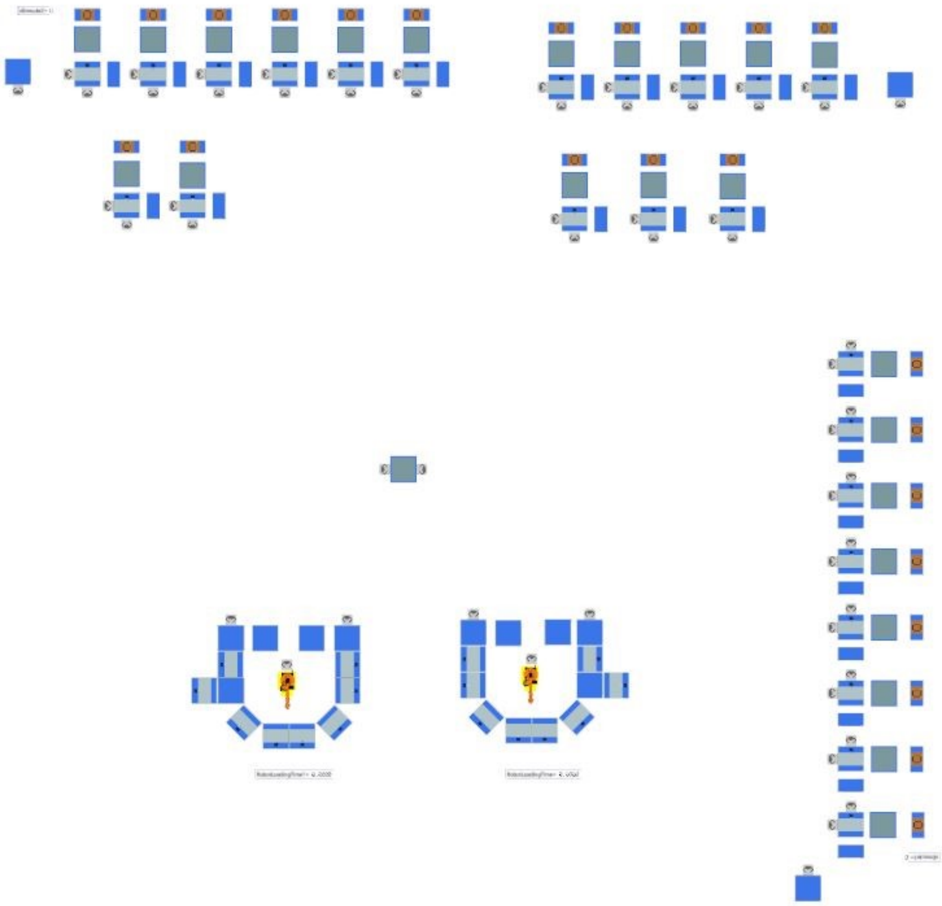

Evaluating Concepts for Automated Tool Handling

Master's thesis in Production Engineering

Hussein Abbas, Albin Broström Vedin

DEPARTMENT OF MATERIAL SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
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Cover: The visualization shows the production layout for one of the experiments in the TECNOMATIX Plant Simulation software.

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Abstract

Production of aircraft parts undergoes processes where tough materials are processed with high-quality requirements. Today's increased demand for production places higher demands on the tool handling that exists within these productions, which leads to the purpose of this report. The master thesis has been carried out to see if there are other methods to improve tool handling within a part of production at GKN Aerospace.

The work was carried out with a background study where important data collection was acquired to then use a simulation tool to see possible results. The background study showed that automated solutions were of interest as they can increase accuracy and productivity.

The execution of these months of work has led to the conclusion that automated solutions can be beneficial. The simulation has given results such as increased productivity, reduced costs, and improved ergonomics, but also how good results a simulation tool can provide to test possible and new solutions.

Keywords: Tool Management, Automation, Simulation, Aerospace Manufacturing

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Also, a thank you to Jon Bokrantz from Chalmers who was involved in guiding us through this work.

Hussein Abbas, Albin Broström Vedin Gothenburg, June 2023

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AGV	Autonomous Guided Vehicles
CNC	Computerized Numerical Control
DES	Discrete-event simulation
FIFO	First in First out
FMS	Flexible Manufacturing Systems
MSD	Musculo-Skeletal Disorder
PPS	Production Planning Systems
SMED	Single Digit-Minute Exchange
WIP	Work in Process
WMSD	Work-related Musculoskeletal Disorders

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1
Introduction

This chapter will describe a brief background for the master thesis, what the thesis's purpose and objectives are, and also its limitations. Research questions will also be introduced to give the reader a clearer overview of what the thesis will investigate.

1.1 Background

Concerning the prompt development in the aerospace industry and with the accelerated demand in aircraft manufacturing. The conventional way of handling tool changes and other material is lacking to meet today's increased demand in production, which result in multiple machining operation station for various aerospace components. This expansion of operations in aircraft manufacturing requires development in production logistics, regarding the transportation of both the parts and the tools to different stations. The transportation of the tools is more complex than the transportation of the parts, due to the tools also need to be removed and transported to the warehouse without holding the production space (Zhang et al., 2021).

The manufacturing procedure of jet engine components at GKN Aerospace Engine Systems consists of metal cutting operations as the most frequent and time-consuming. The number of various cutting tools has resulted in a high number due to very tough materials and meeting exceedingly high demands in quality. Moreover, the tool wear of the cutting tools is exceedingly high and requests frequent tool changes. Furthermore, the state of this procedure is both costly and time-consuming, and the availability of the tools in the machines is significant to the availability of the machines. Therefore, the general planning of the tool management is significant to meet optimal productivity and cost in the production system. The definition of tool management for this thesis is regarding tool removal, change of worn-out tools, transportation, and inspection (GKN Aerospace, 2022).

The proposed solution to this matter is based on previous studies and proof of concept for automated systems in the logistics of tool management, by utilizing industrial robots and automated transportation. Currently, the company has done some research and experiments regarding advancement in flexible automation cells for cutting tool preparations in CNC- machines (Bekk, Moen 2020). Furthermore, concerning the automated transportation of cutting tools, the company has proposed an automated guided vehicle (AGV) as a potential solution (Joshi, 2021). This automated solution is proposed cooperatively to allow flexibility in different tasks and is mostly useful in aircraft manufacturing operations (Zhang et al., 2021). GKN sees this proposed solution as promising, but it requires further study from a more integrated standpoint, to gain full observation and influence on the production performance and analysis of the feasibility (GKN Aerospace, 2022).

The assignment of this master thesis is to create a study, to determine the possibilities and gaps regarding additional technical development work for future automated tool management. This handling system is incorporated with the overall production planning to enhance production performance. This master thesis is a collaboration with the company GKN Aerospace Engine Systems and will be managed by the Global Technology Centre at GKN Aerospace in Trollhattan. This thesis requires a multi-functional procedure with various departments in manufacturing operations (GKN Aerospace, 2022). Figure 1.1 represent the current production layout of what is going to be investigated.

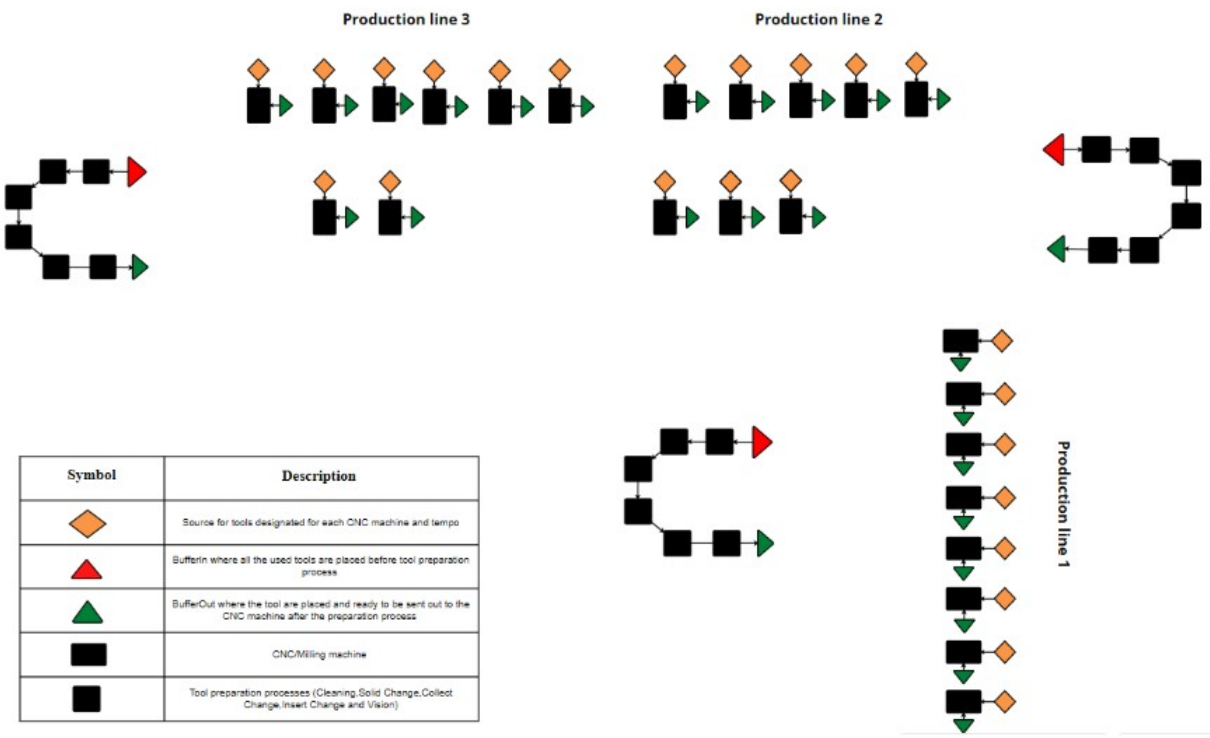

Figure 1.1: Current production layout.

1.2 Aim

This thesis aims to present and evaluate the results of concepts and alternative combinations of automated and manual solutions. This study will also provide a conclusion and analysis of a more integrated standpoint for these developed concepts in terms of optimization and investments.

1.3 Objectives and Research Questions

The objective of this thesis is to present an evaluation of developed concepts for automated systems in tool management. The evaluation is determined by the presented research questions in terms of improved productivity in RQ1 other improved performance factors and needed adjustment when implementing the developed automated concepts in RQ2.

RQ1: How will automated proposed solutions optimize the tool management in the production system?

RQ2: How will other production performance factors improve and what is needed to be adjusted when implementing automated solutions?

1.4 Delimitations

This master thesis is limited to the development of tool management for certain machines and specifically tool preparation and logistics for the GROB production (the three production lines with CNC machines) has been studied, see figure 1.1. The results have not been implemented in the existing production environment, only simulations through the software Tecomatrix Plant simulation have been executed. The work has been limited from the beginning of January and finished at the start of June. The thesis has therefore been limited to a period of 20 weeks and has the potential for further investigations.

2

Theoretical Background

In the theoretical background, the literature study has been conducted to show the relevance in todays and future production systems regarding tool management, possible automated solutions, and further optimizations. Furthermore, it has been divided into three main parts with different subchapters. The literature study has been made to give the reader an insight into the topic and interesting findings about the subject.

2.1 Tool Management within CNC-Machines

For a functional tooling system to be appropriate for the utility of computer numerical control (CNC) machine tools, the tooling system must meet certain requirements. Firstly, the tool handling is required to be flexible enough for adapting to various machining tasks. Secondly, the system needs to be very stiff and competent enough to reach high removal rates while remaining cost-efficient. The productivity and reliability of the cutting tools that are utilized in a CNC machine are essential to the machine's overall productivity. The productivity of the cutting tools can be defined by measurement in terms of cutting data such as cutting speed, feed rate, chip volume, or tool life. The workpiece and tool interact with each other, and the cutting edge of the tool determines how productively and profitably the workpiece can be machined (Kief, Roschiwal, and Schwarz, 2021, ch.5). Therefore, tool selection is needed to be aimed at this target, the wide assortment of tools and operations are required to be joined into one CNC machine. The tooling systems are also required to be easy to maintain, their flexible properties are required to several operators and machining centers (Kief, Roschiwal, and Schwarz, 2021, ch.3).

Flexible Manufacturing System (FMS) consists of work machines and a transport system between them in order to manage variation and maintain a high capacity. Such systems are controlled by a computerized system to get production smoothly and flexibly at a steady rate without interruption (H. K. Shivan and, M. M. Benal, V. Koti, 2006). The large combination of different tools on a single CNC machine can create difficulties in tool handling and especially in production environments that manufacture a variety of products where several machines are needed. FMS is therefore an approach to improve tool handling for CNC machines. In addition, appropriate and functional production planning and logistics systems must be applied to achieve optimal FMS and tool management regarding the tool ordering system (Kief, Roschiwal, and Schwarz, 2021, ch.3).

2.1.1 Production Planning System and Logistics

As mentioned previously to reach the required flexibility and to achieve a structured tool management by which manufacturers can decide the tool orders based on the tools previously utilized in a CNC sequence a sufficient production planning system (PPS) is required. Moreover, this will allow correct planning of tool selection, which also enables low-cost storage facilities and a reduction of costs while preventing bottlenecks (Kief, Roschiwal, and Schwarz, 2021, ch3.).

The primary purpose of a production planning system is to develop and control multiple orders so that the throughput time of the overall process is correct and ensure that delivery dates and costs are met. Especially when involving the correlation of a flexible manufacturing system, then a production planning system is crucial for ensuring a coherent operation. Furthermore, a production planning system (PPS) has three primary areas of application. The first application is regarding the planning of orders and their following administration, and also the scheduling of their production to meet the time limit. The second application is regarding the control of the system that helps execute production orders based on the availability of manufacturing capacities while observing compliance with deadlines. The third application of the system applies for future forecasting of capacity, time, and material availability to support the sales department in making required offers without interrupting or confining the current planning (Hans Bernhard Kief, Roschiwal and Schwarz, 2021, ch3.).

A production system that possesses the elements of a flexible manufacturing system produces a diverse range of parts that can function in a nonparallel manner, resulting in more complicated scheduling and planning challenges in tool management. As mentioned, the intended purpose of a production planning system is to control the throughput time to further reduce the delivery time. On the other hand, the process of scheduling involves assigning resources and decision-making regarding the arrangement of operation, time, and cost (Reddy and Rao, 2006). The aim of scheduling is to either minimize or maximize the allocation of machines personnel and tools. Furthermore, the planning system and the scheduling become more complex in FMS when implementing and integrating an automated solution that may advance the logistics system (Baruwa and Piera, 2015).

In order to obtain a sufficient production planning and scheduling system that could optimize flexibility and tool management, there are some basic laws of production logistics that need to be followed (Nyhuis, Wiendahl, 2009, p.127).

1. The first law of production logistics states that over time, the input rate and the output rate must equalize and maintain balance. Therefore, capital spending aimed at long-term capacity extensions should not be utilized to reduce WIP. This could result in decreased throughput time and WIP, but not sustained output increases.
2. The second law of production logistics mentions that to reduce the throughput time, the work in progress (WIP) must be reduced.
3. The third law of production logistics further mentions that the structure of work content may prevent the reduction of WIP and throughput time due to impacting utilization.
4. The fourth law of production logistics states that the production logistic potential is established by the mean and variance of the work content. So, based on this law the extent amount of obtained work in a workstation to dimmish output losses that are triggered by material flow disturbances is highly dependent on the ideal value of minimum WIP.
5. The dimensions of the WIP buffer needed to maximize the workstation utilization primarily depend on the degree of flexibility in the workload and capacity.
6. The inter-operation time remains unrelated to the operation's separate work content when orders are treated in adherence to FIFO. So, the inter-operation time for workstations is unrelated to separate work content and depends on the WIP level.
7. The sequencing rule has a substantial impact on the mean throughput time only in scenarios with high WIP and varied work content.
8. The sequencing rule, WIP level, and work content allocation collectively determine the difference in throughput time.
9. The ninth law of production logistics states that the reliability of a production logistics process depends heavily on achieving consistent and low throughput times.

The basic laws of production logistics demonstrate the significant correlation between throughput time, WIP, and utilization, and the importance of compromising these factors to achieve a reduced throughput time. For instance, low utilization can lead to achieving low throughput time, by having no queuing time and therefore the flow rate is close to one. Furthermore, the variability in throughput time can increase the scheduling uncertainties and increase throughput time, which further leads to insufficient tool management in production. The reliability of the throughput time and tool management also have a great influence on productivity. So, certain production reference processes for the tool management need to meet a certain logistics objective, shown in figure 2.1.

