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Modeling the Future: A Simulation-Based Analysis for Sustainable Production Transition

Modeling and Evaluating the Future Manufacturing at Beyond Gravity from a Triple Bottom Line Perspective

Master's thesis in Production Engineering

MATILDA BLOHM
RASMUS JOHANSSON

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
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www.chalmers.se

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Matilda Blohm, Rasmus Johansson

Supervisors: Henrik Söderlund, Department of Industrial and Materials Science,
Niklas Hendtman, Beyond Gravity
Examiner: Björn Johansson, Department of Industrial and Materials Science

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Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Visualization of the future production flow, made in Siemens Plant Simulation

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Abstract

Sustainability within the manufacturing industry is becoming more relevant, and the space industry is no exception. The need of satellites is increasing and manufacturers in this industry will need to scale up their production to meet the new demands. A company within this changing industry is Beyond Gravity who is aiming to scale up their production, moving from a fixed production layout to a high volume batch production flow. The purpose of this thesis is to create a Discrete Event Simulation (DES) model of the future production at Beyond Gravity. This simulation model will be created to investigate their transition from the current production to the future production, and how it will affect Triple Bottom Line (TBL) sustainability factors regarding the environment, the workforce and the economy. The data for the project is collected through a narrative literature review, interviews, and personal communication at the company, with Banks model as the overall methodology. The DES model verified that the company would be close to reach their goal of a higher throughput compared to the current production, giving the company valuable information about their future production. This indicates that using a simulation model when transitioning to a new production could be helpful. The TBL evaluation was conducted with the help of the DES model together with the data collected. In this case, the Work in Process (WIP) will become larger with the higher throughput, binding more capital which could affect the economical sustainability negatively. The energy consumption per product will decrease, but on the other hand the total energy consumption will increase for the future production, indicating an impact on the environmental aspect. The DES model suggests that the workload will become uneven in the future production, which could lead to poor cognitive ergonomics among the workforce. In conclusion, a DES model can help a company transition to a future production, and at the same time provide insights within the TBL sustainability aspects.

Keywords: Discrete Event Simulation, Triple Bottom Line, Sustainability, Space industry, Production, Production transition, Banks model

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List of Acronyms

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

AI	Artificial Intelligence
CI	Confidence Interval
CODP	Customer Order Decoupling Point
CPS	Cyber Physical Systems
DES	Descrete Event Simulation
ETO	Engineer to Order
IOT	Internet of Things
KPI	Key Performance Indicator
ME	Margin Error
MTO	Make to Order
OBC	On Board Computer
TBL	Triple Bottom Line
VR	Virtual Reality
VSM	Value Stream Map
WIP	Work in Process

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1

Introduction

In this thesis a study will be conducted on how Discrete Event Simulation can be used to help a company within the space industry evolve their production. It will also study, from a sustainability perspective, how a future production will compare to the current production with the help of the Discrete Event Simulation model. In this chapter, the background of the project is presented and explained. Additionally, the aim, research questions and delimitation will be stated and described.

1.1 Background

The manufacturing industry is developing continuously and moving toward Industry 4.0, with technology and connectivity as essential parts. The space industry is not an exception. This industry is growing rapidly, for instance, in 2022 there were around 2500 satellites orbiting the Earth and this number is assumed to grow to 50 000 by the year 2032 [1]. This means that there is a need for upscaling in the production of satellites, meaning a transition towards mass-production [2]. At the same time, making products for usage in space also puts high demands on the products, resulting in tough constraints on its design and quality, since they are exposed to extreme environments [3]. The transition in the space industry is also called Space 4.0, which indicates that, similar to Industry 4.0, more technology, automation and connectivity is desirable in order to meet the future demand of satellites [4].

Beyond Gravity is an independent supplier of space technology, located in several locations but primarily in Europe. They produce, among other products, on board computers (OBC) for satellites. The shift in the space industry is detectable within the production for their production of OBC. Beyond Gravity are facing the challenge to upscale their production from producing one OBC every other week, to making five OBCs per week.

One way of assisting this transition from low volume production, to a higher volume of production could be to make use of Discrete Event Simulation (DES). DES is a simulation method that can be used to understand the behavior of a system, for instance, a certain production system [5].

As for now, Beyond Gravity does not have a simulation model of their current production or their future production. Therefore, creating a DES model of their production could be an important next step in order to be competitive on the market, raise their digital maturity in production and possibly in the future develop a Digital Twin of their production. Additionally, making use of DES of their production also makes it possible to analyze the energy consumption, workload for the workers, throughput and Work In Process (WIP) which becomes increasingly important in order to create a sustainable production [6].

1.2 Aim

The purpose of this thesis is to create a simulation model of the future production flow for OBC at Beyond Gravity, through a DES program. This simulation model will be created to investigate their upscaled production, and how it will affect sustainability factors regarding the environment, the workforce and the economy.

1.3 Research questions

This project strives to examine how the production at Beyond Gravity could benefit from using DES when increasing their production, and how the sustainability perspective in the future production might be affected compared to the current production.

- **RQ1:** How can creating a simulation model help a company transitioning to a new production?
- **RQ2:** How will sustainability aspects in the Triple Bottom Line be affected in this transition?

The expected outcome includes a proposed model of how the new production flow will look like at Beyond Gravity and a qualitative study of how the sustainability, considering the Triple Bottom Line, will be affected in the future production in contrast to the current production.

1.4 Delimitations

This project will be limited in time, from January to the end of May in 2025. The DES model will be conducted in Siemens Plant Simulation, without considering other options available in the market. Additionally, this work will be limited to the specific part of the current and future OBC production at Beyond Gravity in Gothenburg, as well as the data available at and provided by the company. This means that the authors will not elaborate on or optimize production layouts or manufacturing strategies that has not been used nor will be used at the company, in the context of the scope of the project. Additionally, the authors will not strive to optimize the throughput of the future production. This means that the project is limited to create a base model of the future production flow to verify the goals of the company and gather information about the current production.

Moreover, the sustainability of the current and future OBC production will be evaluated through the Triple Bottom Line (TBL) perspective, and with the use of data gathered through the DES simulation of the production [6]. Within the TBL, the project will be limited to evaluate the throughput and WIP, energy consumption, and ergonomic situation for the workers in the current and future production. The ergonomic situation can include both physical ergonomics, for instance harm to the body, and cognitive ergonomics, such as stress or competence [7]. The project will use data available from current production but will not be able to perform own studies of the current production due to time constraints.

2

Theory

In this chapter, the theory will be introduced as a theoretical basis for this thesis. Firstly, Discrete Even Simulation is presented, along with Banks Model, followed by and introduction to production and some of its strategies. Sustainability Key Performance Indicators will end this chapter.

2.1 Discrete Event Simulation

DES has been practiced since the middle of the 20th century [4] [5]. It is a type of simulation that is used to imitate a real-life system, and how it changes over time [8]. DES consist of discrete, dynamic and stochastic simulation models combined together [5].

DES can be described as a system in which several aspects of the system and variables are modeled and integrated into a set of operations through a simulation program [9]. Instead of changing continuously, some events of interest will change discretely at certain, often at random, points of time called event times [9][10]. It is common that two or more of these variables/aspects have to be changed at the same event time. This is often done through serially manipulating the variables at that time event, which in turn leads to logical complexities which lifts the question about which of the variables should be handled first [10].

Fishman (2001)[9] cites an example of a bus route with three variables:

1. Amount of passengers on the bus.
2. Amount of passengers at each bus stop waiting for the bus.
3. Where the bus is located.

The first two variables can be described as discrete while the third can be described as continuous. How many passengers there are on the bus can only change when it stops at a bus stop, that is, the value of the bus location change to one of the unique values of the bus stops. The number of passengers waiting at a bus stop can only be changed when the bus arrives to pick up new passengers or when a new passenger arrives to the bus stop. Through the combination of the three variables, bus schedule, new passenger arrivals and their combined sequences will decide how many passengers occupy the bus at a certain time or how many wait at each bus stop. The sequence can also show how long each individual waits at the bus stop. This is of course affected by the capacity of the bus.

According to Fishman [9] the waiting time for the passengers at the bus stops can be described as delay, the amount of passengers at each stop is the length of the queue. How many passengers trips that have been completed can be described as the throughput and the time-average seat occupancy through seat capacity on the bus describes the resource utilization. In this example the buffers are the bus stops and have infinite capacity. However, this is most often not the case which means that the model of a system needs to have specific rules addressing the problem if that would happen.

The purpose of a DES model can be described as emulating the real life system. However, the DES model will never be exactly the same as the real life system. This creates a ”credibility gap” [11]. The task of the Simulation-Engineer is to find a way to bridge the gap and make it as small as possible to make the model replicate the system as much as possible. Another important factor to consider when creating a DES model is the importance of repeatability. Repeatability will help create a better understanding of the production system as well as help debug the model during its creation [11]. There are of course methods to describe the accuracy of which is described in chapter 2.1.1.

Within production, DES can play various roles depending on how it is used. It can for example be used when planning new production systems [12]. It will be able to provide insights into for example the throughput, lead time and help find bottlenecks [12] [13]. DES enables the user to simulate different scenarios within the production to understand the impact of different changes [12]. The results from these simulations can in turn work as foundation in decision making process of what changes to make. There are of course advantages and disadvantages with using DES when creating a production flow. In table 2.1 some examples of them are described.

2.1.1 Calculations

When creating a DES-model and running it, it is important to keep in mind that the output will be somewhat random as the value of some of the variable will be randomized during the simulation [9]. It is therefore, as stated before, important to make sure that the model is repeatable [11]. However, each sample won't be the same because of the randomness. To estimate the accuracy of the model a Confidence Interval (CI) can be calculated [15]. The more narrow the confidence interval can be, the better.

$$CI = \hat{x} \pm z \cdot \frac{\sigma}{\sqrt{n}} \tag{2.1}$$

In the eq.2.1 $\hat{x}$ stands for the mean values of the samples, z stands for the critical value based on the selected confidence level, σ stands for the standard deviation and lastly, n stands for the amount of samples [16]. Equation 2.1 can be rewritten as follows with Margin Error (ME),

$$CI = \hat{x} \pm ME \tag{2.2}$$

Advantages	Disadvantages
Improved system understanding - enables the user to get better understanding of the system [9]. With the help of a top-down approach to model a systems behavior, it creates the possibility to view the system from a holistic perspective [5].	There are no guarantees that the modeling of the system will return results that are useful for the organization [9].
DES has the ability to mimic a real life system and dynamics [8].	The model may create incorrect result if it is used outside of its limitations, which will lead to inaccuracy, bias within the model [9] [14].
Cheaper than a direct study of the system [9] [14].	A DES can only provide an estimation of the outcome from the model and not predict the exact outcome [14].
Easier to change and configure than doing the same on the physical system [9] [14].	
Makes the process of an analysis of the system faster, compared to doing it manually [9] [14].	
Supplies a structure from which test of improvements can be tested [9] [14].	
Enables the user to control and create variables or scenarios to be tested that can't be created in a direct study of the system [9].	

Table 2.1: Advantages and Disadvantages with DES

where ME is

$$ME = z \cdot \frac{\sigma}{\sqrt{n}} \tag{2.3}$$

If there are many samples, n, collected, z can be determined based on the standard normal distribution. However, for small sizes of n, z is calculated with the use of a t-distribution in order to balance the increased uncertainty from the small sample size [16].

