing the settings of the machine slightly this can be resolved.
3. Autonomous. In this case, the ring or belt loader is also installed, but the operator can walk away from the machine because the process is stable enough. The machine can produce by itself for as many products that are loaded onto the loading system. When the cobot is installed, the machine can often run for a long period of time.

How to setup a machine for automatic production

The setup of a machine is necessary when the operators starts producing another product. While the machine is still working on another order, the operator can already collect the workpieces and job traveler. If the operation has been performed before, they can check for production details in a folder with setup sheets. There the operators can find what tools they need to use and the setting of the machines. It contains pictures of the correct setup and a list of measurements. If the product is not in the folder with setup sheets or it is the first time a product is produced, the machine operator needs more time to set up the machine. For example, the gripping jaws need to be selected based on the measurements of the product and the right hob needs to be taken. The gripping jaws transport a workpiece from the ring or belt loader into the machine where the operation is performed.

Figure 17: A hob

Then the hob is changed in the machine; Figure 17 shows an example of an hob. After that the operator must measure on both ends, just above the hobbing teeth, to check if the accuracy is sufficient. During the operation, the workpiece is put in place by a pin in the inner hole of the gear. This pin is installed next after that the gripping claws are installed and tested with a workpiece. Each element that is installed needs to be measured. If the operator needs to measure and adjust the tools multiple times, the setup process takes longer. When all the setup is finishe the operator runs one product for 97% of the procedure. While it is running the operator can start loading products onto the ring or belt loader.

Afterwards, the operator checks the measurements of the product; if it is not good enough there is still a chance to change the settings without losing the workpiece. If the settings are correct the operator can start the machine for all the workpieces. Figure 18 shows a process map of the installation of a machine at the hobbing department. The lanes indicate when the machine is on and when the machine is off. The model starts when the operator starts the setup for the next product and ends when the operator is done working with the machine. Appendix D shows the model split in two so it is better readable. Some tasks of Figure 18 are linked together by a group and assigned a number. These groups show tasks that are executed depending on the loading method. Manual is 1, automatic is 2 and autonomous is 3.

Loading system

Sometimes the batch size is larger than the number of workpieces that can be placed on the ring or belt loader, especially when they cannot be stacked. In that case, a machine operator has to take off finished workpieces and put on new workpieces. In that case, the production is not autonomously since the machine cannot finish the batch without an operator. Besides that, operators sometimes decide not to install the ring or belt loader when the batch is small.

According to the operators, some machines are easier to install with automatic loading than others. One which is more difficult is the c04. For that machine the products are placed into the machine by a lift. This lift is not adjustable in height. Not every gear has the same height so to properly clam the product in the machine the operator needs to be able to change the height. The only way that is possible now is to put extra elements on the ring loader, this is time-consuming and difficult. Only for products that return regularly the time has been invested to make setup pieces and therefore make use of the ring loader. On the other hand, the L282 is very easy to install, also in combination with the cobot. One operator indicates that even for 20 pieces it is worth using the automatic ring loader.

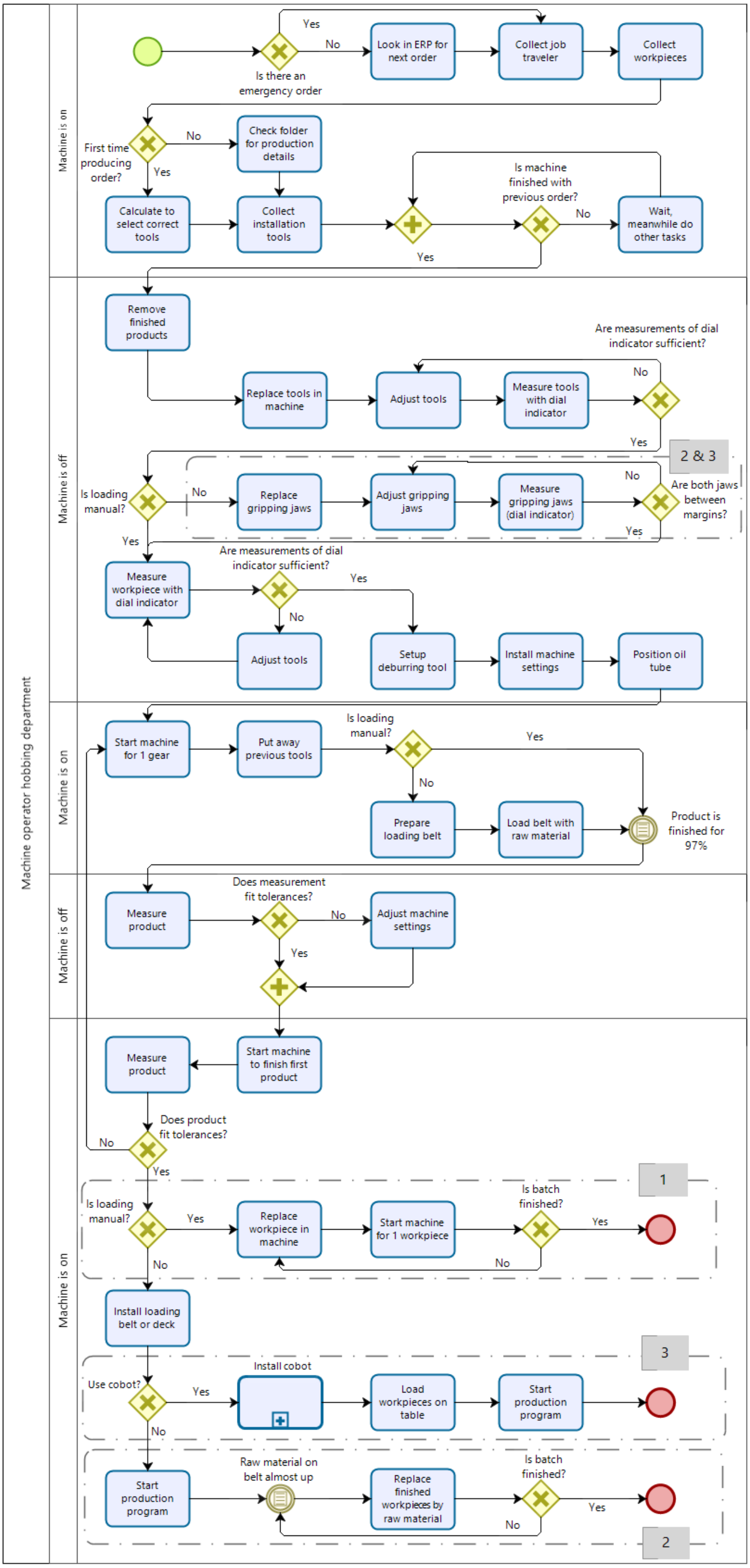


Figure 18: BPMN model setup machine at hobbing department

Cobot

Hankamp has two cobots, Kiki and Sophia. Kiki is paired with the newest machine, the L282. The cobot is placed on a dedicated table and the cobot is controlled by a tablet. Some machine operators experience Kiki's setup to be easier than Sophia's. Figure 19 shows cobot Sophia which is paired with the gvl. To use the cobot the operator has to load a selected the program matching the workpiece. The gripping jaws of the cobot arm have to be replaced depending on the diameter of the product. Then the tablet asks the operator questions that ensure a correct setup of the cobot. For example, the cobot asks how many products are on the table and what the diameter of the tool is. Besides that, the movement of the arm is installed by moving the arm once by hand.

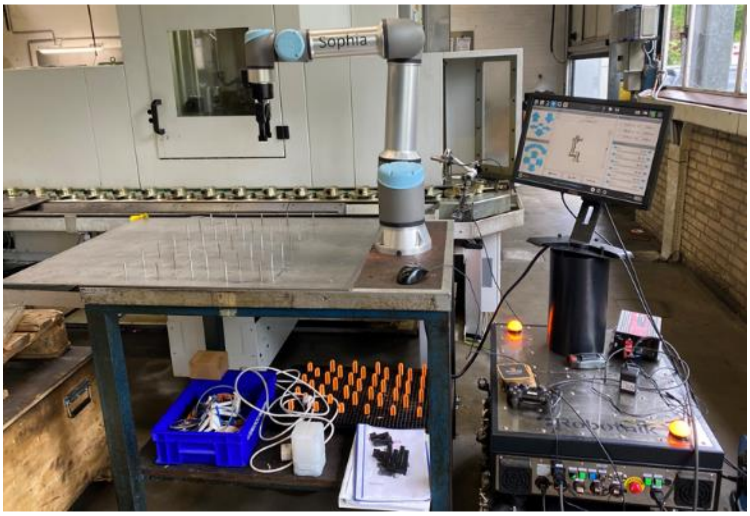


Figure 19: Cobot Sophia with dedicated table to store workpieces

The setup of Sophia is perceived as more difficult. In general, the setup process of Kiki and Sophia is similar. Both work with the same software system. Operators indicated a few differences. First, operators control Kiki with a tablet and Sophia with a mouse and computer screen. Besides that, Kiki has a table especially designed for placing the products. Lastly, the robot arm of Sophia moves in all directions at once compared to Kiki who can move in the x, y and z directions separately. Overall Kiki is a bit more user friendly. When talking to one operator he addressed that he cannot install the cobot but can turn it back on. Another opinion was that it is just as easy to quickly replace the products instead of using the cobot. On the other hand, there is also an operator who is quite experienced with the cobot and turns it on often. In practice, it depends on the machine operator if he uses the cobot.

One difficulty currently encountered is that sometimes the cobot cannot grab the product because it is not entirely positioned correctly. Similarly sometimes the cobot fails to correctly place the product on the ring loader of the machine. In both cases the cobot stops the production until someone intervenes and restores the position of the product.

2.3.2. Cycle and setup time

The cycle time is the time between when the machine picks up one product of the belt until it is ready to pick up the next. Figure 20 shows the different elements of the cycle time, the length of the elements is not based on reality but to give an indication. For example in reality it often takes longer to perform the operation.

Figure 20: Cycle time

The setup time is the time it takes to set up the machine until the machine is running. The machine needs to be set up with every new order. The time excludes gathering the raw material and tools since this can be done when the machine is still running. Figure 21 shows the elements included in the setup time. The duration of the setup time differs per product. It depends on the size of the workpiece and the batch size. When two products that are similar are produced one after the other, some steps might be skipped

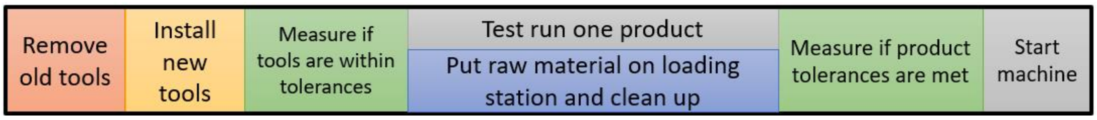


Figure 21: Setup time

2.4. Production planning

Each machine at the hobbing department is scheduled with 63 hours of work per week. In scheduling the production orders, the planner uses estimates of the setup and cycle time. When the product has been produced before, the planner takes the estimates of last time. The ERP system does not register the action production times so therefore estimates remain used. When a product is new the estimations are made based on the different operations that need to be performed. Sometimes the planner consults the technical production planner. He makes and checks the technical drawings and determines what operations need to be performed to make the gear based on the tolerances. Then they together discuss the estimations of the setup and cycle time. After the product is produced there should be subsequent calculation. When an operator notices that the estimations are far off, he informs the planner and then changes the estimations. In practice, the subsequent calculation does not always happen. Another reason for the setup time to be inaccurate is that some parts of the machine installation can take more time when they go wrong. Every time that a tool is placed it must be measured if installed correctly. If it takes an operator several tries, it takes a lot longer.