		Production reference processes		
		Production system	Transportation	Storage and supply
Logistics objectives	Schedule adherence	high schedule reliability	high schedule reliability	low delivery delay
	Throughput time	short throughput time	short transportation throughput time	short storage time
	Output rate	high utilization	high utilization	
	Inventory	low WIP	low WIP	low stock
	Costs	low costs per unit	low costs per transportation	low storage cost

Figure 2.1: Production logistics objectives (Nyhuis, Wiendahl, 2009, p.9).

For example, to achieve logistics objectives in throughput time and inventory for a tool transportation system, it's required to have a short transport throughput time, low WIP, and low stock. To receive high or increased output in production both the transport of tools and machines needs to achieve high utilization. Insufficient tool management in the production system is due to a weak logistics system and further disturbances (Nyhuis, Wiendahl, 2009, p9).

2.1.2 Disturbances and Problems in Tool Management

Redesigning a production system describes Kief, Roschiwal, and Schwarz, (2021) in the CNC handbook that it is essential to have a thorough understanding of the types of disturbances and problems that the current production system has. This knowledge will enable us to make an informed assessment of the possible adjustments that could enhance the current system. It is extremely important to have good planning and control over which tools are to be used in which machine. Therefore, it is important to understand and be able to deal with the problems and disturbances that can occur during tool handling so that they can be reduced or eliminated (Kief, Roschiwal and Schwarz, 2021).

One of the common problems in production systems with tool management is poor tool management and planning. This both reduces the production speed and increases the risk of using the wrong tool. Therefore, good tool handling is preferred for productions that have high-quality requirements and a production speed to maintain. A computerized tool management system is preferable for productions that use many different tools. Unfortunately, several companies are not aware of this and find it difficult to see the advantages of a computerized system for tool management. The benefits of a good tool management system make production more efficient and fewer production errors occur (Kief, Roschiwal and Schwarz, 2021).

In addition, it can also be the case that even if there is a system for tool management, problems can arise in the management. An example is when several different people with different work roles work in the same order in production. It can be an operator, a programmer, or a buyer who all works on the order at the same time, then errors can occur and disrupt the tool handling and lead to common production errors such as machine stoppages. The cause of errors in these cases is often a lack of communication which can be reduced through structured tool management and planning of the tools (Kief, Roschiwal and Schwarz, 2021).

2.2 The Future of Tool Management

In recent years the demand for aircraft manufacturing has increased in the aerospace industry, and there is a pressing need to improve production logistics. The customary methods of handling tool changes and other materials are not adequate to meet the current production demands, resulting in multiple assembly operation stations for various aircraft. To address this issue, there is a requirement for efficient transportation of both parts and tools to different stations. However, tool transportation is more complicated than part transportation as tools must also be removed and transported to the warehouse without occupying valuable production areas. Therefore, there is a need for development in production logistics to handle these challenges (Zhang et al., 2021).

Moreover, the manufacturing system demands agility and flexibility to function efficiently with minor human interference in today's fiercely competitive and unpredictable manufacturing landscape. The recent advancement in Industry 4.0 has made it beneficial, with the current progress in technology and rapid manufacturing system configurations, optimizations can be accomplished by dynamically planning shop-floor logistics and manufacturing schedules in real-time. In the case of tool management and CNC machines, these technological advancements are reflected in AGVs, which have emerged as a suitable solution for performing flexible manufacturing tasks on shop floors. Recently, AGVs have gained in popularity in substituting human labor for material handling and transportation while sustaining high-performance levels on shop floors (Yao et al., 2020).

Zhang, et.al.(2021), mention that to fulfill these complex tool-handling demands, AGVs are commonly employed as material transport between warehouses and stations. AGVs provide enhanced flexibility and accuracy in material handling as they can autonomously schedule courses and move. Various models of AGVs have been developed based on their carrying capacities, such as single-load, multi-load, and hybrid-load. Nevertheless, recent studies have focused on limiting the AGVs to work in separate tasks, which limits the flexibility in material transportation in various loads and scales. This will further lead to AGVs lacking the ability to recombine and enhance flexibility in material handling.

In aircraft manufacturing, it's proposed to have collective AGVs, where multiple AGVs work collaboratively on the same task. The level of flexibility in aircraft manufacturing makes collective AGVs a requirement, but this can't be achieved without a suitable integration scheduling method for AGVs (Zhang et al., 2021).

2.2.1 Integration and Scheduling of AGVs

Recent research has proven that current AGV management solutions often encounter issues with effectively attempting to integrate with real-time manufacturing operations information systems, leading to unfortunate effects on AGV scheduling. What is crucial regarding a seamless integration of AGVs in the manufacturing industry, is efficient communication among AGVs, machines, and human operators. This integrated level of communication among these factors will enable AGVs to work carefully and have the ability to optimize the scheduling based on certain analytical situations (Yao et al., 2020). These recent years of AGVs implementations and integrations mostly focus on AGVs routing and localization. Furthermore, the recent AGVs systems neglect the potential benefits of acceptable management systems that utilize digital twins and real-time information systems for scheduling optimization of material delivery (Zhang et al., 2021).

Scheduling involves allocating a finite amount of resources to labor over time and is particularly crucial to the decision-making process that connects important factors, such as operational activities, time management, cost considerations, and the overall company goals. It further aims to either minimize or maximize the utilization of machines, personnel, and tools (Reddy and Rao, 2006). Scheduling also plays an essential role in improving the performance of a flexible manufacturing system (Baruwa and Miquel Angel Piera, 2015). Furthermore, when attempting to integrate and schedule AGVs it will significantly boost the complexity of scheduling for FMS. This complexity requires the decision of the job operations sequence, material handling task to the appropriate AGVs, and keeping in mind the arrival and departure times of the AGV. To avoid such delays in time and expenses in production logistics systems, a method has been proposed by several research papers to enhance efficiency by implementing a dynamic scheduling approach for self-organized AGVs (Yao et al., 2020).

This online (real-time) scheduling method will allow manufacturing companies to quickly match customer demand by dynamically scheduling their production, thus dynamically adapting the logistics of AGVs based on their demands. The online real-time method is a simulation-based procedure that provides analysis to assist when selecting the optimal solution and in particular when addressing the dynamic AGV routing complications in tool transportation, as they constantly update the real-time information (Yao et al., 2020). Zhang, et.al.(2021), mentions that a dynamic scheduling method for self-organized AGVs with a multi-load carrying capacity has beneficial results. Employing self-organized AGVs in material handling systems will lead to increased AGV utilization and efficiency, as well as reduced expenses compared to single-load AGV logistic systems. In that matter, a developed AGV logistic system is expressed in a forthcoming FMS.

2.2.2 AGVs for Future Flexible Manufacturing

To maintain the requirements in today's production systems such as capacity and quality, agility and flexibility are two key factors that are needed to keep up the performance that is required in today's but also future production systems. To develop better and higher levels of production systems, new strategies, and methods need to be implemented to meet the increasing demands. FMS is one method for future production systems and consists of flexible production logistics which is one method many companies strive for (Yao et al., 2020).

Usually, the basis of a successful FMS is the transport system for materials and workpieces. Depending on how the CNC machines are positioned, in combination with the amount of floor space, different solutions for the transport system can be developed (Kief, Roschiwal and Schwarz, 2021). FMS are well adapted for the concurrent production of numerous part types in small volumes. Workstations, automated storing and retrieval systems, and material handling equipment like robots and AGVs are just a few of the intricate components that make up the FMS. Better scheduling and coordination of production machinery and material processing equipment can improve FMS performance (Reddy and Rao, 2006).

AGVs are one of the solutions to increase agility and flexibility and should therefore be seen as a future solution for "smart" production systems (Kief, Roschiwal and Schwarz, 2021). FMS requires newly developed Industry 4.0 technologies and AGVs should be seen as one of the enablers to reach this level of production system (Yao et al., 2018).

AVGs can improve flexibility and agility in several ways:

- They can reduce production bottlenecks and thus achieve more efficient work.
- They can adapt to their environment using sensors and advanced software technology.
- Increased accuracy of what type of material is needed.

(Vlachos et al., 2022)

2.3 Discrete-Event Simulation

As mentioned earlier, the simulation-based approach is employed to assist in selecting optimal AGV solutions. This approach, known as discrete-event simulation (DES), encompasses a variety of methods used to analyze the behavior of a discrete event system. This system can include various dynamical factors of interest, such as in a production system, where discrete modifications in value occur (George S, 2001).

The simulation modeling approach provides several advantages in both experimental and analysis applications. In addition, the advancement of a simulation system has introduced the potential of optimizing and enhancing the efficiency of a production system. This is achieved by analyzing the material flow in real-world production to subsequently develop a simulation to assess the duration of production and determine potential bottlenecks. The process of identifying the bottleneck in a simulation model is highly effective and provides advantages in reaching optimized variables with no associated cost within the simulated production line (Rosova et al., 2020). The disadvantages of utilizing a simulation model are the many various possibilities to design a model and interpreting the result can be challenging. Discrete-event simulation (DES) may not comprehensively capture all real-world aspects of a production system (Banks, 2010).

When creating a simulation model suitable software is seen as a necessity. The commonly used software to achieve the mentioned advantages is Tecnomatix Plant Simulation. This simulation software serves as a crucial tool in planning, implementing, and operating a production system.

The following stages of creating a simulation model:

1. Problem formulation
2. Assessment of simulation feasibility
3. Objective formulation
4. Analysis of gathered data
5. Model development
6. Carry out the simulation runs
7. Analysis and explanation of results
8. Documentation of the simulation process

Furthermore, the software provides an analysis of bottlenecks, utilization of resources, and total throughput (Steffen Bangsow, 2020).

2.4 Bottleneck Analysis and Optimization

This chapter explains the main findings of methods or tools to improve the previously mentioned simulation-based approach to get accurate results but also to find other solutions to improve the tool management in other ways. This is utilized to optimize production with analysis methods for future improvements.

2.4.1 Bottleneck Detection in Simulations

To improve a production flow, it is necessary to use bottleneck detection to increase the production flow (Roser, Lorentzen, and J.P.L. Deuse, 2014). There are many definitions of a bottleneck. According to Kuo, Lim, and Meerkov (1996), a bottleneck is referred to as a process for a system that must maintain the highest production rate for the system to meet its performance index. The definition proves that the bottleneck will be identified by being able to assess the blocked or starved processes. When a process has to be stopped because the next process or buffer is full, it is called "blocked". When a process must be stopped because the last process is empty, it is called "starved" (Roser, Lorentzen, and J.P.L. Deuse, 2014). In short, the machine or buffer that disrupts the production system the most is the bottleneck (Subramaniyan, 2015). The bottleneck of a system does not always have to be a machine or buffer. It may also be the case that logistics processes and errors in the information flow can be a bottleneck. An important step in bottleneck detection in dynamic systems is to identify the temporary bottleneck, which some methods fail to do (Roser, Lorentzen, and J.P.L. Deuse, 2014).

Different approaches to identifying the bottleneck may provide different good answers as to what the bottleneck actually is. Discrete event simulation is a good tool for this and has many advantages. A simulation can provide very detailed information about the flow, making it easier to find the bottleneck. Another advantage is that it is easy to experiment with new modifications and observe how they affect the system. A disadvantage is that simulation is time-consuming and requires a certain amount of experience (Leporis and Králová, 2010).

Different methods to measure blocked or starved machines:

Active period time:
The procedure can be divided into two distinct procedures, with the most likely bottleneck being the machine with the longest average active period or the largest percentage of active time (Betterton and Silver, 2012).

Shifting bottleneck:
At any given time, the machine that has been running the longest is the bottleneck. The bottleneck shifts between the two machines where the two with the longest active periods overlap. Then, over a period of time, the amount of time a machine spends acting as the single or shifting bottleneck is summed to determine the bottleneck machine (Roser et al., 2001).

Arrow method:
Comparing the data of the machines next to each other will help you identify the bottleneck if you know when the machines become blocked or starved. The arrows drawn for illustration purposes gave the method its name. To utilize this method when identifying bottlenecks its required gathering the utilization for the blocked and starved times in the production. This utilization can demonstrate when the machines experience blocking due to full buffers or starvation due to empty buffers (Betterton and Silver, 2012).

Inter-departure method:
The inter-departure when a part departs from a machine and when the following part departs from the same machine is called the departure time. Since there will be a queue in front of the bottleneck and empty buffers downstream, a bottleneck is less likely to be starved or blocked by other machines (Lagershausen and Tan, 2014). Because of this, the bottleneck can be located using the variation between departure times (Betterton and Silver, 2012).

2.4.2 SMED-Analysis

Single Digit-Minute Exchange of Die (SMED) is an analysis method that is used to shorten long setup times within materials and production control. The SMED – method has proven to be beneficial in many productions and is a common tool to find possible investments and solutions in production systems. The total changeover time over a given timeframe can be the primary factor in efficiency loss in environments where both product variation and changeover time are significant. SMED is also used to implement smaller batch sizes to reduce material waiting and thus create a better material flow. Below are some listed examples of what the SMED method can improve (Segerstedt, 2018, p.100-103).

- The size of the orders can be reduced and thus give positive effects on:
  - Lead times.
  - Products in work.
  - Flexibility.
  - Resource utilization of machines and labour.

An important part of using the method is being able to distinguish between work that is done when the machine is operating and work that is done when the machine is off. This is divided into internal work when the machine is off and external work when the machine is operating. The analysis follows 5 important steps which are described below, and each step can increase the efficiency of the production.

1. *Study of the actual situation.* Make an analysis of the current working method. Collect data through different types of tools such as video, and timing and through this create schedules and diagrams of the situation.
2. *Separate internal and external work.* The tasks performed during setup time are divided between work done during machine work and work done when the machine is off.
3. *Convert internal work to external work.* All external tasks should then be converted so they can be performed when the machine is operating. This decreases the setup time significantly.
4. *Reduce internal work.* At this stage, the internal tasks that have still not managed to convert to external tasks should be tried to be executed in a shorter time by implementing other approaches to further reduce the setup time.

5. *Reduce external work.* The final step is to reduce the external tasks that are performed when the machine is in operation. Here, additional approaches must be implemented so that the tasks can be performed in a shorter time (Segerstedt, 2018, p.100-103),(Coimbra, 2013, ch.7).

2.4.3 Line and Layout Design for Low-Cost Automation

In the previous chapter, it's mentioned that the shortening of setup time reduces the non-value-adding movement for an operator and establishes a more flexible production line with a changeover time close to zero. SMED also establishes minimum setup time which is a primary objective in line design. To reach a reasonable level of SMED and streamline a process is by automating preferred operations within the production to further improve the ergonomics and substitute manual labor. In the implementation of automated solutions for some operations, it's essential to mention that automation can increase efficiency to great measures, but it can also be a considerable expense.

Moreover, automation may not yield a sufficient return on investment and it's also essential to note that before considering automation the production line is required to have the needed features in place. These features include line and layout design, standard work, border of line, and SMED. Examining implementation options and modifications with these features for automated solutions that lead to reduced costs and more elevated returns of investments will uncover numerous opportunities for low-cost automation (Coimbra, 2013, ch.7).

The initial area of focus for optimizing the production flow is the design of manufacturing lines and layouts. The aim is to reach a continuous flow as much as possible for the various product families and to select the best placement of these lines. Especially, when handling the various tools for different product families, organizing the arrangement of these lines is seen as a priority. In the subject of goals and priority, the line and layout design intention is to eliminate all the non-value-adding operations such as transportation and control, while prioritizing the value-adding operations. Some of the value-adding operations can also be eliminated or modified in the redesign to enhance the effectiveness of some operations (Coimbra, 2013, ch.7).

<u>Some essential principles for line and layout design:</u>

1. Designing the production lines in consideration of the product, volumes, and tool types.
2. When designing a production line, work instead with a small production line to reduce the setup time.
3. Arrange the layout according to the different processes involved.
4. Limit the materials to only those that are essential for the process.

5. Minimize all waste or non-value adding in transportation.
6. Utilize simulation models before implementing improvements.

In the case of implementing AGVs, a simulation-based procedure is considered the best setup for designing the layout of complex production systems. In a sense of convenience, the simulation model will establish the ideal design of an AGV system and determine the suitable number of vehicles, scheduling of material, and routing for the optimal layout. This is beneficial when pursuing low-cost automation (Dammacco et al., 2022).

