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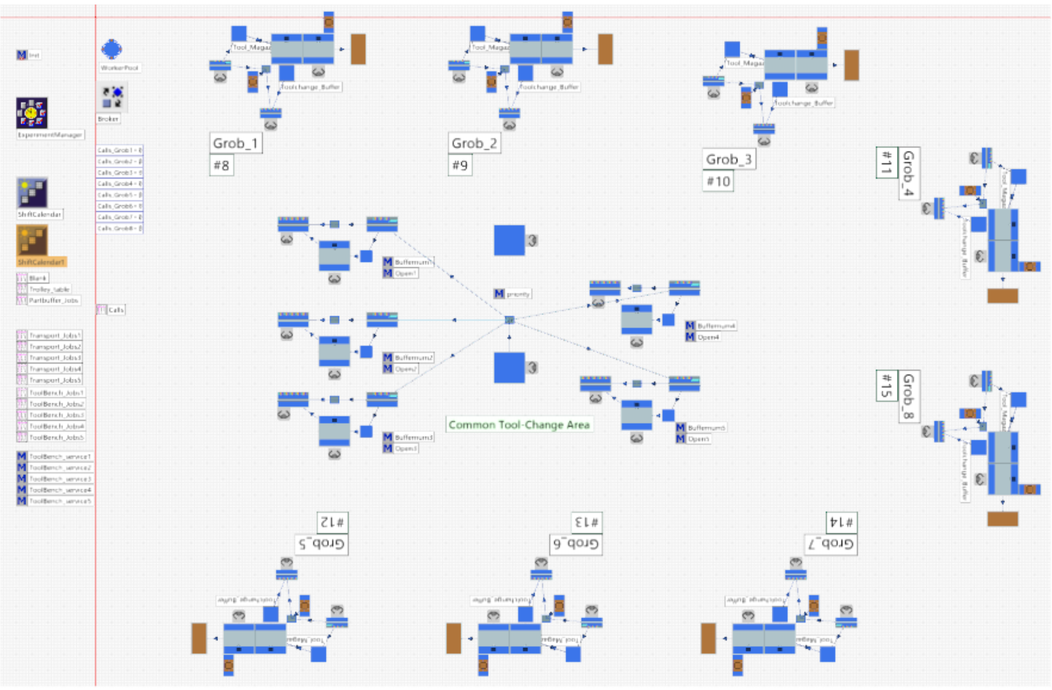

Simulation and optimisation of an automated handling and transport system for tool management

Master's thesis in Production Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

The aircraft industry plays a crucial role across various sectors, leading to a significant demand for the manufacturing of essential components. Metal cutting, a prevalent operation for producing these components, is notably time-consuming and involves tough materials due to strict requirements, expectations, and standards. This necessitates a variety of tools and frequent tool changes, both costly and time-consuming, making machine availability critical. Various studies and concepts, such as industrial robots and automated transport solutions, have been explored for automated tool handling. This study investigates these automated solutions to assess their impact on production performance and optimize tool management. Utilizing Discrete Event Simulation (DES) and creating a flexible simulation model, this thesis provides a foundational and flexible model for further research and investigations. By observing and experimenting with these automated solutions, the study identified opportunities to replace the non-value-adding activities and reduce downtime due to missing tools. The findings offer insights into the necessary steps to realize a fully automated solution and suggest areas for further research to advance towards becoming a "Smart Factory." This research aims to position GKN as a pioneer in automation and efficiency within the aircraft industry, highlighting the potential benefits of fully automated tool handling solutions in reducing costs and improving production performance. The study concludes with recommendations for future research and steps needed to implement these advancements.

Keywords: DES, AGV, Smart Factory, Automation, Tool Management, Collaborative Robot.

Acknowledgements

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Finally, we are profoundly thankful to our families and friends for their unwavering support, patience, and understanding. Their encouragement and belief in our abilities have been a source of strength and motivation throughout this journey.
Thank you all for making this thesis possible.

Roshan Krishna Muthyala, Anton Andric, Gothenburg, 2024

List of Acronyms

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

DES	Discrete-event simulation
AGV	Automated Guided Vehicle
CNC	Computerized Numerical Control
FIFO	First In First Out
FMS	Flexible manufacturing systems

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1

Introduction

In this chapter a brief description regarding the background of the master thesis will be provided. It consists of the grounds for the research, its objectives and limitations. The research questions that drove the project onwards will also be provided in order to give a clear overview on what was investigated.

1.1 Background

The aerospace industry has been one of humanities most forefront and amongst the pinnacle of human technologies ever created. It could be considered the great and fast bridge between all the corners of the world, playing a pivotal role in supply chain, trade, jobs, healthcare and almost any imaginable sector there is. But having such a crucial role also comes with its issues, especially regarding sustainability [6].

Metal cutting operations are one of the most common and time-consuming operations within manufacturing, this also applies for the manufacturing of jet engine components. There are many standards and requirements that need to be upheld and met within the aircraft industry, thus high requirements are put on the material and components to meet these expectations. Due to the tough materials, complexity of the different geometries, and features a high variety of cutting tools are utilized, and frequent tool change is necessary in response to the extremely high tool wear. Hence, tool utilization directly affects process efficiency, corresponding to production costs of these components [25].

Safety also plays a crucial role within the aircraft industry, which puts enormous demand on the material, needing to be durable, hard, yet light. These materials are available for us but put quite a hard demand on the manufacturers that produces these components. Since these components are not that easy to machine, there is quite a lead time until a finished product, but there are not really any rooms for disruption within the supply chain. Thus, these manufacturers need to either figure out ways and different solutions on how to lower their processing time of production or ensure there won't be any internal disruption within the flow that would hinder them to meet the quota [26].

Before delving into the details of the project, it is important to note that our work is based on the current situation and is conducted at GKN Aerospace Engine Systems in Trollhättan.

1.1.1 Production system at the company

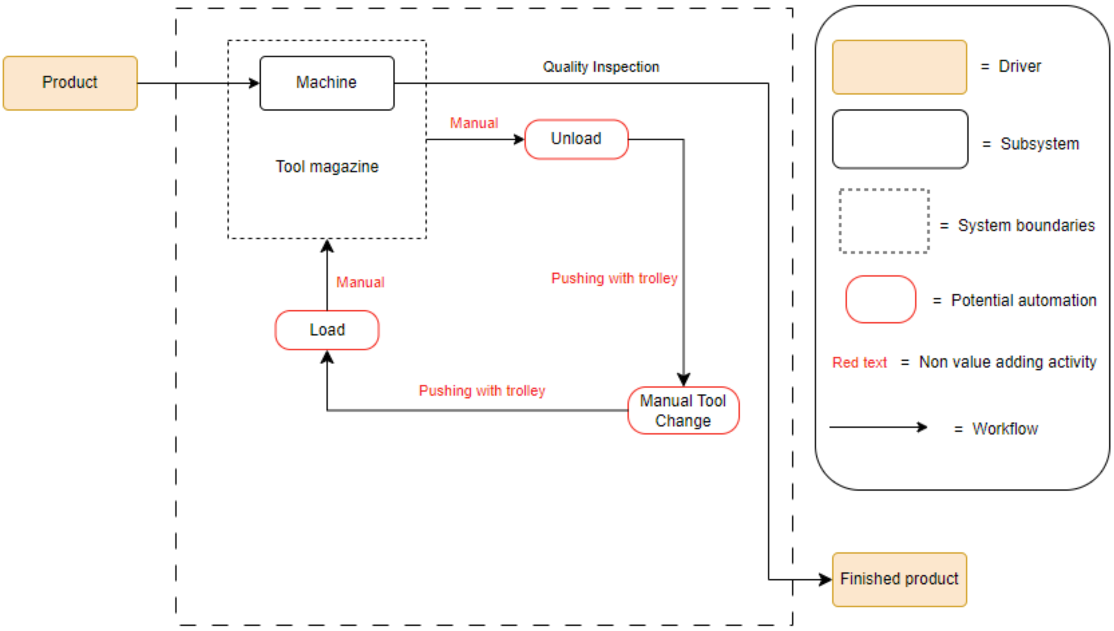

Figure 1.1: Flow of Products and Tools during production

The production scenario at the company consists of three floors dedicated to the manufacturing of various components that are subsequently assembled into aircraft turbine casing. The initial stages involve raw blank plates undergoing various operations such as milling and cutting to create a ready to assemble components. The workflow of the product is quite straightforward, an operator places the blank into the rotating table of the CNC Grob machine. The blank is shaped by using an array of tools that are pre-loaded in the tools magazine of the CNC machine. The process of acquiring the required tool onto the machine spindle and sequence of operations are completely automated. Notably, as previously expressed, the focus of the thesis is the process outside the Grob machine, more specifically the tool-handling process which involves the movement of the tool in and out of the machine.

Focusing on the tool handling process, the figure above illustrates several critical steps involved. Initially, once a tool is utilized and deemed necessary for replacement, then the tool along with its holder is unloaded from the tool magazine manually by the operator and placed on to a trolley. Subsequently, the operator transports the trolley to a common tool change bench. At the change bench the used tool is removed, and a new tool is securely fixed into the tool holder. Now this tool is again manually transported back from the tool bench to machine and loaded again back into the magazine manually.

This sequence of events highlights the distinction between value adding and non-value adding activities relating to the tool change process.

Specifically, the activity of replacing a used tool with a new one directly contributes to the efficiency of the machine and thus is value adding activity and necessary. Conversely, the unloading and loading of the tools and the transportation of tools can be considered as non-value adding and unnecessary activity. These steps do not enhance the product's value and thus reveal a potential to automate or optimize to increase the overall process efficiency.

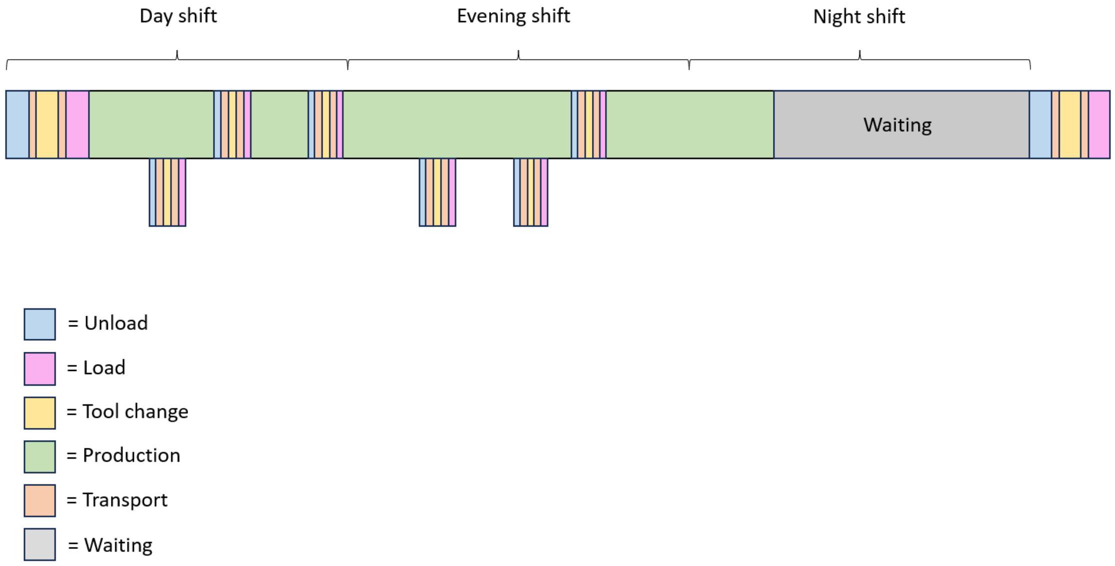

Figure 1.2: Example of how machine utilization is today

As explain earlier, the process follow a straight forward operation of processing the product, and the sequence of replacing tools also follows a straight path of operation illustrated in the figure below:

$$Unload \rightarrow Transport \rightarrow Tool - change \rightarrow Transport \rightarrow Load$$

Its important to know that two type of changes can occur, replacement of tools that have have not stopped the machine. These can be seen in figure 2.2 as the bars that are on the outside. This indicates that a sequence of replacing tools have been done, but have not affected production. The second type are replacement of tools that have affected production, ultimately stopped production and the machine is waiting until the correct and replaced tool is back. These are represented by the bars that are within the bar that illustrates the machine utilization.

Another important factor is how the length of the bars can be affected. The bar for transport stays consistent, in the production the transport is done by a trolley, that has the capacity to push all the require tools of a tempo simultaneously when they are due for change. The operations that can shift in length are unload, tool-change, and load. The reason being, each of these operation only handles one tool at the time, hence the length of each bar can be calculated how long it should take to perform that action when a change is happening. The two formulas are the following:

Total time for one Load or Unload bar = Amount of tools × Time to Unload/Load 1 tool

Total time for one Tool change bar = Amount of tools × Time to change 1 tool

These two play a major role in loss of production after several tools have to be changed at the same time, especially during the "Ghost shift", leaving the operator to perform many and repetive tasks at the start of the day in order to start up production again.

1.2 Utilizing DES

Discrete event simulation is a tool used for analysis of different systems, and how the different variables play a role affecting each other. This gives the user, benefits in order to understand the system, and what affect changes could have. Bearing in mind that there still are dangers with DES, thus can not be trusted at face value.

1.3 Aim

The project aims to study the possibility of improving the tool handling and its transportation system through simulations. With the Discrete Event Simulation (DES) models several experiments should be investigated, thus validating capacity requirements to support Just-In-Time assistance of tools. This will allow the findings of as follows:

- Identify gaps and opportunities for future implementation and technical development of the concepts.
- Relevant Key Performance Indicators (KPI).
- Evaluating the balance of costs and delivery performance.

1.4 Limitations

For this project to deliver promising results, certain limitations had to be made due to the given time-frame. The limitations that were decided upon became as follows:

- The thesis will not be changing the layout or machines.
- Standardizing the way operators handle their way of changing tools.
- GKN’s concept of how the “Smart cell” operates will not be changed.
- Products will not be adjusted.

1.5 Research questions

This section was divided into two segments. The purpose for this was to give the thesis a theoretical and broad segment that would not only research the aspects specific for GKN Aerospace. Although GKN's specific questions are still a part of the thesis, thus will also be answered in order to provide promising results that may be of interest for the organization.

1.5.1 General questions:

- RQ1: What different approaches for tool management are applicable and the impact on the performance?
- RQ2: What is the most efficient tool transport system for a low volume production workshop?