The critical level, z, is based on the confidence level. It is selected with respect to the desired level of certainty, with most selection landing within the range of 0.9 to 0.99 [16]. 0.95 is often used, which corresponds to a critical level of 1.96 [15].

Calculating the confidence level can be useful when assessing different statistical estimates [15]. This can be calculated in areas such as proportions, population means and estimates of variation among groups. Bevans [15] gives a good example of when to calculate the confidence interval. In a survey with 100 Britishmen and 100 Americans, it turned out that both the British and the Americans watch at an average 35 hours of TV every week. There is however a difference between the British and Americans, which is that the British watchers had a larger variation. By having a larger variation means that the standard deviation of the British will be larger. In this example the standard deviation for the British will be 10 and 5 for the Americans. The number of observations was 100 for each category, which means a z distribution can be used. The z-value that will be used in this example is 1.96 that comes from the critical level of 0.95. With the help of the data mentioned the Confidence can be calculated. Using the equation 2.1 the following intervals can be calculated:

- British: 35 ± 1.96
- American: 35 ± 0.98

2.1.2 Tecnomatix Plant Simulation

During the project the software Tecnomatix Plant Simulation created by Siemens was used [17]. Tecnomatix Plant Simulation is a simulation program using DES to help the developer model and simulate production systems. It includes several tools that help evaluate the production system and can visualize the performance of the modeled production system through, for example, charts of different kinds. A model can be built both in a 2D and 3D environment. A model is built up by different types of objects that work together to emulate a production or logistical system [18]. Some of these objects are described in table 2.2.

Beyond the objects described in table 2.2, there are other objects that help the model simulate the reality better, such as the ”Method” block. ”Method” in Plant Simulation are code-snippets that can be used to control how objects behave in the program [18]. Another object that is used when experimenting and collecting data from a created model is the ”ExperimentManager” block. Its main purpose is to help execute simulation studies and present results that can be used in for example improvement studies [18].

2.1.3 Banks Model

There are many ways to perform a simulation study. One of these methods is based on Banks model that outlines a 12 step guide toward how such a study could be performed [19]. It is a structured framework that assist the development and analysis of a simulation in a scientific and systematic way to ensure a clear outcome from the simulation study [19]. The 12 steps can also be divided into three groups, *Preparation*, *Model building* and *Analysis* [20], visualized in figure 2.1.

1. *Problem formulation.* When starting a new simulation project the first step is to create a formulation or statement to make sure both parties, the client and the problem solver, are agreed upon what the mission is [19].

2. *Project plan.* This step builds onto the formulation created in the first step.

Object	Description
MU	Represent the parts and products going through or being produced in the production system [18].
Source	Creates MUs that can be inserted into the production system [18]. It can be programmed to produce MUs at a certain time interval if needed.
Drain	The drains task is to remove the MUs from the production system after the processing is done [18].
Station	Processes one MU at a time and move the MU to it successor after [18]. Often represents a normal working station in a production system. The processing time can be redefined.
Parallel station	Similar to the Station but can process several MUs at a time or several MUs as batches [18]. The processing time can be redefined.
Assembly station	Similar to a Station as it represent a work station in a production system. Mounts or assembles MUs to a main MU [18]. The processing time can be redefined.
Buffer	A buffer temporarily holds MUs between two stations until a free slot is available at the successor station [18]. The capacity of the buffer can be changed.
Store	Can store a defined number of MUs [18]. Most often represents a storage tower or stock.

Table 2.2: Description of some of the objects used in Tecnomatix Plant Simulation

Banks (1998) describes this step as to ”prepare a proposal” [19]. The plan should include several aspects. Firstly it needs to include a statement of the scenarios that will be investigated. Secondly, the project plan needs to include the requirements for the project. Such as personnel, hardware and software [19].

3. *Conceptual model.* To understand the real-world system, a conceptual model can be created. A conceptual model's purpose is to represent the real system, showing the relationships within the system [21]. It is often used to serve as a bridge to create an understanding and better communication between, for example, developer and customer. According to Banks (1998), the best way to create a conceptual model is to begin simply, that is, begin with a simple model, containing only arrivals, queues and servers and from this add on more processes, which will make the model more complex [19]. It is important to keep the customer in the loop when creating the model, which will help increase the quality of the model [19].

4. *Data collection.* How the data collection phase will progress and look like will differ depending on what kind of data the client can procure to the project. Before the data can be sent, a description of what kind of data is needed as well as what kind of format it should be in is required [19]. The best case scenario is that the client have the asked for data ready to send which will speed up the process considerably.

However, it is more common that the situation is not as described above [19]. The focus of this step is to convert and find the data needed to be able to create the model.

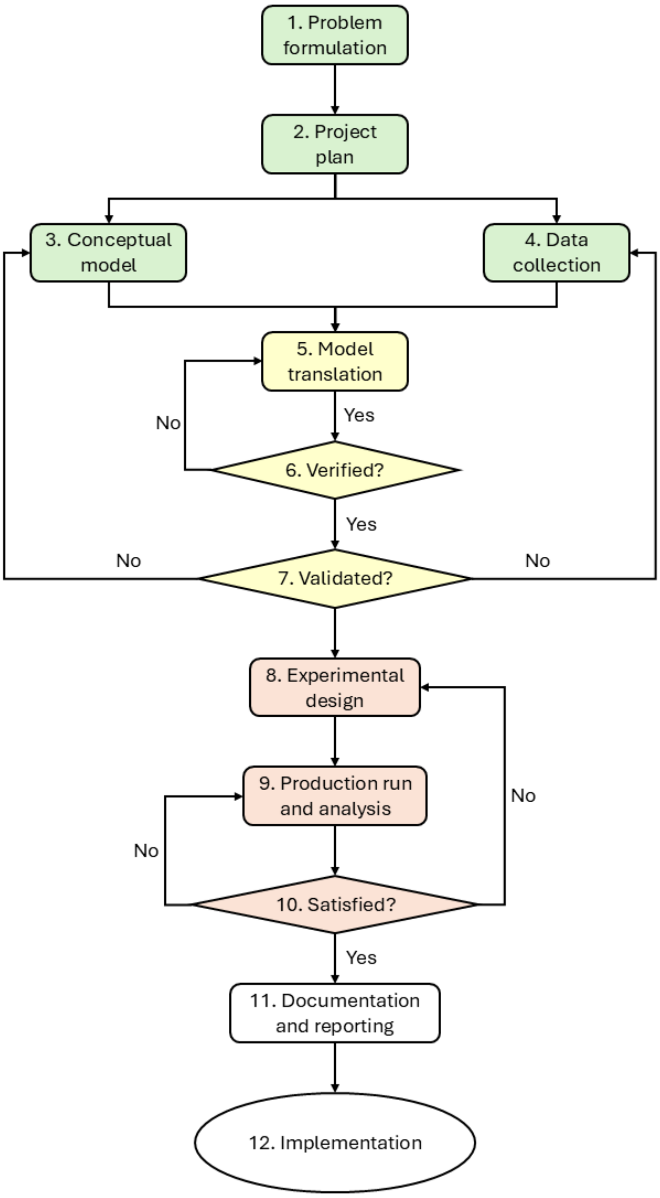


Figure 2.1: Banks model. Created based on similar chart in [19]. Green steps belong to the *Preparation*, yellow steps belong to *Model building* and red steps belong to *Analysis*.

5. *Model translation*. With the help of step 3 and 4 the conceptual model will be

translated into code, into a so-called operational model [19].

6. *Verified?* Verification is important for the whole process as it helps make sure that the operational model performs as indented and represents reality in a good way [19]. The verification process should be a continuous process during the building of the model as it will be easier to discover issues in time and take care of them [19].

7. *Validated?* Similarly to Step 6, validating the conceptual model makes sure it is a good representation of the real-world system. The validation step wants to answer the question ”Can the model be substituted for the real system for the purposes of experimentation?” [19].

8. *Experimental design.* When designing an experiment or test there are some aspects that needs to be considered. There must be a decision about the time-length of the simulation, how many replications of the run should be made and how the initialization is conducted of the run, for example warm-up time [19].

9. *Production run and analysis.* It is in this step where the simulation is performed. From the simulation runs, different measurements, such as throughput, are compared and analyzed [19].

10. *Satisfied?* In this step it is up to the developer to decide based on the analysis of the runs performed if more runs are needed or if there has been enough data gathered [19].

11. *Documentation and reporting.* Documentation of the experiments run and how the model is built up is necessary to create an understanding of how the model operates [19]. This can for example be helpful if the model would be needed to be modified in the future, helping a new developer understand the code the model is based on. The different analyses done should also be documented and reported. It is important the result of the analysis's are written concisely and clearly [19]. This is to help the review of the scenarios addressed in the simulation and compare the alternatives tried and the recommendations based on the different alternatives.

12. *Implementation.* With the help of the documentation made in the previous step a decision can be made on what should be implemented in the real world system. The more the developer have followed Banks model steps the higher the likelihood is that the implementation is successful [19].

2.2 Production

Production can come in many shapes or forms. Although, it can be described as a procedure that converts specific inputs to wanted outputs [22]. In the late 18th century, the first industrial revolution came to life through the rise of steam engines and water powered wheels. These new engines made it possible to produce more, without needing as much manpower. At that time, the machines were mainly used for textile, coal and iron manufacturing. Then came the electricity, which led to the second industrial revolution later in the 19th century. Electricity was a game changer as the main energy source for manufacturing. During this time, the first production line was introduced, which made it easier and affordable to produce more, leading to the forthcoming of mass production [23].

The third industrial revolution took place in the upcoming, namely the 20th, century. During this period, the manufacturing industry advanced with the help of computers and electronics. This allowed for the start of automatization in manufacturing, for instance machines, and even faster production with increased reliability [23].

Late in the 20th century, the internet came and brought a new way of sharing information. This changed the way of manufacturing in numerous ways, and led to the fourth industrial revolution in the early 21st century, also called Industry 4.0 [23]. Industry 4.0 is characterized by the digital transformation within production, such as artificial intelligence (AI) [23], further automation, robots, internet of things (IOT), cyber physical systems (CPS), virtual reality (VR) and simulation [24]. The later mentioned CPS and VR are significant for Industry 4.0, allowing for the physical world to interact with the digital world. Additionally, a centerpiece of this era is the theme of customization [23]. Today, the concept of Industry 4.0 is widespread and also implemented [1].

Moving forward, the manufacturing industry will undergo the fifth industrial revolution, that is Industry 5.0. The achievements and opportunities made possible during Industry 4.0 will be further developed and utilized. IOT will play a huge role, since machines will network with computers, making smart factories possible. Humans will also be of importance in Industry 5.0 as they will be working with collaborative robots. Sustainability will also become more relevant, both regarding the workers and the planet [23].

2.2.1 Space production

As previously mentioned, in section 2.2, the manufacturing industry has evolved over the years and is now positioned in Industry 4.0. The space industry is no different, in the context of developing. Specifically, space industry as a whole is entering a new era called Space 4.0 [1]. The world is depending more on connectivity, and so is the manufacturing industry. Therefore, the demand of satellites from costumers is increasing fast. Space 4.0 means that a larger volume of satellites will have to be produced within a shorter time frame than before, which involves innovations regarding the production processes. Additionally, satellites are of a complicated structure that at the same time needs to be of great quality in order to fulfill their purpose [1].