Furthermore, the second area of focus regarding optimized production flow is borderline, which refers to the arrangement of the essential raw materials and tools required to achieve a continuous flow of production. Border of line is a crucial aspect of the line and layout design but its section improvements domain and interaction with the internal logistics explain a separate area of focus for improvements. For a borderline to be considered properly designed it needs to accomplish certain criteria. For instance, the placement of all materials and containers should minimize the overall picking movement of the operators and logistics workers. Also, the required time to switch from one part of a product family to another should be minimized. To achieve these standards for optimization the overall arrangement must through fully designed (Coimbra, 2013, ch.7).

2.5 Ergonomics

Ergonomics is a constant problem in workplaces where physical effort is required to perform a task. Even sedentary tasks can create long-term damage to the body and should therefore be seen as a challenge for all workplaces. By designing workplaces in such a way that bad ergonomics are eliminated, millions in costs can be saved. Several companies today have learned that better ergonomics lead to higher productivity and efficiency when working in a safer environment. This is because the simpler a task is to perform, the more productive it will be (Khan, 2012).

Work-related musculoskeletal disorders (WMSD) are common when physical work is carried out for a long time or too intensively. People like to be creative and help come up with new solutions that benefit the production system, which can cause Musculo and Skeletal Disorder (MSD). The symptoms of these are pain, discomfort, and repeated injuries. This costs not only the body but also the company as compensation for the injury as well as loss in productivity and staff turnover (Berlin and Adams, 2017).

How the company approaches the issue of ergonomics largely depends on resources, previous experience, knowledge, and interest in the company. A company should see ergonomics as a long-term cost saving because they keep the staff healthy and thus productivity can be maintained. A common problem among companies is that they only see the symptoms and not the root cause of the symptoms. This is one of the reasons why companies should pay attention to ergonomics when redesigning in order to have a healthy staff and a safe environment (Berlin and Adams, 2017).

2.6 Summary of the Literature Study

The result from the literature study that is found most significant is presented below with a summarized table 2.1.

Table 2.1: Summary of the main findings from the literature study.

Literature Study	
Chapter:	**Findings:**
Tool Managment:	A lot of Products are produced at the same time then flexible handling of tools are preffered.
	Especially for CNC machines where a lot of tools are needed for the production to run smoothly.
	Production planning systems makes it easier to produce products in time and correct throughput.
	A good production planning system will enable a more accurate tool management.
	Communication and good management are key factors in the process of tool handling.
The Future of Tool Managment:	Industry 4.0 enables solutions for flexible and efficient manufacturing systems.
	AGVs for autonomous production is one of the solutions for a future manufacturing system.
	Proper scheduling method is needed for implementing AGVs.
	Dynamic scheduling methods has proven to benefit AGV systems.
	To enable flexible manufacturing, AGVs is a key factor.
Bottleneck Analysis and Optimization:	Bottleneck methods for simulation with AGVs can show which improvements that is needed.
	Bottleneck detection is a major step for improving the simulation model and identify new solutions.
	SMED can help to find time loss in the production and new proposal for improvments can be discussed.
	Lines and layout of the production is an important step to achieve better logistics.
	Together with simulations and SMED, new solutions for line and layout can be discussed.
	Implementing autonomous solution can eliminate bad ergonomics, and is cost saving.

3
Methods

This chapter introduces the research method that we pursued this master thesis on. The method for the research design, literature study, and data collection will be introduced as well as the research ethics for this study.

3.1 Research Design

The research design in this master thesis has been chosen to follow a structured approach, “The four phases of production systems” designed by Röisö and Burch, see figure 3.1 (Röisö and Burch, 2014). The method has been chosen since the master thesis is a study of how tool management can be improved and should undergo a similar study and analysis as a production system in general. Once the tool management has been analyzed conclusions could be made about how the production could be redesigned to improve the tool management. This method was suitable for this case and was therefore used. The procedure was as follows.

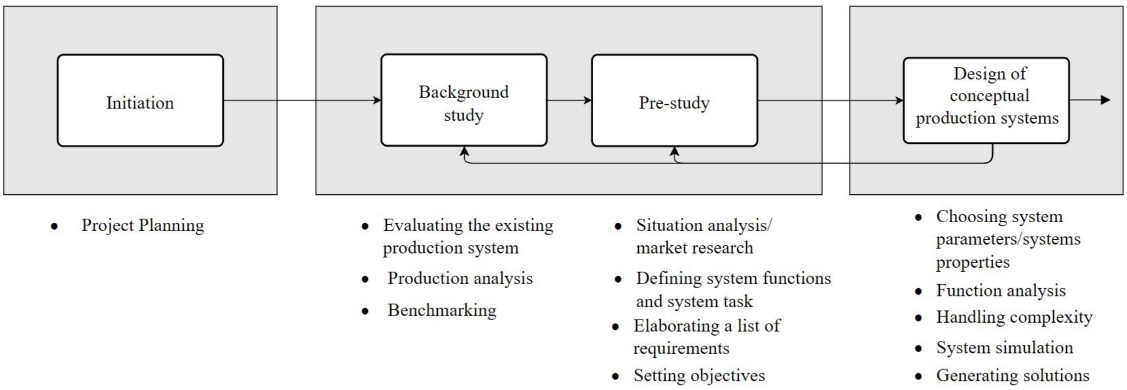

Figure 3.1: The four Phases of Production System Design (Röisö and Burch, 2014).

3.1.1 Initiation

The first step was to create a planning report to be able to know how the thesis is going to be carried out. This made a sufficient procedure for the master thesis and it was done in the right order to get proper results. Another major step in this phase was to get to know the company and the subject that this thesis was touching on.

3.1.2 Background Study

The next step was to do a background study. This included a literature study on similar productions and what the future of productions might look like. Another major step in the background study was to make a value stream mapping (VSM) of the current production. In the background study, most of the data collection was made and collected through a literature study, qualitative and quantitative data collection.

3.1.3 Pre-Study

The third step was to do a preliminary study on the production which includes an analysis of the production to identify and evaluate which parts of the production should be in focus. An important part of the pre-study was the SMED analysis that was performed in the production by observations and clocking the operators in the production. The SMED analysis was made to find possible improvements. More specific objectives were set to make it clearer how the thesis would be carried out. The pre-study part was also the part where most of the preparations for the simulations were made. How the simulation was executed is described in the next chapter of the method part.

3.1.4 Design of Conceptual Production Design

The last step in the Rösiö and Burch method was to find solutions that could improve the current system and together with simulations identify if there were some benefits that could improve today's tool handling. The approach for how the simulation was carried out will be explained in more detail and since the simulation part is such a big part of this project, the decision became that a separate method for the simulation part would be beneficial.

3.2 Simulation Method

The chosen method for the simulation part was the Banks simulation method which consists of three parts with different steps in each, see figure 3.2. Since there are various steps in this method some of them are more prioritized and especially the more time-consuming steps for example model building, experiments, and the analysis part.

3.2.1 Preparation

The main steps of the preparation part consisted of a lot of the background study and preliminary study that was explained earlier from the main method. Including that, also get to know the simulation program and set up deadlines and goals with the simulation.

3.2.2 Model Building

A key step for the simulation was to build a basemodel that could represent the current production at GKN. Important steps in the model building were the verification and validation of the model since it was important that the model was similar to reality.

The verification and validation process of the basemodel was done collectively with the team leaders of the GROB production in a face-validated manner. The process was conducted through a meeting, where a comparison was made of the utilization data and preparation of tools between the basemodel and the current production after running the simulation to a suitable extent. The data from the current production was not provided by the team leaders and they only used it to compare and verify the presented model.

3.2.3 Analysis

To analyze the result, the first thing that was done is to make a proper experimental design to know how to execute the experiments in the right manner. When acceptable results from the experiments have been produced comparison between them and the base model was made to see what improvements or deterioration the experiments can produce. To present the analysis part graphs and different tables were created to visualize the differences with automated solutions.

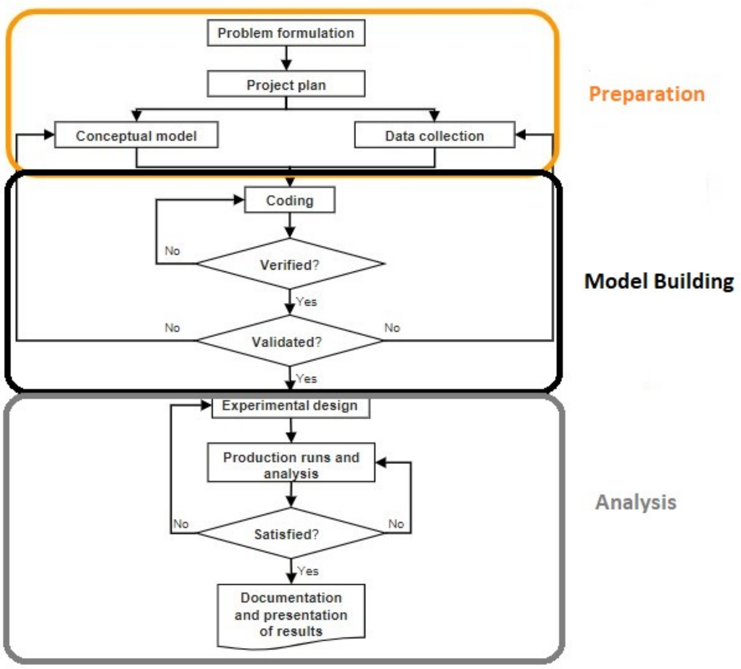

Figure 3.2: Banks simulation method(Banks, 2010).

3.3 Literature Study

To gain reasonable ideas and a clearer insight into the development of this master thesis, a literature study was performed. This literature study information gathering process was divided into two aspects, the purpose of the first aspect is to gain the main understanding of the related topics of this thesis, for example, automated systems in transportation and logistics. The second aspect aimed toward a deeper understanding of breaches regarding the thesis and increase the level of knowledge during the development of the production system. This information-gathering system for the literature study broaden the analysis, eased the comparative research for this thesis, and provided interesting and relevant information.

The first step in this literature study was defining relevant keywords and phrases that lead to relevant information. This was also beneficial when constructing the scope of the thesis to have a clearer focus. The defined keywords are based on prior knowledge from previous educational courses. The keywords that were used: Optimizing Tool Handling, Automated Systems, DES, and AGV. These keywords are combined with additional sub-keyword with Boolean logic to narrow the information search, which is: Production System, Tool Management, Tool Logistics, Challenges, Benefits, and Case Study. The databases that were used are Chalmers Library, IEEE Xplore, Scopus, Research Gate, Science Direct, and Google Scholar. The mentioned databases provide reliable information from Journals, eBooks, and Conference papers.

3.4 Data Collection

The pursued research tools for the data collection are a quantitative study and a qualitative study, thereafter, followed by analysis from both ends. Furthermore, the data collection chapter was considered a time-consuming process, especially when defining the and collecting required data parameters for the DES model. Moreover, several tools are utilized to find the required data for this thesis.

Quantitative Study

This study design means to have numerical data, to turn data into numbers to use statistical tests to gain a better understanding of the research question, and provide more objective and authentic knowledge. The numerical data from this study was utilized to build a functional DES model and such data parameters for the simulation model can be process time, failure time, capacity, and availability (O'Reilly, Ronzoni and Dogra, 2013). Moreover, additional required data may be needed, such as frequent disturbances in the CNC machine for further analysis of improving the tool management.

As mentioned, several tools were utilized to find the required data, such as structured interviews with engineers and operators. Most of the required data for this thesis was already gathered and stored in Excel files from previous studies. If the required data couldn't be provided, estimation was then the alternative to collect the data (O'Reilly, Ronzoni and Dogra, 2013). The data will not be presented in detail due to confidentially reasons.

Qualitative Study

Qualitative data was primarily collected through interviews with industry researchers and experts to get a deeper understanding of the subject. Also, to find the most common problems and important aspects of tool handling and production logistics. The interviewees were chosen based on what kind of background they had and what their field of work is. These conducted interviews with experts within the industry at GKN and Chalmers was contacted privately via email with a short introduction to the work and if they were willing to attend a short meeting for an semi-structured interview (Billups, 2021). Each person who has been interviewed will be anonymous and will only be called by a number. The interview questions that were used are presented in appendix figure A.1. The main objective was to extract data through their knowledge and views about automated solutions and other further changes in tool management.

3.5 Research Ethics

To carry out a master's thesis, the research needs to take ethical aspects into account. The master thesis that was carried out at GKN Aerospace was therefore carried out in an environmentally friendly way and with a low climate impact. Since trips from Gothenburg to Trollhättan were made, the transportation choice was going by train to have a minimal impact on the environment. Unnecessary trips were therefore not made and only important events were carried out in Trollhättan. The possibility of digital tools will therefore be largely to facilitate the master's thesis. After the corona pandemic, people have adapted to digital tools and different types of approaches to carry out work, therefore was not seen as a major problem.

One of the most important aspects was that the master's thesis would be carried out in a safe and risk-free manner. This means that data and information concerning GKN were not to be shared with unauthorized persons and should therefore be treated according to the company's policies. If it shouldn't be followed it could both damage and negatively affect GKN, and the security of data was therefore an important part when carrying out the master's thesis at GKN. In addition, surveys and interviews needed to be conducted anonymously. This means that the people who participated should not be able to damage their careers and feel that something was published incorrectly. Therefore, all participants for interviews or surveys were informed in advance that they were conducted anonymously. Furthermore, what type of interview and how it would be used in the master's work.

4
Results

This chapter describes the main findings from the qualitative and quantitative study. The result of the performed SMED analysis and VSM will also be presented. Lastly, the results from the simulation and further production runs will be presented and described. An impact analysis of the experiments will also be presented.

4.1 Data Collection

The results of the data collection that will be presented are divided into sub-chapters. The qualitative data was from the interviews that were carried out. The quantitative data are provided by various key people, but also observations in the production.

4.1.1 Qualitative Data

The chapter will present the interviewed person's thoughts and answers and lastly a table for the main takeaways from the qualitative data.

Interviewee 1:
Interviewee 1 with a background in production logistics mentions, that when implementing AGV systems it is primarily important to identify the problem of why AGVs need to be introduced.

Notable things to keep in mind are:
- Is a higher availability needed?
- Or is it a higher capacity that is in demand?

In addition, an important step is to study the production flow and the products to find out if an AGV system is the right solution to achieve the goals. Interviewee 1 also mentions that improved ergonomics can be one of the goals for introducing automated solutions for production. An important part of developing the current production is to create a value stream mapping. In order to see possible solutions, this is a significant step to being able to identify possible bottlenecks. Possible KPIs for the work could be to create a faster flow or for the sequence to look better. Furthermore, interviewee 1 mentions that simulation of different solutions is a very good tool for visualizing and proving what can be achieved.

Interviewee 2:

Interviewee 2 with an engineering background in the GROB production at GKN Aerospace mentions that GKN has the biggest challenge in the morning shift when there are many machines that are not operating because they are waiting to be unloaded from the used tools during unmanned hours in the production. Therefore, interviewee 2 believes that automated solutions could improve this process so that the CNC machines can start up earlier and get a higher utilization rate. In addition, interviewee 2 believes that GKN primarily wants to focus on increasing capacity when it comes to improving tool handling. Therefore, AGV scheduling should prioritize the most essential, i.e. capacity.

Furthermore, it is mentioned that if several different automated solutions are introduced at the same time, it is important to create a good connection between them. For example, a robot station for preparation of tools and transport to and from CNC machining of these through AGV systems. Through automated solutions, interviewee 2 believes that the "ghost hours" during night time will be used in a more efficient way and also that the morning shift makes it much easier and smoother to start production in the morning.

Interviewee 3:

Interviewee 3, with an engineering background in the GROB production, carried out this interview in the production at Trollhättan, and explained in detail about how the production works and what is important to think about. GKN uses a tool called CoPilot which shows which tools need to be replaced and which tools are used up or need to be prepared before they are used again. Automated solutions, therefore, need to have an interaction between CoPilot to be able to execute sequences in the right priority.

How tool changes are carried out today in production:

- The operator checks on CoPilot which tools need to be changed on each machine.
- Walks away with a trolley to the CNC-machine and uses a computer to record which tools need to be changed.
- Goes back with the trolley to the preparation station and prepares the right tool for the next operation for the machine which is also in CoPilot.
- Then walks away with the trolley of new tools to register these as well.
- Inserts the new tools and starts a new operation.

In addition, it is mentioned that when the tools for the production line stock are out, they are automatically sent an order for which tools are needed. This is done at 4 o'clock every night so that there are tools for the staff who comes in the morning. There is therefore no risk of running out of tools. Finally, interviewee 3 mentions that the big difference that can be made with automated solutions is to improve the morning shift and reduce the time it takes operators to do all the tool changes in the morning.