1.5.2 GKN specific questions:

- RQ1: What is needed so the down-time due to missing tools is 0%?
- RQ2: How much equipment is required for a 100% automated tool handling scenario?

2

Theory

In the following sections, relevant theory and figures is showcased in order to show relevant and future concepts that can be used for tool management in the current process. Also explaining the necessary steps towards becoming a smart factory and how DES could be a good beginning to showcase these concepts.

2.1 The big losses in manufacturing

Losses come in many different forms in manufacturing and can depend of several different factors. Most often they come in three different main categories, with each main category having two sub-categories [3]. The three main categories are as follows:

- Availability loss
- Performance loss
- Quality loss

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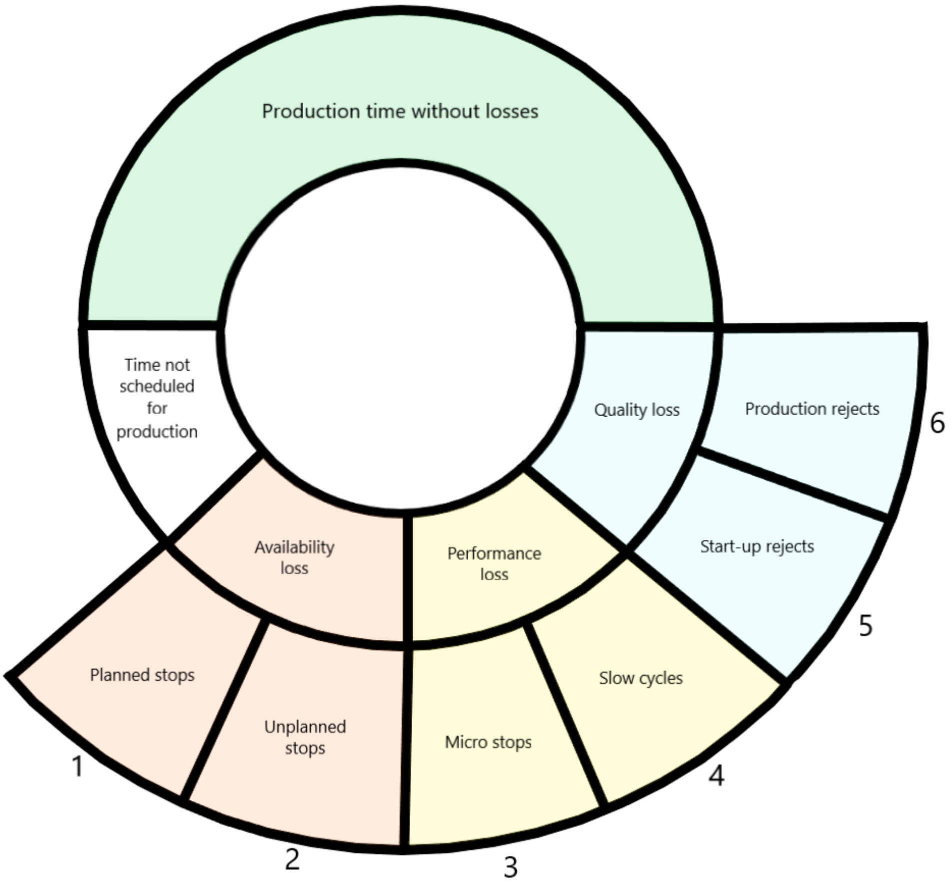

Figure 2.1: Segments within production

These can also be described as sporadic and chronic losses. The common point between these losses is that they consume ones resources without adding any additional value. Some of these losses might go unnoticed but are slowly eating away the resources at the company [9].

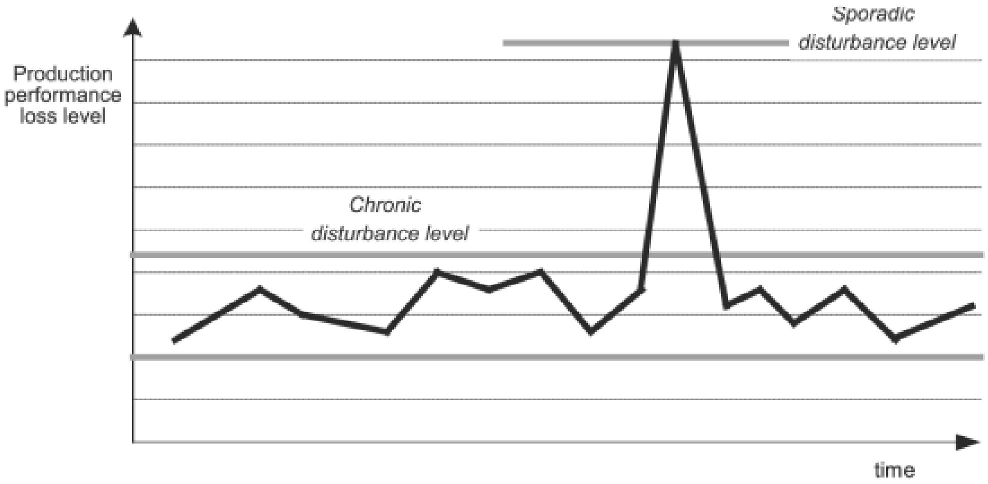

Figure 2.2: Sporadic and Chronic losses

2.1.1 Availability loss

Availability loss can be described as production loss, essentially ones machine should run, but it is not. This can be divided into two different categories, planned stops and unplanned stops [3].

Planned stops depends on different factors, issues revolving quality, systematic losses, planning and optimization, start-up, shutdown, and changeover. Even though these are planned stops, they can still consume production time [3].

Unplanned stops, one which most manufacturers are familiar with and is also one that they look into the most, is what the name suggests, production is planned but is not running. These stops can be due to many different factors, problems in other areas, lack of personnel, machine failure, and etc [3].

2.1.2 Performance loss

These type of losses usually depends on minor stoppages, for instance when something is malfunctioning or is standing idle. But can also depend on different equipment design speed and operating speed [9].

2.1.3 Quality loss

This loss concerns quality related issues, such as start up rejects or production rejects. Start up rejects most often concerns production related issues when start of production is happening. With no one being present and not knowing what has happened since last time can consume production time to ensure that these uncertainties do not happen. Production rejects is what the name suggests, poor products that do not meet the standard. These can occur due to operators or failure equipment [10].

2.2 Industry 4.0

Industry 4.0 and even 5.0 is the new way of thinking when it comes to manufacturing. Allowing companies and organizations to adapt and utilize the digital era that the world have entered. This new concept would allow companies to take real-time decisions, incorporate flexibility and agility with new manufacturing concepts, thus enhancing their productivity and delivery [4].

These so called "Smart factories" that are incorporating industry 4.0 are utilizing the tools and technologies that are currently available. These technologies stretches from smart robots, advanced sensors, and newer software. All of these new concepts collects data and analyzes data, which drives the opportunity for better decision making. These technologies is also what drives companies and organizations to further automate their processes, being able to adapt and predict when maintenance will be needed, and reach greater heights of efficiencies that they have not seen before [5].

A smart factory can be divided by four different levels. These are Connected data, Predictive analysis, Prescriptive analytics, and AI-driven automation [5].

2.2.1 Level 1: Connected data

The first step that a factory need to take, in order to strive towards becoming a smart factory is to connect their data into a single source. This single source gathers and keeps track of all the data that revolves production or the metric that is of interest. By having all the data in one place, both operators, managers, engineers or any party of interest will have access to this data, thus allowing for quick and easy information gathering when a problem arise [5].

Gathering data can be challenging but comes with many benefits. These benefits could be classified into three different groups, these being technological, financial, and competitive [12]. The different categories can be seen in the figure below.

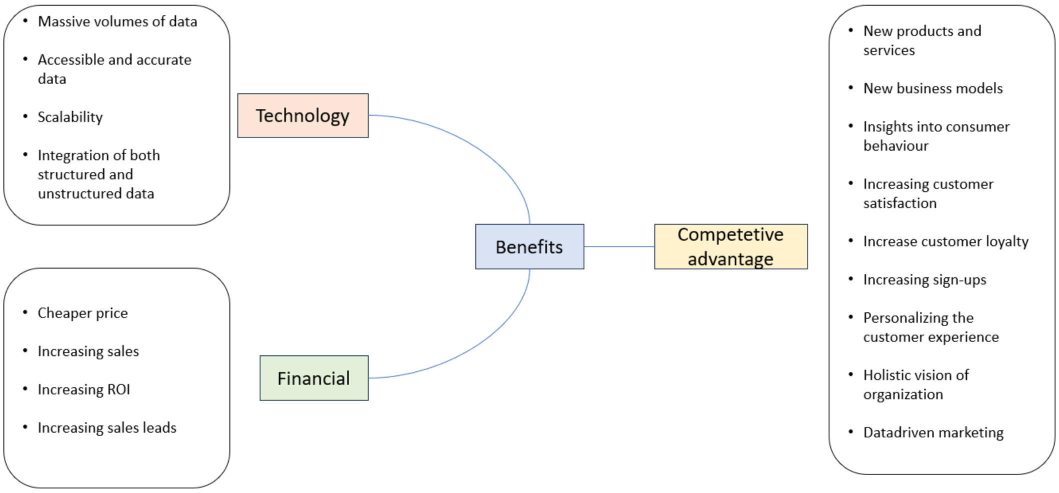

Figure 2.3: Benefits of gathering data

Implementing and gathering data in real-time production and equipment would allow for continuous monitoring of the system. Keeping track on inventory, material and through this information being able to schedule ones order more accurate. This data allow management to get an overview on how the system is performing and thus enables them to make sound judgement and avoid uncertain decisions [13].

2.2.2 Level 2: Predictive analysis

The second level of a smart factory is to shift their way of thinking. Going from reactive to predictive. The usual genre when a issue arise is to react when it happens and tackling the problem when it happens. Instead with a predictive mindset with with the help with the available data from level 1, predictive actions can be taken before is becomes an issue, thus enabling a higher efficiency and productivity due to less down time [5].

This stage would allow the user or organization to find hidden patterns that occasionally goes unnoticed. The process of getting to this level is firstly reaching level 1. From here time and effort to clean and pre-process the data needs to be done. Once this is done, decisions on model training, decision and validation needs to be decided and then applying it to the model. Thus allowing it to make new predictions [14].

2.2.3 Level 3: Prescriptive Analytics

The third level of a smart factory revolves optimizing the production even further. By having more advanced technologies and cleaner data. Greater settings and parameters can be used in order to ensure the best possible runs for production, based on previous records and history [5].

2.2.4 Level 4: AI-driven automation

The fourth and final level for a smart factory, the factory utilizes AI for the decision making for production and decision making. Most factories have yet to achieved this level and is still moving towards it. Reason being that a huge pool of data is needed for the AI in order to make justifiable decisions [5].

2.2.5 Collaborative robots

Collaborative robots, or “Co-bots” represent a significant advancement in robotics, these are designed for the interaction between human workers in shared work spaces. Unlike the traditional industrial robots where the robots are operated in isolation from humans and require physical safety barriers around the robot due to safety reasons whereas co-bots are engineered in such a way that the human operators can work alongside which thereby enhance the capabilities for both the parties. Essentially this is achieved by identifying the presence of humans by the use of various types of sensors which enable features such as obstacle detection and collision avoidance. For example, one of the most common type of sensors for this purpose would be the proximity sensors, which sense the presence of objects without physical contact, often these sensors perform their function by utilising infrared or ultrasonic waves. [27] .

In the context of material handling, co-bots offer substantial benefits. They can assist in handling large and unwieldy objects, reducing the physical strain which curbs the ergonomic strain on the human operators avoiding the risk of injury [2]. Co-bots can also replace human operators in carrying out repetitive tasks that are carried out in bad ergonomic postures by humans. Co-bots play a major role in assembly line and warehouse operations where they can guide payloads in defined pathways with precision by avoiding obstacles and ensure accurate placement, this is often can be done with the help of external sensors as well as mechanical guidance of the humans which can act as an ideal solution for tasks that require both precision and flexibility [1] [27] .

Technological advancements have further enhanced the usability of co-bots in material handling. Modern co-bots are equipped with sensors and machine learning algorithms that allow them to detect and react in real time, through a constant learning process [2], this would further enhance the co-bots to navigate safely and accurately but also interact with the human counterparts in a natural manner. Additionally, the development of intuitive programming interfaces have made it easier for the non-experts to configure and control the co-bots, broadening their accessibility and application in various industries [2].

With the cognitive ability of humans and mechanical capabilities such as precision and strength of robots, co-bots improve both the operational efficiency and promote a safer ergonomic work environment, this in turn reflects a huge leap forward in industrial automation. Their application in material handling demonstrates their potential to revolutionize industrial processes, making them indispensable tools in modern manufacturing and logistics [2].

2.2.6 Automated Guided Vehicles

The integration of Automated Guided Vehicles into manufacturing process is driven by the requirement to improve the operational efficiency and adaptability. As the production environments become complex, the demand for flexible solution that enhance the efficiency increases and material handling is one such aspect of manufacturing which would benefit from implementation of these flexible solutions. AGVs are designed to operate autonomously, navigating through production floors using various guidance systems, thereby reducing the dependency on human labor and minimizing the human errors in manual handling[23, 24].

One significant advantage that AGVs posses is the capability to handle diverse material types which is possible by programming wide range of tasks. This flexibility is required in high paced production environments with varying production demands, such as those seen in flexible manufacturing systems[24]. Moreover, this deployment of AGVs not only poses flexibility but in turn aims to increase the productivity and profitability of the organisation.
While incorporating flexible solutions into manufacturing environments offers numerous benefits, there are stills several considerations to keep in mind before implementation, one such aspect would be the complexity involved in integration of such technologies in an already existing manufacturing setup. Moreover, AGVs could sometimes struggle in environments that are not well-structured or have high human traffic [24].

2.3 DES

A discrete event system most often refers to when one or multiple phenomena that is out of interest change value or state at separate points in time, instead of continuously with time. Imagine a bus and the usual route that it takes during its operational hours. There will be three guaranteed variables in the example [7].

- The different locations of the bus stop.
- How many different individuals that are waiting at these stops.
- How many passengers the bus will have.