The final assembly of the satellite is a step in production that requires high precision, since it is directly influencing the ultimate quality of the product. Due to this, the final assembly of satellites has previously been made in a fixed position layout [25]. Nowadays, with the increasing demand of large number of satellites, mass production is called for [1]. Additionally, satellites are produced to operate in space, which demands high accuracy of the production as well as many evaluation processes carried out on the product. Producing higher volumes of satellites, in shorter times, may require an assembly line in motion instead of being fixed, which can be challenging for manufacturers [25].

On Board Computer

An OBC is a complex hardware containing electronic parts, whom are required to be tolerant for pervasive radiation that is present in space [26]. Producing an OBC for satellites also demands that this structure should manage the thermal variations that emerges in the environments in which products operating in space, for instance satellites, are put through. Meaning that the products need to be of high quality [27].

The OBC is an essential part of the satellite as it controls, among other things, the functions and communication to and from it. Therefore, they also have to be dependable [28]. Adding to this, the structure of and the contents within the OBC has to be able to endure the immense vibration that appears during take off [29], as well as withstand operating in vacuum [27].

2.2.2 Manufacturing strategies

The manufacture strategies presented here correlates with different customer order decoupling points (CODP), meaning the point in time when a costumer is connected with a certain product being produced. The strategies explained below are engineer to order (ETO) and make to order (MTO) [30]. Both of these strategies enables a CODP that is positioned in advance of the production starting [31]. There exists plenty of other manufacturing strategies [31], but as described in section 1.4 this project is limited to only describing the manufacturing strategies that are relevant for the scope. The current strategy is a mix of ETO and MTO, while the strategy of the future production will only be MTO.

Engineer to Order: Within the strategy of ETO, customers are involved early in the process of making the products, meaning that products can be special designed for every customer [32]. This strategy is often applied when making complex products [33].

Make to Order: This approach means that the production starts subsequent to receiving customer orders [32]. Therefore, materials or tools necessary for production needs to be stored at a place where it is easily accessible, in order for production to be ready [31].

2.2.3 Production Layout

In this section, some of the most commonly used production layouts are introduced. The selection of these production layouts is determined by the scope of the project, as explained in section 1.4. As for now, the layout of the current production is a mix of fixed position functional layout, while the future production will be a mix of a batch flow and a functional layout.

Fixed Position

A fixed position layout is suitable for producing small volumes of complex or big products. Instead of having a production in motion, moving the product to certain stations, the operators and material moves to the product being produced. Since the products may be complex, there is usually no standard in the task descriptions, which also leads to the need for experienced operators [34]. Figure 2.2 shows an example of how a production with a fixed position could work.

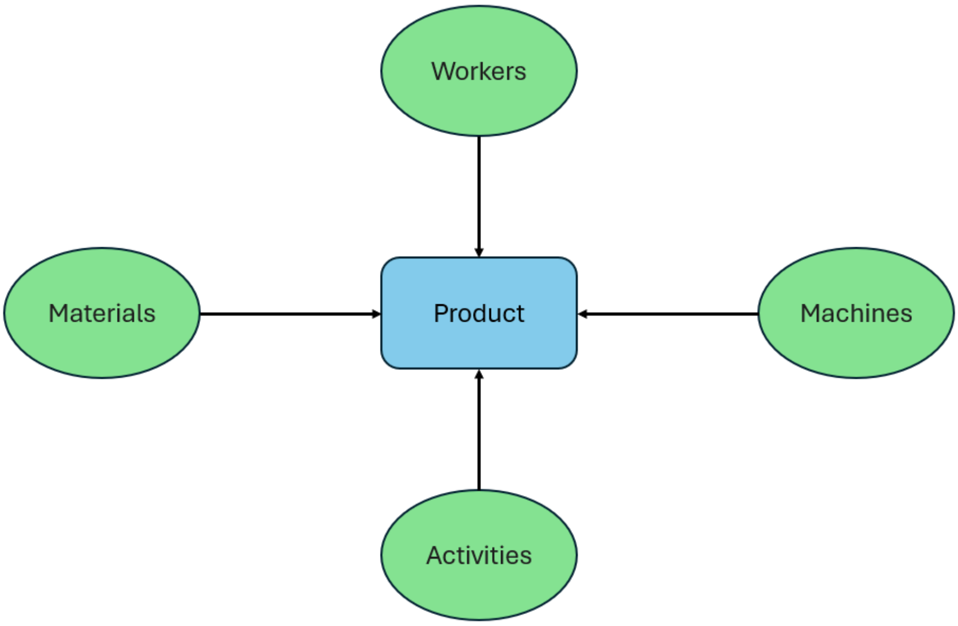


Figure 2.2: A production with a fixed position layout

Functional

Functional layout is common when there is a great variation i products, which are produced in low quantities. In a functional layout, tools or machines are divided into groups of operations, where the machines or tools with related operations are sorted into the same group. Additionally, this type of flow is common to use when producing new parts [34]. The figure 2.3 visualize how a production with a functional layout could look like.

The machines can either be working, failing, or idle. A machine is working when it is operating normally, otherwise it is failing and must be under repair. Machines that are under repair can cause blocking of the flow upstream and starving of the flow downstream. The machines that are blocked or starved are idle, and can not operate normally due to lack of space or products [35].

This type of layout may increase the flexibility of the flow, since production can be planned and executed on unfilled groups of machines or tools, while others are occupied. The downside is that waiting time might occur between different processes, and if disturbances in machines arise it can lead to blocking or starving the flow. This can ultimately affect the performance of the system, such as throughput time, quality and delivery [34].

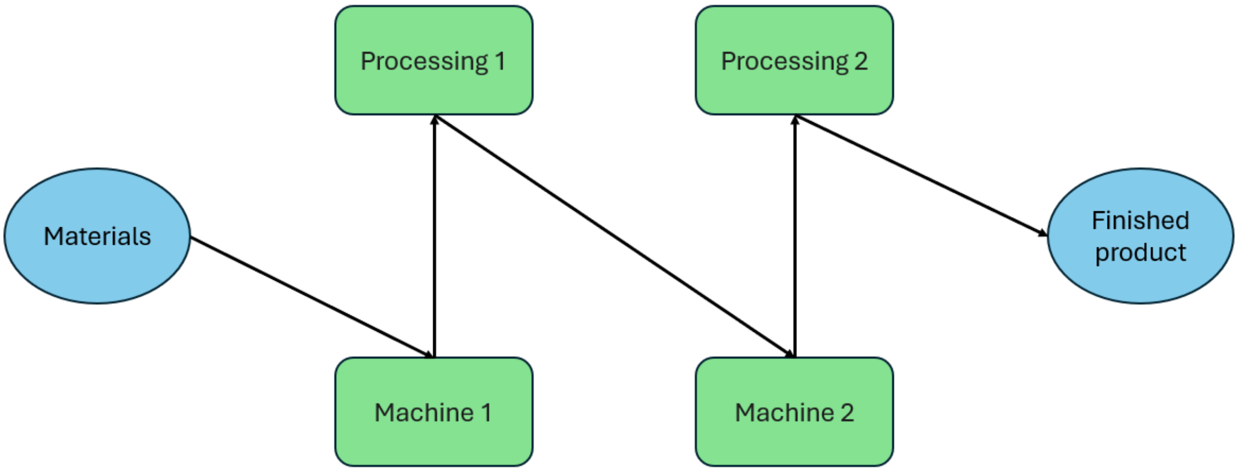


Figure 2.3: A production with a functional layout

Batch Flow

This type of layout may also be named a ”cell-layout”. It is organized after the direction of the production flow, and machines are placed out accordingly. It is often used for production of multiple variants, high quantities and products with longer throughput time. Batch flow layout aims to create a serial flow of the products produced, and therefore it is necessary to have short setup times in order to enable the flexibility required to produce the different product variants. Moreover, it is desirable to place costly machines in the start of the flow to make sure that they are used as much as possible, while cheaper machines can be placed further downstream. This is done to utilize the capacity of the expensive machines, and prevent starving or blocking which may occur downstream in the production flow [34]. An example of how a production with a batch flow can look like is shown in figure 2.4.

Using this typ of flow layout requires the different product types to be divided into batches, which can be challenging if there is no suitable batch for certain products. On the upside, it is common to have fewer workers than machines and to allow workers to take turn on tasks, which creates a higher expertise and accountability [34].

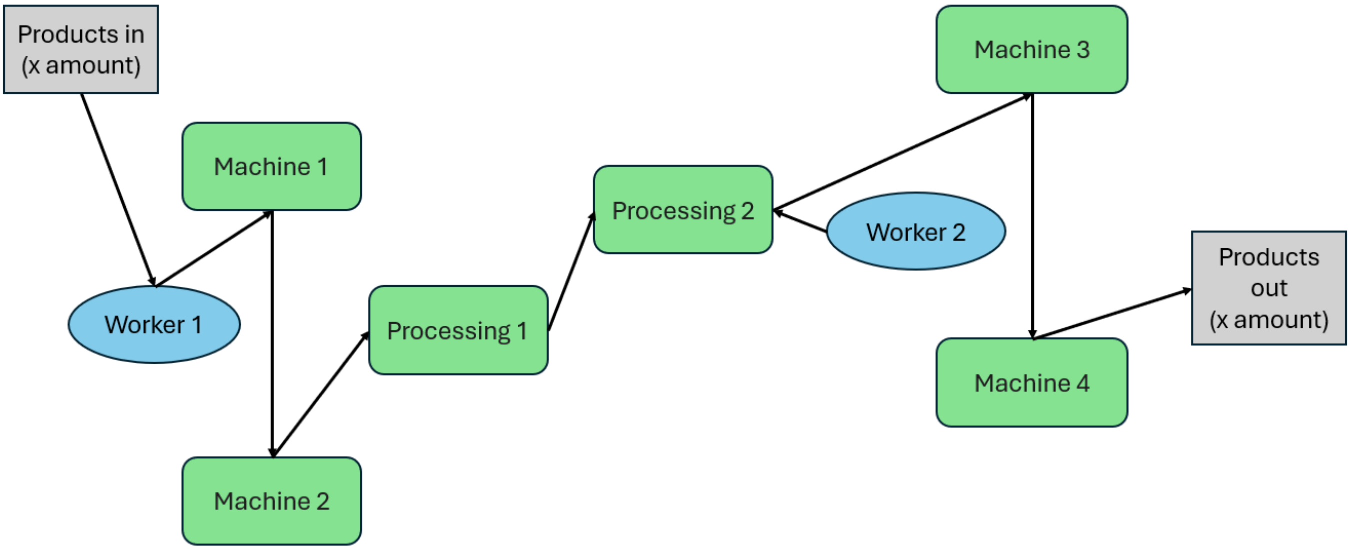


Figure 2.4: A production with a batch flow layout

2.3 Sustainability

Sustainability within manufacturing works towards making the resource consumption more efficient and effective by minimizing waste and emissions [6]. It is often misconceived that sustainability only revolves around the environment. However, sustainability not only includes the environmental aspect but also the economic and social aspects as well [36]. These three aspects forms together the TBL. The TBL is a concept for evaluating the impact an organization has on sustainability, and can be used to push companies to be more sustainable [36] [37]. It consists of three ”bottom lines”, which are the social, economical and environmental [6]. These ”bottom lines” are interdependent in a way that the social is subject to how the economy is, but the economy is subject to the environment. This means that the environment is the bottom line that ultimately affects the other two bottom lines [37].