Since the order in which operations are performed is not the same for every gear, the planning is complex. Between main operations, they schedule one week. Main operations exclude laser engraving, inspection room and packing. The operators see the planning in the ERP system in form of a list. They do not have to take the top item but if an item a bit lower on the list is similar and therefore the setup time is short, they have the freedom to pick that item. The planner also tries to schedule similar products together but then the delivery dates must not be too far apart. In practice this is possible when the delivery dates are less than 4 weeks apart. The hobbing process might be similar but then the product with the later delivery dates also has to be pulled forward with all operations performed before hobbing. Pulling one product forward means that other products have to wait longer. It is important that this does not lead to delays at other departments for these products. This is only the case when the product that has to wait is not immediately expected at another department.

There is no specific planning for night production. Sometimes a machine operator can let the machine run for a few hours autonomously during the night but this is not taken into account in the planning. When the capacity turns out to be larger than 63 hours over a longer period of time the operator schedules more hours of work per week.

Hankamp has 10 customers that generate the most revenue; those get priority in production. They try to meet the promised delivery dates of these clients. In reality, this means that when the management thinks a product needs priority, someone of the management walks up to the operator on the shop floor and tell him or her that this product needs to be produced next.

2.5. Conclusion

By describing the current situation we answer the following research question “What is the current production process at Hankamp Gears?”. We answered this question by providing an answer to these 3 sub questions.

1. What is the production process for a gear?
   Various operations can and have to be applied to go from raw material to a gear. Within Hankamp the operations that need to be performed and the order in which vary per order. A job traveler describes which operations need to be performed and with what tolerances.
2. What is the setup process for autonomous production?
   The setup process for autonomous production differs from general production by the loading method. As explained in Section 2.3.1 there are 3 loading methods: manual, automatic and autonomous. In case of automatic and autonomous production, a loading belt needs to be installed. For autonomous production in some cases the operator also has to install the cobot.
3. How is the production planned?
   The production scheduling focusses on Hankamp's 10 largest customers. These orders get priority compared to orders from smaller customers. Most machines are scheduled with 63 hours of work per week. The planning department does not specifically plan for autonomous night production.

3. Literature review

In this chapter, we provide a theoretical framework for the research. By a literature study, we answer two knowledge problems. Section 3.1 answers research question 2 “What are relevant techniques for process improvement to increase capacity utilization?”. After that, Section 3.2 answers research question 3 “What are relevant theories about the implementation of automation in production?”.

3.1. Optimization methodologies

The literature on capacity utilization and process improvement highlights several theories that can improve the production process. The goal is to answer the following research question; “What are relevant techniques for process improvement to increase capacity utilization?”. This question provides insight into possible techniques that can help improve the production process at Hankamp. Section 3.1.1 discusses the Theory of Constraints. Afterwards, Section 3.1.2 discusses Lean management and some Lean management methods that seem relevant to Hankamp’s situation. We discuss the TOC and Lean management since they try to eliminate the constraint or waste in a process. In this research we also try to eliminate the bottleneck and not using existing capacity is a form of waste, waste of resources. In the conclusion, we sum up the findings and answer the research question.

3.1.1. Theory of Constraints (TOC)

Gupta et al. (2002) demonstrate the usefulness of TOC to make operational decisions. The performance level of a production process is based on its weakest points, the constraints. It states to focus on making more money instead of reducing costs. To achieve this goal, two conditions have to be satisfied, not only now but also in the future. The first condition the employer needs to provide is a satisfying work environment for the employees. The second is to satisfy the customer. The theory believes that satisfied employees provide high(er) quality and high(er) quality satisfies the customer. The TOC consists of five steps (Gupta et al., 2002 & Pereira & Goldratt, 1990) as described by Slack (2016):

1. *Identifying the constraint.* The first step is to identify the weakest part of the system, the bottleneck. This part determines the output rate of the entire process.
2. *Deciding how to remove the constraint*. Search for possibilities to increase the capacity of the constraint, preferably at a low cost.
3. *Subordinate everything else to the constraint*. The other elements of the process need to be adapted to the level of the bottleneck. For example, the throughput time and inventory are set at the level of the bottleneck. This helps to solve large inventory levels before the bottleneck and unused capacity after the bottleneck.
4. *Elevate the constraint.* To elevate means to eliminate. After steps 2 and 3 the elimination of the constraint should work automatically. If not, the company should spend extra time in this step. Search for the reason why the capacity is not increased and take the appropriate measures to still increase the capacity.
5. *Return to step 1.* When one bottleneck is removed there is a new second weakest spot in the process. Now the production pace is set by this bottleneck. The next step is to find this new bottleneck and therefore return to step 1. By repeating these steps the entire process is improved.

The fact that TOC focuses on capacity constraints is relevant in Hankamp’s situation. However, the method helps to identify the bottleneck and in our case the bottleneck has already been identified by the management, so step 1 is already done. On top of that, the theory suggests levelling all other departments to the bottleneck, step 3. This is not a solution that would work for our problem since we are not looking at throughput time or inventory levels but how to increase the capacity at the bottleneck by increasing utilization of the machines. Only step 2 and 4 apply to Hankamp's situation in this research. Next, we discuss Lean management.

3.1.2. Lean management

The literature about Lean management states process improvement is best reached by eliminating waste and non-value adding activities. Dias et al. (2019) suggest different Lean management methods that allow results at a relatively low level of investment costs. We discuss and explain different methods that focus on waste of time, changeovers or utilization rates since these subjects are most relevant to our research. We discuss SMED since it focuses on changeover time reduction and 5S since Hankamp has used this in the past. VSM is also a Lean management method that tries to reduce waste; it is not discussed any further because it mainly focusses on finding the bottleneck in the entire process. For this research we assumed that the hobbing department is the bottleneck since it was indicated by the management of Hankamp.

According to Pearce et al. (2018), the benefit of Lean management is not only that it reduces waste, but it reduces any non-value adding activities in the production process. The non-value adding activities do not seem like waste at first but these are activities that do not make a difference in the satisfaction of the customer. When Lean management is implemented successfully, this increases quality and utilization and decrease lead times. Implementation of an improvement program is however not always successful. The benefits of Lean management are widely published but organizations often struggle to implement it, especially in small and medium enterprises (SMEs). According to the European Commission (*SME Definition*, n.d.), Hankamp classifies as a medium-sized enterprise, since its yearly turnover is between 10 and 50 million euros and they employ less than 250 people.

According to Lean management theory, there are different types of waste (Liker, 2004) as described by Slack (2016). Waste can occur from irregular flow, inexact supply, inflexible response, and variability. First, an irregular flow is caused by anything that prevents a smooth process. For example, the waiting time of machines or employees can be measured in the machine or employee efficiency. Another example are process inefficiencies; these could have been prevented by maintenance or tasks that add no value. Second, inexact supply can be caused by under- or over-production, early or late deliveries and inventory. Next, an inflexible response is caused by large batches. Last, variability can cause waste when equipment breaks down or when delivered products are below quality standards and sent back to be changed or reproduced. These types of waste are always caused by one of these three types of causes: muda, mura and muri. Muda are activities that do not add value for the customer and therefore are a waste. Mura is unevenness in workloads and muri is "waste created through overburden" (Kim, 2015). Overburden means that work is unnecessarily complex. An example in the case of gear production is when the measurements are asked to be very precise even though that might not be necessary for the product.

There are 5 Lean management principles that are important for achieving Lean management goals (Gebeyehu et al., 2022 & Lamani et al., 2020). The 5 steps are especially relevant for reducing waste (muda):

1. Define the value. Specify the value of the process from the customer's point of view.
2. Identify the value streams. Identify which tasks are valuable for the customer and which are not. Remove the unnecessary steps.
3. Smooth process flow. Make the flow of goods as continuously as possible, by for example eliminating waiting time for employees or material.

4. Establish pull. Instead of producing everything according to the capacity produce only the demanded products. In this way it is possible to pull products through the system instead of push.
5. Pursue perfection. It is important to keep paying attention to Lean management so that the improvement remains and people do not fall back in old habits.

5S

5S is an improvement tool from Japan that aims at a clean and organized working environment (Sunder Sharma et al., n.d.). A clear and organized structure should decrease the waste of time and resources. 5S stands for five Japanese words with the following English meaning:

1. *Selection (seiri).* Eliminate all items in the workspace that are unnecessary.
2. *Systematization (seiton).* Organize all items in such a way that they are easily accessible.
3. *Cleaning (seiso).* Keep the workspace clean to reduce the chance of mistakes and equipment failure.
4. *Standardization (seiketsu).* Set rules so employees follow the first three pillars.
5. *Self-discipline (shitsuke).* Self-discipline is necessary to keep applying 5S, also in the future.

In the past Hankamp has tried to implement 5S. For example, a machine operator organized and labeled all the tool storage cabinets, so it is easier to find tools. This is not relevant for autonomous production but it is for increasing capacity utilization. When tools are easy to find it reduces changeover times. In the production hall there is also a large whiteboard with an outline specifically for the 5S method. During the research, we have never seen this whiteboard be used. At this moment not must time is spend on 5S anymore.

SMED – single minute exchange of dies

SMED is a Lean management methodology that focuses on the setup and changeovers in a process. The goal is to reduce the setup time as much as possible. The setup can be divided into two parts. In the internal setup, these tasks can only be done when the machine is shut down. And the external setup, these tasks can be performed while the machine is still running. The method exists of three steps (Cakmakci, 2009):

1. Separate the internal and external setup: Asses for all setup tasks if they need to be executed when the machine is running (external) or when it is shut down (internal).
2. Convert the internal setup to external setup: Try to convert internal setup tasks to external setup tasks. This can be achieved by advanced preparation of operating conditions and standardizing certain functions. The last step makes the setup process easier but does reduce the customizability of the product or service delivered.
3. Streamline all aspects of the setup operation: In this step, the operations have to be standardized and executed parallel whenever possible (Ahmad et al., 2017).

SMED can result in lower downtime between batches and increase output production. Cakmakci (2009) also argues that SMED needs improvement. The method does not take the motivation of employees enough into account to be successful. The lower downtime is not really a goal of our research. We hope to increase the utilization by producing autonomously during the night. However, we think it can be useful to look into internal and external setup tasks.

3.1.3. Conclusion

By reviewing the literature we try to answer the following research question: “What are relevant techniques for process improvement to increase capacity utilization?”

Section 3.1.1 explains why TOC does not apply to our research. Lean management is relevant since tries to reduce waste and Hankamp encounters waste, namely the waste of resources. However, we do not choose 5S and SMED as improvement methods, see Section 3.1.2. What we use from the SMED method is making a distinction between internal and external changeover tasks to give a better understanding of the setup process. The literature also states that the implementation of improvement methods is not always effective. Apart from improvement techniques, Górnicka et al. (2019) state that the efficiency of the process is greatly affected by the utilization of human and mechanical capacity. About human capital specifically, job satisfaction is an important factor in the productivity of a worker (Gunasekaran et al., 2000).

3.2. Implementation techniques

The goal is to answer the following research question; "What are relevant theories about the implementation of automation in production?". This question is relevant because to know when autonomous production is beneficial it is important to know about implementation theories.

Section 3.2.1 discusses factors to keep in mind regarding implementation. In Section 3.2.2 we explain two different implementation approaches: unilateral and participatory. Much of the literature on the implementation of new technology pays particular attention to change management. For example, Chen (2011) states that change management is necessary to smoothly implement and standardize new technology. "Change management is an enabling framework for managing the people side of change." (Balluck et al., 2020). The people side is relevant to the research since the core problem is that there are no clear conditions for the employees when it is beneficial to use autonomous night production. Different theories exist in the literature regarding change management and we discuss two theories relevant to Hankamp's situation in Sections 3.2.3 and 3.2.4. To conclude we answer the research question based on the findings in Section 3.2.5.