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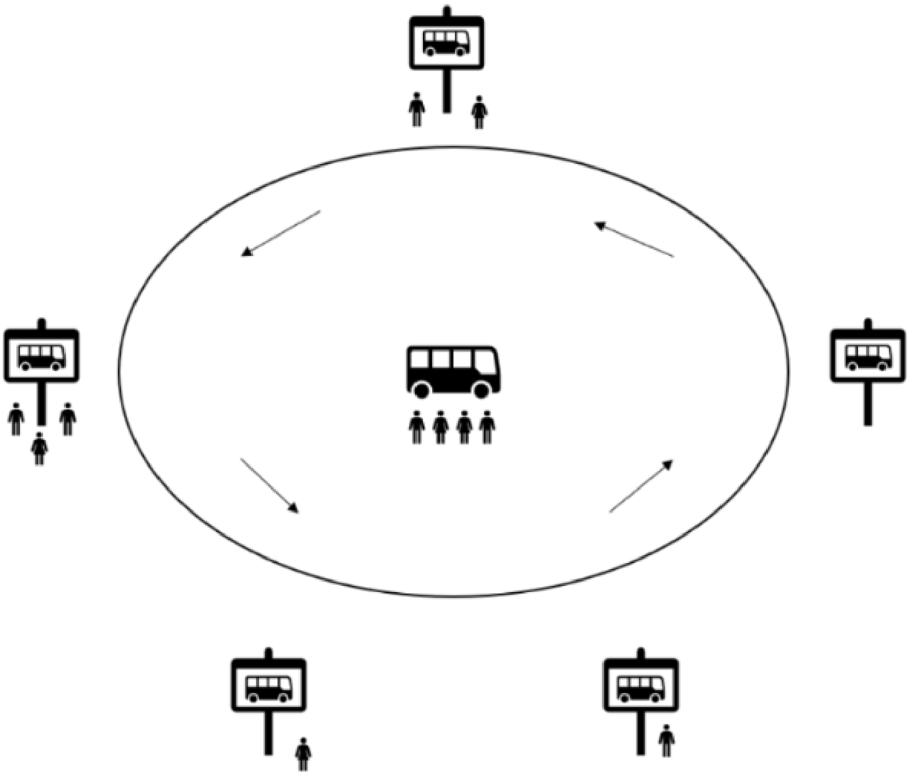

Figure 2.4: Bus example regarding DES

The first point will be considered as a continuous, as it will never change and will always occur no matter what, whereas the other two are discrete, they can change depending on when the bus arrives or if someone else arrives to wait for the bus. With only these three factors, a lot can happen, the arrival time of the bus can be affected, how many can take the bus depending on its max capacity, how long one must wait for the bus if there was not enough room, etc. This example can also be used for the manufacturing industries and their plants [7].

Concerning a discrete-event system, it embodies a minimum of seven different concepts:

- Buffers
- Sequencing
- Work
- Resources
- Scheduling
- Performance
- Routing

.

You can compare these seven concepts to the previous provided example:

Buffers: A type of storage/containers that contain work that awaits service. The capacity of the buffers can vary, some have infinite whilst others have a finite amount, in the example the bus stops had an infinite amount.

Sequencing: Stands for what order in which the resources provide the service for the waiting work. For example, FIFO (First In First Out) or priority lane.

Work: Concerns the goods, product, job, or customer, etc. It is something or someone that goes into the system, searching for service/a service.

Resources: Resources refers to equipment, manpower, etc. It helps/provides the service.

Scheduling: Regards the availability of the resources and their pattern.

Routing: Which order the services are supposed to be provided in. In this example, the route which the bus takes [7].

2.3.1 Why Discrete event simulation

DES is a tool of analysis, to put it into context, it is needed to describe its relation to the concept of modeling in general. To start with, when it comes to studying a system, is to use the accumulated and collected knowledge and experience to build a model. A model could be described as a representation based on theory or empirical observation, usually both. The model itself can have many different purposes, depending on the user and what it was built for, but the common ones are [7]:

- 1: The user could utilize the model to organize their theoretical beliefs and empirical observations about the system in question, thus deduce logical implications.
- 2: The user can learn and understand more about said system.
- 3: Showcases and illustrates the necessity of detail and relevance.

- 4: Rapid increase in the speed at which analysis can be done and accomplished.
- 5: Laying the foundation for experimenting and see the desire for modifications of the system.
- 6: Manipulation of the system becomes easier.
- 7: Allows control of multiple sources of variation compared to directly studying the system.
- 8: Most often less expensive the observing the system directly.

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2.3.2 Dangers with modeling

As stated, there are plenty of benefits when modeling, but there are also dangers. There is never a guarantee that says that the time spent on creating the model will return the results that the person in question was hoping for, or any useful results at all. Sometimes these failures could be out of one's hand due to not enough resources or that the quality and amount of data was not correct [7].

An additional shortcoming and danger with DES models are its ability to predict more outcomes than it was intended to do and using it for that purpose. Since all the numbers are approximations, its impossible to say with a 100% certainty this is how it is going to turn out, especially if the model consists of limitations or assumptions in certain areas [7].

Some other points of considerations when it comes to DES are:

- DES is only applicable if the model can replicate the real system to an extent that is sufficient [8].

- Some level of experience and knowledge is required in order to create a simulation model. Some models might also take more time than an organization might assume in order for it to suffice to the level that is desired [8].

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2.4 Banks model

The Banks Model in Discrete event simulation is a structured framework that helps in developing and analysing simulation models in scientific and systematic manner. This involve three phases namely preparation, model building and analysis, which further is divided into finer steps such as problem formulation, data collection, coding, verification, validation, experimental design and documentation. This comprehensive approach will ensure a reliable and effective simulation study which would ensure clear outcomes through the simulation studies [18]. For more detailed information about each of these steps please refer [18]. A picture and explanation of the revised banks model is in section 3.1.2, here a detailed explation is provided about the implementation and adaptation of the banks model to this thesis.

2.5 FIFO

First In First Out is the simplest method within queuing and what order services should happen. The product or component are ready to be processed depending on their arrival time in the queue. The one that arrived first is essentially the first one that will move out, the rest will be at the rear of the queue. It is a simple rule that is easy to implement. Though its main disadvantage is that it can create something called the convoy effect, the average waiting time could also be quite extensive [15].

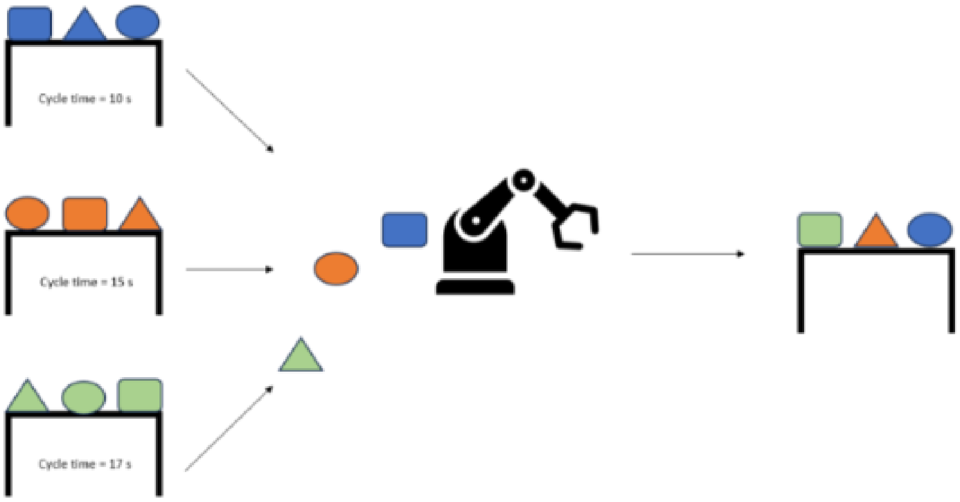

Figure 2.5: How First in First out operates

2.5.1 Convoy effect

The convoy effect is e phenomena that happens due to FIFO, since there is only a simple rule that determines the flow, that rule and flow becomes absolute, even though its not the most optimal. It slows down the process if a longer service is happening even if a lot shorter ones could have been performed instead, but due to the rule and that the first one that arrived at the scene was the longer process it must be run first. See picture below for clearer understanding [11].

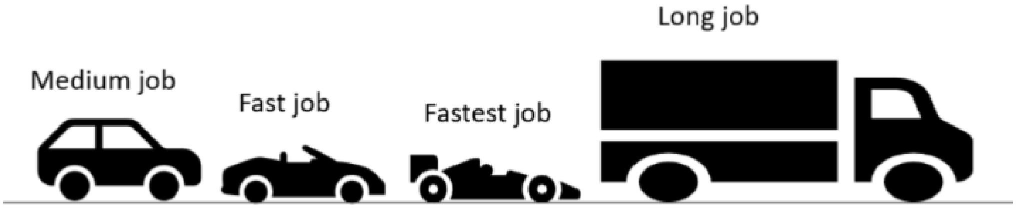

Figure 2.6: Illustration of the convoy effect

The faster jobs can not get passed the long job, due to the rule that has been set in place for it, thus leading for an increase in average waiting time.

3

Methods

This chapter focuses and is centered around the methods that were used during this research. It includes research design, literature study, quantitative and qualitative analysis, current state analysis, as well as the procedure on how the decisions around the experiments were decided upon. It also dives into decisions on how the simulation model should be built and function.

3.1 Research Design

The structure of this thesis was based around two approaches that were merged together. These two methods were "Early phases of production system design" designed by Röisö and Bruch, the second method was based around Banks model. These methods seemed like a suitable approach for this project due to their structure. The basis for choosing the method proposed by Rösiö and Bruch is due to the shared similarities. Taking an approach were investigation of the tool handling and its management could be compared to a common production system, as well as the desired outcome is a reconfiguration of the current system and analyze potential improvements [16].

3.1.1 Early phases of production system design

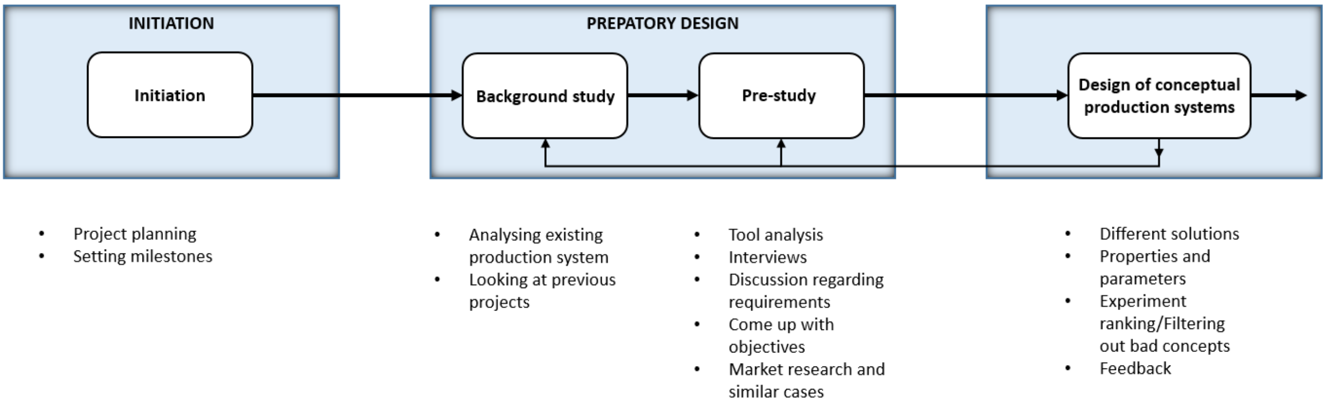

Figure 3.1: The four steps in production system design [16].

3.1.1.1 Initiation

The first step for the project was to create a planning report. The reason for this is to get a grasp of what areas and segments this project will touch upon. It is also important to set up milestones and objectives within certain dates and creating deadlines. Thus the project and all stakeholders can get a general idea on the project's process, if deadlines are not being met and some areas in the planning need adjustments to another date. All this allowed the project to keep progressing at a steady pace, as well as stay flexible to changes that occurred.

3.1.1.2 Background study

The following step in the four phases of production design consisted of a background study. This mainly consisted analysing the current production system and how it operates, as well as reading previous reports and projects that this thesis has been a part of. In order to get a clearer picture, VSM and a functional diagram was used to get a clearer picture of the production, what value adding activities are being performed but also which area holds a significant value were changes are plausible.

3.1.1.3 Pre-study

As for the next step, preliminary studies of the production system needed to be made. Thus, evaluating areas of the production how it operates, explicit information regarding the tools and specific information between the different types. Researching for similar cases and issues, how they were handled.

3.1.1.4 Design of conceptual production systems

The final step for this methodology is the design of different solutions that could be applicable and tested. It is also important to set what the different parameters and properties of these systems are, in order to analyze and reflect what effect it can have on the results. Since this project is also based around GKN's desires, feedback and reflection will also need to be considered from there point of view. Thus a ranking of experiments will also be conducted, in order to utilize the time and resources of this project as efficient as possible. In order to avoid unnecessary solutions, unrealistic or obvious improvements outside of the scope.

3.1.2 Banks model

Refer regular information regarding this model in theory
Before starting the simulation, there were steps that had to be taken before starting to build the model, to ensure that the intended model would work as the customer wanted it to work. It also gave a clearer understanding of what will be needed, what kind of limitations will be in place, as well as what type of experiments could be expected and if the results could provide any significant value.