TBL is a concept considering many aspects of sustainability, and it can consequently be difficult to measure exactly how sustainable a company is. Therefore, TBL is used to evaluate if a company is moving in the path of becoming more sustainable [37]. When looking from the perspective of the economical aspect, TBL relates to a organization's business practices impact on the economical system [36]. From the environmental aspects perspective, TBL refers to how an organization engages in practices that preserve environmental resources for future generations [36]. From the third aspect, the social, TBL refers to an organization's engagement in beneficial and fair business practices that benefits labor, human capital and the community [36].

2.3.1 Workers in Production

Within production, the social aspect of TBL can be interpreted as the worker within the production. For instance, this could be the workers, their work organization, the technologies used, the safety and the ergonomics at the workplace [38].

A significant part of the well-being of workers in production is ergonomics. This includes the physical, cognitive and environmental ergonomics at the workplace. The physical part of ergonomics means, for example, risks, safety, postures and reiterative work. Cognitive ergonomics is more about how the workers can interpret the processes. It can, among other things, be about visualization of information, attention span, workload and work instructions [39]. The more complex the tasks is, the more important cognitive ergonomics becomes. This is gaining attention nowadays, since production as a whole is moving more towards CPS and thereby demanding workers to handle more information about processes which increases their workload mentally. Moving on, the environmental part of ergonomics is about the surrounding factors that may influence the workers ability to perform their job. Such factors could be the temperature, clatter and light setting [39]. Poor cognitive ergonomics can lead to disorganization, confusion, frustration, and mistakes being made. While poor physical ergonomics may cause pain, harms to the body or feelings of distress [7].

It is common that manufacturing companies lack behind in investing in their immaterial resources, such as workforce, while investing more in physical means. The risk of this is that the workforce is not able to develop in the same speed as other parts of the organization, and the company can further have a hard time reaching their long term goals [38]. Research has even suggested that it is of high importance to build a company that takes the humans into consideration, if the company wants to succeed [38] [40].

The work within a production can be of various kinds. It could, for instance, be having several shifts, one during the day and one during the night. No matter how the production work is set up, the workload for the operators working in production needs to be even. If it is not even, there is a risk that the workers will have a hard time completing the tasks, both mentally and physically, and it is possible that the workers motivation for achieving the goals of the production decreases. Additionally, uneven workload could lead to stress among the operators [38].

To perform their work in production, it is also important to have the right equipment at hand. This could be, for example, tools or technology that supports the tasks they are performing. Moreover, when determining the use of tools or technology, it is of high significance to bear in mind that everyone is different. For instance, there could be a variation of expertise or experience between the workers. It is therefore important to strive for meeting the need of all of the workers. If the need of the workers is not met, the tasks might be harder och more complicated to complete, possibly leading to uneven workload. Additionally, if the workload between the workers is uneven, there is a risk that the tools are used in different ways or not used the way they are intended to [38].

2.4 Key Performance Indicators

In this section, the KPI's that will be used during this master thesis will be described. These indicators were chosen based on the research questions asked in this thesis. A KPI can for instance be described as a mean to provide vital information that explains and conveys the progress of a company towards a stated goal [41]. The measurements of the KPI are often stored in a database where they later can be compared to each other to easier understand the progress towards the goal or compare two results against each other when for example doing improvement work [41]. Almström et al. [41] states that there are three major purposes of a KPI, they are report, control and improve. The purpose of reporting can for example be benchmarking and to make sure the company follows the legislation. The purpose of control is to make sure that a measurement is within an acceptable limit. Lastly, the purpose of improve is to help indicate if an improvement has improved the system or not.

Almström et al. [41] recommends using the tool SMART objectives when creating KPIs. SMART stands for Specific, Measurable, Assignable, Realistic and Time-related.

- Specific - The specific area of improvement.
- Measurable - Indicator of progress.
- Assignable - Who will be responsible for it?
- Realistic - With existing resources, be able to realistically achieve results.
- Time-related - When can the results be achieved specifically?

Apart from the KPI's presented in table 2.3 this thesis will also investigate the social sustainability of the production at the company. Within the aspect of social sustainability, the approach could be to examine how the work environment is for the operators now, and how it may change in the future production. One way to examine this is to measure the *Number of accidents* that has happened during, for instance, one year. Although, social sustainability may be difficult to measure in the SMART approach, as it can depend more on subjective interpretations. Therefore, the social sustainability is not included much among the KPI's in table 2.3.

2.4.1 Sustainability

There are many ways to measure how sustainable a production is [41]. When deciding what kind of KPI to use when measuring out of a sustainability perspective, there are some aspects that needs to be considered. For instance, the chosen KPI needs to cover one of the three TBL aspects [41]. Another aspect that needs to be considered is that the KPI should be measured by using standards and best practices.

KPI	Explanation
Throughput	How many products are produced each week? [22]
Average WIP (Work in Process)	On average, how many parts is being processed in the production, including parts in buffers and stores? [42]
Total Energy Consumption	What is the energy consumption per product?
Scrap	How many products are scrapped during one year, and what are their values?
Finished products	How many products are finished in one year, and what are their values?
Number of accidents	How many accident has occurred in one year in the production?

Table 2.3: KPI's that are relevant during the research of this master thesis

Social
From the perspective of social-aspect in TBL, safety is important as it is of significance that the employees feels safe at their workplace. One example of a KPI that can be used to measure safety is number of accidents with an injury [41]. This is a KPI too keep as low as possible to reach the goal of a safe workplace.

Economic
There are several ways to measure the profit of a company or production with a KPI. Throughput rate is such a KPI, it measures how how often a production system can deliver a finished product [41].

Environmental
KPIs that help measure how a company is performing from an environmental perspective often measure the consumption of material or how much emission the production system releases. Example of KPI used for this types of measurements are how much waste, such as scrap, a production system produces [41]. Another is the energy consumption which measures how much energy is used [41].

2.5 Simulation Input Data

When working with DES-modeling and simulation there are design parameters and input data that needs to be provided [43]. Depending on the software and which technique is used the design parameters and input data can vary [43]. In Table 2.4, below, the design parameters needed for the tests that will be performed in Tecnomatix Plant Simulation during this thesis will be presented [18].

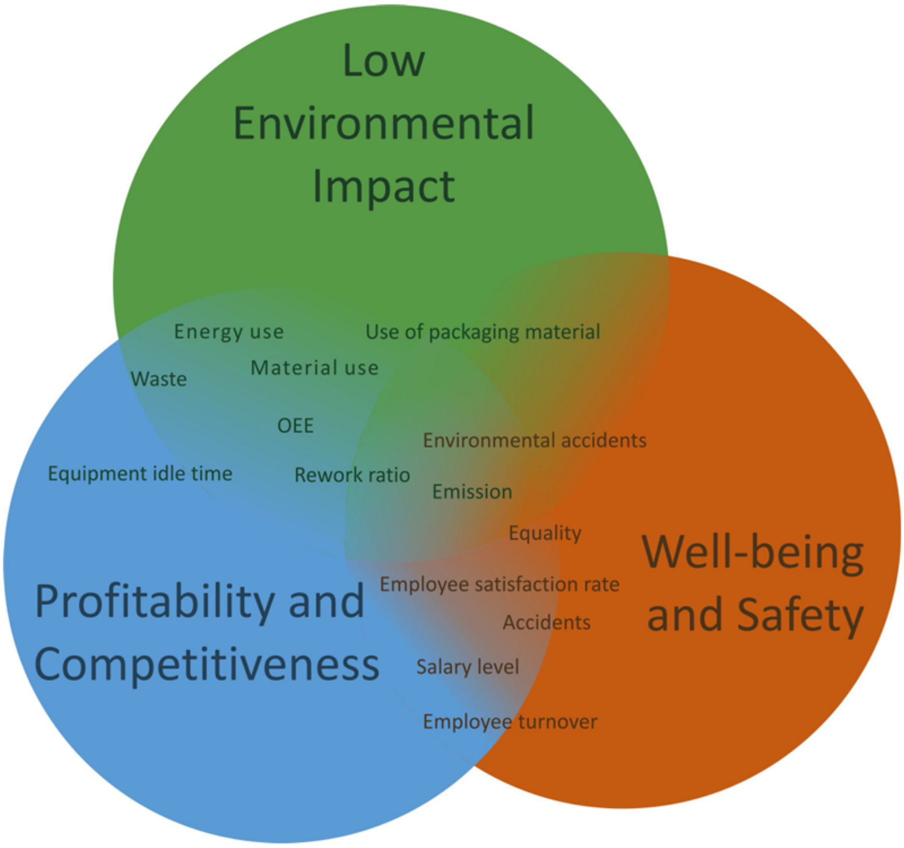


Figure 2.5: Examples of different KPI belonging to the TBL [41]. Reprinted with permission from the publisher.

Input Data	Explanation
Cycle time	The time it takes for a machine or workstation to perform a full task.
MTBF	Mean Time Between Failure. Describes the pattern of distribution in the production, that is how often a failure occurs. Could represent machine failure, mistakes made during assembly etc.
MTTR	Mean Time To Repair. Describes the time it takes to fix or solve failure that may arise during production.
Set-up time	Describes the time it takes to prepare a station.
Recovery time	Describes the time it takes to take care of a station after it has produced.
Material arrival time	Meaning the time when the material arrives to the area of production, the material could arrive in batches.
Production schedule	Explains when the production is active or at least when the operators will be actively working.
Energy consumption	Describes the amount of energy a workstation or machine consumes. Can both describe the consumption when the machines are in standby or when they are working.
Capacity/Batch size	Describes the capacity of buffers and stores. Also describes if a machine can work with batches and how large those batches can be.
Variation	Variation concentrates on the calculated divergence of the output compared to the scheduled output. Variation will always be present in all processes, and it can either be random or not. Although, all variations ultimately impact the capacity negatively [22].

Table 2.4: Data parameters that will be used in the simulation model

3

Methodology

This chapter will describe the methodology that has been used during this master thesis. Since the project included creating a DES model, Banks model was used for the overall methodology. Consequently, the outline of this chapter will follow the framework of Banks model. However, as the scope of the project was limited to creating a model of the future production system, and not to optimize it, not all steps of the model was used. The steps that was used mainly belonged to the Preparation and Model building steps in Banks model [20]. The project used some of the steps from the experimental design phase to create data that could be used by the company to verify the model as well as to help collect data for the sustainability comparison. As shown in Figure 3.1, the steps one to eight in Banks model were utilized.