3.2.1. Important factors in the implementation

The literature revised to answer this question suggests that before implementing automation it is important to gain insight into the current situation (Herm et al., 2022). Herm specifically describes the implementation of Robotic Process Automation (RPA) and suggests using three stages: initialization, implementation and scaling. The cobots used at Hankamp are part of RPA. The next important factor is communication. Communication can take place in the form of an announcement of the change, training and feedback. It is important to communicate with employees because change can cause uncertainty. The uncertainty can cause stress or dissatisfaction because employees feel like they lose control (Bordia et al., 2007).

3.2.2. Unilateral vs participatory approach

There are two broad categories of implementation approaches, unilateral and participative. The participative approach assumes that the attitude of employees plays a vital role in the adaption of change. It is important to get support from the employees before implementing the change. The approach works bottom-up and may include sensitivity training, participation and redesign of teams (Waldersee & Griffiths, 2004). The unilateral approach works the other way around. When employees see the success of the implemented changes it is more likely they will support it. The approach is top down and the changes are simply implemented by the management without consulting the employees.

Not every method is simply unilateral or participatory; many methods also contain a bit of both (Waldersee & Griffiths, 2004). Explaining whether the chosen method is unilateral, participatory or both might help form the implementation approach.

3.2.3. ADKAR

Each letter of the word ADKAR stands for a stage that is required for successful people change, awareness, desire, knowledge, ability and reinforcement. It has to be executed sequentially for the best possible result (Jaaron et al., 2021). The model helps employees understand, embrace and commit to the change by involving them (Markopoulos et al., 2021). Jaaron et al. (2021) explain the 5 steps as follows:

1. *Awareness of the need for change*. In the first step it is important to provide enough information to the people involved why there is a need for change. Then explain what needs to change. Make it possible to let the involved ask questions.
2. *Desire to participate and change.* The next step is to convince people to participate in the change. This can be done by illustrating the benefits to the individuals and leaving room for their concerns and opinion.
3. *Knowledge on how to change*. It is important to have a clear plan on how to implement the change and take the insight gained from the people involved in steps 1 and 2 into account. Then, provide people with detailed information about how to realize the change. Sometimes providing the information is not enough, in that case, training should be provided (Nakigudde, 2018).
4. *Ability to implement required skills.* In this step, the change is actually implemented. It is important to provide supervision and adequate monitoring to make the implementation successful.
5. *Reinforcement to sustain the change.* The last step is to provide feedback about the obtained results to the individuals involved. Sharing the results obtained by the change can motivate people to continue to use the new method.

An advantage of ADKAR is that it takes the individuals involved into account. The change is tackled bottom up. ADKAR is better suitable for smaller changes. Since it focuses on people and ignores program management it is difficult to implement large scale changes (Nakigudde, 2018). A disadvantage is that the literature revised about ADKAR is not very elaborate on how to use it in practice. There are limited implementation tips available about how to achieve the 5 steps.

3.2.4. Kotter

The Kotter's change model consists of 8 phases. It can guide companies through large organizational changes. For the model to be successful the order must be followed and no steps may be skipped. Kotter (1995) established the following steps:

1. *Establishing a sense of urgency.* It is important to communicate the urgency of the change. Therefore the benefits and risks need to be analyzed. The goal is to be able to communicate why the change is necessary (Nakigudde, 2018).
2. *Forming a powerful guiding coalition.* The guiding coalition consists of the people who will manage the change. A group of people has a higher chance of succeeding than when one person leads the change (Kotter, 1995). The members of this coalition have to fully support the change (Nakigudde, 2018).
3. *Creating a vision.* The guiding coalition has to form a clear and easy to understand the vision (Kotter, 1995). This is important because employees who understand the benefits and effort are more likely to support the change (Appelbaum et al., 2012).
4. *Communicating the vision.* It is important to use multiple ways to communicate the vision to all employees involved. Deeds are often more powerful than words. Besides that, if the message is not repeated then it is unlikely to stick to the receivers (Kotter, 1995).

Communication is key for the implementation of organizational change as it can reduce uncertainty (Bordia et al., 2007).

5. *Empowering others to act on the vision.* The employees who need to execute the change need help to do so. First, it is important to listen to their concerns and search for ways to remove these barriers (Nakigudde, 2018).
6. *Planning for and creating short-term wins.* Kotter (1995) advises planning in such a way that improvements can be shown. After that, it is important that the gains are communicated and that the people involved are rewarded. Short time wins show employees that the change is beneficial and creates support and motivation for the change (Appelbaum et al., 2012).
7. *Consolidating improvements and producing still more change.* When the first successful results of the change are achieved it is important to keep working on the vision. Analyze what still needs improvement and work on it (Nakigudde, 2018).
8. Institutionalizing new approaches. Kotter (1995) believes that the implemented changes will disappear if it does not become a part of "the way we do thing around here" (Kotter, 1995). The goal is to make the process after the change the standard process.

An advantage of the model is that the steps are clearly defined. Every step suggests several methods to achieve the goal. A downside of the model is that it is time-consuming since it contains so many steps. The method also advises not to skip a step but steps 7 and 8 might not be relevant when the implementation is a one-time task, like buying a new facility (Nakigudde, 2018). According to Appelbaum (2012), another limitation is that Kotter based the model on this experience and not on existing academic literature. The individual steps can be supported by literature but there is no literature that supports all steps and that they should be done in sequential order. Yet the model became popular. One explanation for its popularity is that it is written in a more practical way instead of scholarly literature.

3.2.5. Conclusion

The literature found indicated several factors to succeed in the implementation of automation. Besides that, we discussed the methods ADKAR and Kotter's change model. With the information gathered we try to answer the following research question: "What are relevant theories about the implementation of automation in production?"

The most important factor to keep in mind is communication. Almost all the literature used indicates it is important for the successful implementation of change. Communication reduces uncertainty (Bordia et al., 2007) and helps to get employees involved and motivated for the change (Kotter, 1995). The change that needs to be implemented at Hankamp is autonomous night production if the conditions indicate that it is beneficial. The implementation of autonomous night production can be classified as a smaller change. Only the employees at the hobbing department and the management are stakeholders. It is therefore not a large organizational change. Therefore ADKAR suits Hankamp better because it is better suitable for smaller changes (Nakigudde, 2018). It focuses on the people involved which is also relevant for Hankamp since the decision to produce automatically is made by the machine operators.

4. Finding the solution: When is autonomous production beneficial?

The next step is to investigate when autonomous production during the night is beneficial. So we answer the following research question: “Which conditions should be met to make autonomous production of gears during the night at the gear hobbing department beneficial?”

At the hobbing department 7, machines can run autonomously. Due to time constraints, it is not an option to answer the research question for all machines; therefore we select 2 machines. Every machine is unique and therefore we cannot simply apply what works for one machine to another. We select one machine with a cobot and one without. The machines with a cobot are the L282 and the gvl, see Table 3. Of these machines, we select the gvl to answer the question because the L282 in combination with Kiki is already making a lot of autonomous hours. The gvl in combination with Sophia is doing this less compared to the L282. There are 5 machines without a cobot. The c04 is used for gears with large diameters, often more than 300mm. The c03 is used for inner hobbing. The k150hlc and kv200 are horizontal gear hobbing machines which are used for hobbing shaft gears; for an example see Figure 22. The K200 is quite old and therefore less easy to use autonomously. The L382 is similar to the gvl and L282 and is used to produce smaller gears, 30 to 200mm. The goal of autonomous night production is to increase production output. For Hankamp it is most interesting to look at the machines where they have the highest backlog. Figure 5 in Section 1.5 shows for how many weeks the machines are booked with work. The k150hlc has the highest with around 30 weeks. The L382, kv200 and gvl are booked with work for around 10 weeks. The second machine we answer the research question for is the k150hlc since that machine has the highest backlog. In that case, we investigate one ring loading combination with a cobot and a belt loader.

Name	Automatic loading
c03	Ring loader
c04	Ring loader
gvl	Ring loader+ Cobot
k150hlc	Belt loader
kv200	Belt loader
L282	Ring loader+ Cobot
L382	Ring loader

Table 3: Autonomous machines at the hobbing department

Figure 22: Cylinder gear

In Section 4.1 we discuss how the loading capacity influences the autonomous production time during the night. Section 4.2 explains requirements that need to be met in order to produce autonomously. We explain more about cobot Sophia and autonomous production in Section 4.3. Next Section 4.4 discusses the compressors that need to stay on the entire night and the cost related to that. Together with the management of Hankamp, we raised this question. In Section 4.5 we discuss the possible consequence of machines standing still in the morning because of night production. Section 4.6 combines all findings in a calculation tool and provides a framework with which operators can decide if night production is beneficial. Lastly, Section 4.7 summarizes the findings.

4.1. Loading capacity

As described in Section 2.3.1 and as shown in Figure 18, the operators can choose between 3 different loading methods: manual, automatic and autonomous. The choice of loading method influences the total operation time; the time between collecting the work order and passing it on to the next operator. Figure 18 shows that the setup requires extra tasks in case of automatic and autonomous production since the gripping jaws and loading belt need to be configured. On the other hand, time is saved because an operator does not need to replace the products manually. To say anything about what is more beneficial, we first determine the differences between the production time for each loading method. This is done by making a timeline of the setup process in which we focus on tasks that are different between the loading methods. The blocks in Figure 23 do not represent the timeframe in scale. The colors indicates the type of events, which is explained in the legend.

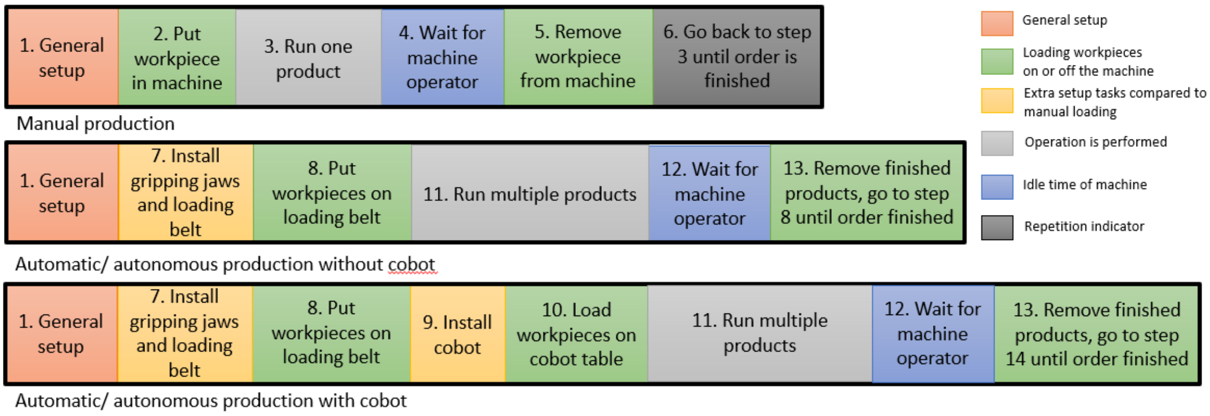


Figure 23: timeline of the setup focussing on differences between the setup processes

For manual loading, steps 2 up until 5 are repeated for every product. When using automatic/autonomous production without the cobot, the operator has to perform extra installation work, see step 7 in Figure 23. The process is autonomous unless the batch size is larger than the capacity of the loading belt. For large batches, part of the batch can run autonomously but after a while, the finished products have to be replaced with new workpieces. An advantage compared to manual production is that the operator can change the workpieces while the machine is running, see step 13. However, during the night the machine can only produce the parts that can be loaded automatically. The cobot increases the capacity of automatic loading and therefore it takes longer before an operator has to change parts. Lean Management theory suggests looking for waste in the production system. The waste, in this case, is the time a machine stands still because it is waiting for the operator, indicated as in steps 4 and 12 in Figure 23. In the case of manual production, the total waiting time for the machine operator is the sum of the waiting times before each product, so N times step 4. In the case of automatic/ autonomous production, there is only a waiting time for the operator when the machine is finished with all the products on the loading system before new material is loaded. Lean management also states that unnecessary tasks are a form of waste. The extra installation activities (yellow blocks) can be seen as waste when they are unnecessary. However not using the capacity of autonomous night production is also a form of waste.