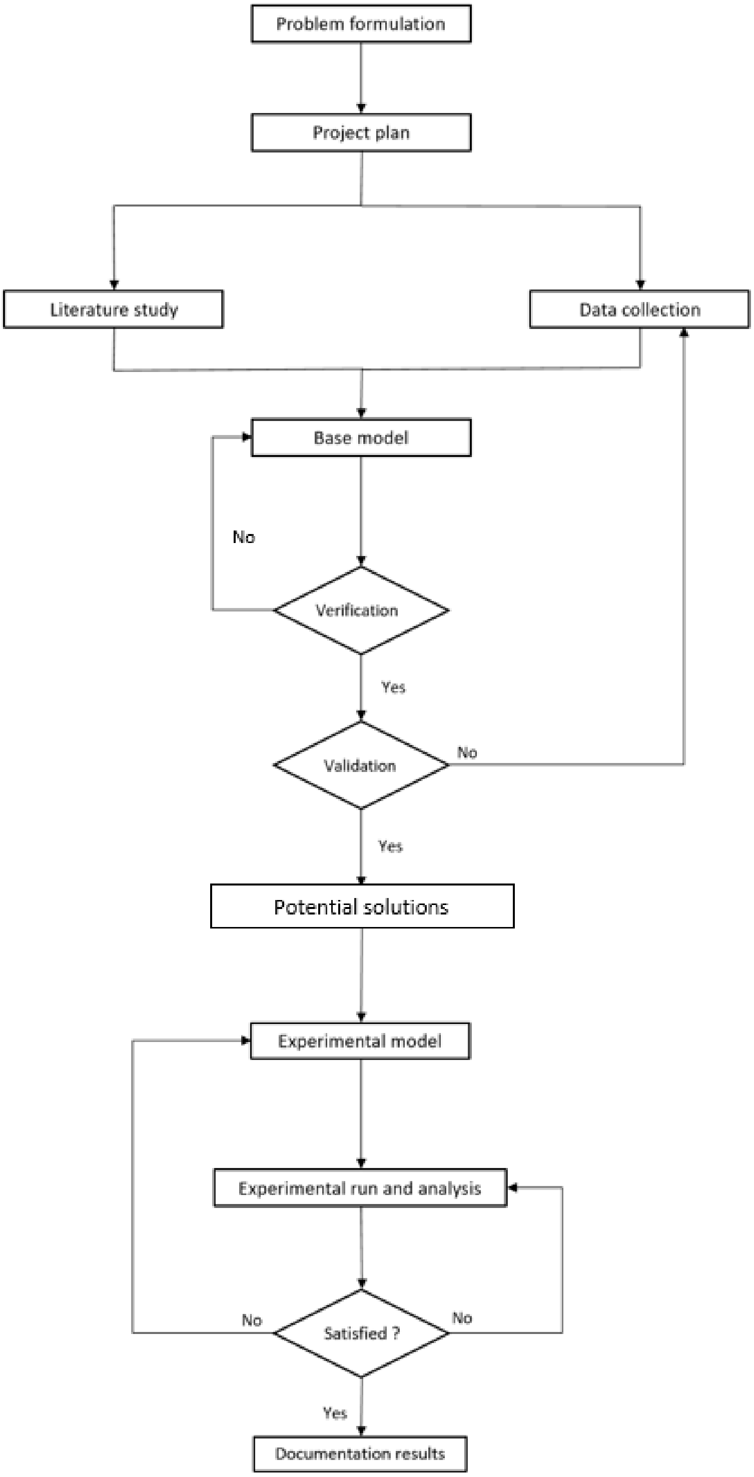

Figure 3.2: Revised Banks Model

3.1.2.1 Problem formulation

For this project's case, the scope was already somewhat given, and the problem could easily be formulated through the heading of the project, "Automation and optimization of the tool handling system". Although the term itself is very vague and could suggest different types of optimizations and automation. So, to keep it in line and within the scope of the time-frame, it was narrowed down further, seeing what areas could be improved, what limitations would the base model have from the actual production system, and what are the specific questions that GKN would like to be answered.

3.1.2.2 Project plan

The project plan was vital to keep track of the project but also ensure there is enough time to work on certain steps. Some areas took longer than anticipated, which disrupted the flow of the project. Although a well-prepared project plan had been established it would allow for decisions were minor sacrifices were necessary, with consultation with the supervisors at GKN and their thoughts regarding these decisions.

3.1.2.3 Data collection

Once the previous steps had been taken, more knowledge regarding the current production had been understood. After decisions regarding how the structure of the base model should be built and how it will act, it was crucial to retrieve the necessary data to replicate the model to reality as much as possible.

The necessary data that was of interest for this thesis was the following:

Product data:

- Processing time: The amount of time it takes to process a product/tempo into the finished part.
- Setup: The average time taken for an operator to change tempos. (The time it takes to remove previous tempo from the fixture + place new tempo in the fixture).
- Other times: Amount of time for any other activities apart from the setup or processing times.
- Maintenance intervals: How often the maintenance activities are conducted.
- Maintenance duration: How long are the maintenance activities conducted.
- Failure rate of the machines: How often do unexpected failures occur.
- Availability of machines: In case no data of failure rate of machines.
- MTTR: Mean Time to Repair

.

Tool data:

- Tool list based on tempo: The tools used for a specific tempo.
- Tool run times: The run time for each tool.
- Tool sequence: The sequencing of the tools for their respective tempos.
- Total tool cycles per tool: What life cycle each tool has.
- Recovery time: The time it takes internally for the machine to switch between tools.

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3.1.2.4 Verification

The verification of the model was made step-wise with weekly meetings together with the supervisors at GKN. Each week, a segment of the model was always worked on and later discussed and presented to GKN to find common ground on how it runs, or if it should be looked at differently. At the final phases of the project, a mid-term meeting was held with the department and affected parties to illustrate and explain how the model operates, differences between the real production and the simulation to capture as much as possible, etc.

3.1.2.5 Validation

At this step, the base model was compared to the real statistics regarding number of products produced over a certain time-period, and the availability of tools and downtimes due to missing tools.

3.1.2.6 Potential solutions

There were an overall number of solutions that could be experimented and could be done. Some simple and cost efficient, while others had a higher degree of complexity and were more expensive. Thus, an adaptation of Banks model was made, adding an additional step, called "Potential solutions". This step lowers the number of experiments and verifies what solutions are out of interest for the stakeholders. Obvious solutions were disregarded due to their shear simplicity and the obvious outcome. This sub-chapter will go through what type of different solutions could be performed and explain them, leading to the ultimate decisions on what solutions were chosen, and the comparison between them.

Some requirements for the solutions would need to be put in place to keep them within the project's scope. These requirements were as follows:
- Feasibility
- Try to introduce some type of automation
- Optimization
- Cost

Potential solution 1:
Introducing more operators, ultimately implementing a night shift. A simple solution to reduce downtime and waiting time for the process, thus increasing the output. This solution would fulfill all the requirements, though would not be a good solution for the second and fourth point. Analysis of the solution from the four different requirements.

- Feasibility: Would follow the same principle of production as the day and morning shift. Meaning no required changes to the production.

- Trying to introduce some type of automation: No type of automation would be used.

- Optimization: The process would be optimized due to reduced downtime and waiting time. There would be no more ghost shift, were no operators were present as mentioned in the introduction.

- Cost: An increase in cost would be inevitable. There are primarily two increases that would happen, the hiring of more staff, and the steady cost of having the factory running at night. As well as the logistical implications that could happen due to overproducing. If there is no actual need to produce more than the demand, the logistical cost of overproducing goods will increase. It is also possible to view it in another direction, slowing production down during the night to the precise demand, though this will increase the waste of having hired staff that are not needed.

  A brief calculation can be made to estimate what the cost could be for the hired staff. From the Swedish statistical bureau, it is said that the median income of Sweden is 34200 SEK [17]. Using the median age of Sweden that has been collected by the Swedish statistical bureau the median age of Sweden is approximately 30-34 years [19]. Having used a tool provided by Fortnox the calculated cost for an employer is estimated to be 47450 SEK [20].

  It was assumed that this production floor would need the same number of operators as the other shifts (four operators), one team leader and one manager, as well as two technicians present if the machines broke down. For simplicity, all the positions receive the same salary.

  47 450 SEK/month × 8 employees equals 379 600 SEK/month

  Making it an annual cost of 4 555 200 SEK, that increases with every year.

Potential solution 2:

Introducing collaborative robots. An automated solution for one of the non-value adding activities that was discovered. This solution would remove the loading/unloading operation that every operator must perform to keep the production running. Not an unknown concept with a lot of reference work to start with. Expensive investment cost, though it is a one-time expense for a certain period until its life cycle is over. Analysis of the solution from the requirements point of view is as follows.

- Feasibility: Not a new concept and has a proven record of working. Could be implemented in various ways. The point to consider is the complexity of what the robots' tasks are going to be. Safety standards are also an important factor, ensuring no harm to the operators.

- Trying to introduce some type of automation: Yes, a type of automation would be used.

- Optimization: he load/unload of tools step would be removed from the operators' tasks. They could spend their time performing other value-adding activities. Potential reduction of operators. The Unloading of tools would be performed during the night, potentially saving some minutes of downtime of the machines. Could potentially be implemented in collaboration with another concept.

- Cost: The prices of collaborative robots depend on the specific needs and tasks that the customer has. The pricing of collaborative robots often varies between 8000$ - 20 000$, though some can reach towards 100 000$. For the decision making, it is assumed that a robot would cost approximately 20 000$ [21]. Assuming a robot per machine, this would give an estimate price point as follows:

  20 000$ × 8 robots = 160 000$, roughly translating to 1 740 000 SEK.

  It should be considered that other expenses such as installation and energy need to be considered, so this value might be closer to 3 - 3.5 million SEK. Cobots also have an approximate depreciation rate of 20 percent [28].

Potential solution 3:

Implementing Automated Guided Vehicles or more commonly known as AGV. This suggestion would remove the activity of travelling with the tools to the tool-change area and vice versa. A popular concept that is getting more attention with the years as a type of transport in many industries. Expensive investment that often requires planning and changes to the current layout. Analysis of the solution from the requirements point of view is as follows.

- Feasibility: An automation concept that is becoming more popular with the times. Although simple in theory of simply moving and staying at places when they are needed, there are complexities within it. These challenges usually lie in the technical areas, the reason for this is that the system in its entirety needs to function with the AGV's, in comparison with the collaborative robot which only affects one machine.

- Trying to introduce some type of automation: Yes, a type of automation would be used.

- Optimization: The carrying/travel of tools step would be removed from the operators' tasks. They could spend their time performing other value-adding activities. Potential reduction of operators. The carrying/pushing the trolley with tools would be removed. Easing the physical strain with the operators. Could potentially be implemented in collaboration with another concept.

- Cost: The prices of AGV's depend on the specific needs and tasks that the customer has. The pricing of AGV's often varies between 40 000$ - 200 000$. For the decision making, it is assumed that a robot would cost approximately 60 000$ [22]. The total price of an AGV system is hard to estimate without knowing all the factors. For simplicity, this thesis only considered the costs that could be found.

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Potential solution 4:

GKN Smart automation cell. A principle of a smart industrial robot being able to perform multiple tasks. Having modules that can be changed and adapted to what is needed and being highly flexible. The idea is to replace the tool-change area with the smart cell. A highly complex and expensive idea, that is looking long into the future. Analysis of the solution from the requirements point of view is as follows.

- Feasibility: Feasible but complex and requires a lot of research, time and effort.

- Trying to introduce some type of automation: Yes, a type of automation would be used.

- Optimization: The tool-change operation would be removed from the operators' tasks. They could spend their time performing other value-adding activities. Potential reduction of operators. Easing the physical strain on the operators. Could potentially be implemented in collaboration with another concept. Though, increasing complexity .

- Cost: No data available, though due to its size, complexity and need of resources. Its anticipated value would be above all other suggestions.

Potential solution 5:
Implementing concepts 2,3 and 4 all in one model.

- Feasibility: Difficult.
- Trying to introduce some type of automation: Yes, a type of automation would be used.
- Optimization: All non-value adding activities would be removed.
- Cost: Highly expensive.

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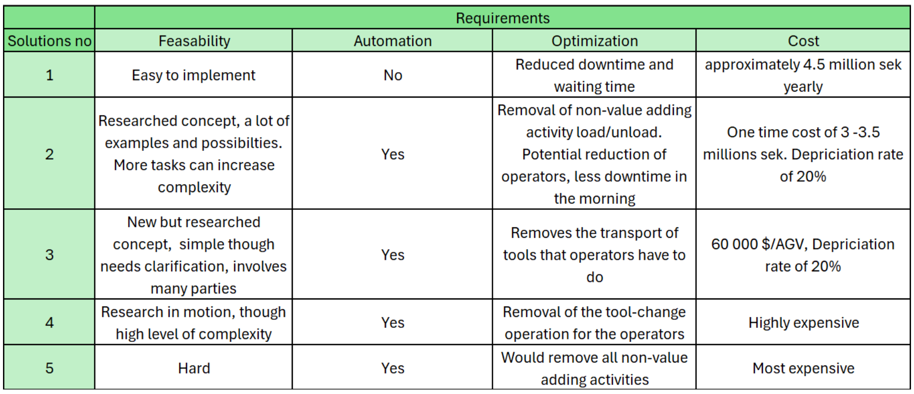
These suggestions have all benefits, drawbacks and potential. In order to summarize all five concepts, and get an idea how they could be combined, all of them were gathered in the figure below.



	Requirements			
Solutions no	Feasability	Automation	Optimization	Cost
1	Easy to implement	No	Reduced downtime and waiting time	approximately 4.5 million sek yearly
2	Researched concept, a lot of examples and possibilties. More tasks can increase complexity	Yes	Removal of non-value adding activity load/unload. Potential reduction of operators, less downtime in the morning	One time cost of 3 -3.5 millions sek. Depriciation rate of 20%
3	New but researched concept, simple though needs clarification, involves many parties	Yes	Removes the transport of tools that operators have to do	60 000 $/AGV, Depriciation rate of 20%
4	Research in motion, though high level of complexity	Yes	Removal of the tool-change operation for the operators	Highly expensive
5	Hard	Yes	Would remove all non-value adding activities	Most expensive

Figure 3.3: Comparision between potential solutions

3.2 Hypothesis

Two hypothesises were made regarding on how some of the automated solutions would impact the production in terms of machine utilization. This in comparison with how the current production is impacted by the different activities the operator have to perform during the production and what would happen if these activities were to be automated.

- Hypothesis 1: Replacing the load/unload operation to be performed by a collaborative robot would be the most effective solution.

- Hypothesis 2: The implementation of AGV's will not show much improvements unless a fully automated production can be fulfilled.

These statements are based around two factors, the first one is that the unloading of tools is the first operation in the sequence of tool change. The second factor is that the transport of the tools only holds a small margin in downtime due to missing tools. From figure 1.2 in section 1.1.1 it is observed that the other operations time is based around the amount of tools that are currently being handled. Whilst the transport of them stay consistent with 5-15 seconds. Meaning that the replacement of that operation would only save that amount of time.