The chapter is divided into seven sections, and their respective subsections. Step one to eight, applied in this project, from Banks model will be introduced in section 3.1 to 3.6. Section 3.1 includes step one to two in Banks model, creating a foundation for the project through a literature review. Next, in section 3.2, step three in Banks model, the process of making the conceptual model is presented. In section 3.3 is the fourth step within Banks model and this includes the methodology used for collecting data. After the data was collected, the next step in Banks model is the model translation, which is section 3.4, where the simulation model is built. Then, the model should be verified and validated according to step six and seven in Banks model. This process is further described in section 3.5. After the verification and validation, step eight in Banks model was carried through which is presented in section 3.6. In this section, it is described how the experiments were designed and conducted within the simulation model.

After step one to eight in Banks model were carried through, an additional part of the methodology for this project was the post processing of the data gathered. This is presented in section 3.7. The post processing of the data collected means that not all data from the current and the future production were of the same kind, and therefore needed some additional refining. The reason for this was to make the data from the current production and the future production comparable.

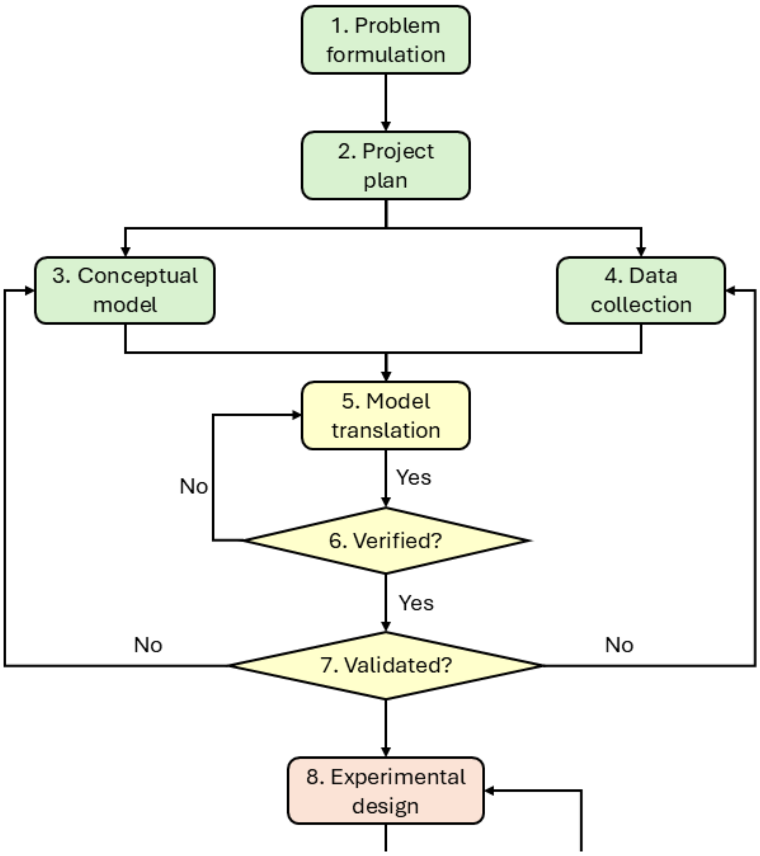


Figure 3.1: The steps in Banks Model that were used when creating the base model

3.1 Theory Building

This section is conducted through the first two steps of Banks model, problem formulation and project plan. The problem formulation is stated in chapter 1, along with the research questions for this project. The company is facing changes in their production, and a DES model of their future production as well as a comparison to their current production is of interest. Therefore, the plan of the project was to create a DES model of their future production, and to compare the results from the model with their current production, from a sustainability perspective.

Additionally, in order to build a solid theoretical foundation for the project, a literature review was conducted. Its content was based on literature from previous courses taken by the authors on the subject. Other literature was found using backwards snowballing exploring literature referenced in other studies and master theses with similar scope, and narrative literature review using the Scopus database. The narrative literature review process is further described below.

3.1.1 Literature review

To find relevant literature on the subject of DES and sustainability in manufacturing a narrative literature review was selected, as it allowed for a broader scope of publications to be reviewed and form the theoretical frame of reference [44]. The narrative review is characterized by four steps, from looking for literature to evaluating their contribution to the written text [44]. These four steps are:

1. Finding suitable material [44]
2. Hand picking information from the material [44]
3. Incorporate these in written text [44]
4. Evaluate the contribution of the material [44]

The search strings used to find information in Scpous can be found in Table 3.1, which shows the combinations of keywords with the boolean operators AND and OR. After using these search strings, the results in Scpous were also sorted by either ”Relevance” or "Cited by (highest)”.

Search strings		
”tripple bottom line”	AND	simulation
”discrete event simulation”	AND	production
”space industry”		
workers AND industry AND ”social sustainability”		
”mass production”	AND	”customized production”
production	AND	”space 4.0”
”satellite production”	AND	sustainability
workers AND production		
”mass production”	AND	”space industry”
”on board computer”		
”on board computers” OR ”on-board-computers” OR obc OR ”onboard computer”	AND	space
”on board computers” OR ”on-board-computers” OR obc	AND	satellite
”on board computer”		
mto OR ”make to order”	AND	eto OR ”engineer to order”
”order based production”	-	-

Table 3.1: The keywords and the combinations they were used in, creating the search strings for the narrative review

Additionally, the function Scopus AI was used. This was only made use of with the intention of getting an overview of existing literature, and the search result in Scopus AI was used as guidance for the authors to find suitable literature. In other words, the in text result generated from Scopus AI was never cited directly. The material provided through this tool was carefully read through before determining if it was relevant for this thesis or not.

When suitable material was found, the next step in the narrative review was to handpick information. From the literature found during the first step, relevant information was selected and put into a separate sorting document, where a thematic analysis was carried through in order to identify relevant information [45]. The document contained four different categories called ”production”, ”DES”, ”sustainability” and ”space 4.0/ industry 4.0”. The hand picked information was therefore sorted into the category which was most suitable.

This document was then the basis for chapter 2, where information put into the document was picked out and assembled into a new text, which was the third step within the narrative review. This process is visualized in Figure 3.2, and includes the first three steps in the narrative review.

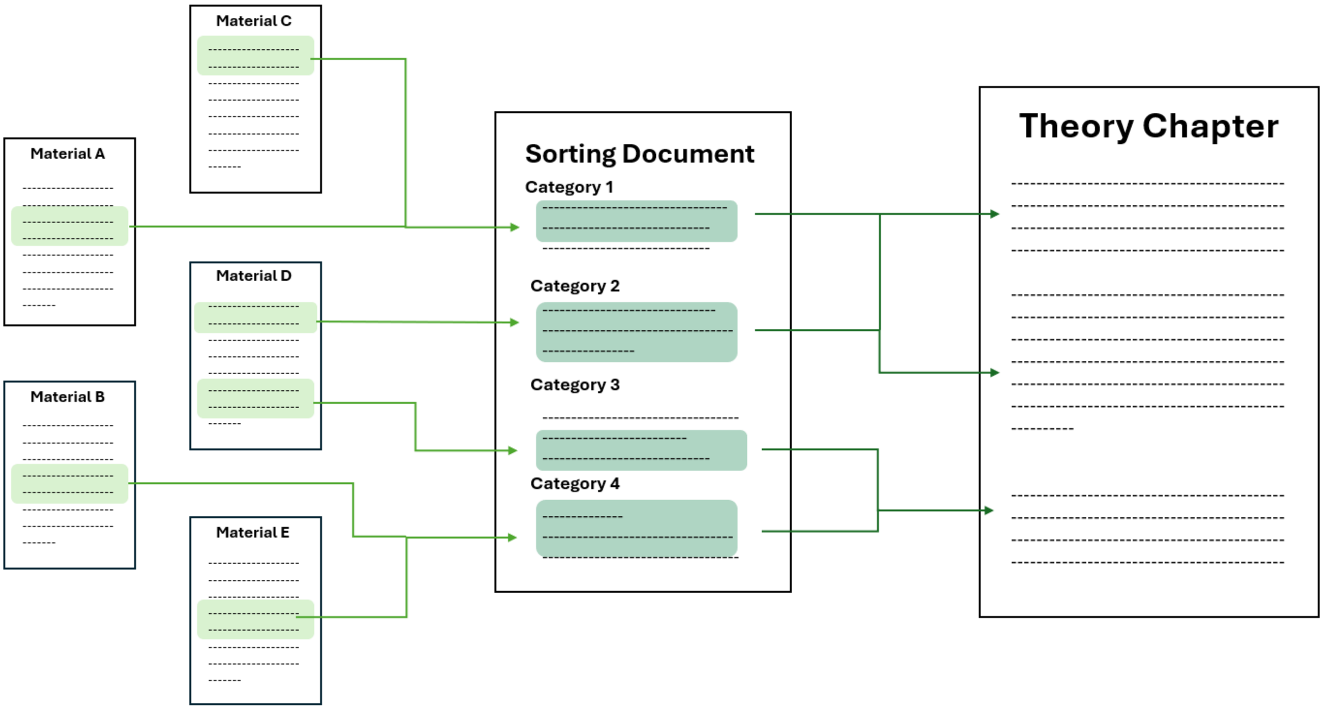


Figure 3.2: The methodology used during step one to step three within the narrative review

When the material had gone through the process shown in Figure 3.2, the last step of the narrative review was to evaluate the contribution of the material. This was done through a discussion in Chapter 5.

3.2 Conceptual Model

With the theoretical foundation in place, as well as the problem formulation and the plan of the project, step three in Banks model was to create the conceptual model of the future production at the company. The conceptual model worked as a foundation for the later built base model.

Some information was necessary to gather in order to create the conceptual model. This was done through having initial informal meetings providing an understanding of the layout and the flow of the future production at the company. When the information needed was collected, the conceptual model was created in PowerPoint. The reason for this was to be able to make use of different visualization tools, making it easier to distinguish different parts of the production from others and visualize the production flow.

Moreover, when the conceptual model was finished it was obvious that additional information and data was necessary in order to create the simulation model of the future production. The process of collecting additional data for the simulation model will be further described in the next section.

3.3 Data Collection

The fourth step in Banks model is the data collection, and in this section the methodology for data collection is handled. The collected data was the input for the DES-model of the future production. The input data for the model was gathered from experts within the area at the company, both through qualitative interviews, personal communication and an existing Value Stream Map (VSM) of the future production. In this section, the way the data was collected will be described in chronological order.

The first step was to understand how the future production would look and how different stations were connected to each other. For gathering this knowledge, personal communication was used. When this was done a conceptual model was created. The conceptual model was further used as the basis for the layout of the simulation model.

Since the current production at the company was conducted in a fixed position, the next step was to analyze where the operations would be located in the future production. The majority of the operations from the current production, and their respective times, were documented and provided by the company in an excel sheet and edited with the help through personal communication with one of the experts at the company.

The times provided came from the operations done when producing a similar product in the current production. These were combined in the excel under the stations they were planned to be performed on, in the future production, more of this will be explain below. Furthermore, the excel document with times for the operations contained two categories of times, namely ”Planned man hours” and ”Actual man hours”. The ”Actual man hours” were based on the workers own time reporting, while the ”Planned man hours” were based on estimations made my production planning experts at the company. The decision was made to not use the ”Actual man hours”, because of the knowledge that of the large variations, depending on which worker is working. It was decided to use the ”Planned man hours” with a standard deviation in Plant Simulation, along with maximum and minimum values. In consultation with the expert that provided the times it was concluded that the times could be used in a normal distribution where 20% of the time could be used as the standard deviation. The 20% standard deviation was chosen to emulate and simulate the large variation in how long time it takes to finish a task in the current production [15]. Moreover, some of the operations in the current production did not have a time documented in the excel sheet. Therefore, these specific operation times were collected from further personal communication with other experts at the company.