To conclude automatic/ autonomous loading is beneficial compared to manual loading when the extra installation time (7) plus the waiting time (12) is smaller than the sum of the waiting times for manual production (4). In this case, we do not take into account that an operator could perform other tasks during the day when the machine is loading autonomously. This is because the research question asks to indicate when autonomous night production is beneficial, not just autonomous production.

During the night the production can only run autonomously. The longer the machine can run autonomously the better, since those are extra production hours. Night production is beneficial compared to manual production when the production time during the night is larger than the extra installation time (7 & 9) – the total waiting time (4). Night production with a cobot is beneficial compared to night production without a cobot when the extra production time yielded by the extra capacity is larger than the installation time of the cobot.

In the case of autonomously production, the production that is gained is determined by the capacity of the loading system, cycle time and batch size. Formula (1) can be used to calculate the extra production time when producing autonomous during the night.

(1) Extra production time = cycle time * min(loading capacity, batch size) - installation time of cobot

4.1.1. Loading capacity of gvl

This machine has 30 spots on the ring loader for workpieces. Only when the diameter of the workpiece is larger than 75 mm one spot in between two workpieces needs to be left unfilled. In that case, the capacity of the ring loader is 15 spots. In the red circle of Figure 24 it shows the cobot, Sophia. The capacity of Sophia is determined by the diameter of the workpiece and if the workpieces can be stacked. Table 4 shows the number of workpieces that can be loaded autonomously depending on the diameter of the product. The last column shows the number of workpieces that can be loaded autonomously when 3 products are stacked at the cobot table. It depends on the product if it can be stacked and how many; we explain this further in Section 4.3. The average cycle time of operations performed between the beginning of March 2022 and the end of May 2022 is 3.0 minutes, based on ERP data. Cycle times depend on the diameter, height of the product, material and type of gear teeth that are made. For the orders processed on this machine (more than 500), the average batch size is 212 products.

Figure 24: Loading ring gvl in combination with Sophia

Diameter product	Number of products on loading belt	Number of products on cobot table	Total of belt and cobot without stacking	Total of belt and cobot with stacking 3 products
X < 45 mm	30	30	60	120
45 mm ≤ X < 75 mm	30	12	42	66
75 mm ≤ X < 95 mm	15	12	27	51
95 mm ≤ X < 145 mm	15	0	15	15
X ≥ 145 mm	Manual loading			

Table 4: Loading capacity of the gvl depending on the diameter of product and use of cobot

4.1.2. Loading capacity of k150hlc

This machine has two different loading systems, a rolling track and a chain conveyor, Figure 25 shows the last option. The capacity of this loading system is determined by the length of the chain conveyer. The gravity loading belt is not used often; it has some difficulties in practice. It is used for really small gears that roll into a slot. In practice, the small gears stick together because of the oil and they are pushed over the edge by gravity. When using the chain conveyer, an operator loads the workpieces on chain conveyer and the finished products are put back on the blue belt, see the bottom of Figure 25. The chain conveyer has an iron chain with teeth where the workpieces are loaded on. These chains are replaceable for different kinds of diameters of the workpieces. At the end of the blue belt, there is a sensor that stops the machine as soon as it measures a product. In the situation of Figure 25, both the chain conveyer and blue belt have a capacity of 29 workpieces. The autonomous production time of this machine is therefore 29 times the cycle time. The capacity, therefore, varies by the diameter of the workpiece. The average cycle

Figure 25: loading system of k150hlc

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Al meer dan 100 jaar in beweging

time of operations performed between the beginning of March 2022 and the end of May 2022 is 2.1 minutes, based on ERP data. Therefore the estimation of the average autonomous production time is 29 * 2.1 = 60.9 minutes. The average batch size on this machine is 316 based on more than 150 orders. Figure 26 shows the hours of production that can be yielded during the night if the capacity of the loading belt is 29.

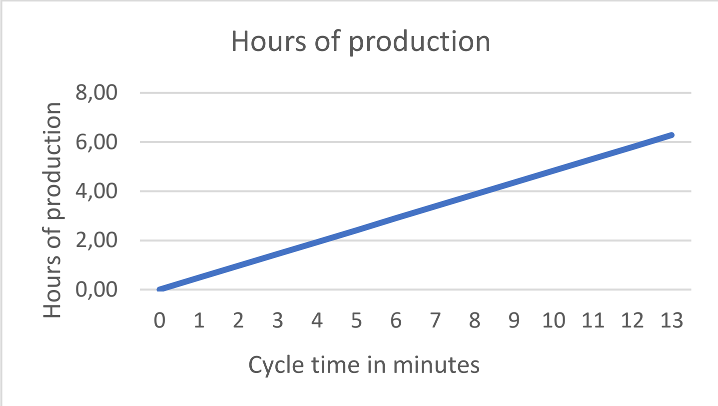

Figure 26: Hours of night production on the k150hlc if loading capacity is 29

4.2. Technical conditions

4.2.1. Tolerances

The tolerances of the measurement of the workpiece also influence whether it is possible and beneficial to run a process autonomously. When tolerances are small a product has to be measured after N number of products produced. For example, for a tolerance of 1/100mm, a product is measured after every 4 to 5 products. The production process is simply too unstable for such a low tolerance. When the operator notices that the measurements differ from the tolerances, he adjusts the process so the requirements are met. In the current situation, it is simply not possible to let the production run autonomously. The production process is in most cases stable enough for a product with a tolerance of 0.03mm. In that case it depends more on the stability of the operation process of the machine. The stability of the process is also influenced by the maturity of the process in terms of documentation, quality control and suitable knowledge level of the operators.

There is another factor that influences the decision to run autonomously. Two types of work go through the department: pre-hobbing and one-time processing. Pre-hobbing means that the gear tooth undergoes multiple operations in which the blemishes can be removed. One of those operations is grinding. Therefore at pre-hobbing, the tolerances are not as strict. When it concerns one-time processing, the product does not undergo other processes that can correct blemishes created during the hobbing process. Therefore it is important to stick to the tolerances when hobbing.

4.2.2. Other conditions that need to be met

There are factors that make autonomous production impossible:

- Operators never decide to run the first production of a new product run autonomously. After every N products, they check the measurements since the process of this operation is unknown. Whether the product operation can be performed autonomously next time depends on how the last batch went. If the process was stable during the last production, so no adjustments had to be made, then next time the production can be run autonomously since the correct settings are known.
- Some types of products cannot be clamped by the gripping jaws of the machine and therefore have to be installed manually.
- For some types of products, there is no correct machine fixture. A machine fixture is a tool that holds the product in place when the hob is making the tooth. It secures the product from the bottom of the gear in the centre hole, in this way it centers the product. The machine fixture has to secure the product so it does not move during the large force of the hobbing process. If there is no correct machine fixture, the product has to be installed manually.

4.3. Cobot Sophia

First of all, all conditions mentioned in Section 4.2 have to be met to use the cobot during the night. When it is already beneficial to use the ring loader during the night there are a few extra conditions that should be met to use the cobot. The diameter of the workpiece should be smaller than 95 mm with the current setup of the cobot table. Next to that, a program that moves the workpiece to the loading belt should be available on the computer or it should be created. Only two people can create such a program at Hankamp.

Using the cobot is beneficial when the installation of the cobot takes less time than the extra production time yielded during the night because of the extra production. This again depends on the cycle time of the product and the number of products on the cobot table, see Table 4. The table contains a column with the capacity of the cobot table when products can be stacked. In this table, we assume that 3 products are stacked but that depends on the height of the gear blank. When products are stacked, there is a risk of products sticking together when the cobot arm lifts one product. When the arm loads two products on the loading ring this causes the machine to stop since the gripping jaws cannot load the two items into the machine. The cobot has a pre-programmed method to peel off products. In that way, it prevents the bottom product from going with the other product. Operators can turn this method on by answering a yes or no question if they think it is necessary. However, this does not resolve all sticking problems. When there is a large contact surface there is a larger chance of products sticking together. Besides that the more oil the stronger the adhesive force and the larger chance they stick together. Workpieces sticking together can be prevented by cleaning the products beforehand.

4.4. Compressors

When a machine is left on to run during the night it uses the same amount of electricity when running during the day. However when the machine is finished, only one machine in the department shuts down, one stays on and the others go into standby mode. Standby mode entails that the machine is still under air pressure. To have this air pressure the air compressors need to be on from 22:00 until 6:00, even if the machines only produce autonomously for 2 hours. Compressors use quite a lot of energy when turned on. Therefore the management is interested if night production is still beneficial knowing that the air compressors need to be on during the night. If not, it can be seen as a waste of resources according to Lean management. Hankamp has three compressors: one smaller and two larger. Currently, the smaller compressor is on during the night because some machines at other departments continue producing during the night.

The cost of 1 m^3 air compressed air can be calculated by the following formula (*Kost van Perslucht | Energieverbruik van Een Compressor*, n.d.).

Cost of 1 m^3 0compressed air = compressor power * time in hours to produce 1 m^3 * the price of electricity.

The average use of Hankamp is 4.9 m^3 per minute. To calculate the cost for one night the value also needs to be multiplied by 60 (minutes per hour) and 8 (hours per night). Hankamp has two different electricity prices. €0,063 from 7:00 until 23:00 and €0.052 during the other hours. The average price during the night (from 22:00 until 6:00) per kWh is therefore €0.053. This yields an outcome of around €31.34 per night. These are the cost for running all machines at the factory. The energy cost of the compressor can be divided by the number of machines used during the night. At this moment around 5 machines run some hours during the night. For each machine, this would be a little over 6 euros which are negligible compared to the gain of the extra production.

To roughly check if €31.34 per night could be true we looked at the energy bill of May 2022. During that month there were 22 working days. The total expenses for that month when the electricity price is low were €981.80. Dividing the cost by the 22 working days yields €44.63 per night for electricity. Based on this we conclude that our estimate is accurate enough since the machines also use electricity during the night.

4.5. Machines stand still in the morning

In this section, we look at what if not only the gvl and k150hlc but multiple machines run through the night. A machine operator is always responsible for two to three machines. If he arrives in the morning and all three machines that he is responsible for have run through the night, they need a new setup simultaneously the next morning. If the order is not completely finished the operator could first load extra material on the machine and then start it again; this would not take too much time. However, if multiple machines have completed their orders, some stand still for a longer period since the operator is working on the setup of another machine. This is less likely to happen when a machine did not run through the night because the machine was most likely stopped during a batch at the end of the last shift.

Since it is difficult to exactly estimate how much time a machine stands still, we look at a positive, and negative situation for 0, 1 and 2 machines standing still in the morning. To determine the waiting time of the machines we estimate an average of the setup times of all machines in the hobbing department as indicated in the ERP system, 1.13 hours. When one machine is standing still in the morning we subtract 1.13 hours from the total production time during the night. When 2 machines stand still we subtract 1.13 + 2 * 1.13 = 3.39 hours.