Interviewee 4:
Interviewee 4 with an engineering background in logistics believes that by introducing automated solutions, the number of operators will decrease and less personnel costs, thus a long-term investment. Improved ergonomics are also mentioned as something positive for increased safety and reduced costs. However, the interviewer does not believe that they would be a faster way to prepare or transport the tools through automated solutions, but that it could improve "ghost hours" when the operators are not working during the night shift. In addition, the biggest losses in work are during the morning hours when several tool changes need to be made and the interviewee believes that an automated solution would have improved this since automated solutions can prepare before the morning shift starts. Even errors in tool changes are seen by the interviewer as a loss, and with automated solutions, the accuracy of this can be improved.

Interviewee 5:
Interviewee 5 with an engineering background in the GROB production also mentions that their biggest problem is in the morning when around 30-40 tools need to be changed per machine. This also depends on how much the evening shift has prepared before the night starts, the more that is prepared the less the operators in the morning has to do to start up the CNC machines. When the machines have been started up in the morning, preparations for tools can be made when the machines are processing so that it is easy and smooth to make tool changes when a process is finished.

Furthermore, the interviewee mentions that each tool has a chip that shows if the tool is out of order or if it can be reused through various preparation methods that can get the tool back in the right condition. One problem the interviewee mentions is that the changes can only be made at a certain speed. The operators see that this process should go faster as it has to wait a few seconds each time a change takes place. The ergonomics of these movements of tool changes are also not completely optimal because they are performed with weights and expose the body in an unnatural way.

Table 4.1: Summary of the qualitative data collection.

Qualitative Data
The morning shift is the most challenging in production to maintain the utilization of CNC machines.
AGVs needs connection between automated solutions and a prioritized scheduling method.
Lower costs in the long term with through fewer operators and a reduced risk of injuries.
Improved "ghost hours" during night time - higher utalization.
Improved accuracy with automatde solutions.
Improved ergonomics by introducing automated solutions.

4.1.2 Quantitative Data

The quantitative data will be presented in table 4.2 to clarify the relevant data used for simulations and calculations.

Table 4.2: Quantitative data collection

Quantitative data collection	
Activity	**Unit**
Amount of CNC in production	x
Process time CNC tempo 1	[h]
Process time CNC tempo 2	[h]
Required tools for CNC tempo 1	x
Required tools for CNC tempo 2	x
Loading tempo 1	[minutes]
Loading tempo 2	[minutes]
Unloading tempo 1	[minutes]
Unloading tempo 2	[minutes]
Manual cleaning process time	[minutes]
Module cleaning process time	[minutes]
Manual vision check process time	[seconds]
Module vision check process time	[seconds]
Manual solid change process time	[seconds]
Manual insert change process time	[seconds]
Module solid change process time	[seconds]
Module insert change process time	[seconds]
Amount of operators	x
Costs for AGV	SEK
Costs for robotcell	SEK
Costs for operator	SEK
Average speed of operators	[m/s]

Table 4.2 describes the gathered data that was needed to evaluate the current production, but also used in the basemodel for the simulation part. The tools required at each machine may vary depending on the CNC-machine and which detail is to be processed. For a part to be processed, it needs to run through the processing time for tempo 1 and tempo 2. Loading and unloading describe the times for an operator to change tools, to insert new and remove used tools. Manual change is when the preparation of tools is handled by an operator and module is when an automated robot handles the preparation of the tools. Solid and insert describe what type of tool it is. The cleaning and vision check is included in the preparation part for the tools, which is also described in the table depending on if it is performed by a robot or an operator. The amount of speed for an operator and amount of operators for the production is also shown in the table since it is important data in order to evaluate differences between automated solutions and operators, but also for business calculations and costs.

Table 4.3 visualize an easy description of how the operators work for one week. This is also important data for simulations but also for business calculations and costs. The shift times described are not detailed due to confidentiality reasons.

Table 4.3: Data for shifts and amount of operators in the GROB-production.

Shift	Production line 1	Production line 2	Production line 3	Total amount of operators
Shift 1 (06.00-15.00)	4-5	4-5	4-5	12-15
Shift 2 (15.00-00.00)	4	4	4	12-15
Weekend shift (07.00-18.00)	3-4	3-4	3-4	9-12

4.2 Value Stream Mapping

The value stream mapping shown in figure 4.1 demonstrates how the current flow system work in each GROB production line. The demand is sent out to the production control in a weekly forecast for the required quantity of finished parts. Thereafter, the production control (CoPilot) utilizes real-time data from the GROB production to plan and signal desired tool changes. The displayed data in production control is also used to prepare the tool after the tool removal has been conducted and the used tool is transported to the tool preparation process, as shown in figure 4.1. Furthermore, the tool preparation process is performed in a FIFO sequence, indicating that the first used tool for the preparation is the first tool out. The tool preparation process involves different operations depending on the tool type, but the stated process is cleaning, insert change, solid change, and vision check. It's also worth mentioning that every production line has 8 CNC machines that operate in 2 tempo programs that have different processing times and required number of tools.

The process in the current production is performed by manual labor, everything from tool removal to tool preparations. According to the qualitative study, the current production experiences disturbances in the overall utilization and availability of resources in the processes. The proposed solution is replacing the manual labor automation solutions in tool transport and preparations, which will demonstrate the futuristic version of the current VSM. A more detailed description of elements in the tool removal and preparation process will be introduced in the SMED analysis as to how those current elements will be replaced. This will further create a foundation for the simulation chapter.

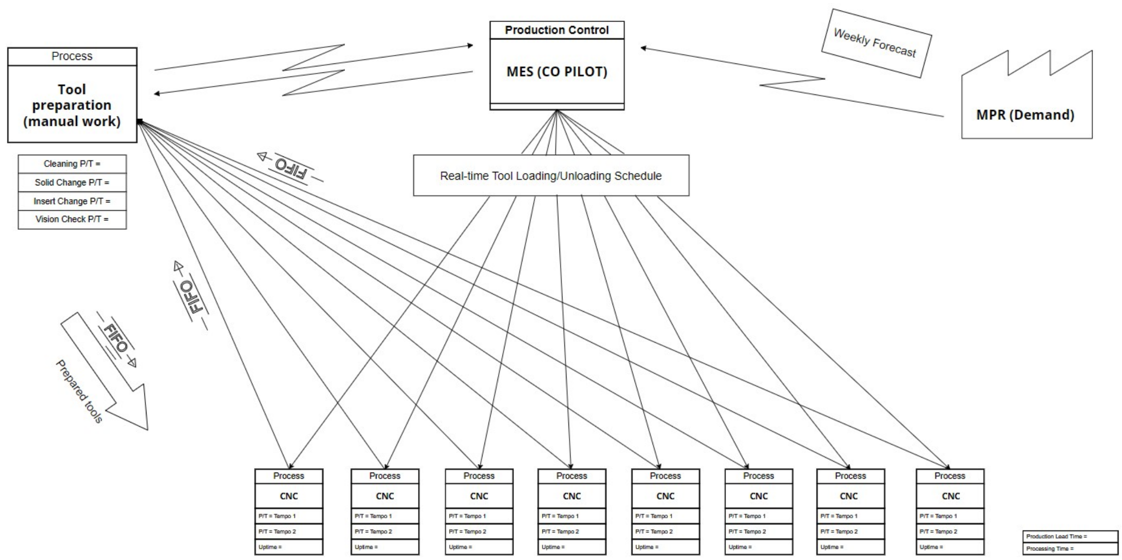

Figure 4.1: VSM of the current GROB production.

4.3 SMED-Analysis

In order to evaluate the current production an SMED analysis has been performed. Results from interviews and observations have caused the focus to end up the analysis in the morning when there is the most work to prepare to start the day and the CNC machines to start processing. The analysis was performed to see if there are other ways that could enable more efficient production. Even an analysis of the tool change has been made to see if automated solutions are preferred. The SMED analysis will be presented through figures and tables from investigations that have been carried out from the production in Trollhättan. In addition, suggestions on how they could improve their preparation will be presented.

Table 4.4: SMED analysis of the preparation part in the production.

Work sheet - SMED analysis of tool preparation			
Location - Tool setting area	**Operation -** Tool preparation (manual labor)		
Shift - Morning shift	**Total time -** 50 - 60 sec		
Activities	When?	Time	Who?
1. Choose tools to prepare according to Co-Pilot	External		Operator
2. Pick used tools from trolley	External	5 sec/tool	Operator
3. Place the used tools on the fixture and clean	External	15 sec/tool	Operator
4. Scan the tool with chip reader	External	5 sec/tool	Operator
5. Pick a prepared tool and place on tool holder	External	15-20 sec/tool	Operator
6. Perform a vision check on the prepared tool	External	10 sec/tool	Operator
7. Place the tools on the trolley and transport to CNC	External	5 sec	Operator

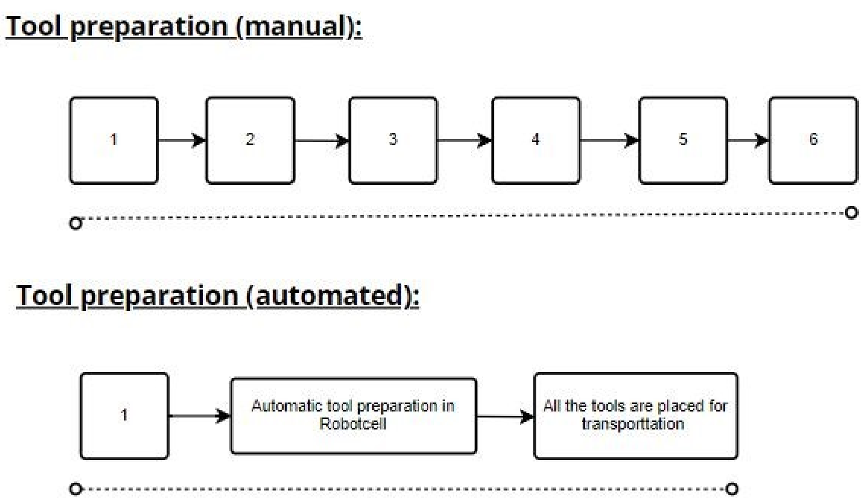

Figure 4.2: A proposal on how the current preparation of tools can be automated to increase productivity.

Table 4.4 is the SMED analysis of the tool preparation in the morning shift where a lot of tools are required to be changed. Step 1 to 7 describes how the preparation of tools is carried out. Observation in production has shown that this process can be exhausting and take time to start up all the CNC machines for the day. The time is for the steps can vary in the production, the maximum time for the steps has taken into account. Figure 4.2 describes the automated proposal that could improve the process of preparing tools before the staff arrives in the morning and reduce the total time in tool preparation, making it smoother and faster to perform the tool changes when tools are already prepared. This could increase the utilization of the CNC machines and thus increase productivity. Figure 4.2 also demonstrates the reduced steps in the tool preparation process which can further lead to an enhanced working environment in terms of fewer steps.

Table 4.5: SMED analysis of the tool changes in the current production.

Work sheet - SMED analysis of tool change			
Location- CNC machines	**Operation -** Tool removal (manual labor)		
Shift - Morning shift	**Total time -** 36 - 69 sec		
Activities	When?	Time	Who?
1. Choose tool from monitor to trigger the PLC	External	2-5 sec	Operator
2. Clim the staircase	External	2 sec	Operator
3. Push the bottom and wait	External	10-20 sec	Operator
4. Open window of CNC when tool ready for removal (30 - 40 tools)	External	7 sec/tool	Operator
5. Close the window and push the bottom for next tool	External	10 - 20 sec/tool	Operator
6. Place the tools on the trolley and transport to preparation station when all tool removed	External	5-15 sec	Operator

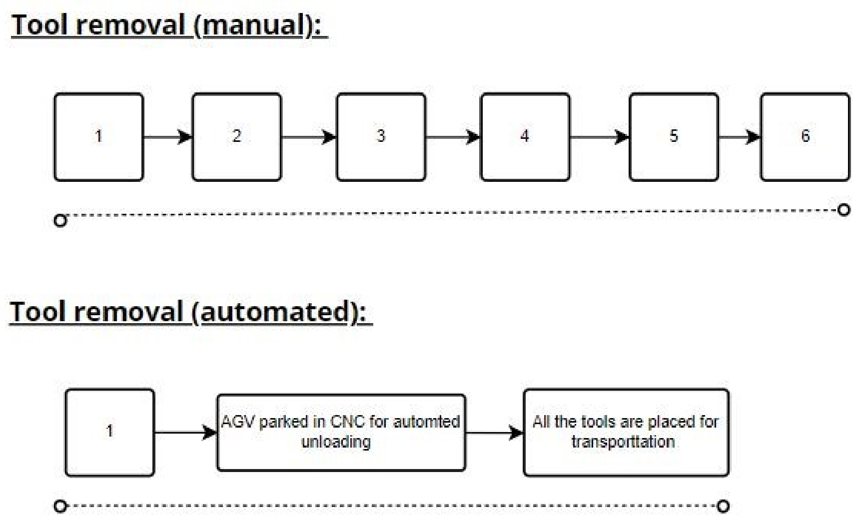

Figure 4.3: The current production in comparison with an automated solution.

The second SMED analysis performed was focused on the tool change because observations from production showed that this step took longer than it should. Together with automated tool preparation, the process can be further improved for automated production and more elevated utilization can be maintained. Table 4.5 describes the SMED analysis of the tool change in the current production, which consists of a number of steps that make the process take a certain amount of time. Figure 4.3 shows how an automated tool change could have simplified this process or at least increased the "ghost hours" and simplified the process for the morning shift and decrease the total time. This is a step that is seen as a proposal to automate production as an additional step after the tool preparation has been automated and is therefore not as prioritized as an automated tool preparation solution. The simulation model will visualize and present results from the mentioned automated proposals.

4.4 Simulation model

To thoroughly answer the research questions mentioned in the first chapter a simulation model has been created, consisting of a basemodel and experimental production runs for further analysis. The experimental design for the production runs is entirely based on our previous qualitative/quantitative studies and to answer our research questions.

4.4.1 Basemodel

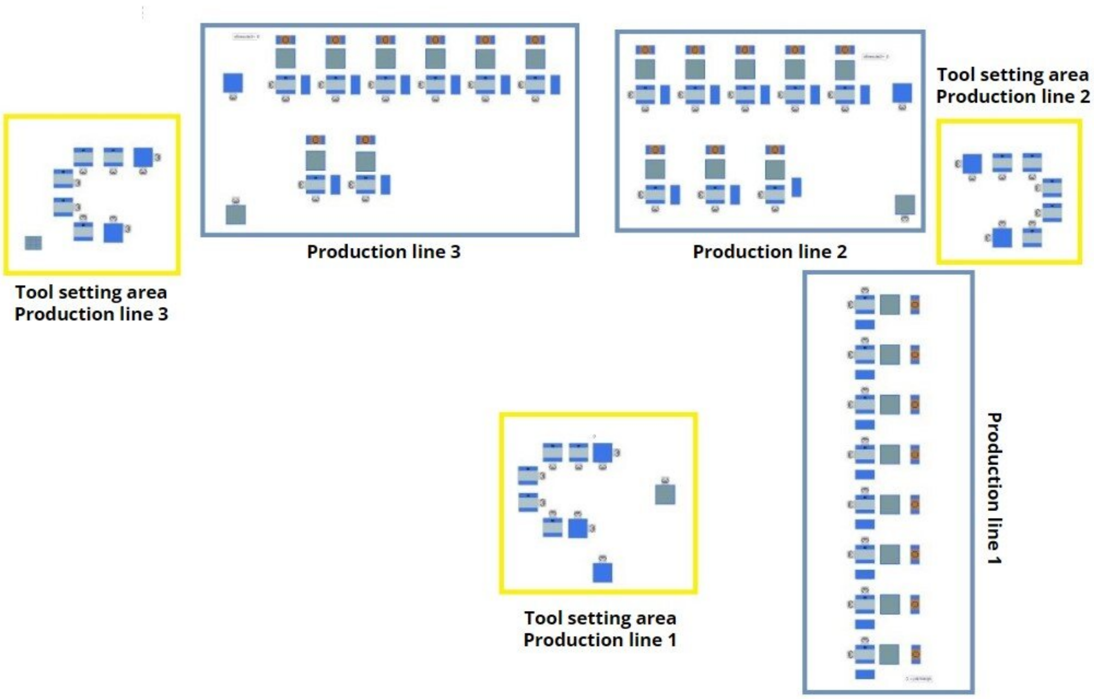

Figure 4.4: The layout of the basemodel.