The most benefits of these operations being automated can be observed during the night shift, when no operator is present. Whilst the machines are running at night, the first operation that will occur when there is a need of tool change is the unloading of the tools. If this would be replaced from a manual operation to an automated, that action would happen during the night and save x amount of time based on the amount tools that would not have to be unloaded for the day shift when operators are available again and they need to start up production. This can be seen in the figure below:

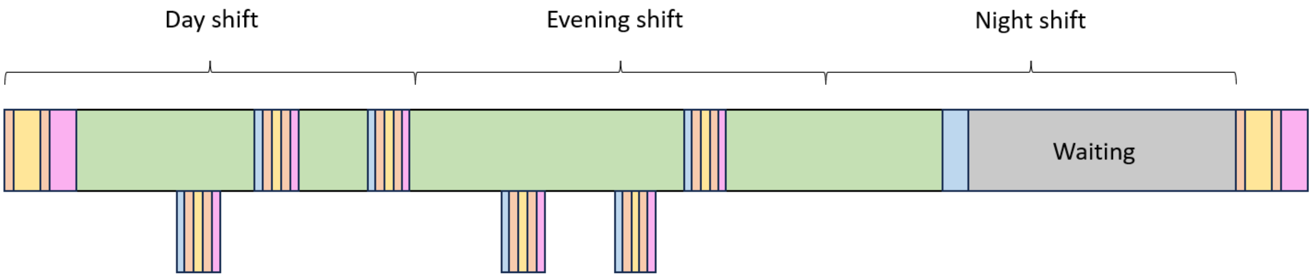


Figure 3.4: Collaborative robots effect on production

From figure 3.4 it is observed that this solution would prove to be a huge benefit, lowering the total time spent in the morning to start up production again.

As mentioned in the sections above, it can be observed that only automating the transport of the tool, or automate two out of the three operations would serve very little purpose and would not be that beneficial. The reason being is that they follow a straight logic in how they are supposed to be performed. So implementing AGV's to figure 3.4 would only save 5-15 seconds when day shift begins again and would not increase the machine availability much at all. See figure below:

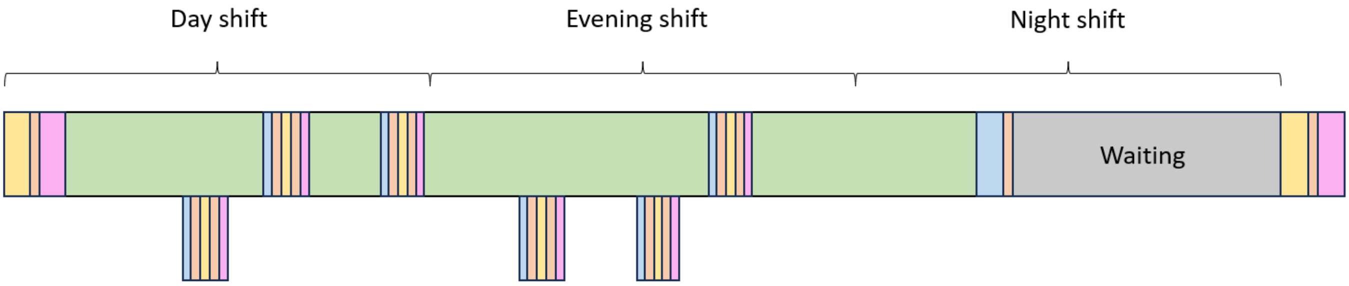


Figure 3.5: Collaborative robots + AGV's effect on production

There is also now way to keep production running further during the night if the solution would be collaborative robots and the smart cell, reason being that the transport of tools would still have to be the step in between. Thus, AGV's will only show its full benefit if all three solutions can be Incorporated. See figure below:

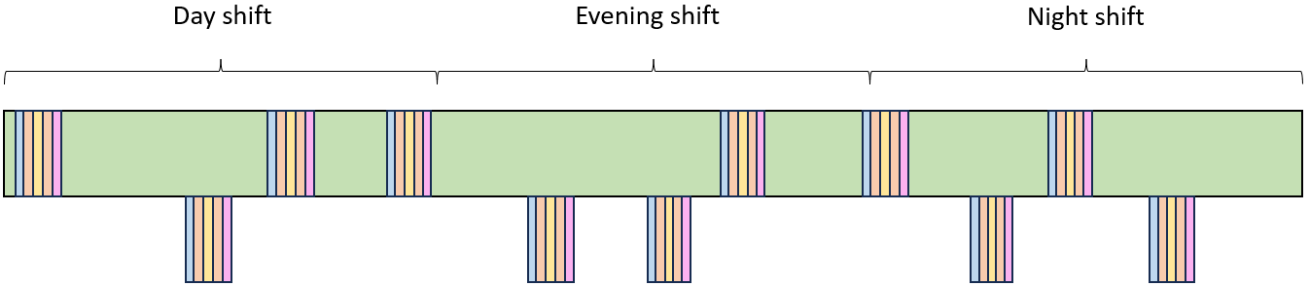


Figure 3.6: Fully automated concepts’ effect on production

3.3 Model Building

This segment will guide the reader through and how the simulation model was built, its main functions, and what tools were utilized in the software in order to make a accurate base model.

3.3.1 Modelling Frames

Firstly, after drafting the basic production requirements and the process methodology, the process of modelling this scenario was begun in Technomatix plant simulation.

As previously mentioned in the bank's model, this part was divided into modelling of the base model and experiments as to separate in order to make a distinction between the current existing situation and what it would look like with relevant improvements done to the process.

When it regards the base model, one critical expectation from the company's side was to achieve a flexible and modular simulation which would allow effortless data input and feasibility for changes in the future. Hence to facilitate these requirements, it was decided to proceed with frames approach in the simulation. A frame is used to group a set of objects and create a structural framework , where a sub-frame is used as an object in the mainframe.

A sub-frame is used as a template object which replicates the Grob Machine; this mimics the behavior of the CNC regarding movement of products and tools, which influenced the decision of having two separate stations within the sub-frame, where one is product station and tools station. This would mean the as the product enters its station the tools required for the machining will be pulled into the tools station essentially mimicking the behavior of the CNC. Hence on further exploring, the product related aspects of the frame were quite simple consisting of a list of products that are meant to be processed along with relative times such as processing, setup, changeover and others. When it regards the tools, the sub-frame would include various objects including the tool station and buffers which act as a tool-magazine and tool-change buffer, additionally input tables including tools related to each product and tool life-cycles. These various input tables in the sub-frame make it feasible to expand the model more efficiently by importing the data into these tables and adding them as a separate object into the mainframe.

3.3.2 Modelling Grob Behavior:

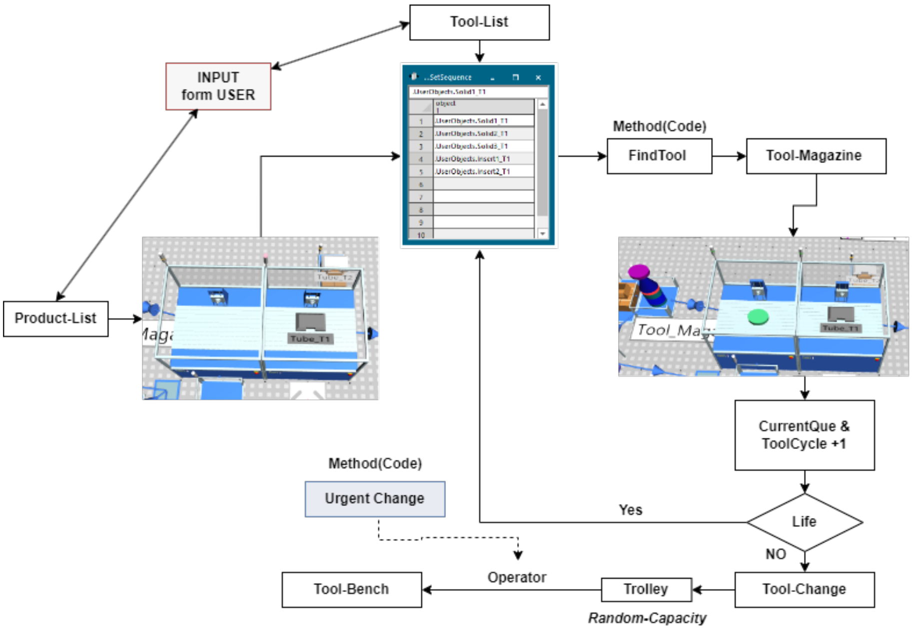


Figure 3.7: How the Grob operates

Once the functional and visual representations of the grob are modelled in the sub-frames, further development is done with regard to logic in which process should proceed. To incorporate the machine behavior in a logical way the use of methods is done. To begin with the production, first a product enters product station according to the provided product list from the user, once a particular product is identified by the method in the station, the set of tools related to the product is assigned to a queue object known as set-sequence and current-queue in the sub-frame. Further, due to the absence of a tool in the station a method find-tool is activated which thereby looks for the required tool according to the current queue which mimics the tool being used to machine the product. Once the product is processed the tool leaves the tool station further an exit method updates the current queue. Alongside the current queue being updated, in order to assess whether a specific tool has enough life to be used again, a user-defined attribute called tool-cycle is predefined which is increased by an increment of 1 as the tool leaves the tool-station. Hence, if a tool has enough life, it is circled back into the tool magazine, whereas if the tool has been used to its fullest extent, the tool is sent to the tool change buffer which is further loaded on to the trolley.

Furthermore, tool-change happens either due to operators' decision or an urgent change scenario. Firstly, as a result of general sequence of actions in the sub-frame the tools that are needed to be changed are stacked on the trolley, but an operator is required for loading the tools on the trolley and moved to a common tool change bench, hence it is left to the operators' will when he/she initiates tool change based on the number of tools ready for tool change. In order to simulate this scenario, a random value is assigned to the by a method trolley which waits until the trolley capacity is reached and later an operator is called to change the tools. Apart from the regular actions as stated previously, a special case would be when a tool is missing to the reasons that the tool is out for a change, or a tool is waiting to be changed. During this case, after the simulation is run for a certain time a method called “urgent change” is called which initiates a immediate change of tools as the grob has been waiting for a certain time.

3.3.3 Modelling operator behavior:

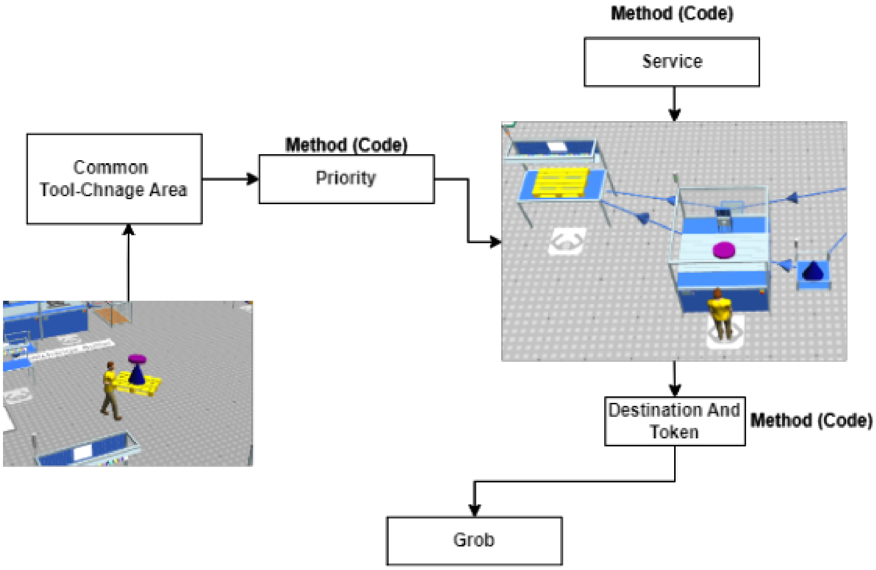


Figure 3.8: Operator behaviour

Now as stated previously the tools are initiated for a tool change due to either off the cases, once this is done a operator who is responsible for a particular grob machine is called to the machine for a tool change, the operator spends certain amount of time picking up and loading the tools on to the trolley and moves it to the common tool bench. At the common tool area a method is initiated to assign the trolley to a empty tool bench. Henceforth the the operator proceeds to process these tools for a short while at the bench which simulates him or her changing the tool from the holder and replacing with a new tool, the time they spend on each tool is based on the the type of the tool such as solid or an insert, and these relative process time is set by a method in the Change bench. Once the tools are changed and loaded on to the trolley, they are then placed back into the tool magazine of the corresponding machine.

3.4 Key performance Indicators

In contrast to the typical production simulation scenario, where statistics for each station are analysed to identify bottlenecks, this project required development of specific KPIs. These KPIs were necessary for the verification and validation of base models. The specific KPIs are as follows

- Throughput per day
- Number of tools sent for a tool-change
- Number of Change calls
- Stoppage time at the Product station

3.4.0.1 Throughput per day

Throughput essentially provides a clear picture on how well a station is performing. Stations that meet or exceed a target are meant to be operating efficiently, and the contrary is suggested for the ones that fall short. In this simulations the throughput per day indicates the number of tempos that are being producded at a specific station on a given day, this inturn indicates the number of the products that are being produced. For example, is the throughput per day indicates 3 which means two tempo-1 and 1 tempo-2 or vise versa.

3.4.0.2 Number of tools sent for a tool-change

This KPI is a direct indication of the number of tools that are being used at a particular station in a given week. This statistic was recorded by considering the "statNumIn" statistic in the tool-change buffer. As there is a current estimate of the number of tools that are being used, this KPI also actes as an important verification parameter for the model.

3.4.0.3 Number of Change calls

The KPI that measures the number of change calls essentially, counts the number of times an operator is called to a given station in a particular week. The number of change calls is indirectly dependent on the number of tools that are being used and moreover demonstrates the effectiveness of the current system, where the operator decides to change the tools after a specific number of tools require a change, eventually this number can also reveal any need for standardisation.

3.4.0.4 Stoppage time at the Product station

Apart from the default behaviours at a station such as waiting, working and setup, stoppage was specifically modelled in relation with tools availability. Hence whenever, there is a tool exchange from the tool magazine or if a particular tool has gone out for a change then the relative station is depicted as stopped. This KPI would explicitly describe on how long a station has been stopped due to the unavailability of tools.