4.6. Solution

If a product fits the technical requirements to produce autonomously can be determined by the operator. To indicate if autonomous production is beneficial when looking at the time the extra tasks take that need to be performed we have drafted the following formula.

(2) Autonomous production time = cycle time * min(loading capacity, batch size) - installation time of cobot – waiting time in the morning

The autonomous production time is calculated with VBA in Excel; for the interface see Figure 27 and for the VBA code see Appendix E. For every product the operator needs several input parameters; these are indicated by the green background: cycle time, batch size, diameter and the number of stacked products. The number of stacked product concern the cobot; if 0 products are stacked the operator does not use the cobot the installation time of cobot is turned to 0. According to operators the installation time of the cobot is on average 20 minutes; however, this input parameter can be changed. Next to that, we estimate the waiting time in the morning by assigning chances of the situation occurring. These have a yellow background to indicate that they can be changed but usually stay the same. The result is displayed in the blue box. This specific tool can be used for the gvl, L382 or L282 in combination with Sophia. To also use it for Kiki the capacity of the cobot table has to be changed. The result displays the

Variable	**Input**	
Installation time cobot	*20*	
Cycle time in minutes	*4,5*	
Batch size in pieces	*20*	
Diameter in mm	*70*	
Use cobot? If no fill in 0 if yes fill in the number of products stacked		
stack x products on cobot table	*1*	
Result in hours	1,132767	
	Time	**Chance**
Waiting time morning in hours	2,034	
High (2 machines waiting)	*3,39*	*0,6*
Average (1 machines waiting)	*1,13*	*0,25*
Low (0 machines waiting)	*0*	*0,15*

Figure 27: Interface of calculation tool that indicates whether night production is beneficial

estimated extra production time because of night production. When the calculation results in a negative outcome it displays 0. In that case, autonomous night production is not beneficial.

Next to the tool we provide a framework with which the operator can indicate if it is beneficial without using a computer. We make a decision tree because it is unlikely that operators will use the Excel tool in practice. There are a few computers in the workshop but these are hardly used for other activities than clocking time on work orders. In two cases the decision tree refers to the Excel tool to answer if it is beneficial since we cannot generalize that in the decision three. For the decision tree see Figure 28. The first three decisions eliminate the orders for which autonomous production is not possible because of technical reasons as stated in Section 4.2. The last decisions indicate if it is beneficial based on the calculations in Sections 4.1 and 4.5.

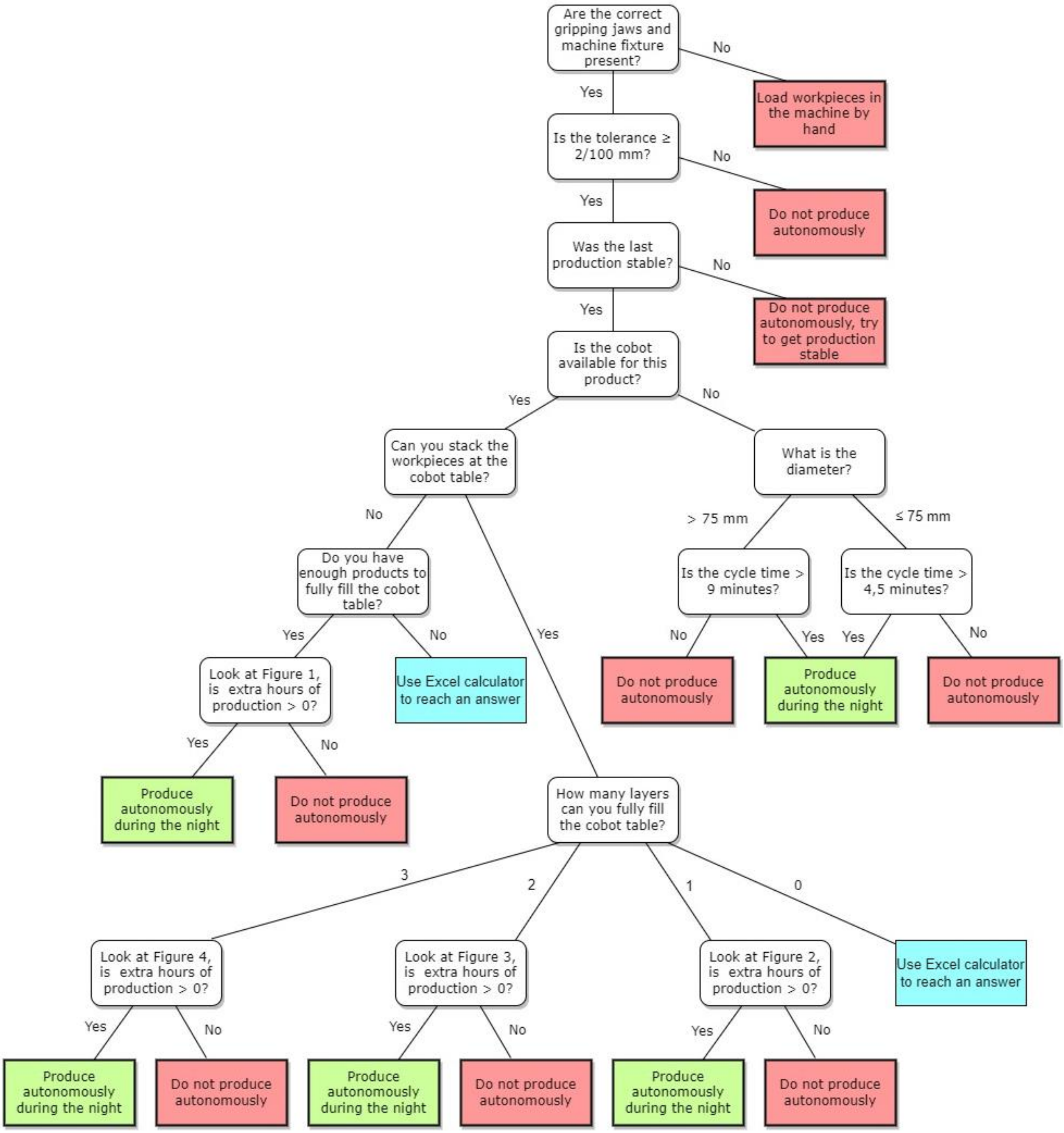

Figure 28: Decision tree for determining if autonomous night production is beneficial

Figure 28 refers to other figures: 1, 2, 3 and 4. This is done so the decision tree does not get too large and unclear. These figures display graphs in which the operator can read how many hours he can gain or not from using night production based on the cycle time and diameter of the product. For an example see Figure 29; Appendix F displays the other figures which are referred to in the decision tree. To use the framework the operator has to answer all the questions and he sometimes needs to consult one of the figures. The Excel tool and the graphs take also the time that is lost because of night production into account. Therefore it indicates the time that is won by producing autonomously during the night. Red indicates not to produce autonomously and green does. The blue results indicate that it is a specific case and to get a result the operator has to use the Excel tool displayed in Figure 27.

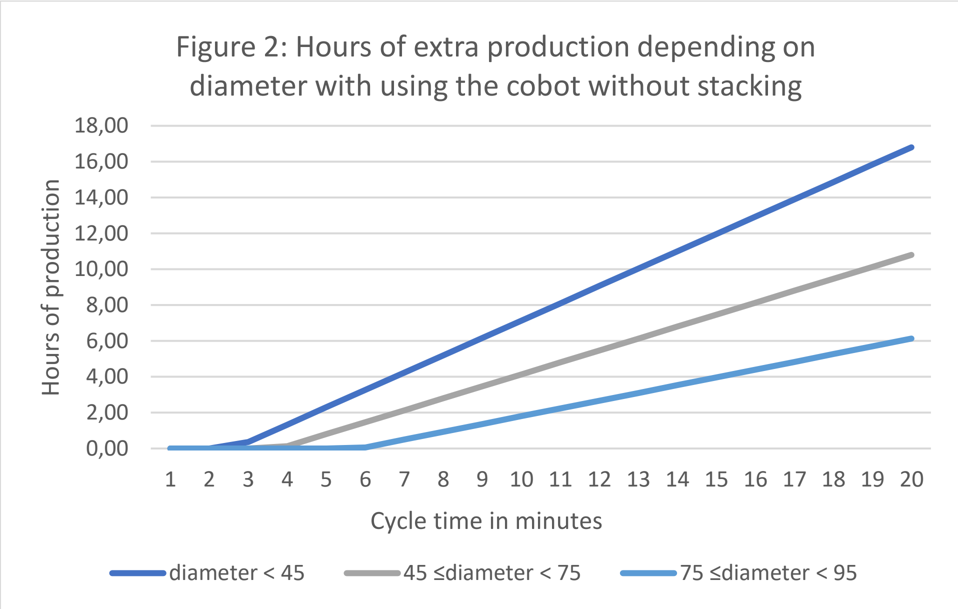

Figure 29: Figure 2 from the decision tree

The framework could now work for Sophia in combination with the gvl or L328. With a few small adaptions, it can also work for the Kiki in combination with the L282. For the k150hlc we can conclude that with the current loading system autonomous production is not beneficial often. To run at least 2 hours during the night with is currently estimated as the time a machine stands still in the morning the cycle time has to be larger than 4.5 minutes. Between March and May 2022, this occurred only 7% of the time. However from these product we do not know if they meet the technical conditions as described in Section 4.2.

4.7. Conclusion

This chapter answers the following research question: "Which conditions should be met to make autonomous production of gears during the night at the gear hobbing department beneficial?".

First the technical conditions, as we described in Section 4.2, have to be sufficient:

- The correct tools have to be present to install the loading systems.
- It should not be the first time the order is produced.
- With the current machines and circumstances, the tolerance of the product has to be larger than 0.02 mm.
- The operation process should be stable and known.
- The operator should not have to measure a product after every N products given a batch size of X to see if the machine settings need to be adjusted.

When a product meets these conditions, it is technically possible to use night production. To answer if it is beneficial to use night production we created an Excel tool that takes into account the extra setup time, loading capacity and possible extra time a machines stand still in the morning, see Section 4.6. To increase usability by operators on the shop floor we created the decision three that can be placed on the sides of the machines.

5. Implementation

The goal of the research is to increase the capacity at the bottleneck department by implementing autonomous night production. Therefore the next question to answer is: “How can Hankamp implement night production at the bottleneck department when indicated that it is beneficial?”

The literature from research question 3 has indicated that ADKAR is a useful method to implement change in this situation. ADKAR defines 5 phases to successfully implement change: awareness, desire, knowledge, ability and reinforcement. First, because it is best used for small organizational changes and second, it involves all relevant people. Due to the short time, we do not execute the ADKAR implementation process during this research. Instead, we provide an implementation plan according to the ADKAR theory, we explain this in Section 5.2. However, first, we explain how to implement the decision tree in Section 5.1. This is used to implement the night production since it indicates when it is beneficial.

5.1. Implementation of the decision tree

We estimate that the Excel calculation tool is not easy to use for the machine operators. Operators need to go to a computer to use the Excel tool, which there is one in the department. At this moment the computers are only used for clocking the hours an operator works on a machine. However this does not always happen, sometimes operators forget to do this. To increase the usability of the solution we create the decision tree.

The decision tree can indicate whether autonomous night production is beneficial with limited use of the Excel calculation tool. The decision tree and the graph should be printed on large sheets of paper and then plasticized. Then they can be placed on the side of the machine and added to the folder with setup sheets. It should be located at the glv and L382 since these are similar and both can be used in combination with Sophia. We also provide a document where the decision tree and Excel calculation tool are clearly explained. The next step is to explain the use of the framework to the operators who need to use it. We further elaborate on how to do this in Section 5.2.

5.2. Implementation of night production

We provide advice to Hankamp on how to implement night production according to the 5 steps of the ADKAR model.