The simulation basemodel has been created to imitate the current manual CNC production or so-called GROB production and as a starting point for further experiments, also shown in the VSM. Figure 4.4 presents that the simulation model consists of three production lines and in each production there're eight CNC machines that operate at two different tempos, the required tools and processing time can vary in each tempo. Each CNC machine has buffer where the tools are loaded, a source for the required number of tools and a store to visually demonstrate how all the required tools are sequenced before being sent to the CNC machine, as displayed in figure 4.5.

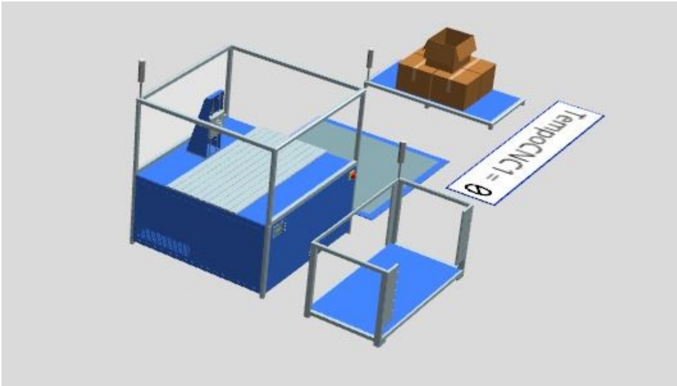

Figure 4.5: Representation of CNC-machine in the basemodel.

Thereafter, when the tools have been processed and used, they're sent to the tool setting area to go through a preparation process for the next tempo, each production line has its own tool setting area. The tool preparation process in the simulation model consists of a cleaning process, solid tool changes, insert tool changes and vision check for inspection. This model will involve two different types of tools: solid tools and insert tools. The layout of the tool setting area is shown in figure 4.6.

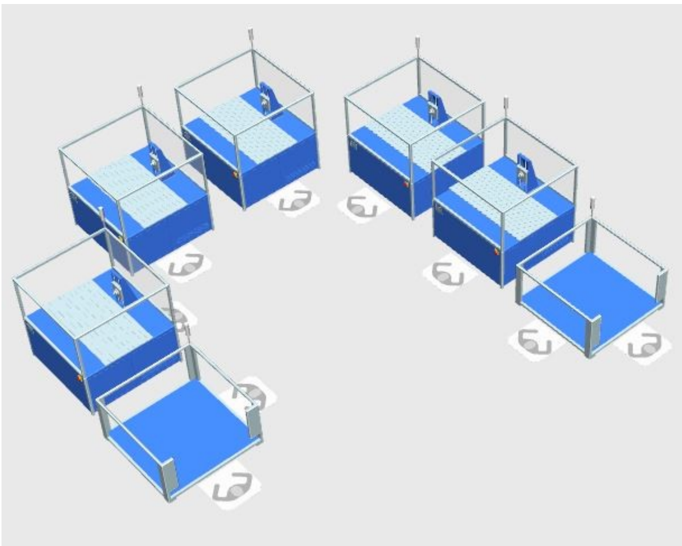

Figure 4.6: Representation of tool setting area in the basemodel.

4.4.2 Verification and Validation

After conducting an extensive meeting and carefully examining the data using a face-validated approach, the team leaders affirmed the verification of the basemodel. Furthermore, it was established that the basemodel maintains its stability and reliability over long durations.

4.4.3 Experimental Design

To answer the presented research questions, the simulation model needed to undergo several experiments that were based on the previously mentioned studies in this thesis. The presented experiments in table 4.6 demonstrate experiments to create a further comparison between manual and automated labor by increasing the proportion of workers and introducing night shifts in manual production to observe any improvement in utilization and other parameters.

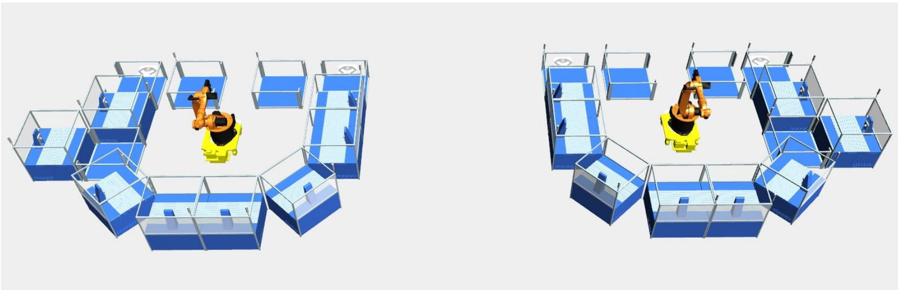

Figure 4.7: Representation of two robotcells in the simulation.

The proposed automated solutions first consist of two robot cells made for separate preparation of the Insert and Solid tools, as displayed in figure 4.7. Thereafter, conducting proportional and modification experiments of the resources (operators, buffer size and speed) based on the robotcells behaviors after an extended number of runs and observations. The last experiment will introduce the AGVs to production and activate a new possibility for night shifts. Further proportion and modification experiments were done after the AGV implementation, such as the number of operators and altering the shift times. Every experiment was simulated from 2 weeks to 1 year and observed several times to find variations and inconsistencies that might affect the result. The experimental design for each experiment is shown in table 4.6.

The tables below describe the shift calendars for the presented experiments, consisting of the number of hours and operators during different shift hours. In table 4.8 the night shift is introduced with operators to create a further comparison with the automated experiments. From table 4.9 to 4.11 the shift tables for the automated solutions are introduced with a reduced amount of operators from 4 to 2 operators, due to the robotcell being introduced and replacing the operator in tool preparation. In tables 4.10 and 4.11 the automated night shift is being experimented with, but not shown in the table. In table 4.11, the shift table is further reduced by decreasing the number of hours the operator works in tool transportation, due to the AGV replacing the operators in most of the hours.

Table 4.6: The experimental Design.

Experimental Design		
Experiment:	**Name:**	**Description:**
Exp 0	Basemodel	Modeling a identical simulation version of the current production and utilization of resources.
Exp 1	Workforce increase	Increasing the amount of workers during the different shifts. Introducing manual nigh-shift with operators.
Exp 2	2x Robotcell	Two robotcells for tool preperation separate for the solid and insert.
Exp 3	Modi. 2x Robotcell	Modifications of exp 2. Balancing the workload between the robotcells.
Exp 4	AGV + 2x Robotcell	Combining automated tool preperation and transportation, a continuation of exp. 3. Introducing automted night-shift with AGV and robotcells
Exp 5	Modi. Exp 4	Shift calender modifications from exp 4. The automated transportation and preparartion will be introduced in the day shift and the shift time for the operators till change.

Table 4.7: Shift calendar and amount of operators for basemodel.

Basemodel					
Shift	Production line 1	Production line 2	Production line 3	Total amount of operators	Amount of hours
Shift 1 (06:00-15:00)	4	4	4	12	9
Shift 2 (15:00-00:00)	4	4	4	12	9
Weekend shift (06:00-18:00)	4	4	4	12	12

Table 4.8: Shift calendar and amount of operators for experiment 1.

EXP 1					
Shift	Production line 1	Production line 2	Production line 3	Total amount of operators	Amount of hours
Shift 1 (06:00-15:00)	4	4	4	12	9
Shift 2 (15:00-00:00)	4	4	4	12	9
Night-shift (00:00-06:00)(weekdays)	2	2	2	6	6
Weekend shift (06:00-18:00)	4	4	4	12	12

Table 4.9: Shift calendar and amount of operators for experiment 2 and 3.

EXP 2 and 3					
Shift	Production line 1	Production line 2	Production line 3	Total amount of operators	Amount of hours
Shift 1 (06:00-15:00)	2	2	2	6	9
Shift 2 (15:00-00:00)	2	2	2	6	9
Weekend shift (06:00-18:00)	2	2	2	6	12

Table 4.10: Shift calendar and amount of operators for experiment 4.

EXP 4					
Shift	Production line 1	Production line 2	Production line 3	Total amount of operators	Amount of hours
Shift 1 (06:00-15:00)	2	2	2	6	9
Shift 2 (15:00-00:00)	2	2	2	6	9
Weekend shift (06:00-18:00)	2	2	2	6	12

Table 4.11: Shift calendar and amount of operators for experiment 5.

EXP 5					
Shift	Production line 1	Production line 2	Production line 3	Total amount of operators	Amount of hours
Shift 1 (06:00-12:00)(1)	2	2	2	6	6
Shift 2 (19:00-00:00)(1)	2	2	2	6	4
Weekend shift (06:00-15:00)	2	2	2	6	9

(1) During these unnmaned hours, the AGVs are working with the supervision of one operator in each production, but the AGVs are perfomaing the main transportation task

4.5 Simulation Runs and Analyses

The designed simulation basemodel is intended to reflect the current production lines and to work as a starting point for the experiments and production runs that will be introduced in this chapter. After running the basemodel for a fixed time of two weeks the observation of the utilization chart could be done. The utilization result is demonstrated in figure 4.8.

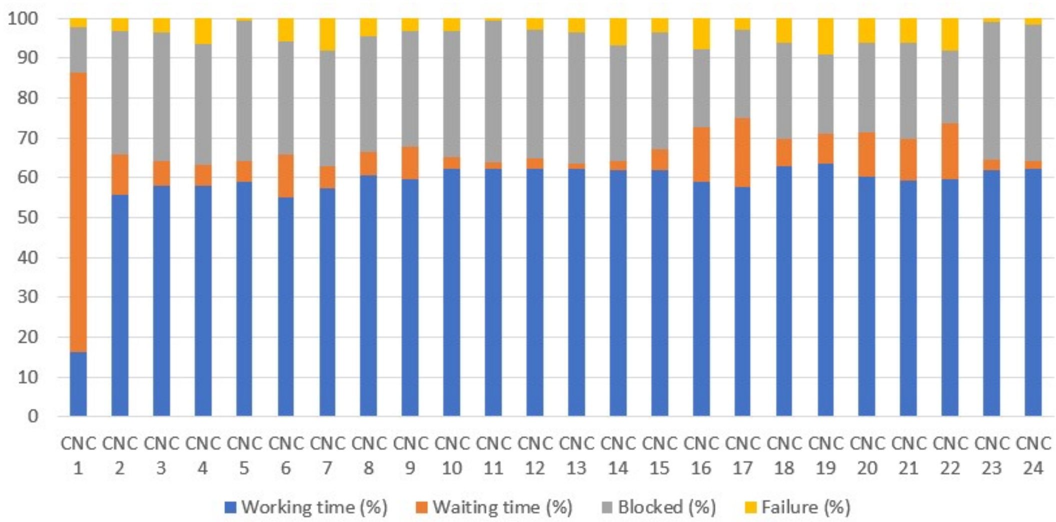

Figure 4.8: Utilization chart of the CNC machines in the basemodel.

The working time in figure 4.8 represents the time when the CNC machine is operating and active. The waiting time represents the time when the CNC machines are waiting for the sequenced tools to be placed and begin with the next tempo. The failure displayed in the utilization chart represents the alarm failure the production faces and is maintained by the maintenance operators, which will not be disclosed in detail. CNC 1 has the highest waiting time because it operates exclusively within a single tempo.

The blocked portion depicted in the utilization chart represents a situation in the production where all the utilized tools accumulate at the end of a work cycle, awaiting unloading, while there is no operator present to carry out this task. The blocked duration primarily occurs during unmanned hours, when there is a significant increase in the number of CNC machines awaiting the unloading of used tools to be transported to the entry buffer of the tool preparation process. This accumulation of machines leads to the creation of a blocking situation. The blocked portion in the utilization chart also represents the unplanned time that occurs during unmanned hours. During this time, the CNC machine is not operational or available for production due to the mentioned situation, resulting in unexpected downtime and unavailability. The pursued set point value for the average for blocked time should not exceed over 10% for the whole production when attempting to reach optimal utilization, and this is determined by a reasonable estimation for optimal production.

It's confident to state that the bottleneck is located at the entry of the tool preparation process and its most significant contributing factor is the blocked portion caused by unmanned production. Briefly, the bottleneck is considered to be caused by the operators. This can heavily affect the output of tool preparation and finished parts.

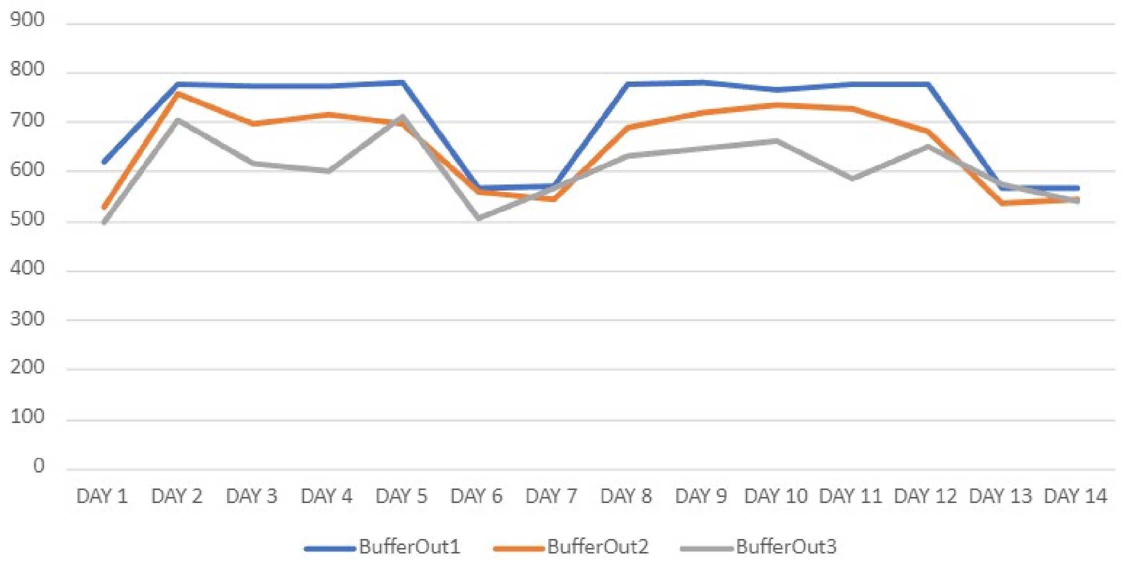

Figure 4.9: The output of prepared tools in each production line.

In the basemodel the production prepares 81,9 tools/hour.

Figure 4.9 shows the total amount of tools prepared in the tool setting area in each production line, where production line 1 has the highest output. The considerable decrease in tool preparation on days 6 and 14 is during the weekend with shorter shift hours and increased unmanned hours, which contribute to the high block portion and unplanned time.

4.5.1 Experiment 1: Increase the Operators

This experiment is all about increasing the parameters of operators to observe an increase in output. This experiment will be conducted twofold, firstly increasing the number of operators during the morning and day shifts in the basemodel. The second part is introducing night-shift with two operators in each production line, working in the tool preparation process to prepare tools for the morning shift. Surprisingly, despite increasing the number of operators during the morning and day shifts without any significant changes, it was the implementation of the night shift that brought about noticeable results.

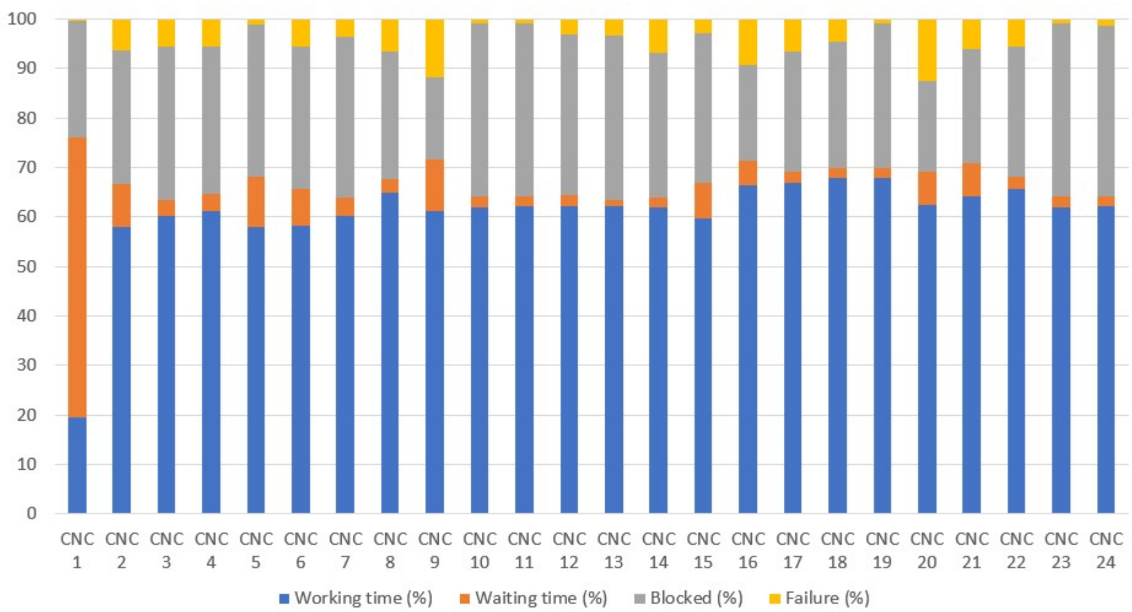

Figure 4.10: Utilization chart of the CNC machines in experiment 1.