4

Results

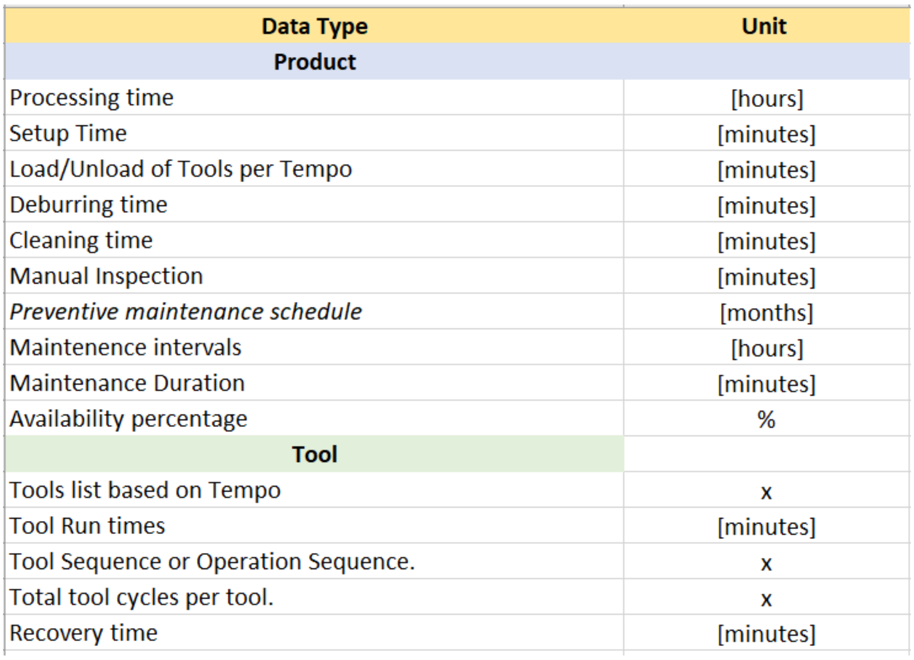
This chapter describes the various findings during the quantitative study, along with the simulation model. Furthermore the results from the base model and the experiments will be presented and described here.

4.1 Data Collection

4.1.1 Quantitative Data

The Figure 4.1 contains the relevant quantitative data used for the simulation models.

Figure 4.1: Quantitative Data Collection



Data Type	Unit
Product	
Processing time	[hours]
Setup Time	[minutes]
Load/Unload of Tools per Tempo	[minutes]
Deburring time	[minutes]
Cleaning time	[minutes]
Manual Inspection	[minutes]
Preventive maintenance schedule	[months]
Maintenence intervals	[hours]
Maintenance Duration	[minutes]
Availability percentage	%
Tool	
Tools list based on Tempo	x
Tool Run times	[minutes]
Tool Sequence or Operation Sequence.	x
Total tool cycles per tool.	x
Recovery time	[minutes]

The above displayed data was gathered from the production team in order to provide as an input for the base model and experiments as well. Based on the statistical outputs from this simulation model the current state of the production will be assessed along with verifying if an improvements through automation will show any significant improvements. This quantitative data was divided into two data-types, such as product related data and tools related data, this was done in order to distinguish and distribute the data accordingly to the product and tool station respectively. Firstly, concerning the product-related data, even though times for setup, deburring, measuring, and manual inspection were collected separately, an assumption was made in the simulation model that the sum of these times is equal to the setup time. Moreover input such as the preventive maintenance schedule is inputted into a dummy station as this schedule wouldn't have any affects on the existing stations and processes. Regarding the tools data, the most important inputs would be the set off tools that are used for a particular tempo which is mentioned as the tools list and tool run times which regards to the individual run times of each tool during production. Additionally, recovery time was recorded in order to simulate the small duration of change of tools between different operations. The above table 4.1 describes the number of shifts and number of operators that are currently work at the production floor 2 during the weekdays. This data is important as, it would facilitate in simulating the scenarios after the ghost shifts, essentially the night shift between 00:00 - 06:00 when workers are not present at the production line.

Shifts	**No. Operators**
Shift 1 (06:00 - 15:00)	4-5
Shift 2 (15:00 - 24:00)	4-5
Shift 3 (00:00 - 06:00)	x

Table 4.1: Shift Schedule and Number of Operators

4.2 Simulation Model

To answer the research questions posed in the first chapter simulation models reflecting the current state base model and experiments including the automation solutions were modelled for further analysis.

4.2.1 Current state Base Model

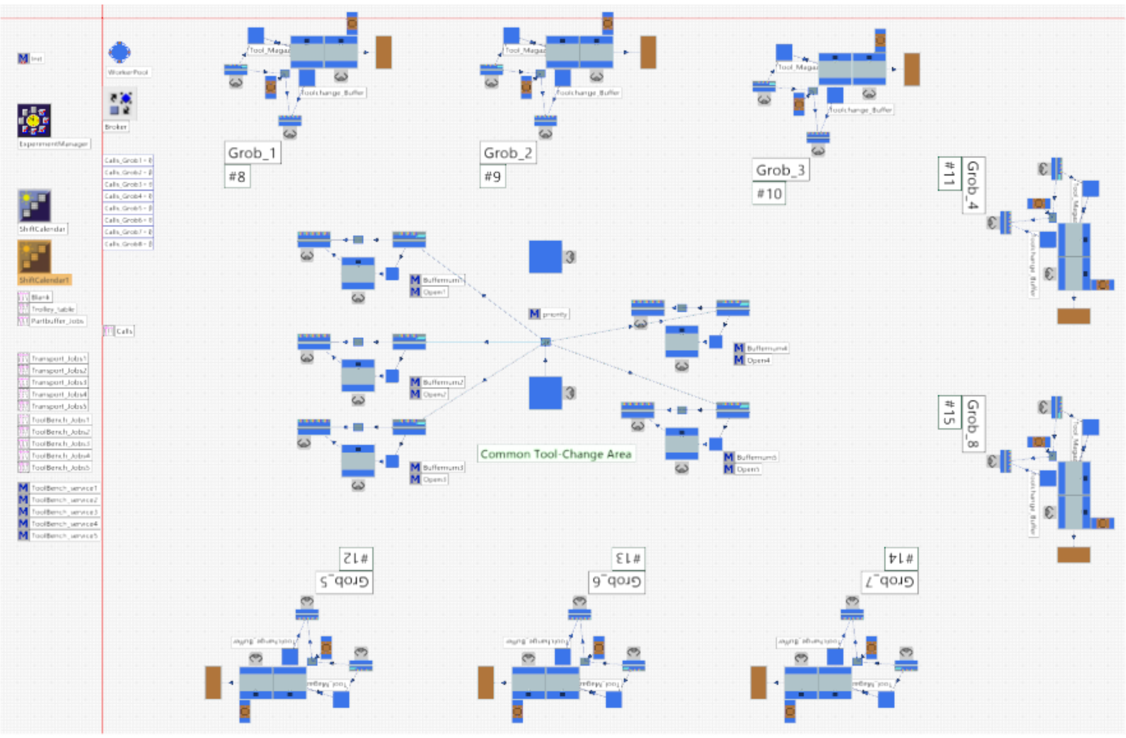


Figure 4.2: The current state base model

The fig. 4.2 above depicts the production floor-2 consisting eight CNC machines, with a common tool change area shared by all the machines in the particular floor. Each operator is responsible for 2 machines, who carries out various activities related to both the products and tools. The common tool change area consists 5 tool benches for the operators to replace the used tools with new ones into the holders. As described in section 3.3.2 each of these frames act as CNC Grob, hence when a certain amount of tools are ready to be changed the operator is called to collect the tools and place them in common buffer which sends the tools to a vacant tool bench whereby the operator can carry out activities such as removal of the used tool, place the new tool in and verify a check if the tool is placed according to the specified dimensions, for simplification all these processes are modelled as one single process at the tool bench. In relation to this production line, it is noteworthy that two out of the eight CNC Grobs are dedicated to processing one product, while the remaining six are assigned to a different product. Essentially meaning there are four various tempos that are processed in this production line with a requirement of four sets of tools accordingly. Moreover, unlike a production floor, here the products enter a CNC Grob as a raw material and exit as a finished product. It is also interesting to know that machines 8 and 9 process product A hence contain the same set off tools needed for product A, whereas the rest of the machines in floor 2 process product B, hency they contain the corresponding set of tools.

4.2.1.1 Results - Base Model

Table 4.2: Results obtained from simulation runs in the Base model

Machine	Throughput/day	Tools Used/day	Change Calls	Stopped time/week
#8	3.3	92.6	8	12:46:20
#9	3.3	103.2	10	14:40:41
#10	3.7	57	5	07:44:20
#11	3.5	55.2	5	09:54:11
#12	3.3	54.8	5	10:29:32
#13	3.4	56.6	5	10:54:48
#14	3.5	56.6	4	09:59:41
#15	3.6	56.4	4	09:38:48

The above table 4.2 depicts the results of various KPIs that were discussed in the previous section. The simulation was run for 94 weeks with two manned shifts and one un-manned shift. The table 4.2 above presents various statistics pertaining to the different machines, As observed, the throughput of the number of tempos per day is highest for CNC Grob 10 with 3.7 tempos per day which means 1 and a half product is processed at this particular station. Whereas, the number of tools used is highest at CNC Grob 9, which directly correlates with the high stoppage time observed for this particular machine.

4.2.1.2 Analysis - Base Model

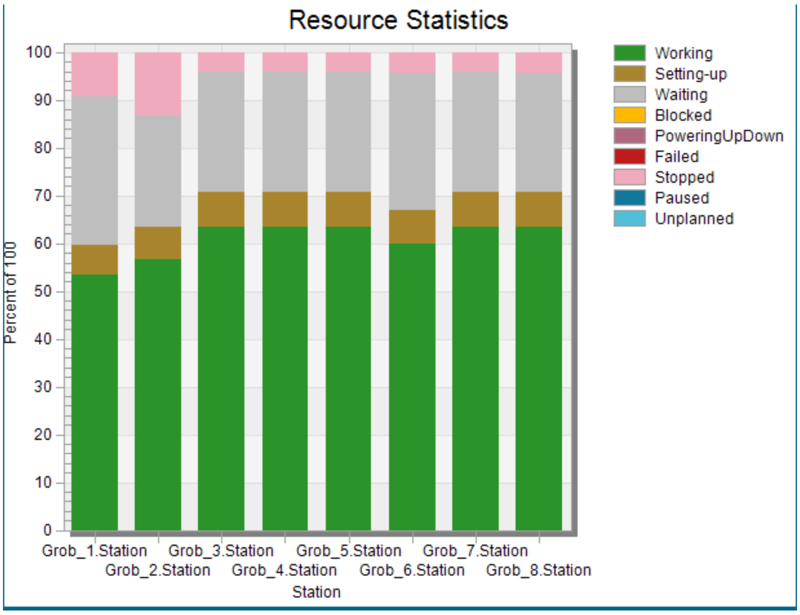


Figure 4.3: Resource Statistics of the Base Model

The fig. 4.3 visualises the resource utilization at each CNC Grob in the production floor-2, specifically focusing on the product stations at these respective frames. From fig. 4.3, the most interesting statistics to observe would be working, stopped and waiting. The CNC Grob machine with the lowest working percentage is Grob_1, which has a notable amount of waiting time. The working statistic indicates the duration a station spends performing various operations on the product. In contrast, the waiting time arises from situations where the station is idle, awaiting for an operator to remove the finished product from the fixtures of a machine work-bench and setup a new one. Here, the distinction between waiting time percentage and stopped time percentage plays a major role, in general both the stopped time due to tool un-availability and waiting time is considered to be waiting percentage, but as it is modelled to be a separate statistic, it allows the simulation to portray a clear picture. As it is clear the stoppage time at the Grob_2 is the highest amongst all, and this is justified in the results section, as seen in table 4.2 the station with the highest number of tools changed was Grob_2 with an average of 103 tools/day, comparatively as the station has higher number of tools used hence the high stopped time percentage.

4.2.2 Experiment - 1

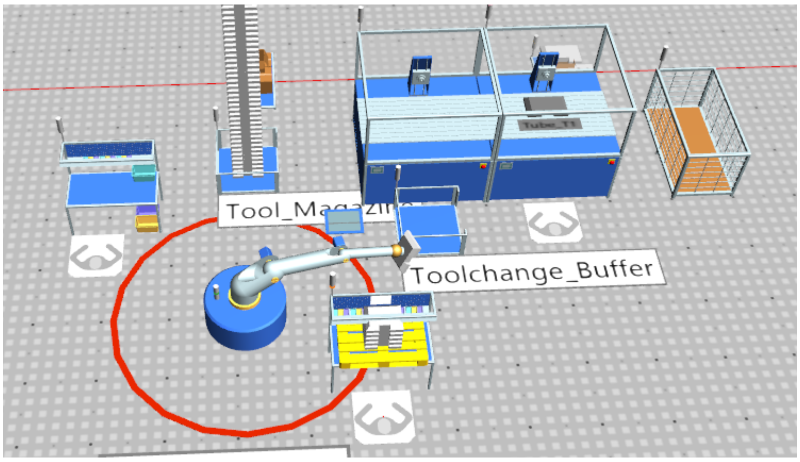


Figure 4.4: Implementation of Co-bots for Load & Unload of tools

The Experiment 1 or the level-1 automation improvement to the base model would be the elimination of the load/Unload manual activity at the Grob station. The motivation to implement this automation solution stemmed from the ergonomic strain that the operators would experience while carrying out this activity and the un-necessary non-value adding activity of loading and unloading large number of tools in a daily basis which would consume a significant amount of their time. As seen in fig. 4.4 a Co-bot is placed next to each of the CNC Grob machine, totaling up to 8 co-bots for this particular production line. The Co-bot functions as a pick-and-place robot, facilitating the handling of tools in and out off the CNC Grobs. Its operational sequence would be picking and placing the used tools into the trolley. Once a trolley returns back from the tool change area with a new set of tools, the co-bot then picks up these tools and places them back into the tool magazine of the CNC Grob. This process ensures an efficient and automated tool handling process which is essentially aim to reduce the ergonomic strain on the workers and elimination of the unnecessary non-value adding activity by effective use of the man hours during production.

4.2.2.1 Results - Experiment 1

Table 4.3: Results obtained from simulation runs in Exp.model 1

Machine	Throughput/day	Tools Used/day	Change Calls	Stopped time/week
#8	3.3	102	10	12:43:28
#9	3.3	104	10	13:18:01
#10	3.7	59	11	10:22:37
#11	3.6	58	11	08:03:19
#12	3.6	59	6	09:55:22
#13	3.6	58	5	11:25:25
#14	3.3	59	8	09:57:29
#15	3.7	59	9	10:38:09

Similar to the previous section, the experiment model was run for 94 weeks with two manned shifts and one un-manned shift, which resulted in the above displayed values of the various KPIs discussed. By comparing the results from table 4.3 & table 4.2 it can be observed that the throughput remains almost the same at every CNC Grob, but an improvement can be seen in the other three KPIs. Whilst the number of tools being used and the change calls have increased at most of the CNC Grobs there is a significant decrease in the stoppage time at Grobs 1,2,4,5,7 and with Grob 4 having the highest reduction in stoppage time by 18.6 percent. This reduction in the stoppage time can be justified due to the elimination of the time the operator spends on loading and unloading a large number of tools on a daily basis. Moreover, a mentioned in section 4.2.2 the ergonomic strain on the operators hands and shoulders from accessing for high positions during load and unload process is also curbed.