Awareness of the need for change.

Explain that the hobbing department is currently the bottleneck by showing to the operators how much work there still is for the department. Also, explain how improving capacity utilization at the hobbing department can help Hankamp. Show a few examples of products that we know of that can run very long during the night and reoccur regularly.

Desire to participate and change

The people who need to execute the change, in this case, night production, should be convinced that it is beneficial. The decision tree and Excel calculation tool can help in this case. The decision tree and the graphs do not only indicate if it is beneficial but also how much extra production time can be achieved in a specific case. The operators should be convinced that the tool can help them and this can be reached by explaining how it works. At that point, there should be an option for operators to ask questions and raise their possible doubts about the framework.

Knowledge on how to change

Possible doubts that arise in steps 1 and 2 should be investigated and either be solved or explained why the management expects it not be a problem. Make sure that the operators feel heard.

Once the tool itself is explained there is no need for training about the tool itself. There is, however, a knowledge gap regarding installing the cobot. As stated in Section 2.3.1, not all operators working at the hobbing department use the cobot. Some of them do not know how to set up the cobot. Therefore the knowledge and usage of the cobot can differ per shift. Using the cobot increases the automatic loading capacity significantly and it is, therefore, more likely to be beneficial to produce autonomously during the night when the cobot is used. At this moment Sophia is not always installed in every shift even when it could have. To implement night production on a regular basis it is important that these operators receive training, so they can set up the cobot. I In this way all conditions are met to enable autonomous night production.

Ability to implement required skills

Once all operators are trained to use the cobot the implementation can start. Make sure that one person is every day involved in the change process by talking to the operators about their experience. Keep track of the number of products that are produced during the night and possible problems that arise. If it is not possible with the ERP system, do it in a manual form.

Reinforcement to sustain the change

After a while, the operators have to provide feedback about their experience with night production and the use of the decision tree. Hankamp should share the results with the operators. If they reach extra production indicate how much. Since the ERP system does not register night production, it is difficult to do this. One way Hankamp can still improve the framework is by improving the estimations of the number of machines standing still in the morning and the duration of this. Besides that ask the operators how they think the framework can be improved.

5.3. Conclusion

In this chapter, we answer the following research question: “How can Hankamp implement night production at the bottleneck department when indicated that it is beneficial?”

First, the operators need to know when it is beneficial. They can use the decision tree to do this, see Section 4.6. Next to implement night production Hankamp can follow the ADKAR model. In this way, they involve the operators in the process which gives it a larger chance to succeed.

6. Conclusion

The research provides a framework with which operators can determine if autonomous night producing is beneficial. To do so we answered multiple research questions. The conclusions of these questions help to answer the main research question:

Under what conditions is it beneficial to produce batches autonomously during the night so the capacity utilization is increased at the bottleneck department?

Section 6.1 provides conclusions to the research questions. Next, we discuss some limitations of the research in Section 6.2. Then in Section 6.3, we give recommendations to Hankamp. Lastly, Section 6.4 gives advice for further research.

6.1. Conclusions

This section provides the main conclusion per sub-question to then answer the main research question. The aim of the research is to indicate when night production is beneficial.

What is the current production process at Hankamp Gears?

Various operations have to be applied to go from raw material to gear. Within Hankamp sequence and the operations that need to be performed vary per order. A job traveller describes which operations need to be performed and against which tolerances. The production scheduling focuses on Hankamp's 10 largest customers. These orders get priority compared to orders from smaller customers. Most machines are scheduled with 63 hours of work per week. The planning department does not specifically plan for autonomous night production, but some machines do already use autonomous night production. This does not happen in the hobbing department, which is their bottleneck.

What are relevant techniques for process improvement to increase capacity utilization?

Lean management is relevant since it tries to reduce waste and Hankamp encounters waste, namely the waste of resources. However, we do not choose 5S and SMED as improvement methods, see Section 3.1.2. To answer the question of when it is beneficial we look at the current waste in the process, but also what waste could arise if autonomous night production is implemented.

What are relevant theories about the implementation of automation in production?

Hankamp wants to implement autonomous night production if the conditions indicate that it is beneficial. This is some form of change management. We discussed the Kotter and ADKAR models. The implementation of autonomous night production can be classified as a smaller type of change. Only the employees at the hobbing department and the management are stakeholders. Kotter's model focuses more on large organizational change. Therefore, for implementation, the ADKAR model suits Hankamp's situation better because it is better suitable for smaller changes. It focuses on the people involved, which is also relevant for Hankamp since the decision to produce automatically is made by the machine operators.

Which conditions should be met to make autonomous production of gears during the night at the gear hobbing department beneficial?

We have made a framework that can indicate to an operator if autonomous night production is beneficial for a specific order. Whether autonomous production is possible depends on technical aspects, such as the availability of the right tools, the tolerances of the product and if the stability of the operation process is sufficient. This can be determined by the machine operators setting up the machine. The input for the model is: cycle time, batch size and diameter of the product. It is possible to indicate if the cobot is used and how many products are stacked; that case also takes the extra installation time into account. If beneficial, the result of the framework shows the extra production during the night taking all extra installation and waiting time into account.

How can Hankamp implement night production at the bottleneck department when indicated that it is beneficial?

Hankamp can use the ADKAR model as a framework to implement night production. By following these 5 steps, they involve the operators who need to execute the night production. To help operators with indicating when it is beneficial, the decision tree can be implemented.

Under what conditions is it beneficial to produce batches autonomously during the night so the capacity utilization is increased at the bottleneck department?

Research question 4 in Section 4 summarizes best when producing large batches autonomously during the night or not. This cannot be answered for all batches in general and therefore we provide the framework. To shortly summarize:

- Tools to install the loading system are present.
- It should not be the first time the order is produced.
- With the current machines and circumstances, the tolerance of the product has to be larger than 2/100 mm.
- The operation process should be stable and known. The operator should not have to measure the products after every N products to see if the setting need to be adjusted.
- If the abovementioned conditions are met then the Excel calculator indicates if it is beneficial based on the diameter, batch size, use of cobot and number of items stacked on the cobot table.

6.2. Limitations

Operators only clock the time they work on an order in the ERP system. Since an operator works on multiple machines at the same time it can be that an operator clocks out at a later time or simply forgets to clock out an order. Only when the entire order is finished, the number of products are marked as complete. Therefore, when the production takes multiple days, it is not possible to know when exactly how much was produced at which day. This makes it difficult to keep track of the number of hours of production during the night. It also makes it more difficult to have an accurate cycle time in the ERP system because you do not know if the data is valid. What could be done to improve this is to let operators clock the number of products they produced. This however increases the workload of the operators since they have to count the number of products produces.

Second, the chances that 1, 2 or 3 machines need a new setup simultaneously during the morning when the shift starts is now estimated based on conversations with the management and operators. This estimation leaves room for quite large errors and also influences the outcome of the Excel calculation tool and therefore the framework. This can be improved in further research, see Section 6.4

Third, since it is a bachelor thesis research, we have to perform it within a time limit. We decided together with Hankamp to only give advice on how to implement the framework, and the actual implementation will be done by Hankamp.

6.3. Recommendations

The first recommendation is to train the operators at the hobbing department who are not capable of setting up the cobot yet. In case the cobot can be used, the chance that autonomous production is beneficial is larger since the autonomous production time can be increased significantly. Next to that in both shifts, there then is enough skill and knowledge to use the cobot more to implement night production. Operators have indicated that they are willing to learn how to set up the cobot. Using the cobots can also be beneficial during the day since the operators can perform other tasks meanwhile.

Aside from that, we advise Hankamp to try to stick to the plan in the ERP system. Currently, management employees go to the workshop to instruct operators that they need to do a certain order first before looking at the schedule again, as explained in Section 2.4. When the operator can select the next order from the schedule in the ERP system he has the freedom to choose one of the few orders at the top of the list. This gives the operator the opportunity to produce two similar products right after each other which reduced the setup time of the second order. It also creates a possibility for the operator to select an order which can make many autonomous production hours during the night. If the management still feels like the order needs to be moved forward this can also be done via the ERP system.

Next to that, Hankamp should evaluate the use and output of the framework. Due to the shortage of time, it was not possible the evaluate the usability of the tool properly. The management could interview the operators after a few months if and how often they use the framework. Besides that, they can ask if the results seem reliable and if they have any possible improvements.

We expect the Excel tool not to be used at the computers in the warehouse since the threshold to go to these computers would be too high. There are two tablets in the warehouse which are used to add and withdraw data from the ERP system. Operators might experience the use of the tool on the tablet as more user-friendly.

Last, look into the possibilities to increase the loading capacity of the k150hlc. Because of the low loading capacity, autonomous night production is not indicated to be beneficial often. Hankamp is already looking into how to place an extra cobot at this machine. At this point, the finished products are put back unprecise the blue belt conveyor. A cobot needs to have an exact location of where to pick up the product; otherwise, it shuts down. To solve this, we recommend replacing the gravity loading system with another chain conveyor. This gravity loading system is not used often currently, because it does not work that well and at this moment there are not that many products that use it. If the second chain conveyor is installed, the machine can put the finished products on it at the correct position to be picked up by a cobot. A downside of this is that Hankamp does lose production flexibility in the future since it is no longer able to use the gravity loading system.

6.4. Further research

The first option for further research is to improve the framework. During this research, there was no time to spend much attention to the frequency and amount of time machines stand still in the morning after night production. The estimation is based on interviewing employees but no measurements or ERP data was used. When these estimations are improved it can also significantly improve the accuracy of the Excel calculation tool.

Following on this or possible combined research could indicate how to minimize the hours a machine stands still because there is no operator present. In this research, we assume an average waiting time in the morning. For further research, it is possible to investigate if the operator at the end of the evening shift already knows that the complete order is not yet finished the next morning. In that case, the operator only needs to reload workpieces the next morning; which does not take much time. Maybe it is possible to implement this factor into the tool.

The next step to implement autonomous night production at the hobbing department is to specifically plan for night production. Future research could focus on scheduling the orders in such a way that the highest output production is yielded. In this step, it is also possible to look into how the Excel calculation tool can be useful for the planning department. The technical aspects, e.g. if the process is stable enough, are not registered in the tool, but all the data used in the Excel tool is known beforehand. For example in Section 4.6 we conclude that for the k150hlc it is only beneficial to produce 7% of the production autonomous during the night. This disregards the technical conditions but if this information is added to the ERP system by the operators some of theses products can be specifically planned during the night.

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Appendix A: List of problems

This list explains each process in the problem cluster, see Figure 4.