According to the data given in figure 4.10 and comparing the result to the previous utilization chart for the basemodel, the total working time for the whole production has increased by a total of 59 percentage units in difference and the waiting time decreased by 77,9 percent difference for the whole production lines. However, the blocked portion in the utilization chart has increased by a total of 12,5 percent difference. The changes in failure time are not significant and a comparison with the basemodel will not be made. Unfortunately, the bottleneck has not been addressed in this experiment.

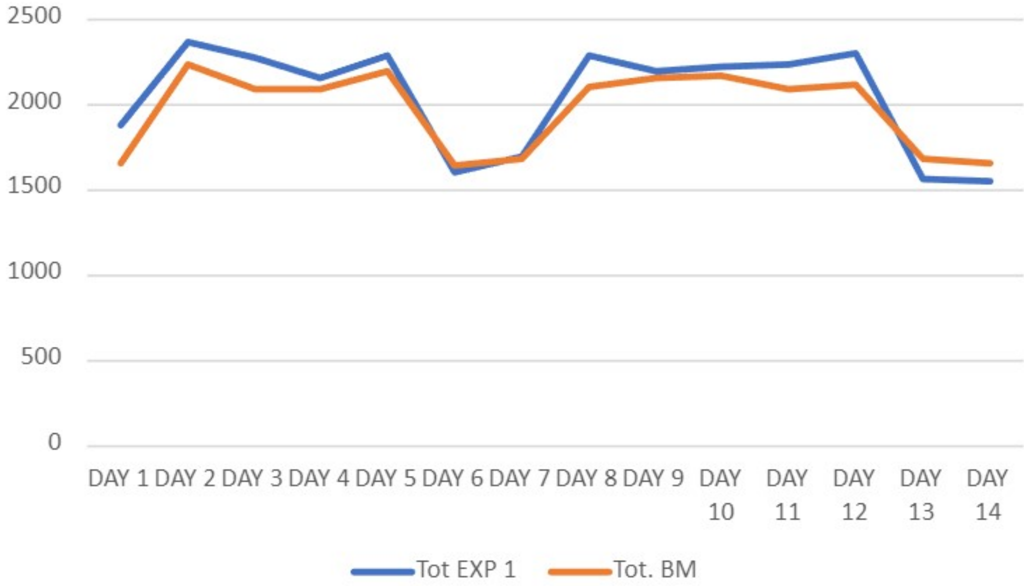

Figure 4.11: Comparison between the total amount of prepared tools from basemodel and experiment 1.

<u>**In experiment 1 the production prepares 85 tools/hour.**</u>

Figure 4.11 shows the total amount of tools prepared from every production line in the basemodel and experiment 1. The results indicate a 3,8% increase in output concerning prepared tools. However, there has been minimal change observed during the weekends, and the decrease in output is still visually evident.

4.5.2 Experiment 2 and 3: Robotcell for Tool Preparation

These experiments will introduce the first automated type experiment, starting with the implementation of two robotcells dedicated to the tool preparation process in the simulation model for every tool type, insert, and solid. Thereafter, reviewing the result and finding potential modifications to implement for experiment 3.

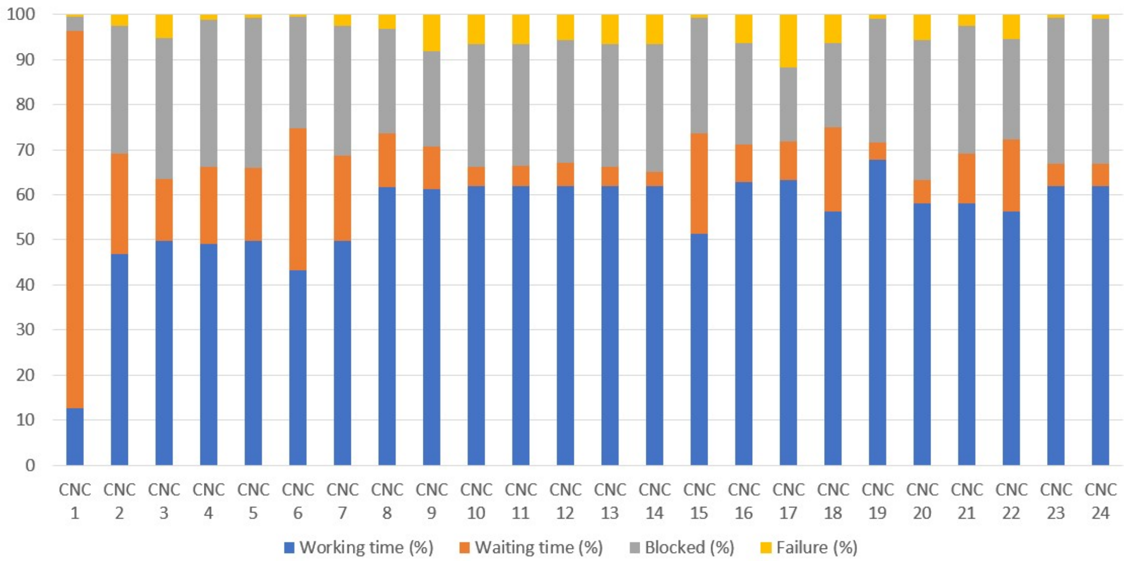

Figure 4.12: Utilization chart of the CNC machines in experiment 2.

Figure 4.12 presents the utilization results of the two robotcells, which are considered inadequate but promising. In comparison to the basemodel, the total working time for production has decreased by 67,77 percent difference, while the waiting time has increased by 118,8 percent difference. It is worth mentioning that the robotcells continue to operate during unmanned hours with on-call maintenance operators. However, there is a significant decrease of 45,3 percent difference in the blocked time.

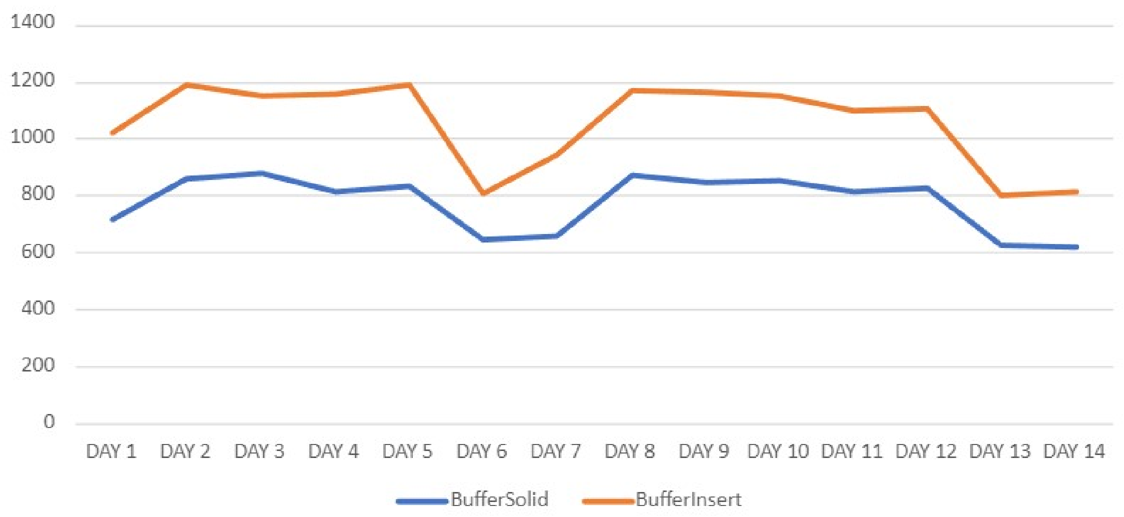

Figure 4.13: The output of prepared tools in each robotcell from experiment 2.

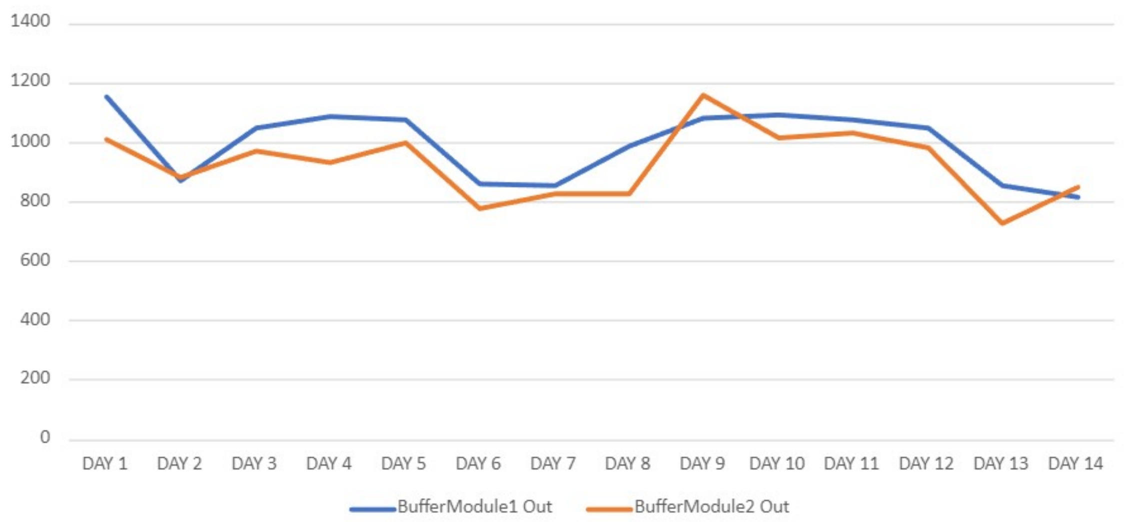

Figure 4.14: The output of prepared tools in each robotcell from experiment 3.

From figure 4.13, it can be observed that when dividing the tool preparation process for different tool types within each robotcell, the production experiences higher idleness and an unbalanced output of prepared tools from the robotcells. The implemented modifications in experiment 3 are dividing the total number of required tools to complete a component in each CNC machine between the two robotcells. The first robotcell performs the tool preparation from the first 12 CNC machines, and the second robotcell performs the preparation of the 12 remaining CNC machines. The result displayed in figure 4.14, indicates the modifications resulted in a more balanced flow, and the gap between the exit buffers becomes smaller. Additionally, implementing experiment 3 led to a 5% increase in the output of prepared tools.

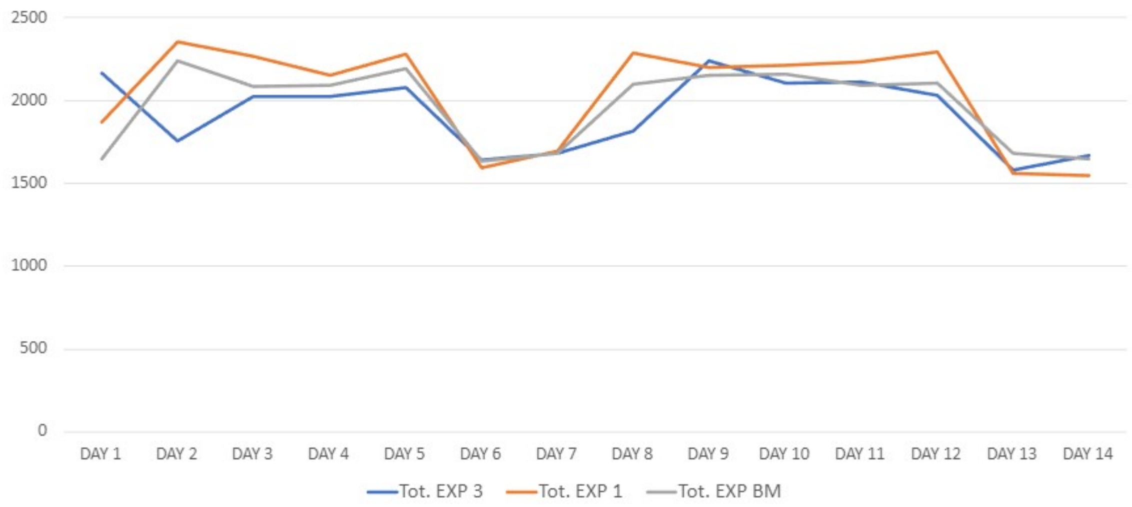

Figure 4.15: The total output of prepared tools from basemodel and experiment 1 and 3.

In experiment 3 the production prepares 80,2 tools/hour.

Figure 4.15 clearly illustrates that despite efforts to moderately balance the workload between robotcells and perform tool preparation during unmanned hours, experiment 3 still underperformed compared to both the basemodel and experiment 1. Visually, there is close competition in total tool preparation among the experiments. However, it is worth noting that the basemodel achieved 2.1% higher output in total tool preparation, while experiment 1 outperformed experiment 3 with a 5.7% increase in tool preparation output. The decrease in the prepared tools for experiment 3 clearly displayed on days 2 and 8.

4.5.3 Experiment 4 and 5: Robotcell and AGV

These last sets of experiments are a followup of experiment 3 and will combine the robotcells from the previous experiment and introduce the AGV for automated tool transportation on both day and night shifts. In experiment 4, the automated transportation with AGVs will only be introduced on the night-shift. But the shift times for the operator will be adjusted in experiment 5, where operators work a total of 10 h divided in the morning and the last hours before the introduced nigh-shift. The shift calendar for experiments 4 and 5 is displayed in table 4.10 and 4.11. These experiments had the most promising simulation results.

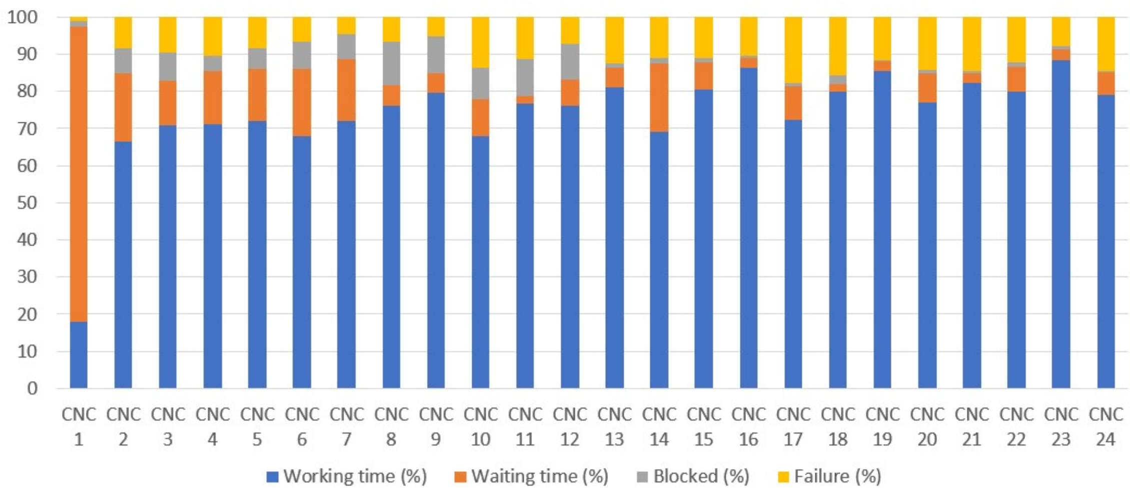

Figure 4.16: Utilization chart of the CNC machines in experiment 4.

The utilization chart depicted in figure 4.16 exhibits a promising outcome in experiment 4. Comparing the utilization of experiment 4 with the basemodel, notable improvements can be observed. The total working time has increased by 377,6 percent difference, indicating enhanced productivity. Additionally, the total waiting time has increased by 46,22 percent difference and the total blocked time has decreased significantly, with a total reduction of 566,12 percent difference for the entire production. These results highlight the positive impact of the implemented changes on overall efficiency and effectiveness. But, the failure time has shown a noticeable increase compared to the basemodel, with a total increase of 139,8 percent difference from the whole production.