4.2.2.2 Analysis - Experiment 1

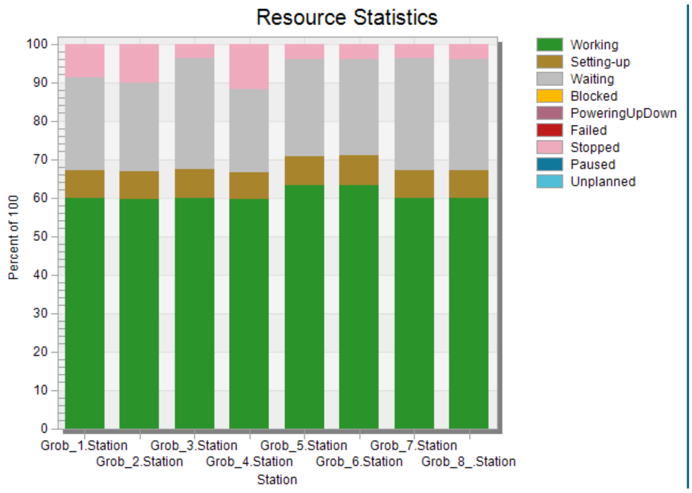


Figure 4.5: Resource Statistics of Experiment 1

The fig. 4.5 illustrates the resource utilization at each CNC Grob on production floor-2 in a given day, where co-bots assist with tool handling adjacent to each machine. Although the overall improvements are not drastic, the machines previously mentioned in section 4.2.2.1 show a slight increase in working statistics and a decrease in stoppages. Consequently, the implementation of co-bots as part of level one automation can be justified in the long run for addressing ergonomic issues and enhancing resource utilization.

4.2.3 Experiment - 2

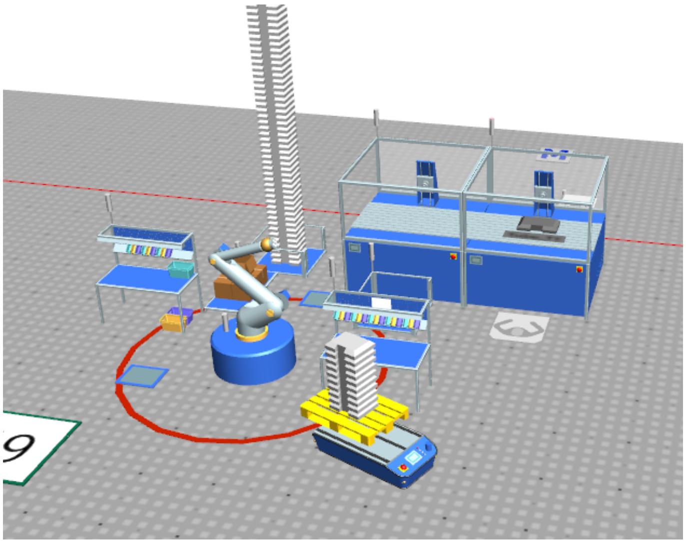


Figure 4.6: Implementation of Co-bots along with AGVs for automated transportation of tools.

Experiment 2 or level 2 automation solution would include co-bots and AGVs for tool handling and tool transportation respectively. The implementation of AGVs was choosen in order to eliminate the second most non-value adding and unnecessary activity by the operators, apart from assisting the operators with transportation during manned shifts, this implementation is done in order to achieve the overload of tasks after the un-manned shifts. This experimental model consists eight AGVs for the floor-2, essentially to provide an immediate assistance for transportation of tools at each CNC Grob. This strategic deployment of AGVs is aimed for a continous assistance and optimal productivity particularly during manned and un-manned, hence reinforcing the overall operational efficacy for the CNC Grob units.

4.2.3.1 Results - Experiment 2

Table 4.4: Results obtained from simulation runs in Exp.model 2

Machine	Throughput/day	Tools Used/day	Change Calls	Stopped time/week
#8	3.2	101	7	10:54:15
#9	3.4	107	8	15:40:26
#10	3.6	59	4	07:47:43
#11	3.5	58	6	09:50:56
#12	3.6	58	4	09:42:31
#13	3 8	62	4	10:50:14
#14	3.6	59	4	10:08:50
#15	3.6	58	4	10:26:59

Similar to the base model, the second experimental model was run for 94 weeks with two manned shifts and one un-manned shift, which derived the results displayed in table 4.4. In comparison to the current state model, experiment to has resulted in higher stoppages in turn decreasing the number of tempos produced and tools used in a given day. This high amount of stoppages could be result of the sequence of operations after the un-manned shift where the operator allocates higher preference to complete the setup of products that are yet to be processed rather than carrying out the tool change for the tools at the tool change area. This often leads to scenarios where the required set of tools are still at the tool change area while the operator is setting up the machines that he/she is responsible.

4.2.3.2 Analysis - Experiment 2

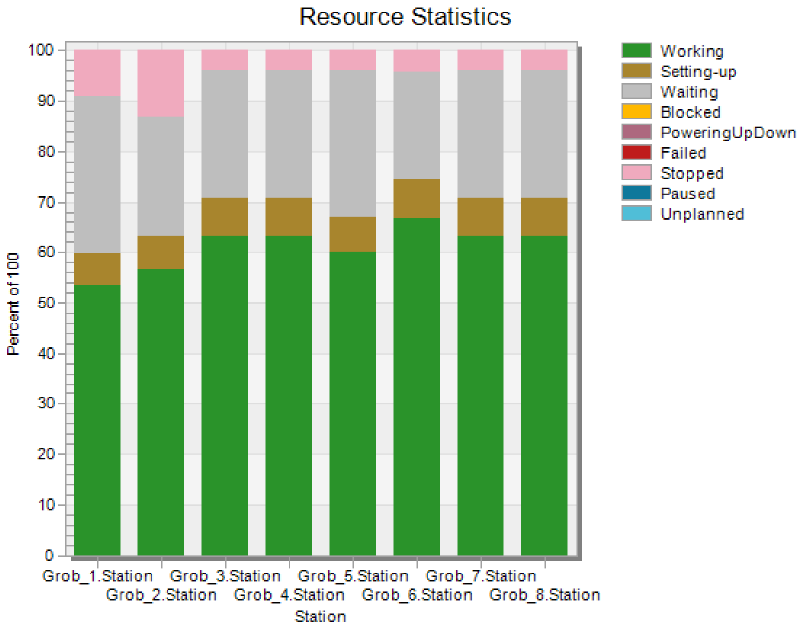


Figure 4.7: Resource Statistics of Experiment 2

The fig. 4.7 illustrates the resource utilization at each CNC Grob on production floor-2 in a given day, with co-bots and AGVs assisting the tool handling and transportation respectively. It is quite evident that the working percentage has increased compared to the base model resource utilization. However, as mentioned in section 4.2.3.1 there is a notable increase in the stoppages due to missing tools.

4.2.4 Comparison between results

Table 4.5: Range of Percentage Changes in KPIs Between Base Model, Experiment 1, and Experiment 2

KPI	**Base vs Exp1(%)**	**Base vs Exp2(%)**
Throughput/day	-5.71 to 9.09	-3.03 to 11.76
Tools Used/day	0.78 to 10.15	2.84 to 9.54
Change calls	0.00 to 125.00	-20.00 to 20.00
Stopped time/ week	-18.66 to 34.09	-14.63 to 8.32

The table above includes the range of percentage changes pertaining to the KPIs that were previously presented in the results chapter. As seen in the table, the results from the based model are compared to the results from the experiment 1 and experiment 2. As it can be observed, both experiment 1 and experiment 2 have obtained an increase in the throughput per day by 9.09% and 11.76% respectively, moreover it can also be observed that the difference in increase between experiment

1 and experiment 2 is not significant. Furthermore, another metric that is interesting to look at would be the decrease in the stoppage time, where experiment 1 has resulted in the highest decrease by 18.66%, whilst experiment 2 presents more balanced production system with lower increase in the stoppage time compared to experiment 1.

5

Discussion

5.1 General research Questions

This section answers the research questions that were decided by us.

5.1.1 RQ1: What different approaches for tool management are applicable and the impact on the performance?

There are various approaches that can be taken applicable for tool management and this thesis have only touched upon a few of those. In section 2.2 the development of industry 4.0 was discussed, as well as some of its concepts and its future. Collaborative robots were utilized in order to replace the repetitive and non-value adding task of loading and unloading, which leaves room and allows the operator to perform other value adding activities, for example quality inspection. Even though the overall output of this idea did not show an significant increase, the operational hours of the machines increased.

Regarding experiment one, it was observed that the Machines were more in a working state then previously, and the amount of tempos done per day stayed consistent. Whats interesting is that the amount of tools changed was greater than the base model. This shows that even though the working rate was higher, it might not be due to the tool transportation itself, but rather an effective method of replacing the load/unload, allowing the operators to get to his other machine quicker.

The second experiment, where AGV's were introduced to the current model can be seen as a further extension of experiment first experiment. Implementing collaborative robots together with AGV's seemed, where it was observed that the output per day got decreased although this decrease is that much of interest. Since it only means we got a bit further on a tempo on average. What is interesting is that less tools were in fact changed per product whilst having a better running percentage. This indicates that a useful transportation system have been found. We can not say that this is the most optimized solution, but rather it seems to be the way to go. But we also believe that there is a flaw in the simulation model, the first machine has a lot of stopped time due to missing tools, compare to the other ones. This goes against what we initially thought would happen, since it should in fact allow the operator to be able to start production the next morning much faster, but rather somewhere during the night, that specific AGV seem to not be called, or get stuck somewhere.

A different approach that could not be research during this thesis would be the concept of machine learning. The final step of a smart factory is the introduction of AI, especially integrating it into ones production in order for it to make smart decisions. Something that was a challenge regarding this thesis was the different data of the tools, and the potential that they could have if they are analyzed and later implemented into machine learning. This is based on their different life cycles, run-time and amount of tools that each tempo utilizes. Some of the tools are not in a critical stage where they need to be changed at specific times, even though they get changed. With machine learning there is a potential of making the AI make and take decisions on what tools does in fact need to be changed based on the time when they are needed again, hence lowering the total time spent in the tool-change area and therefore minimizing downtime.

5.1.2 RQ2: What is the most efficient tool transport system for a low volume production workshop?

This depends on what is needed, we believe based on the results and observations from the experiments that the combination of collaborative robots and AGV's is the way to go. This argument is based around that the utilization of the machines increased, the number of tools got lowered, and the amount of tempos processed stay consistent. Thus this have freed up the operators to perform other value adding activities as well as lessening the ergonomic strain on them.
From a cost efficient perspective, it is hard to give an answer of "what is" the most efficient, the reason for this is that these experiments have not cut costs, but rather only made investments that would optimize the production. The next step would have to be and see with these automated solutions, where can the workshop cut costs. In section 3, it was stated how much a production team for a shift costs annually, if a fully automated concept could be incorporated, the workshop would reduce two whole teams for that area leading to a much faster ROI. Other experiments could be to reduce the number of operators for the two experiments that were carried out, and see the outcome and therefore determine the ROI.

5.2 GKN specific research Questions

This section answers the research questions that were out of interest from GKN's side for the thesis work.

5.2.1 RQ1: What is needed so the down-time due to missing tools is 0%?

A hard question to answer due to many variables were still missing, as well as mentioned in section 2.3.2, the dangers of trusting simulation models completely. DES are essentially representations based on the requirements that were set, as well as the way the model was programmed and its intent.

To give an answer based on the data available and what conclusions that can be made from the results, there are potentially two issues that can be identified. These are the production during the night with no operators present. No matter how well these automated solutions will perform during the day and evening shift, there will still be down-time during the night due to missing tools. There is a potential that if, all three different automated solutions would be incorporated, the downtime of missing could potentially be zero, though since that test was never carried out, we can not give a concrete answer.

This can clearly be seen from the two experiments that have been carried out. Even though these automated solutions have freed their time and lowered the downtime of the machines. It is still roughly the same amount of production happening or more, but number of tool changes are lowered and downtime due to missing tools seem to get decreased. An exception regarding machine number 1.

To further see how the downtime could be reduced to 0%, a experiment that allows the production to run during the night would have to be added. As this thesis has stated, the final non-value adding activity is the change of tools and that is the final area that is left for improvement. This is where we believe GKN's smartcell would be an ideal implementation to remove this activity and be able to keep the prodution running during the night.

The second point would be the different data regarding the tools. As mention in section 5.1.1, there is a potential of implementing machine learning hand hence have the AI itself make logical decisions based on availability and need when tools needs to be changed.

5.2.2 RQ2: How much equipment is required for a 100% automated tool handling scenario?

In order to have a fully automated tool handling scenario, all three non-value adding activities would have to be removed. These would consider, incorporating collaborative robots to handle the load/unload task, introducing AGV's to replace the trolley and not having the operator push the tools to the tool-change are and back to the Grob. The final change would have to be replacing the tool-change area with GKN's own concept of a smart cell. Exact details on what would be required can not be given, although it would need, equipment such as cameras, sensors, small collaborative robots and more. Essentially it would replace all, quality inspection tasks to ensure that the right tool, alignment, and quality is reached.

5.3 General Discussion on Simulation and modelling

In the theory chapter, the convoy effect was discussed as a potential flaw with FIFO. There are measures being taken by the production in order to lower the amount of waiting time due to this effect. After the ghost shift, a operator might prioritize to only change the critical tool out of the amount of that need to be changed. Thus, lowering the down time of the machine as much as possible. This was not replicated into the simulation model to that extend. But rather it takes action by prioritizing to start one machine rather then switching between the two. If the real behaviour could have been implemented, the replication and experiments could have provided a much more fair and realistic results.

5.4 Improvements for the future

Observations from this thesis have given different insights and suggestions that could be implemented towards the production in order to optimize it further. Some of them are automated solutions whilst others are based on statistical research.

We firmly believe that a fully automated solution is the way for the company to move towards. Based on every experiment, it could be seen that there would always be an improvement. In regards to production volume, at the current system and the way that products are being processed, increasing the production volume with the current amount of Grob's is is almost impossible, thus if that would be the goal, either more Grob's would have to be installed or the manufacturing process itself would have to be researched and improved.