When the data regarding the planned times for the different operations were collected, the process of pairing the operations to the stations in the future production began. In the current, fixed production, most of the operations are done at the same station. Figure 3.3 illustrates how the work was done. This was an iterative process, having several meetings with experts within the company to confirm that the operations were at the right place in the future production.

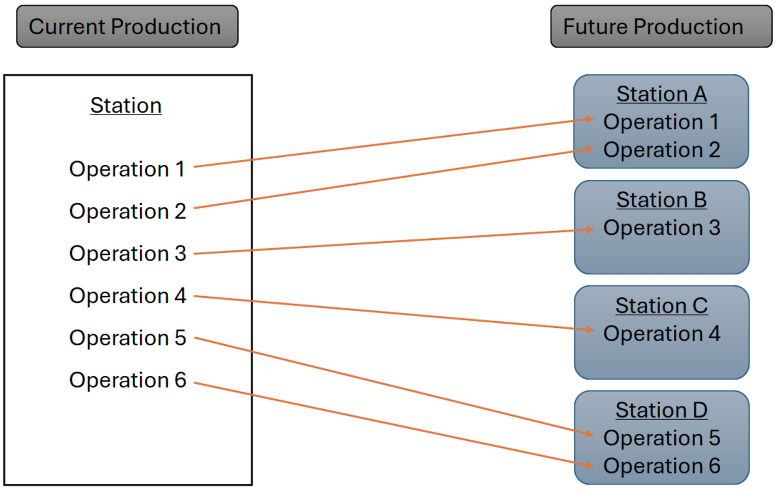


Figure 3.3: Shows the way operations from current production were paired with their station in the future production

The company had in the past collected times on the operations in the current production setting. However, these were according to the company not reliable as the variance was very high due to how the time reporting was performed. Due to time constrictions it was decided to not perform a time study. According to the company the planned man hours were more accurate for the future production and they were therefore chosen for this project.

Other information that would be used for input to the model, such as material flow and number of workers, were gathered through an interview, further described in section 3.3.1. Lastly, through personal communication with an expert at the company, the working times for the shift in production was clarified.

3.3.1 Interviews

Three qualitative interviews were conducted, named Interview A, Interview B and Interview C. The questions asked during the interviews were prepared in advance. For Interview A and Interview C, a semi-structured approach was used. The reason for having semi-structured questions was to allow for a discussion during the interview, possibly providing additional insights and not making the scope of the interview too narrow [46]. Interview B was conducted through a structured approach, in order to get specific answers in a narrow scope [46]. Additionally, some of the interviews were conducted in groups, making it possible for participants to interact with each other [47] and possibly leading to further findings [46].

The groups consisted of experts within different parts of the production at the company. The amount of interviewees and the roles of the experts will be explained further down. Since the the future production was still at the state of planning, it meant that several people at the company were involved in different areas of the planning. Therefore, by interviewing some of these experts involved in the process could give more insights in the area. The choice of making interviews with groups of experts was based on the need to form a better understanding of the future production. Adding to this, the interviewees also had much experience of the current production.

Interview A was held early in the DES modeling phase to get information necessary for creating the base model, since the basic knowledge needed for the conceptual model had already been gathered. Therefore, the focus during this interview was to get more details about the future production. Prior to this interview a PowerPoint was created to present an introduction of the scope of the interview for the interviewees. The questions that were asked during Interview A can be found in Appendix A.

During Interview A, there were five interviewees invited and present. They were informed that the interview would be recorded by audio, and further on transcribed for this thesis report, which they agreed to. In addition, to assure their privacy, they were aware that anonymity would be applied to their identities in the transcription and in the report [47]. The five interviewees are presented in Table 3.2, anonymously, with areas of responsibility briefly described.

Interviewee	Responsibility within production
Participant 1	Assembly
Participant 2	Planning
Participant 3	Engineer
Participant 4	Planning
Participant 5	Inspection

Table 3.2: The interviewees, and areas of responsibility within production, present at Interview A

The second interview, Interview B, took place when the base model was created. The focus of this interview was to verify that the base model was acting in accordance to how the future production would operate in reality. Table 3.3 describes the interviewees that were present at this interview. The interviewees were informed, in the same way during Interview A, that they would be anonymous, and that Interview B would be recorded and transcribed. One of the participants in Interview B had also attended Interview A, and therefore has the same name as in Table 3.2.

Interviewee	Responsibility within production
Participant 1	Assembly
Participant 6	Quality
Participant 7	Test
Participant 8	Operations

Table 3.3: The interviewees, and areas of responsibility within production, present at Interview B

Since Interview B was aimed at validating the simulation model, a document was created and handed out to all attendees. This document consisted of information about what operations, and their corresponding times, were applied to which station in the future production. The reason for this was so that the interviewees could get a clear understanding of how the future production flow worked, and follow how the model was built, in order for the validation of the simulation model to be as accurate as possible. The questions asked during Interview B can be found in Appendix B.

Moving on, Interview C was the last interview. This interview was with one participant, namely Participant 6. As shown in Table 3.3, the responsibility of Participant 6 was quality. Although, this participant also had several years of experience working within the production at the company. The reason for choosing Participant 6 for Interview C was to gather information about the working conditions within the current production. The questions asked during interview C can be found in Appendix C. Additionally, Participant 6 was also informed that the interview would be recorded and transcribed, and that Participant 6 would be anonymous.

After the interviews had been conducted and recorded, they were transcribed and analyzed through thematic coding [45]. The coding was carried through in order to sort findings, from the transcriptions, into different categories [45].

Some data was collected merely through informal meetings and personal communications such as email. The reasons for the data collection being made this way was because it was not possible to ask all questions during the interviews. Additionally, the people at the company did not have time to have additional interviews, therefore informal meetings and quick communication were key to get complementary information.

3.4 Model Translation

When the data collection had been carried through, it was possible to create the simulation model. This is the fifth step in Banks model, called model translation. The DES model was created in the software Siemens Tecnomatix Plant Simulation [17]. The version of the software was 2203.0017 as it was the version available at the time of the beginning of the project.

The first step when creating the model in Siemens Plant Simulation was to create all the stations and give them the correct attributes and behavior that they would have in reality. Such attributes could be set-up times, processing times and how many parts each station can process at a time. Beyond the attributes, methods were created to help the model simulate the real life behavior of the stations and parts. The methods were commented to help debugging and give documentation for the company when the model will be handed over to them.

With the different time settings in place for all processes and stations in the base model, the workers were added. They were working in different groups, where the groups were assigned to different stations in the production. At first, the focus was to make sure that the material flow, and the workers, were correctly modeled. This was an iterative process, in which several meetings were held with the project supervisor at the company. When this process was carried through, the focus shifted towards making the base model layout and visuals more like how the future production would look in real life. During this part of the model building process, the shifts for when the workers were working, as well as the stations operated by the workers, was added. This was done in order to receive more accurate statistics from the stations. The last step in the process was to arrange the stations according to a proposal on how the stations would be arranged in reality.

3.5 Verification and Validation

After the simulation model was created, it had to be verified and validated. These validation and verification activities are in Banks model presented as two steps, namely step six and seven. In this project, the verification and validation was considered as one process, which was carried out iteratively during the time of the project. The verification and validation was conducted to make sure that the simulation model of the future production was acting like it would have in real life. How the validation and verification was conducted is further described below.

The DES model of the future production was validated and verified several times throughout the process. The verification and validation was performed both through informal meetings and through Interview B. The meetings were usually conducted with one person at a time, while the final validation was performed with experts within the production area at the company as a group interview, Interview B. How the interview was performed and structured can be found in section 3.3.1.

Prior to when the interview for validation and verification of the finished base model was held, the throughput of the base model was extracted from the simulation. This was done through a tool called ”Experiment Manager” in Siemens Plant Simulation. How the Experiment Manager was used is described in section 3.6. The focus when using the Experiment Manager prior to Interview B was to get the result of the throughput of the base model, which was further calculated as a throughput per week, as shown in equation 3.1. The reason why throughput per week was of interest was because the company already had established a target for the throughput each week for their future production. The throughput per week from the base model was then presented at Interview B.

$$\text{Throughput per week} = \frac{\text{Average throughput}}{\text{Weeks simulated}} \tag{3.1}$$

After Interview B, the simulation model of the future production was considered verified and validated by the participants in the interview. This meant that the model was acting like how the future production was anticipated to act. It was also possible to make the experiments required for this project, which will be described in the next section.

3.6 Experimental design

When the model was approved, it was decided that the model was ready for experimentation. This was the last step used in Banks model during this project, which is step eight that is called experimental design. In this case, experiments were performed on throughput, scraped products, WIP and energy consumption.

The tool used to perform the experiments was the ”Experiment Manager”. It can run several experiments on a model, and thereafter provide the results that the user has specified. Although, to get an accurate result from the models through the Experiment Manager, the model must be in a steady state. To get the simulation model to the steady state, a ”Warm up time” is necessary.

The Warm up time for the base model was determined through registering the throughput for every week, from day 0, until the throughput had become ”steady”. That is, the fluctuation of the output had become steady after a certain amount of time. This was done by plotting the throughput for every week against time in an excel document that made the plot from the input data. The time interval was 4 weeks (28 days). With the Warm up time established, the next step was to change the settings so that that the Experiment Manager should start the simulation experiments when the Warm up time had passed.

Additionally, in the Experiment Manager, the number of observations needed to be specified. The number of observations will determine how large the ”confidence interval” will be of the result of the Experiment Manager. As stated in section 2.1.1 the smaller the confidence interval is, the more accurate the result is. The confidence level was chosen to be 95% which gives a critical level of 1.96. The Experiment Manager was run several times with different number of observations before determining a good amount of observations that gave a reliable confidence interval. When the number of observation had been determined, it was entered into the Experiment Manager.

After the Experiment Manager was setup, the first experiment run was the throughput of the model. This was done by connecting the ”drain” to the Experiment Manager module in the model and starting the experiment. Furthermore, the different part-classes representing the different stages of the final unit and it subparts were connected to the experiment manager to get the average WIP in the production flow. The results would then be presented in an ”experiment report” created by the program. All the stations added to a chart that showed in percent how much of their time was spent in waiting, operating and blocked-mode etc. The workers was connected to a similar chart that show how much time they spent working, waiting and transporting etc.

An additional experiment that was created was how large the energy consumption of the production line was. This was done through the model ”EnergyAnalyzer” in the program. All the machines that had energy data was connected to this module. When the simulation then ran, the results showed up as a chart in the program, showing the energy consumption of the machines.

Moreover, to analyze the scrapped products of the production another experiment was set up. The parts that were scrapped needed to be evaluated since the products could have different costs, depending on how far in the production they had come before being scrapped. Therefore, the scrap-drain was connected to different variables that counted how many of each part that were scrapped and from what station in the production they came from. These variables were further included in the Experiment Manager to get a mean value of how many parts were scrapped and from what stations.