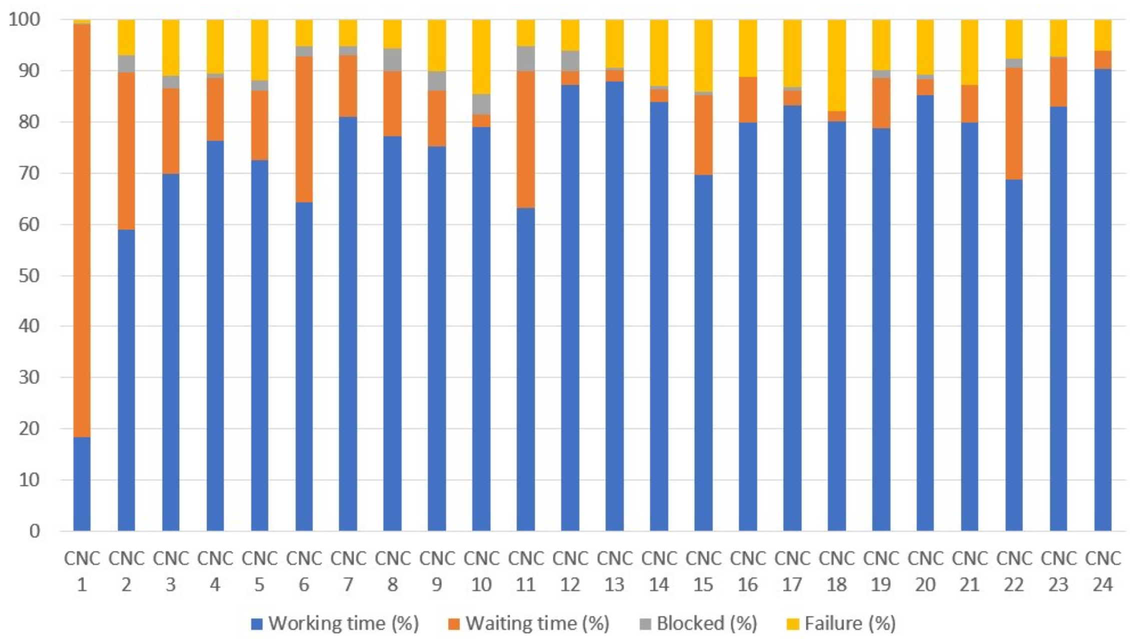

Figure 4.17: Utilization chart of the CNC machines in experiment 5.

Figure 4.17 presents the utilization of experiment 5, which serves as a follow-up experiment to experiment 4 with modifications made to the shift calendar. For further comparison with experiment 4, the total working time has increased additionally by 17,7 percent difference and the total waiting time has increased by 60,8 percent difference. The total blocked time has further decreased with 58,1 percentage units in difference compared to experiment 4, showcasing continued progress in optimizing efficiency and reducing disruptions.

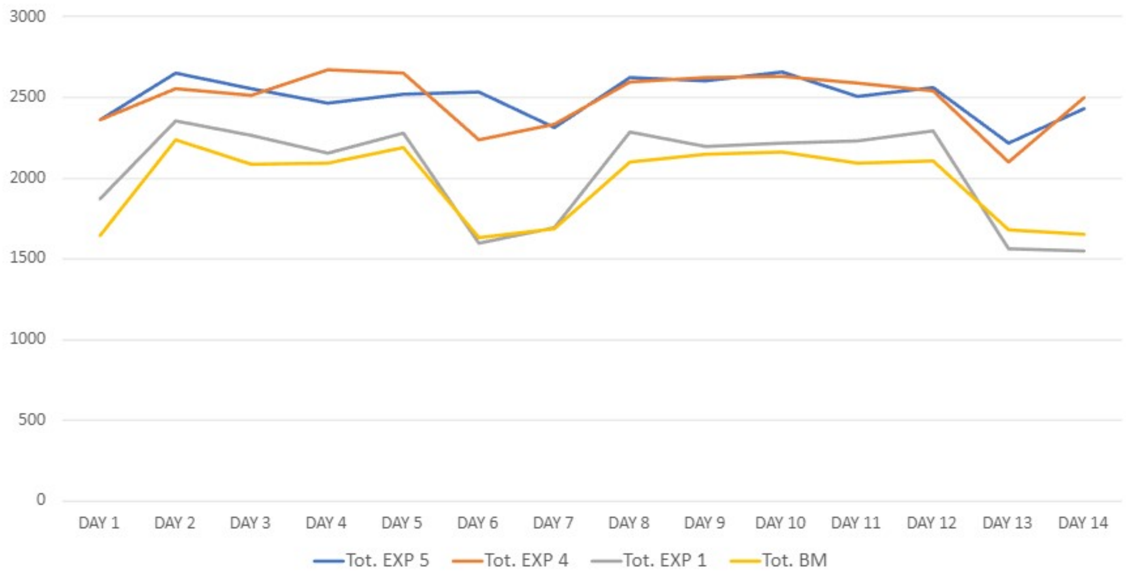

Figure 4.18: The total output of prepared tools from basemodel and experiment 1, 4 and 5.

In experiment 4 the production prepares 103,9 tools/hour.

In experiment 5 the production prepares 104,2 tools/hour.

Figure 4.18 visually illustrates how the simulated experiments with automated solutions outperform the manual labor in the basemodel and experiment 1 in terms of the total output of prepared tools. After running experiment 4, there was a significant 26,9% increase in tool preparation output compared to the basemodel, and a 22,6% increase compared to experiment 1. Comparing experiments 4 and 5, there was only a slight 0,3% increase in tool preparation output. Its also worth mentioning that the variation in the number of the daily prepared tools represented in the curves has significantly been reduced in the automated solution compared to the experiments with manual labor.

4.6 Average Values of Utilization

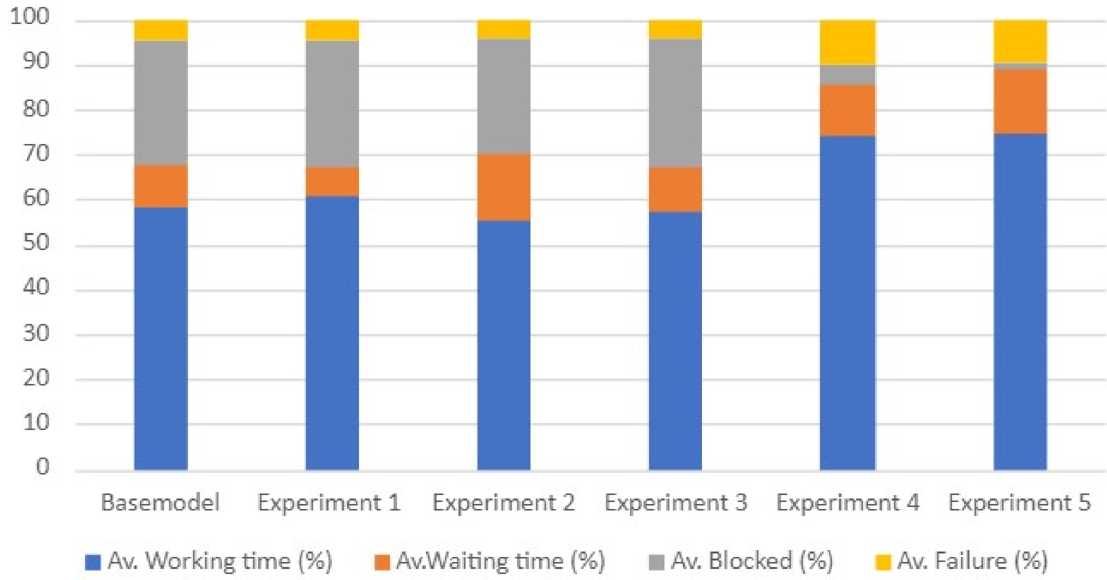

Figure 4.19: Average values of utilization for all experiments.

Figure 4.19 represents the average value of utilization for all CNC machines in each experiment after simulating the production for an extended time. The average percentage of working time in the experiment with manual labor is 58,3% for the basemodel and 60,7% for experiment 1. Regarding, experiments 2 and 3 the average working time was reduced to 55,4% and 57,3%. Experiments 4 and 5 with a combination of automated solutions reached the optimal average working time of 74% and 74,4%.

Furthermore, with the implementation of combined automated solutions, the average blocked time was reduced to 4,1% in experiment 4 and 1.7% in experiment 5. Compared to the alternative with manual labor, the production experienced an average blocked time of 27,7% in the basemodel and 28,2% in experiment 1. This showcases that only the experiments with automated solutions achieved an average percentage of blocked time below the pursued set point of 10%. But it's also worth mentioning that the automated solutions in experiments 4 and 5 experienced an increase in waiting time and failure.

4.7 The Output from the Experiments

Figure 4.20 showcases the production output for finished parts, highlighting the deficiency of experiment 2 and experiment 3 compared to the basemodel and other experiments. Experiment 1 demonstrates a 5.6% increase in output compared to the basemodel, while experiment 4 exhibits a substantial 24.4% increase. Notably, experiment 5 achieves the highest production output for finished parts with a 25.4% increase compared to the basemodel.

After conducting simulations for a longer duration, it was observed that neither experiment 2 nor experiment 3 exhibited any substantial improvements in their underperformance. As a result, these experiments were not considered for further investigations. The lack of significant changes in their performance led to the decision of excluding them from further analysis and exploration.

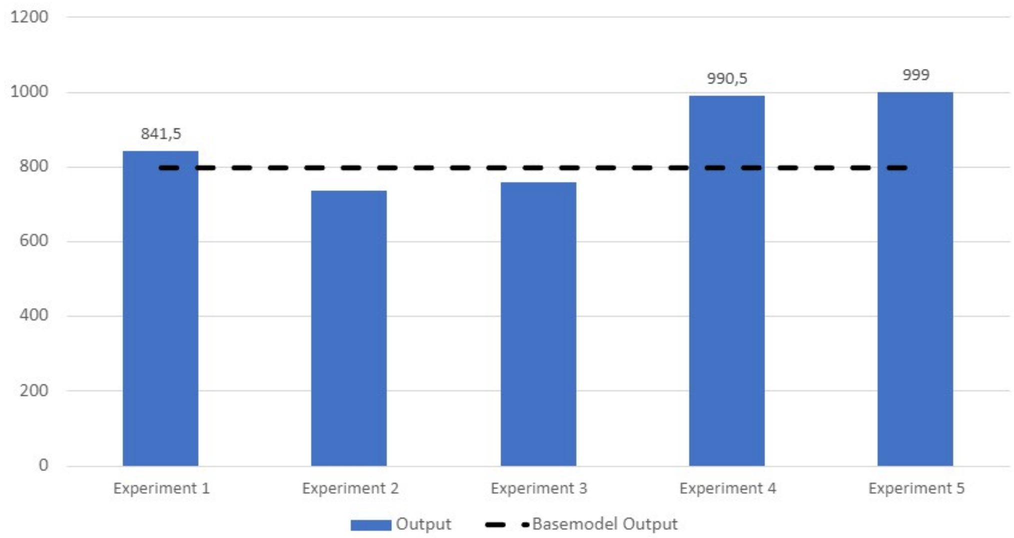

Figure 4.20: The production output of each experiment after 14 days.

After conducting simulations for a year, the selected experiments exhibit variations in the increased production output compared to the basemodel. Figure 4.21 presents the production output of finished parts over the course of a year. Experiment 1 achieves a 12% increase, experiment 4 achieves a 23.1% increase, and experiment 5 achieves the highest increase of 27.7% compared to the basemodel. The slight changes in the increased output can be caused by variations when running the production for a year. The production output for a year will be further utilized in the business calculation.

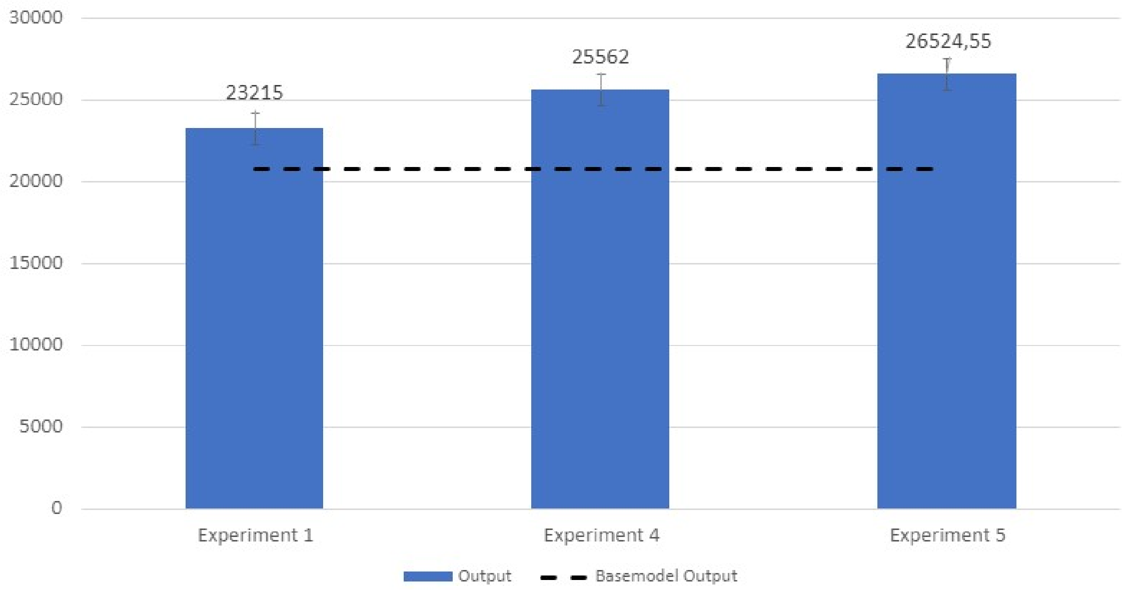

Figure 4.21: The production output of experiments 1, 4, and 5 after a year.

4.8 Impact Analysis

The next step in the result documentation is performing an impact analysis of the potential solution selected from the simulation experiments with the most promising result. The objective of this analysis is to determine which of the potential solution is the most time-effective and fulfills the needed criteria to reach optimal results in productivity and performance.

4.8.1 Operators Working-Time

The needed data to calculate the yearly working hours for the operators to perform the required manual tasks was gathered from the shift calendars in the experimental design. The number of operators needed in each experiment is also stated in the shift calendars and therefore not stated in table 4.12.

Table 4.12: Total working hours of experiments.

Potential soultion	Output (1 year):	Total operator working hours (yearly):	Increased/Reduced operator working hours (yearly):
Basemodel:	20759,5	5 358	
Experiment 1:	23215	6 768	1 410
Experiment 4:	25562	5 358	0
Experiment 5:	26524,55	3 196	-2 162

The result from the total working hours calculation presented in table 4.12 reveals that experiment 5 requires the least amount of operator working hours in tool handling processes compared to basemodel and experiment 1. Experiment 5 also requires fewer operators in tool handling, while achieving the highest output of finished parts. Concerning experiment 4, the total operator working hours remained the same compared to the basemodel but produced a higher output with fewer operators required as stated in table 4.12. These calculations highlight the contrasting impacts of the different experiments on the operator's working hours in tool handling and output in production. The reduction in operator total working hours has established that experiment 5 is the most time efficient while producing the highest output, but further factors are needed to be considered for a complete impact analysis.

4.8.2 Solution Selection Matrix

After performing the operator working time calculation, the final step in the impact analysis is placing the potential solutions in the solution selection matrix to determine decisively which solution to potentially implement. There are several criteria that are being considered in the selection matrix and their influence to determine the optimal solution is weighted from 1-10, such as the potential to meet goals in utilization and output, positive employee impact, and operator working hours presented in the previous calculation.

Table 4.13: Solution selection matrix.

Very Low (less good)		Moderate		Very High (best)
1	2	3	4	5

Potential Solution	Potential to Meet Goals	Positive employee Impact	Operator working hours (1= More 5 = Less)	Time to implement (1 = Long 5 = Quick)	Training time (1 = Long 5 = Quick)	Total Score	Implement? Yes/No
Weighted Criteria	10	9	8	6	5		
Experiment 1	3	2	2	5	5	119	NO
Experiment 4	4	4	3	3	2	128	NO
Experiment 5	5	5	5	2	2	157	YES

According to the data presented in table 4.13, experiment 5 achieved the highest score on the most weighted criteria and the lowest score on the least weighted criteria. As a result, it obtained the highest total score among all the experiments. In contrast, experiment 1 did not perform well on the weighted criteria compared to experiment 5, but it did score the highest on the least weighted criteria. On the other hand, experiment 4 fell between experiments 1 and 5 in terms of scoring, resulting in the second-highest total score.