In regards of optimizing the current process, there are the three areas that have been discussed were non-value adding activities are present. With these removed, it creates a better utilization of the operators tasks, were they can focus on other areas, if no operators would be needed at that shop, or they could be lowered, the running cost for that shop would decrease. A fully automated solution would lower the downtime, which is mainly caused by the night shift (ghost shift) that is one of the key players in the down time of the machines.

In order to further optimize it, the company would have to strive for machine learning in this process, having the AI decide on what and when the specific tools need to be changed in order to optimize the processing time and have the production running as much as possible.

There is also a manual step that could be utilized with this model, in section 3.2.2 it was said that changes are based by two decisions, either the machine stops due to it missing the required tool, or the operator changes the tools at random based on their decision. With this simulation model, it is possible to investigate for the optimal time when changes need to happen, based on the life- cycle, processing times and sequence. It is possible to find a optimal moments when and what tools need be changed, thus leading to a decrease in downtime.

5.5 Limitations of the thesis

During the thesis some limitations and assumptions had to be made due to lack of data, and complexity of the programming and coding of the simulation model. These were as follows:

- Tool change area: The actual tool-change are consists of three tables were inserts can be changed, and two were solids can be changed. Due to the complexity of keeping sure that the tools do not get lost in the model and remember which trolley they are connected to, all the tools get changed in the table that gets chosen.

- Failures: There were no actual statistics provided regarding failures and breakdowns, hence the simulation is running without that and shows an ideal scenario on how the factory is intended to run, rather than what it actually does due to these inconvenient failures.

- Costs: There were no actual requirements set on the automated technologies that were tested, hence it would be hard to gauge what the actual costs would be, instead a higher value that is believed is necessary was chosen to compensate for it.

- Randomness: The randomness is chosen based on our assumptions that we believed would suffice, operators act very differently and have their own way of working and how they want to do it. To incorporate all their reasoning would be far to complex in the model.

- Scrap of tools: In reality some tools might not be of good enough quality after inspection and would be thrown away, this is not considered.

- Logistics of tools in stock: It is assumed that when changing of tools happen, they are always available on stock and no additional waiting time due to reasons outside of the shop floor is considered.

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6

Conclusion

This thesis has successfully laid the groundwork for exploring various automated concepts and different solutions in a short time-frame. Thus, emphasizing the importance of creating a flexible and adaptable base model. By using well-defined requirements, and agreeing on the inputs of different data together with GKN, desirable results were reached, realizing areas that need further exploration, as well as the a better understanding on what needs to be further explored. The investigations and findings during the thesis provided and highlighted the potential benefits of different automated solutions, what the impact of the different non-value adding activities have on production time, and how their elimination could further enhance the efficiency.

The experimental findings provided a map towards what would be needed towards a fully automated solution, although it was inconclusive whether such a solution would completely reduce the downtime that is caused by missing tools. Whilst the experiments suggests that there is a improvement with the automated concepts, it also revealed that it might not be the only contributing factor.

Whilst having a better understanding of the impact of different automated solutions and their benefits, additional experiments should still be carried out. Future models could focus more on areas where cost reduction could be carried out, in order to see when a ROI could be expected. As well as incorporating more details into the model, to further realize were potential bottlenecks might be located, thus affecting the production. The suggestion of AI was mentioned, an area that should be investigated and integrated in order for it to make smart decisions when changes should be carried out based on different variables such as, lifecycle, processing times, and sequence. As the thesis presented, this is the following steps in order to reach the levels of becoming a "smart factory".

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A

Appendix 1

A.1 User-Guide

A.1.1 Setting up the Machines

Once the user has come up with the number of CNC GROBs that they would want to simulate. The first step would be to "duplicate" the existing frames accordingly in the "user-objects" folder in the class library. This can be done my right clicking on one of the grobs and selecting duplicate. This creates the new frame with all the material flow objects and the logics associated with the functioning of the CNC GROB.

Once this is done, a simple drag nad drop can be performed in order to add these CNC GROBs into the mainframe. Further spatial arrangements can be made to these machines according to the existing plant layout.

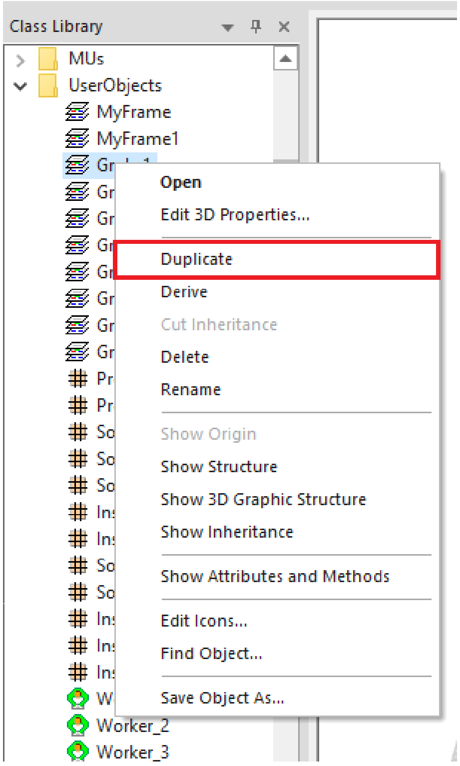


Figure A.1: Class library depicting duplication of frames

A.1.2 User inputs

After setting up the CNC GROBs according to the required spatial adjustments, the user can input the relative information for these frames. Firstly, the product or tempo related data must be entered into the table called "Product List" here the types of products/tempos can be entered, further more the individual runtime can be inputted as well. Once the products list is updated, the next step would be to input the tools information, here the user must in put the list of tools used as per the product/tempo that is processed. These lists must be entered twice, that is first in the tables that are called "Tools_T1", "Tools_T2" and later in "Tool_List_T1", "Tool_List_T2", here the data from the first set of tables are automatically inputted to "Tooling_source" which is used to create all the mentioned tools into the tool-magazine, while the second set of tables are inputted to "Tooling_List" which is used to set the sequence in which tools have to enter the station, one aspect to notice here would be the order of the tools list in the second set of tables maters the most because it replicates the operational sequence of these tools. Furthermore, regarding the tools the user can input the individual runtimes of these tools in "Tool_Runtimes" and the table "Toolcount" can be used to input the life cycles of these tools. Apart from the product and tools data, the "times", "setup" and "failures" tabs within the station can be used to input the data that relates to the machine.

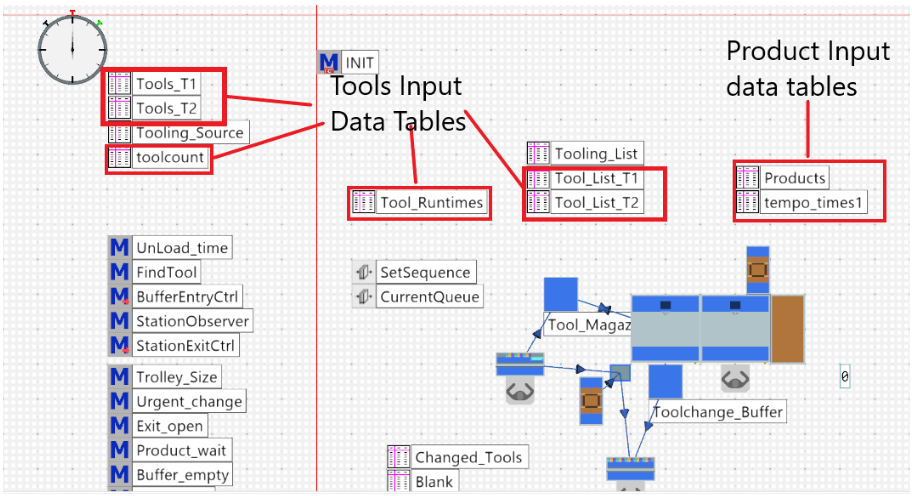
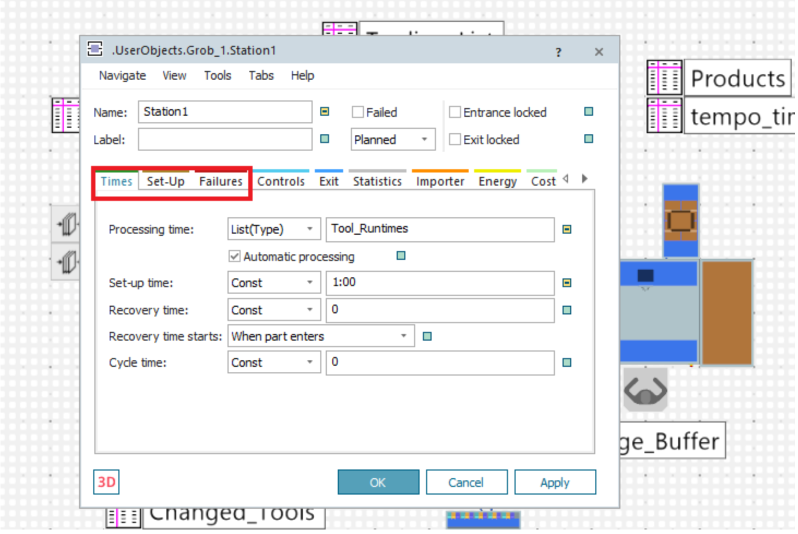


Figure A.2: Various User Input tables within a frame



.UserObjects.Grob_1.Station1

Name: Station1

☐ Failed

☐ Entrance locked

Label:

Planned

☐ Exit locked

Processing time: List(Type) Tool_Runtimes

☑ Automatic processing

Set-up time: Const 1:00

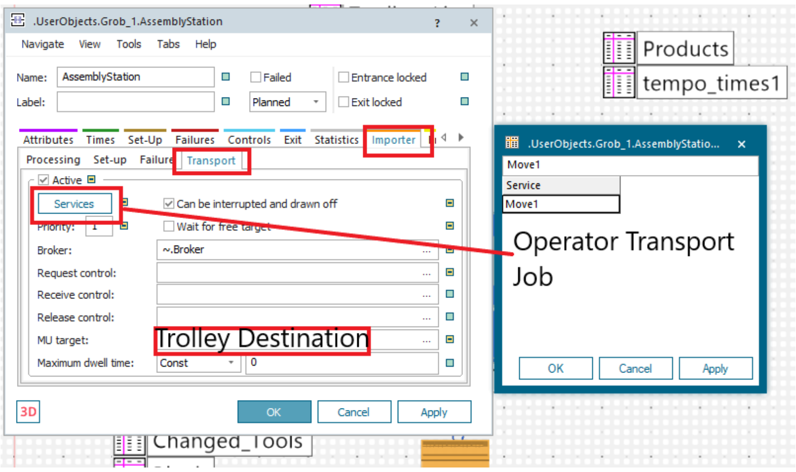
Recovery time: Const 0

Recovery time starts: When part enters

Cycle time: Const 0

Figure A.3: Machine related inputs by the user

Furthermore, one more final adjustment in the frames would be setting up the job for the related operator and specifying the destination the trolley, this is done by accessing the "Importer" tab in the "Tool_Assembly" station, where the user can name the job of transporting the trolley and mention the MU target to where this trolley has to be delivered from the CNC Grob. One thing to keep in mind would the name of the job for transporting this trolley, if one operator is responsible for two CNC GROBs then both the tool assembly stations must have the same name.



.UserObjects.Grob_1.AssemblyStation

Name: AssemblyStation

☐ Failed

☐ Entrance locked

Label:

Planned

☐ Exit locked

☑ Active

☑ Can be interrupted and drawn off

Priority: 1

☐ Wait for free target

Broker: ~.Broker

Request control:

Receive control:

Release control:

MU target: Trolley Destination

Maximum dwell time: Const 0

.UserObjects.Grob_1.AssemblyStatio...

Move1

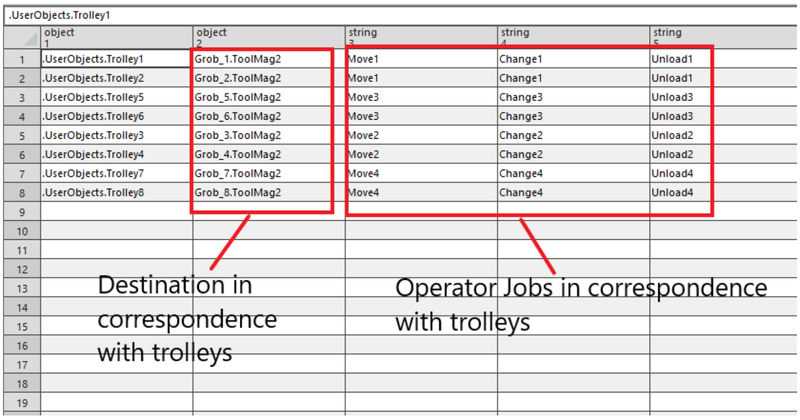
Service

Move1

Operator Transport Job

Figure A.4: Transport importer

Once these frames are setup accordingly, the final input to the simulation would be the input table called "Trolley_table" in the mainframes. This table is used to specify the jobs related to changing the tools and transportation to the various operators in the simulation and also the destinations to which they have to deliver the trolleys from the common tool change area. The "Trolley_table" is accessed by various methods with in the change benches at the common tool change area in order to assign the jobs and set the destinations based on the trolley that was brought to the particular station. Similar to the frames, the user must be aware about which operator carries which trolley and thereby assigning same name for the jobs to change and transport the trolleys.



.UserObjects.Trolley1

	object 1	object 2	string 3	string 4	string 5
1	.UserObjects.Trolley1	Grob_1.ToolMag2	Move1	Change1	Unload1
2	.UserObjects.Trolley2	Grob_2.ToolMag2	Move1	Change1	Unload1
3	.UserObjects.Trolley5	Grob_5.ToolMag2	Move3	Change3	Unload3
4	.UserObjects.Trolley6	Grob_6.ToolMag2	Move3	Change3	Unload3
5	.UserObjects.Trolley3	Grob_3.ToolMag2	Move2	Change2	Unload2
6	.UserObjects.Trolley4	Grob_4.ToolMag2	Move2	Change2	Unload2
7	.UserObjects.Trolley7	Grob_7.ToolMag2	Move4	Change4	Unload4
8	.UserObjects.Trolley8	Grob_8.ToolMag2	Move4	Change4	Unload4
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					

Destination in correspondence with trolleys

Operator Jobs in correspondence with trolleys

Figure A.5: Input table consisting various jobs and destinations in correspondence to trolleys

Once all these inputs are provided, the experiment manager can be accessed and the simulation can be run for the number of weeks the user would desire, and thereby could achieve the various results for the KPIs that are being monitored.

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