3.7 Analysis of Results

In this section the post processing of the experiments in the model will be presented, which is not included in the Banks model. The following subsections will describe how data gathered from experiment in the simulation model, interviews and personal communication was processed in order to conduct a comparison between the future production and the current production. Since the scope of this project was to compare the future and the current production from a sustainability perspective, the TBL approach was applied. Therefore, the following subsections will present the methodology of processing data regarding the energy consumption, cost of scrapped products, average WIP, and social aspect of both the future and the current production at the company. Moreover, some calculations considered the value over a year. In these calculations, the value of 220 work days for one year was used, which is equivalent to 44 work weeks.

3.7.1 Energy

From the simulation model of the future production, data regarding the energy consumption was gathered as described above. Data from the current production was processed to be comparable with the data gathered from the simulation model of the future production. This was done through calculating how much energy the machines in the current production used, and multiplying it with how often they were used.

The reason for the recalculation of the energy consumption was to make sure that the energy consumption from the current and the future production were both in the same unit, namely energy consumption per year. The recalculation was only necessary to do on the current production, since the energy consumption per year for the future production was provided through the simulation model. The formula used for calculating the energy consumption for the current production was as follows. Equation 3.2 calculates the energy consumption of any machine. Although, some machines might be used every day of the week, and some may not. Therefore, to calculate the energy consumption per day, equation 3.3 was used as well.

$$\text{Power [kW]} \cdot \text{Time [h]} = \text{Energy consumption [kWh]} \tag{3.2}$$

$$\begin{aligned}\text{Energy consumption [kWh]} \cdot \frac{\text{Runs per week [days]}}{\text{One week [days]}}\\ = \text{Energy consumption per day [kWh/day]}\end{aligned} \tag{3.3}$$

When the total energy consumption per day was calculated for each of the machines, it was multiplied with 220 days to get the yearly energy consumption for the corresponding machines. After that, these were added together to get a better understanding of the energy consumption in the current production.

3.7.2 Scrap and average WIP

The cost of each product in the different stages, for both the current and the future production, was provided through the company. The cost was calculated considering one year of production. As described in section 3.6, the number of scrapped products and from what station they came from was provided through the Experiment Manager. To get the cost of each scrapped product, the number of products scrapped were multiplied with their corresponding cost. The number of scrapped and finished products produced in the current production was also gathered through the company, and the cost for these products was calculated in the same way as above.

The average WIP was calculated for the future production through, as described above, with the help of the Experiment Manager. The average WIP from the current production was gathered through personal communication with the supervisor at the company.

3.7.3 Workers in Production

Most of the data and information about the workload and working environment for the workers in the current production was gathered from Interview C. The simulation model was able to provide statistics, as described in the previous section 3.6, such as utilization of the workers in the future production. This statistics together with support from literature was used when comparing the current production with the future.

4

Results

In this chapter the results of the data collection of the current and future production will be presented. Moreover, the simulation model of the future production is introduced. Adding to this, data and information regarding the sustainability aspects energy consumption, throughput, scrap and average WIP, and workers in production is presented.

4.1 Data collection

In this section, the result from data collection will be presented. Moreover, the presentation of the result is divided into two subsections, current production and future production, in order to easily distinguish the information and where it came from.

4.1.1 Current Production

From personal communication at the company, information about the current production was provided. They were producing one OBC every other week, and most of the operations conducted to produce an OBC were carried through at a work bench, by one worker. Additionally, two parallel work benches were used capable of producing two OBC at the same time in the current production.

As described above, most operations were conducted on one work bench by one worker. This was in line with the description of a fixed position production layout described in the literature [34]. Through further personal communication it was given that some operations, such as testing of the product, were conducted at other places within the production. According to literature, this would be more of a functional layout [34]. This means that the current production at the company was a mix between a fixed position layout and a functional layout. Figure 4.2 represents a visualization on the current production layout.

Producing an OBC at the company was conducted through a procedure that will here be described. First of all, there were two different types of cards within the OBC, called P and C. These cards were assembled into modules, called P-module and C-module. In the P-module there were two P cards and in the C-module there were two C cards. The modules were then assembled into the OBC, and this was then called a unit. In each unit there were two P-modules and one C-module. This information was also gathered from personal communication. Figure 4.1 is an exploded view of how a unit could look.

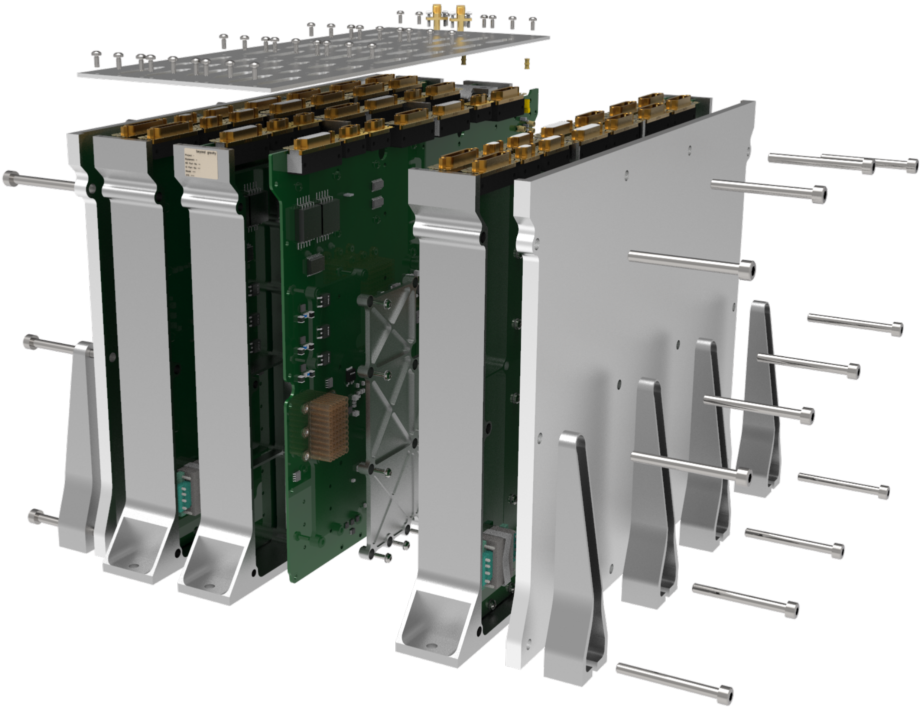


Figure 4.1: An exploded view of an OBC produced by Beyond Gravity

The operations that were conducted outside of these work benches were kitting, [redacted], [redacted] and [redacted]. The kitting was conducted manually by the worker working on the OBC. The test station were consisting of an oven that was connected to a test machine. Lastly, the [redacted] and [redacted] procedures also included using additional ovens, but the difference was that these procedures did not include any tests. Additionally, the [redacted], [redacted] and [redacted] procedure were activities that did not demand a worker working there during the processing. The worker only had to work, at the [redacted] and [redacted] station, during setup and after the part had been processed.

The figure 4.2 is a brief visualization of the current production at the company. It shows how the inflow of material goes to the work benches, where the worker performs most of the operations. At some points the product needs to go to other stations, undergoing processes that does not require a worker. Moreover, there are [redacted] ovens. These ovens are in figure 4.2 shown as one. The figure does not include the kitting process, which was conducted by the worker during some time periods throughout the current production process.

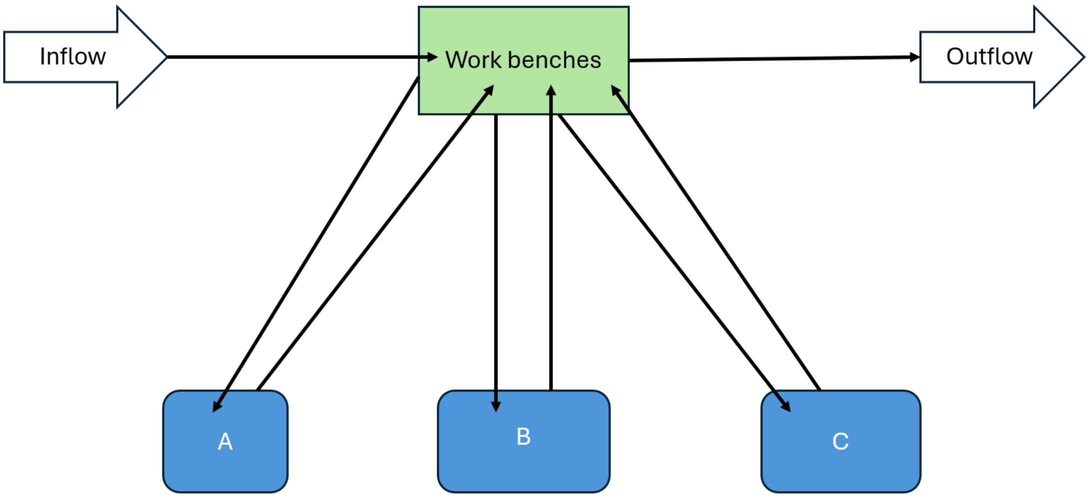


Figure 4.2: Visualization of the flow in the current production

Energy consumption
In the current production setup at the company there was no measure of how much electricity the production was consuming. Additionally, the work benches were considered to consume an insignificant amount of electricity. Therefore, in agreement with the company, it was decided to analyze energy consumption of the stations that were considered to consume the most electricity within the production, namely the [redacted], the [redacted] and the [redacted].

The [redacted] procedure was divided into [redacted] ovens. One was mainly used for P cards and the other for C cards. The ovens each had a total power of 6 kW, so the two ovens together had a total power of 12 kW. Additionally, it was estimated that each of the ovens were actively working 4.08 hours per day. The calculations were done accordingly to equations 3.2 and 3.3, whom are declared here through calculation 4.1. This resulted in the total power consumption of the [redacted] to be 48.96 kWh per day and 10 771.2 kWh per year.

$$\begin{aligned} &12 \cdot 4.08 = 48.96 \text{ kWh} \\ &48.96 \cdot \frac{7}{7} = 48.96 \text{ kWh per day} \\ &48.96 \cdot 220 = 10771.2 \text{ kWh per year} \end{aligned} \tag{4.1}$$

Moving on to the [redacted]. In the current production, there was one oven for this procedure. It had a total power of 6.3 kW and it was estimated to be working for 6 hours, three times a week. The calculations, declared in 4.2, gave that the total power consumption for the [redacted] was 16.2 kWh per day and 3 364 kWh per year.

$$\begin{aligned}
&6.3 \cdot 6 = 37.8 \text{ kWh} \\
&37.8 \cdot \frac{3}{7} = 16.2 \text{ kWh per day} \\
&16.2 \cdot 220 = 3364 \text{ kWh per year}
\end{aligned} \tag{4.2}$$

Lastly, the [redacted] was considered as one machine consisting of an [redacted]. The [redacted] had a total power of 15 kW and it was estimated to work 48 hours, once each week. The total power consumption was calculated in 4.3 with the result of 102.9 kWh per day and 22 638 kWh per year.

$$\begin{aligned}
&15 \cdot 48 = 720 \text{ kWh} \\
&720 \cdot \frac{1}{7} = 102.9 \text{ kWh per day} \\
&102.9 \cdot 220 = 22638 \text{ kWh per year}
\end{aligned} \tag{4.3}$$

The total annual energy consumption of the current production was estimated by adding the yearly energy consumption of the [redacted], the [redacted] and the [redacted] together. The result was 36 773.2 kWh per year for the current production.