5
Discussion

The objectives of this master thesis were to see if automated solutions would optimize tool management and find out which performance factors that would improve. Also what is needed to be adjusted in the production to implement new automated solutions? During the project, solutions have been developed to see if this is possible. The discussion part will reflect on the results that have been produced and describe how they could have been further developed and if there were other approaches that could have been used to produce a better result.

5.1 Simulation and Bottleneck Analysis

The result gathered from production runs proved that automated solutions were the optimal choice to increase productivity, availability and output in production. The blocked time during unmanned hours was significantly reduced when a combination of automated solutions was implemented, and the average percentage of blocked time was reduced to below the pursued set point. This indicates that the bottleneck was tackled and resolved the accumulated number of machines that waiting for unloading. In addition, the output in tool preparation and finished parts was significantly increased. This answers the first research question on how will the proposed automated solution would optimize tool management in the production system. Regarding answering the second research question, ergonomics were improved as visualized in the SMED analysis and what was mentioned in the preparatory studies. The adjustment needed after implementing the automated solutions was regarding line and layout principles. Also, the number of operators working when introducing automated solutions was adjusted and reduced. This will be further analyzed in the coming sub-chapters.

The process of identifying the bottleneck requires utilizing different methods while observing the blocked and starved portion of the resources. Comparing the percentage of resources affected by blocking and starvation in the production process can be helpful in determining the localization of the bottleneck and identifying the true bottleneck. The literature study suggests that the bottleneck may not necessarily be in the production department but could also be in the logistics department, which was observed in the simulation model and utilization chart (Roser, Lorenzen, and J.P.L. Deuse, 2014). The literature study also mentions various tools that can be utilized to identify bottlenecks.

However, when applying the active period method mentioned in the literature study, it couldn't be directly applied to CNC production as it doesn't follow the typical continuous flow where the activity level of each CNC machine can be observed. Each CNC machine operates independently on its own flow (Betterton and Silver, 2012). Similarly, the Inter-departure time method and shifting bottleneck approach face similar limitations. On average, each CNC machine has the same amount of active period in production and experiences the longest interruptions during unmanned hours, as observed in the utilization charts presented (Roser et al., 2001) (Betterton and Silver, 2012). In this case, the arrowhead method is utilized to identify and resolve the bottleneck. By observing the blocked time in the utilization resulting from accumulated tools waiting to be unloaded and transported to the tool preparation inlet buffer, it becomes evident that this causes starvation in the buffer. The reason for this starvation is the insufficient number of used tools being transported for preparation, which leads to an empty buffer during unmanned hours. Thus, it is determined that the bottleneck is located at the inlet buffers and is caused by the blockage in production.

The literature study extensively discusses this phenomenon, highlighting how starvation in buffers occurs due to their emptiness and lack of tools (Betterton and Silver, 2012). In a more detailed and precise explanation, the bottleneck arises from the unavailability of operators to perform the required task, which results in this bottleneck and contributes to the high blockage and starvation as observed. The bottleneck was later resolved after implementing experiment 5 with automated resources that increased the availability to perform the required task in tool handling.

Furthermore, it's worth mentioning that to reach the optimal solutions showcased in the production runs, it's required to implement a combination of automated tool preparations in robotcells and automated transportation in AGV. The automated tool preparations alone hardly reached the required output in the basemodel, even if the tool preparation was still ongoing during the unmanned hours. In the first experiment, the tool preparation process was introduced in the night shift for manual labor and the result outperformed the robotcells, as shown in figure 4.11. But some elements of consideration should be noted, such as the performance of the operator, repetitive work, and their ergonomic state. In real-world scenarios, some contributing factors result in reduced productivity and efficiency during shifts for manual labor. This limitation is one of the drawbacks associated with the utilization of simulation models, as discrete-event simulation (DES) may not encompass all the intricacies and real-world aspects present in the actual production system (Banks,2010). Even though the robot cells hardly reached the required outcome some challenges of productivity could be tackled, this will be further noted in this chapter.

Another observation from the result worth mentioning is the correlation between increased working time, waiting time and failure. After conducting experiment 4 and 5 then reviewing the simulation result, it can be observed that the working time reached its highest percentage compared to the previous experiments. This was due to the fully automated tool handling during the night-shift, which increased the active hours of the CNC machine and therefore increased the required maintenance for the alarm failure. The increased failure mostly involved the needed maintenance for the CNC machine during the night-shift. The problem appeared during the fully automated night-shift, where only on-call maintenance was available for the robotcell. As a result, there were no operators available to perform the required maintenance for the CNC machines in production. The failure that occurred during the night-shift remained unresolved until the morning shift when maintenance operators were available. Consequently, this resulted in increased waiting time, as the machine could not proceed with incoming prepared tools until the maintenance issue was resolved. For future work this could be analysed by researching suitable maintenance management during the automated night-shift.

5.2 Reflection of Preparatory Studies

During the course of the project, the literature study has given us studies and sources on how automated solutions can affect in different ways. Both how production can be improved but also how the operators' safety and work can be developed. From the data collection and specifically the qualitative results, we have obtained different aspects of how automated solutions in tool handling effect. This leads us to whether our results are consistent with the literature studies or if they differ in some way from what already exists. Based on the literature study regarding tool handling, Kief, Roschiwal and Schwarz (2021) mention that tool handling needs to be flexible in order for an operator to be able to handle the tools as smoothly as possible in order to avoid errors and have an error-free throughput. Compared to the qualitative results, automated solutions are a suitable measure to increase the accuracy of tool handling, but it is not obvious whether it increases capacity.

The research shows that new technologies can replace human operators to perform flexible tasks (Yao et al., 2020). AGVs are a solution for transporting materials and products and increase both flexibility and accuracy (Zhang et al., 2021). In order to implement AGVs, communication between the working parties on the floor is crucial to maintaining good production (Yao et al., 2020). The qualitative results suggest that AGVs can be a solution but that the current speed can be reduced and that it should be questioned whether it is the right solution. In addition, it is emphasized that good communication between robots and operators is important for automated solutions to be useful.

It is of value to have a thorough understanding of what kind of disturbances and problems the current production system has in order to be able to make an assessment of which adjustments could improve. It is especially important to understand this in productions where many machines work simultaneously and a proper production planning system is of interest for a through-flow production (Kief, Roschiwal and Schwarz, 2021). On the other hand, the qualitative results mention that it is important to understand why automated solutions should be introduced and if they solve specific problems. Implementation of automated solutions should therefore focus on the right priority so that the solution becomes valuable. In this study, the results have proven that the morning shift is the most crucial part and should in this case be seen as the prioritized area, to whether automated solutions have an impact.

The studies also point out how important it is to have the right lines and layouts for the various stations within production, all in order to have as continuous a flow as possible (Coimbra, 2013, ch.7). In order to be able to optimize the flow, this is an important step for production logistics to be made more efficient. The input speed should be in balance with the output speed, without well-functioning logistics this is not possible (Nyhuis, Wiendahl, 2009, p.127). The results point out that productions that do not have a lot of surface area, AGVs, and other automated solutions can become a problem as there is not much space, and thus an optimal layout for the production cannot be achieved. The question should therefore be asked if the production needs to be redesigned or if an alternative is even possible.

The literature study also mentions how ergonomics is an important factor in why productions are increasingly moving to automated production (Khan, 2012). Above all, safety and the unnecessary costs of work-related injuries are of value. Productivity losses due to the loss of personnel are also significant (Berlin and Adams, 2017). The qualitative results also indicate that this can be an improvement in production if automated solutions are introduced. Mostly because the current production has tasks that are not optimal to perform for a longer period of time.

Development possibilities for the work would have been to investigate whether it is somehow possible to redesign the production in order to obtain an even more optimal one. A deeper literature study and additional data collection would have improved the possibilities for developing innovative solutions for developed production. Another development opportunity for this work would have been if analyses were carried out using proven methods that could show even more clearly that the ergonomics of an operator are not optimal at all. In addition, a long-term ergonomic analysis of an operator in comparison with a robot had shown which costs could have been saved.

5.3 Preparatory Studies Reflected in Simulation

According to what is mentioned and reflected in the previous chapter regarding the required flexibility that tool management is needed to acquire to avoid inconsistencies, and how both the qualitative study and literature study agreed on automated solutions. Its further mentioned in the literature study that to reach higher output the utilization in the production is needed to increase (Nyhuis, Wiendahl, 2009, p9). The simulation result from the experiment provided the same outcome. After conducting the final experiments with an automated solution consisting of AGV for tool transportation and robotcell for tool preparation the production experience the optimal outcome regarding working utilization and output.

As both the result from the preparatory studies and simulation agreed on automated solutions as new technologies that replace manual labor to perform more flexible tasks with higher availability, would the current production disturbance be resolved in the same manner as the basemodel. As mentioned, it's an essential process to reach an understanding of the disturbance to make an assessment on automated solution (Kief, Roschiwal and Schwarz, 2021). According to the qualitative study, the production experienced the highest disturbance during the morning shift, where all the tools from the CNC machines await unloading causing a bottleneck and an intensive production both in tool preparation and unloading. A similar situation could be reflected in the simulation result in the basemodel where figure 4.8 highlighted the high percentage of blocked time during the unmanned hours and causing the same disturbance as the current production. After implementing experiment 5, which introduced AGV and robotcell during the night shift, the morning shift disturbance was resolved in the basemodel, as shown in the utilization chart in figure 4.17 and the comparison in tool preparation in figure 4.18. It's also worth mentioning that experiment 5 also enabled collaborative work between operators and AGV during the morning and evening shifts. This is an important aspect mentioned in the preparatory study that effective communication among the various parties involved on the production floor is essential to ensure smooth operation when implementing AGV (Yao et al., 2020). It's worth mentioning that this was only visualized in the simulation, some real-world factors may cause variations in the result.

Furthermore, the elements of consideration mentioned in the simulation and bottleneck analysis that is taken into account in real-world situations may differ in output compared to the simulation model. The result from Experiment 1, where the night shift in tool preparation was introduced to the manual labor and outperformed the robotcell in tool preparation. In real-world scenarios, the actual productivity and efficiency may be affected by various contributing factors, including the ergonomic state of the operators during different shifts. These factors can result in reduced productivity and efficiency levels. The result from the qualitative study states that the operators experience poor ergonomics after long hours of repetitive work which affected their performance. The literature study highlights the connection between poor ergonomics, productivity losses, and unnecessary costs associated with work injuries. As a result, an increasing number of production facilities are shifting towards automated production to address the limitations of inadequate ergonomics and mitigate the associated challenges (Khan, 2012). The SMED analysis provides a visual representation of the differences between manual and automated processes for tool removal and preparation. In the manual flow, there are multiple repetitive steps involved in the setup, whereas the automated flow eliminates these frequent repetitive steps. In addition, this reflection addresses the second research question regrading further improved performance factors when implementing automated solutions. The subsequent paragraph will provide further analysis when addressing the second research question, concerning the needed adjustment in automation.

After conducting experiments 2 and 3 the simulation result for experiment 2 showed that the number of tools was unbalanced causing higher idleness for the robotcell when preparing solid tools, as shown in figure 4.13. In line and layout design it's essential to design the production by considering the volume, tool types and the arrangement of raw materials to reach optimized flow and low-cost automation (Coimbra, 2013, ch.7). In addition, to achieve low-cost automation in AGV implementation a simulation-based approach is convenient when limiting the needed resources and scheduling of material. This was proved after conducting experiment 3 when the simulation results displayed increased output in tool preparation after moderately balancing and arranging the tool preparation between the cells. The operator's shift time is also needed to be adjusted when introducing AGVs and robotcell. Figuring out the optimal amount operators was through running the production several times with varied amounts of operators and shift hours. This is also essential in line and layout principles to allocate the necessary resources and eliminate the unnecessary (Coimbra, 2013, ch.7). Furthermore, redesigning the whole production layout after implementing the automated solution required more information to be performed in this study, but considering some principles in line and layout design to reach optimal results is essential.

5.4 Reflection of Impact Analysis

The result gathered from the impact analysis section further proves the implementation of experiment 5. The following solutions yielded reduced results in total working hours with tool handling. The reasoning behind this reduction can be observed in shift table 4.11 for this experiment, where the number of operators and working hours are reduced when implementing automated transportation and preparation. As mentioned, the implementation of automated solutions minimizes poor ergonomics, which also made experiment 5 score the highest in positive employee impact compared to experiment 1.

The disadvantage of experiment 5 is the integration and installation process of automated solutions, which is also reflected in the time to implement and training time when performing the solution process. Even maintenance and other costs to keep the automation in operation should be seen as a disadvantage in the aspects that they become an additional cost. The impact analysis is a very simple calculation of the operator's working hours with tool handling. It is important to point out that it can be developed into a broader analysis where costs and other aspects are included in order to expand the benefits of the various experiments.

5.5 Recommendations and Future Work

In summary, it is profitable to implement a combination of automated solutions in the long term. Mainly because they can perform monotonous tasks without interruption for a longer period, which was used to solve the bottleneck caused by the operator's unavailability. This thesis introduces aspects that were not explored in previous similar projects, which is the comparison of the behavior between the alternative combination of the existing developed automated concept and manual labor in GROB production. It also examines how these developed concepts optimize resource utilization and enhance the output of tools and finished parts.

It is important to point out that automated solutions require constant maintenance in order for them to remain in operation for a longer period of time. This should therefore be seen as a development potential of the work. To find out which maintenance methods are required to keep an automated production in operation and how much it pays off in terms of capacity and costs. Further potential for future research is gathering enough data to optimize production layout when implementing automated solutions.

6 Conclusion

In conclusion, this thesis commenced with a preparatory study encompassing a literature review, a qualitative study, and a quantitative study. The literature study findings emphasized the importance of flexibility in tool management when dealing with diverse product production. It also highlighted the necessity for implementing automated systems in tool management to attain the desired flexibility and minimize disruptions. These conclusions were reflected through interviews, where it was found that automated solutions had the potential to address current disruptions during the morning shift and improve ergonomics in production. Moreover, the SMED analysis showcased how automated solutions could be integrated into tool transportation and preparation processes. These conceptual solutions were then tested and evaluated using a simulation model. This allowed for a comparison between automated solutions and manual labor, ultimately addressing the research question posed in section 1.3.

Based on the findings of **RQ1**, it can be concluded that the implementation of automated solutions leads to higher productivity, availability, capacity, and increased output. The results demonstrated that the combination of automated solutions, such as AGV (Automated Guided Vehicle) and robotcell, offers significant performance improvements. Furthermore, enables investments in enhanced tool management and production performance. To achieve these favorable outcomes, the introduction of a fully automated night shift is necessary. This would address the existing bottleneck and enhance resource availability, thereby positively impacting productivity.

To answer the **RQ2**, it is evident that ergonomics can be enhanced by utilizing combinations of automated solutions to replace manual labor, as viewed in the SMED analysis and preparatory study. By conducting additional analyses and tests with automated solutions, the case for improved ergonomics can be further substantiated, and over time more reasons can be identified and proven. Regarding the adjustments required when implementing automated solutions, one aspect to consider is the working hours and amount of operators. Additionally, it is important to take into account certain line and layout principles regarding the allocation and arrangement of necessary resources and materials. This further facilitates the integration of cost-effective automation into the production lines.

This is a relatively broad area with many different approaches. Therefore, the thesis is viewed as a preliminary study of how a combination of developed automated solutions can improve production in tool handling.

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A

Appendix 1

1. What does the tool change process look like?

2. Which approach do you consider to be the best for signalling of tool changes?

3. How is it ensured that the right number and types of tools are available at the preparation station?

4. What happens to all tools after they are used?

5. What type of control does the transport of tools have?

6. What does the process look like during ghost time?

7. What do you think GKN mainly wants to achieve by improving tool handling?

8. Regarding the information flow, what does the ordering system look like when you signalling for tool changes? What information is exchanged? Which actors are involved?

9. What are the most frequent disturbances and losses experienced when changing tools?

10. If you introduce an AGV system that transports tools, what will the location of the tools look like?

11. Would a robot cell and AGV solution optimize production performance in the morning shift and in what way do you see it as most possible?

12. How important do you think FMS is in tool handling and transport?

13. What long-term goals can be set if automated solutions are introduced?

14. What problems have you had with production logistics?

15. How do you think a simulation model with alternative solutions will improve the problem around tool changes and logistics?

16. What is one thing we should think about when it comes to simulating AGV and other automated solutions?

17. What is the most important thing to consider when introducing an AGV system? Which goals should be prioritized?

18. Do you think there are other alternatives that can replace operators for the transport of tools other than AGVs?

19. What do you think about an AGV combined with a robot cell?

Figure A.1: Interview questions.

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