- **Machines are fully booked for months.** Because of the current high demand some machines are already fully booked for the next upcoming months. Partly by backlog but also by orders that are ordered well in advance.
- **Too little capacity.** Hankamp Gears encounters more demand than it can produce. Especially at the gear hobbing department, which is their bottleneck. A new machine is delivered in March. However, the management does not expect it to solve all capacity issues.
- **Capacity utilization is low at the gear hobbing department (during the night).** Hankamp has several machines at which large batches can run autonomously. Using these during the night (22:00 until 6:00) could increase their production time. At this moment they make no use of this.
- **Not beneficial to run batch autonomously.** In certain conditions, it is not possible or beneficial to run a batch autonomously. We discuss some well-known restrictions:
    - **Quality needs to be monitored manually during production.** Some products need quality monitoring after a certain number of products is produced. For example, the operator has to check the tolerances of the gear. When the product turns out not to be within the tolerance the machine's settings have to be changed manually. As a result, it is not possible to run the batch autonomously.
    - **Production process is too unpredictable/ unknown.** Before we can automate a production process it has to be predictable. We need to know when the tool wears off and the exact settings so the quality is satisfied.
    - **Machine cannot run autonomously long enough.** To run a machine autonomously during the night it needs to be set up, this takes an operator half a certain amount of time. In the morning the machine needs to be built back again which also takes time. *Therefore the production time of the batch needs to be longer than the extra time it takes to setup the machine.*
    - **Batch size is too small.** When the batch size is too small the machine cannot run autonomously long enough. The processing time should also be taken into account in this case. When a batch size is only 5 but each product has a processing time of 30 minutes it might still be beneficial.
    - **Not enough tools in the machine.** If the tool wears off too quick and/ or the machine cannot change between tools, it cannot run autonomously long enough to make it beneficial.
    - **Not enough places to store products.** Some machines have belts or a build in tray from which a robot arm can pick a new product. In some other machines a robot arm can be placed that can put items in the machine. The storage of these products is limited and sometimes not enough products can be stored so the machine cannot run long enough autonomously.
- **Machine operators decide not to produce during the night.** Machine operators have the freedom to make decisions on the production floor. The operator who has the evening shift decides to set up the machine to run autonomously or not. At Hankamp Gears they notice resistance from (some) employees when it comes to setting up the machine.
- **Machines are not specifically planned to run during the night.** Machines are planned for 63 hours per week. This is only during the day. The order of the planning is also not specified to running the machine at night. This means that it is not explicitly planned that a large order is planned for the end of the day so it could be decided by the operator to run it autonomously.

- **Emergency order, no time to set up the machine.** Sometimes someone from management walks up to the production floor and asks an operator to do a certain task first, a "spoedje" as called in Dutch. Because of this order, the operator has no more time to set up the machine before his shift ends.
- **No clear conditions when it is beneficial to run during the night.** At this moment Hankamp has difficulties implementing the night production. One of the reasons for this, there are no clear conditions for when it is beneficial to run autonomously.
- **Production of products takes longer than expected.**
- **Planning turns out not to be realistic.** The planning of the machines is based on the setup and cycle time of a product.
- **Estimation of installation and cycle times are wrong.** The estimation of the installation and cycle times are based on experience, knowledge and possible previous production of the product. The planner is responsible for this estimation. In reality, these estimations deviate from reality.

Appendix B

Images of the machines which can be used for autonomous production.

Figure 30: kv200

Figure 31: k150hlc

Figure 32: Loading belt of k150hlc

Figure 33: gvl

Figure 34: gvl and cobot Sophia

Figure 35: L382

Figure 36: c04

Figure 37: L282 and cobot Kiki

Appendix C

BPMN makes use of swimlanes to indicate who is involved in the process. Figure 38 shows an illustration of these swimlanes. The different pools can indicate different companies or customers in a process. For example it can indicate the client and customer in two different pools or company and (multiple) supplier(s). The only flow between pools are message flows, further explained in Table 5. Within a pool it is possible to have different lanes which indicate different departments within a company. Table 5 is a legend for the BPMN models used in this thesis.

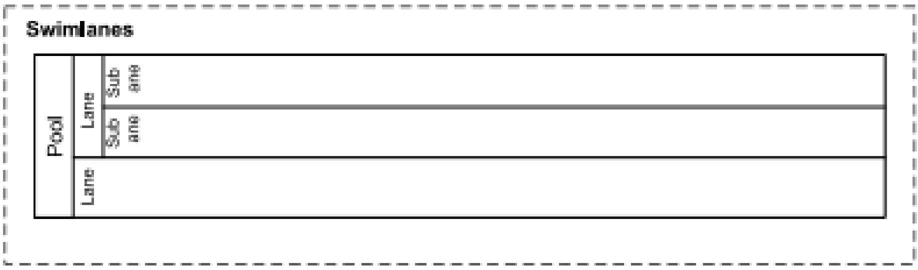
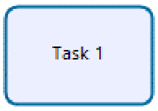
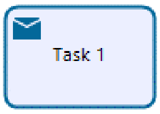
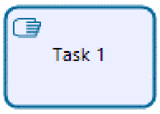
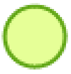
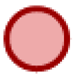
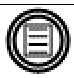
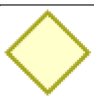
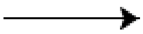


Figure 38: General explanation of BPMN elements, (Weske, 2012, pp.209)

Name	Picture	Explanation
Flow objects		
General task		An activity object that can be any task.
Receive task		A task that includes sending out a message.
Manual task		A task that is performed manually.
Start event		Start point of the process.
End event		End point of the process.
Message event		The process continues when a message is received.
Conditional event		A condition needs to be satisfied before the process continues.
Exclusive gateway		At a gateway the flow splits. An exclusive gateway means a question is asked and based on the answer the process will continue in a certain way.
Parallel gateway		This gateway splits the flow in two directions.
Connecting objects		
Sequence flow		A sequence flow shows the order in which activities are performed. Each flow has only one source and one target.

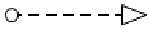
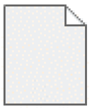
Message flow		A message flow shows the flow of messages between two entities. Entities are two different pools, often a company and its client or supplier.
Association	··············	An association is used to associate information and artefacts with flow objects.
Artefacts		
Data object		This artifact indicates a data object that contains some type of information.
Data store		This indicates a system where data is stored. In case of Hankamp it represents their ERP system.
Group		A visual artefact that groups elements of a diagram.

Table 5: Legend and explanation of BPMN model

Appendix D

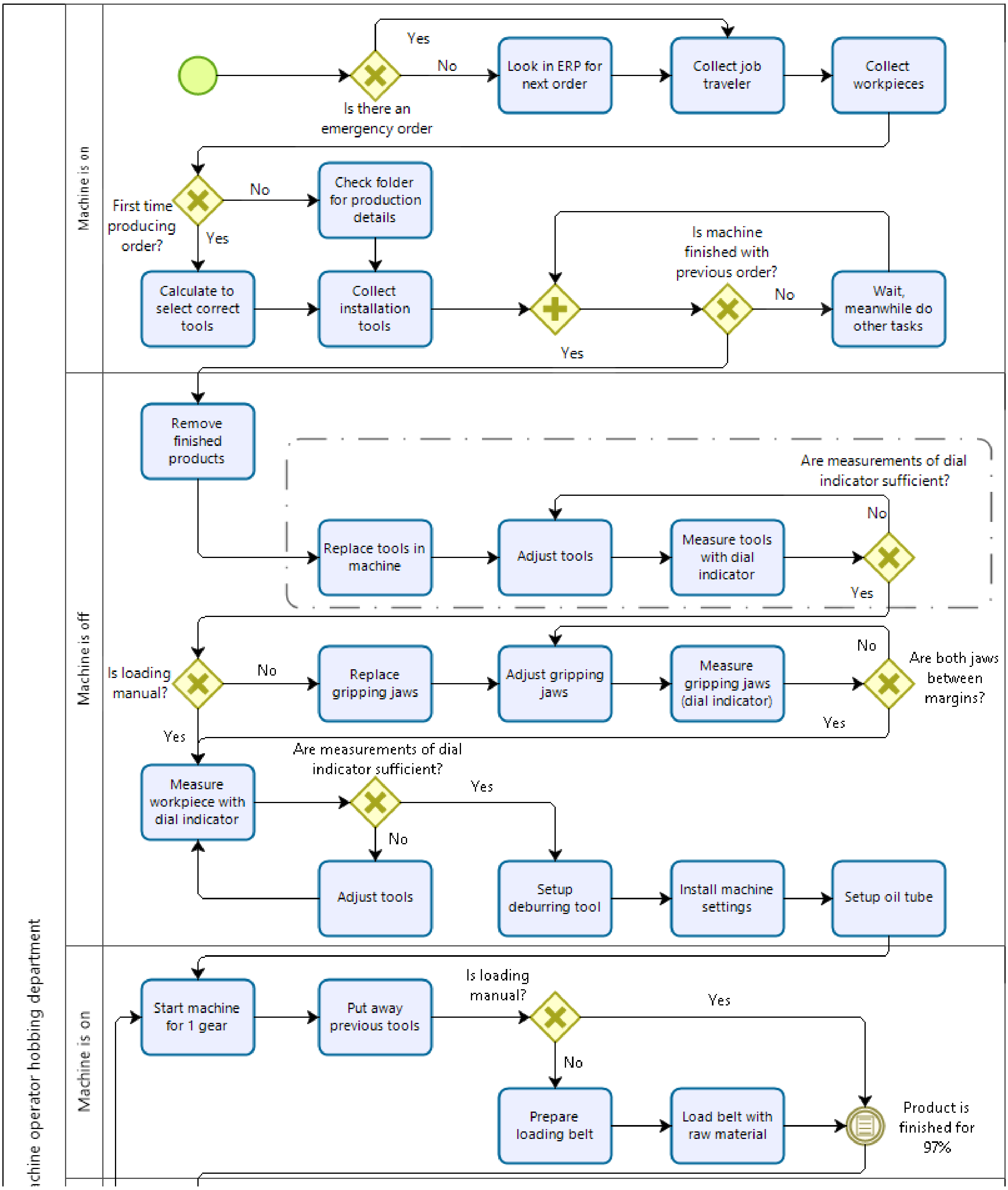


Figure 39: BPMN model setup machine at hobbing department part A

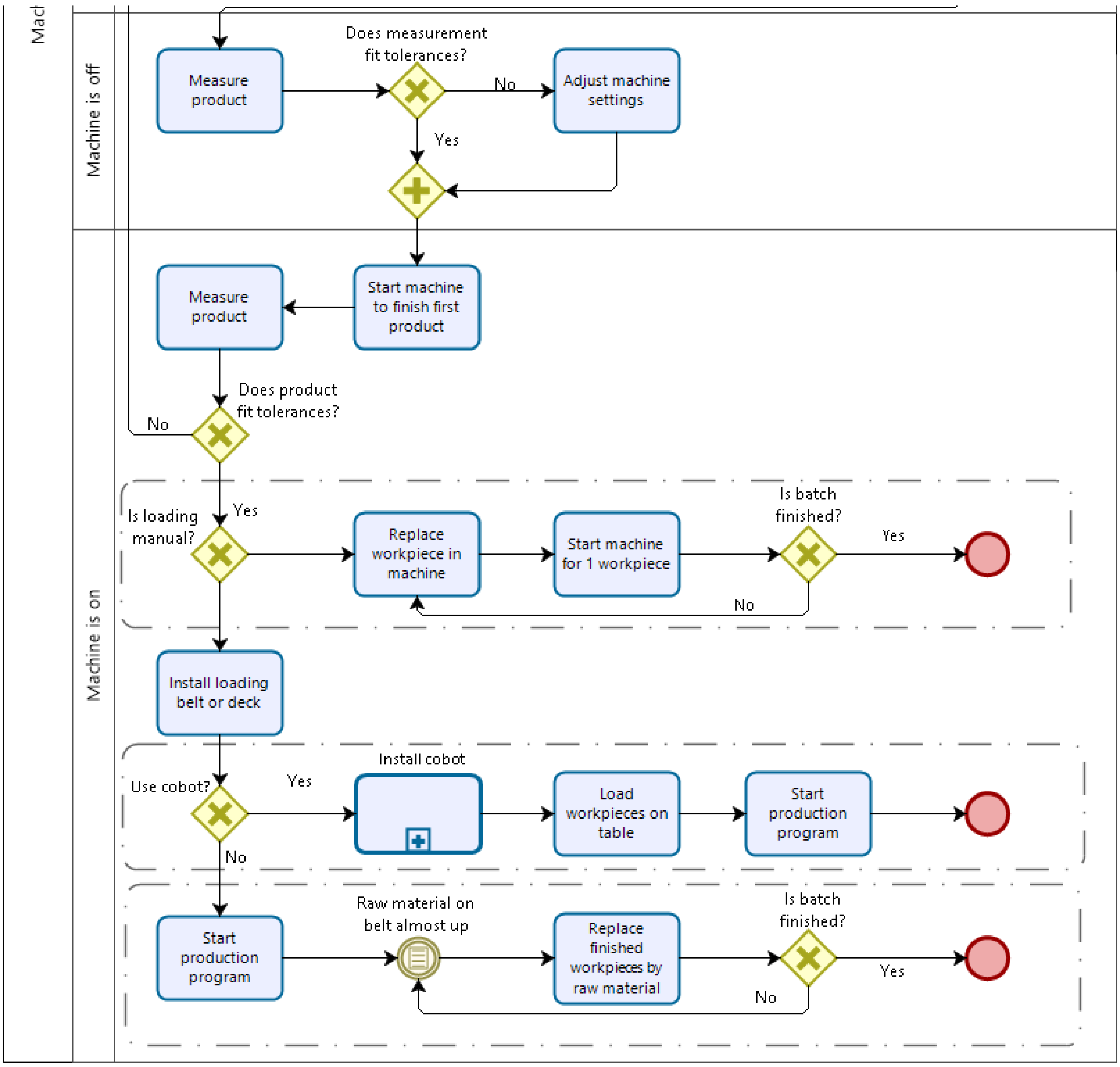


Figure 40: BPMN model setup machine at hobbing department part B

Appendix E

```
'indicate when the night is more beneficial

Sub UseCobot()

Dim install As Double      'Installation time of cobot [input variable]

Dim cycle As Double        'Cycle time of product [input variable]

Dim BatchSize As Integer   'Batch size of order [input variable]

Dim WaitMachine As Double  'The waiting time in the morning for a machine before it is setup

Dim x As Integer           'number of items stacked [input variable]

Dim i As Integer           'number of products on loading belt

Dim table As Integer       'Number of products on cobot table

Dim capacity As Integer    'capacity of cobot

Dim diameter As Double     'Diameter of product [input variable]

Dim AutonomousProductionTime As Double


'Get all the input from the sheet

install = Worksheets("calculator").Cells(2, 2)    'installation time input

cycle = Worksheets("calculator").Cells(3, 2)      'cycle time input

BatchSize = Worksheets("calculator").Cells(4, 2)  'Batch size input

diameter = Worksheets("calculator").Cells(5, 2)   'diameter input

x = Worksheets("calculator").Cells(7, 2)          'Number of products stacked on the cobot table

WaitMachine = Worksheets("calculator").Cells(10, 2) 'waiting time in the morning for a machine
before it is setup

'Capacity is: i if diamter < 95mm 30 and > 95 mm 15 --> i + x * table --> table is 30 if diameter < 45, 12
if 45 < diameter < 95, 0 if diameter > 95

If diameter < 75 Then

  i = 30

  Else

  i = 15

End If

If diameter <= 45 Then

    table = 30

  ElseIf 45 < diameter <= 95 Then
```

```
        table = 12
    Else
        table = 0
End If
capacity = i + x * table
'is the cobot used. When more than 0 products are stacked than the install time =
Worksheets("calculator").Cells(11, 2), else 0
If x = 0 Then
    install = 0
Else
End If

'Use batch size if capacity > batch size, use capacity if batch size > capacity
'Autonomous production time = cycle * (capacity, batch size - loadingcapacity) - install
If capacity >= BatchSize Then
    AutonomousProductionTime = (cycle * BatchSize) - install - WaitMachine
Else
    AutonomousProductionTime = (cycle * capacity) - install - WaitMachine
End If

If AutonomousProductionTime > 0 Then
    AutonomousProductionTime = AutonomousProductionTime
Else
    AutonomousProductionTime = 0
End If
Worksheets("calculator").Cells(8, 2) = AutonomousProductionTime / 60

End Sub
```

Appendix F

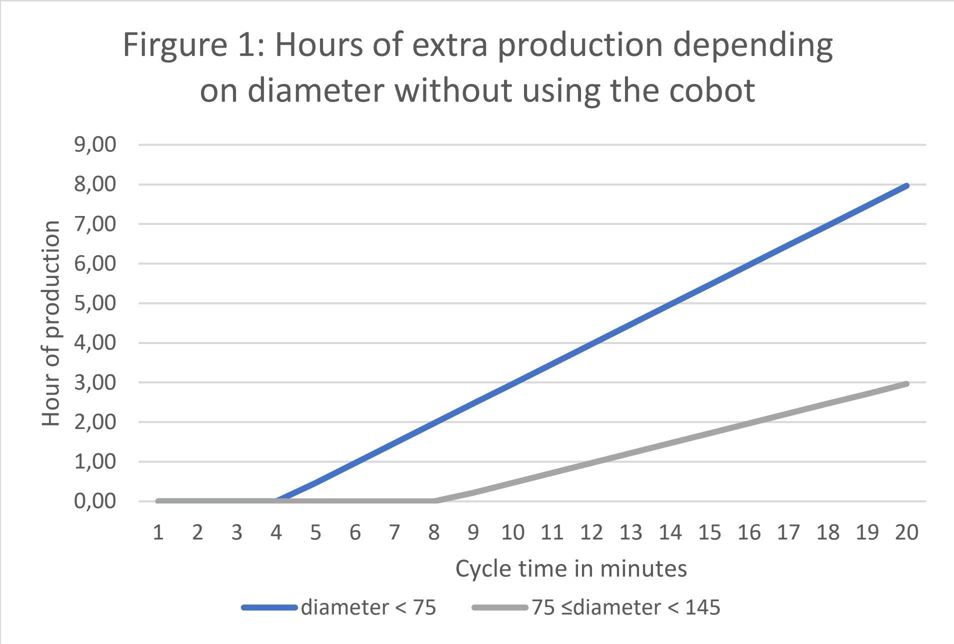


Figure 41: Hours of extra production depending on diameter without using the cobot

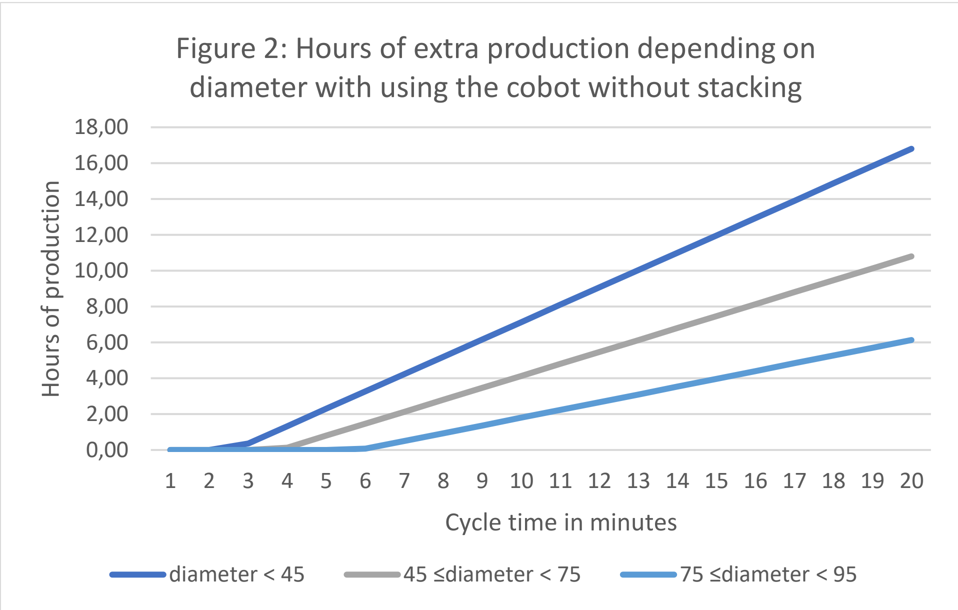


Figure 42: Hours of extra production depending on diameter with using the cobot without stacking

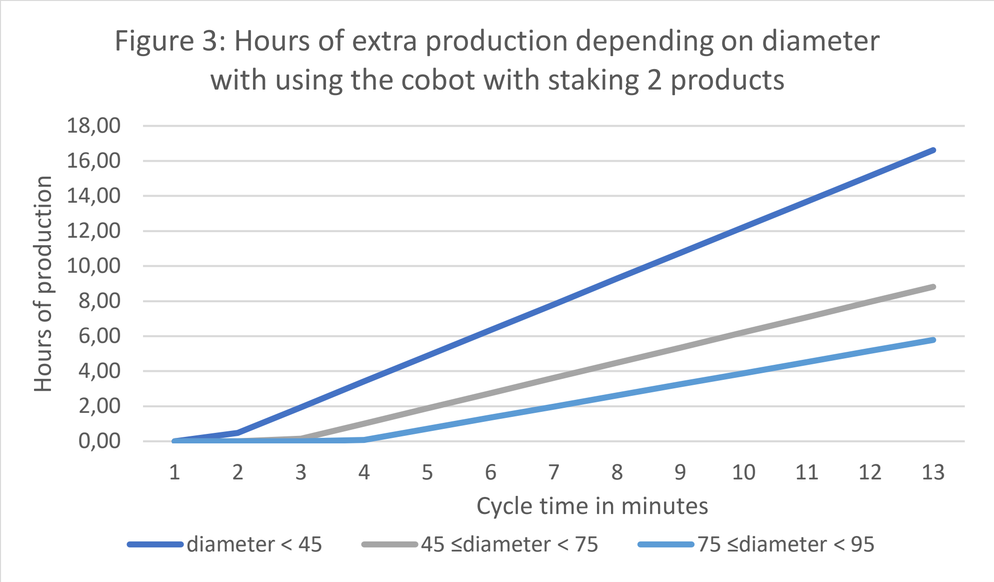


Figure 43: Hours of extra production depending on diameter using the cobot staking 2 products

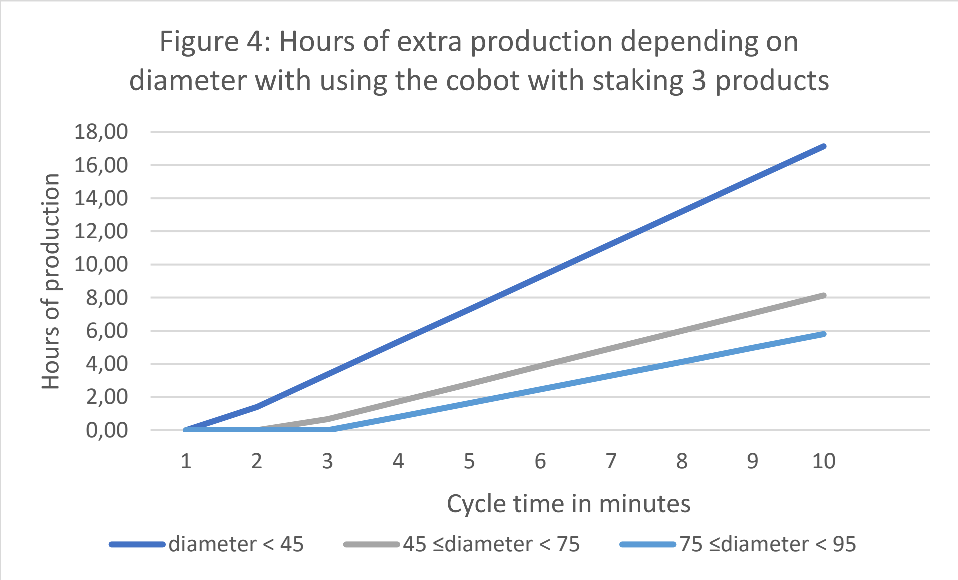


Figure 44: Hours of extra production depending on diameter using the cobot staking 3 products

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