Since there were 19 units produced in the current production during 220 days, the energy consumption per product was calculated. This was done through dividing the total annual energy consumption with the number of units produced in a year, giving the result of 1 935,4 kWh per product.

Scrap and Average WIP

The cost for the products at different stages in the current production are shown in table 4.1. The data of the costs were gathered through personal communication at the company. The reason for the increase in cost per stage is as the products move through the production flow the more parts and functions are added to the product, which increases its value. Since the value of the products increases throughout the production, the cost of scrapping products are also increased.

In one year, 220 days, [redacted] P cards and [redacted] C cards were scrapped. [redacted] P cards and [redacted] C cards were scrapped at the [redacted] step. The rest of the C cards and P cards were scrapped at the [redacted]. As shown in calculation 4.4 the cost was [redacted] SEK regarding the four scrapped P cards. The cost of the four scrapped C cards is calculated through equation 4.5 to be [redacted] SEK. The total cost of scrapped products in the current production was calculating by adding the cost of the scrapped P cards and C cards together, which resulted in [redacted] SEK.

Step in current production	Part	Scrap cost [SEK]
Pre burn in	C card	[redacted]
	P Card	[redacted]
Post burn in	C card	[redacted]
	P card	[redacted]
First inspection	C card	[redacted]
	P card	[redacted]
Second inspection	C module	[redacted]
	P module	[redacted]
Unit test	Unit	[redacted]
Final inspection	Unit	[redacted]

Table 4.1: The scrap cost for each product, depending on how far it had gone in the current production

$$\text{[redacted]} \cdot \text{[redacted] SEK} + \text{[redacted]} \cdot \text{[redacted] SEK} = \text{[redacted] SEK} \tag{4.4}$$

$$\text{[redacted]} \cdot \text{[redacted] SEK} + \text{[redacted]} \cdot \text{[redacted] SEK} = \text{[redacted] SEK} \tag{4.5}$$

Moreover, the average WIP in the current production was 29 parts. The value of the parts was dependent on what stage of the production they were in. The WIP of the current production is presented in table 4.2 with their corresponding value and the total value of the WIP. The value of the WIP-product are based on the scrap costs from table 4.1.

Part	Amount	Value of each part [SEK]	Total value [SEK]
C card	6	[redacted]	[redacted]
P card	12	[redacted]	[redacted]
C module	2	[redacted]	[redacted]
P module	4	[redacted]	[redacted]
Unit	5	[redacted]	[redacted]
Cumulative value of WIP			[redacted]

Table 4.2: The WIP, in the current production, with corresponding values

Workers in Production

In the current production, the workers were working in one shift. The shift was from 08.00 to 16.30 with 30 minutes lunch at 11.00. Additionally, they had two breaks between 09.00-09.20 and 14.00-14.20.

From Interview C, it was provided that the worker in the current production were working under much stress. This stress was caused by a high demand and many projects ongoing at the same time. Additionally, there were not enough workers to deal with the projects and tasks. The workload was too high. This led to stress, which further had led to mistakes in the production. The interviewee suggests that if the stress were on a more manageable level, the environment in the production for the workers would be better. Adding to this, the interviewee mentioned that the workers often get interrupted in their work. The interruption was often caused by a project of higher priority, causing the workers to pause and leave the work they were doing. This further led to the interrupted work taking longer time to finish.

Moreover, during the interview it was obtained that ergonomic tools were used in the current production such as microscopes. The interviewee highlighted the importance of using the microscope in the right way, to prevent injuries in the neck. Furthermore, the job in the current production was mostly done in a sitting position, also pinpointed as an ergonomic risk if the worker was not sitting correctly. On top of that, the interviewee raised a concern regarding the microscopes in the future production. In the current production, the workers had their own work benches and their own microscopes. The concern was regarding if the workers would have time to reset the microscopes if the production was in another layout, where the workers did not have their own benches nor their own microscopes.

During Interview C, information was also given about the instructions for the operations that the workers do. Some of the instructions were considered, by the interviewee, to be good and easy to follow. Although, other instructions demanded that the worker using them already had quite some experience, in order to follow them, and some instructions were not considered good at all. The interviewee stated that the instructions should all be written in a way that anyone could understand, no matter how much or how little experience a worker had. If the workers did not have the right preconditions, it would also be a higher risk of making mistakes during the operations. This was also regarded as a part that could lead up to stress among the workers.

Additionally, the interviewee talked about the training sessions that a new worker goes through. Training sessions could vary in time, but it was not uncommon that they could take weeks. These training sessions were carried through in order for the worker to get used to the operations, and learn to do them correctly. It was also highlighted that an worker would most likely never stop participating in training sessions, since when the operations for a project in production had been learned, it would always come new projects and new things to learn. The interviewee thought that they had the right preconditions to keep on training and learning, as long as the workers were willing to.

4.1.2 Future Production

Through personal communication at the company, a VSM of the future production was provided. The VSM provided an overview of what processes that would take place in the future production. It gave information that the future production would have 40 activities. According to the scope and the limitations of this project, only the the steps from 23 and forward would be taken into account. Moreover, the VSM also contained an overview of what processes were completed in each step. Table 4.3 shows these steps, whom were considered as stations, and their corresponding processes. The future production would also be a flow, where the product moves from station to station. Figure 4.3 shows the layout of the stations in the future production. Not all stations are included in figure 4.3, which will be explained later.

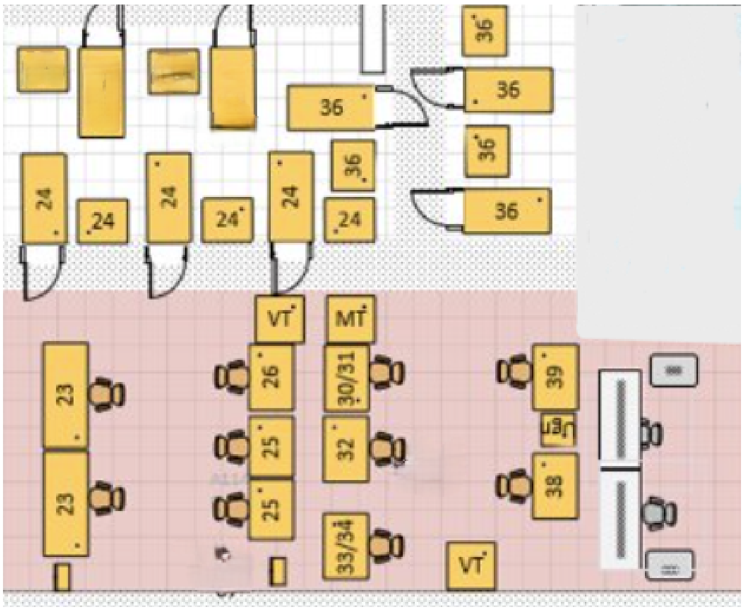


Figure 4.3: The layout of the future production at Beyond Gravity

Moving on, table 4.3 contains information about what type of stations there are and what level of production the different stations operate at. The stations in table 4.3 were all going to be separate stations, with the exception from station 31, 34, and 38 whom were conducted within the same oven. This meant that even if many of the stations were of the type ”workbench”, they would not be performed at the same workbench.

Moreover, the process time for each station in the future production was estimated through personal communication and informal meetings at the company. The result of the process times for the stations is shown in table 4.4. Additionally, a standard deviation was applied to all processing times. The standard deviation was 20% of the total processing times for all stations. This standard deviation was determined through personal communication at the company. The reasoning behind this choice was that there were a large variation in how long time it took to finish an operation. Since the operation times of the future production were based on the planned man

Station	**Type**	**Level**	**Process**
23	[redacted]	Card	[redacted]
24	[redacted]	Card	[redacted]
25	[redacted]	Card	[redacted]
26	[redacted]	Card	[redacted]
27	[redacted]	Card	[redacted]
28	[redacted]	Card	[redacted]
29	[redacted]	Card	[redacted]
30	[redacted]	Module	[redacted]
31	[redacted]	Module	[redacted]
32	[redacted]	Module	[redacted]
33	[redacted]	Unit	[redacted]
34	[redacted]	Unit	[redacted]
35	[redacted]	Unit	[redacted]
36	[redacted]	Unit	[redacted]
37	[redacted]	Unit	[redacted]
38	[redacted]	Unit	[redacted]
39	[redacted]	Unit	[redacted]
40	[redacted]	Unit	[redacted]

Table 4.3: The processes done at each station, and the corresponding level of production

hours in the current production, a standard deviation of 20% was therefore considered enough to estimate the fluctuations of operation times.

Some of the stations in table 4.4 has a standard deviation set to [redacted]. This means that these processes had a predetermined time that was not possible to deviate from. For instance, the cards had to be in the [redacted], station 24, for [redacted] hours. Station 28 was, as mentioned, an outsourced process which would take [redacted] hours, in other words [redacted] days.

Visible in table 4.4 is that the stations 31, 34 and 38 has the same processing time. The reason for this is because these stations would in reality be the same oven, used for [redacted] the product. The products will in the future production be processed within this oven at different times in the production flow, hence the different stations 31, 34 and 38. Although, since it is the same oven, it will further be named as station 31/34/38.

During Interview A, it was also noted that in the plan for the future production there would be a separate repair flow for products that have failed a test. The repair flow would be located at another station, and not demanding any of the nine workers presented in table 4.7. In other words, there would be other resources working in the repair flow, if or when it would be necessary.

The test stations, from where the products could fail a test and thereby move on

Station	Part	Processing time [h]	Standard deviation [h]
23	C card	[redacted]	[redacted]
	P card		
24	C card	[redacted]	[redacted]
	P card		
25	C card	[redacted]	[redacted]
	P card	[redacted]	[redacted]
26	C card	[redacted]	[redacted]
	P card		
27	C card	[redacted]	[redacted]
	P card		
28	C card	[redacted]	[redacted]
	P card		
29	C card	[redacted]	[redacted]
	P card		
30	C module	[redacted]	[redacted]
	P module	[redacted]	[redacted]
31	C module	[redacted]	[redacted]
	P module		
32	C module	[redacted]	[redacted]
	P module		
33	Unit	[redacted]	[redacted]
34	Unit	[redacted]	[redacted]
35	Unit	[redacted]	[redacted]
36/37	Unit	[redacted]	[redacted]
38	Unit	[redacted]	[redacted]
39	Unit	[redacted]	[redacted]
40	Unit	[redacted]	[redacted]

Table 4.4: The stations, the parts processed in the stations and their corresponding total processing times

to the repair flow, were station 23, 25, 29, 32, 36/37, and 39. Through personal communication, an estimation from the company was given on what percentage of the cards, modules or units would go into the repair flow. This is shown in table 4.5.

Moreover, personal communication gave the estimation that [redacted]% of the products in the repair flow of the future production would be scrapped. The products that were not scrapped would go back to the test station they came from prior to the repair flow. Since products in the future production could go to the repair flow from different stations, it would consequently take different amounts of time to repair the products. According to the same communication, an estimation was that a product would be in the repair flow between two to twelve days. How long a product stays in the repair flow was not dependent on from which stage the products originated from.

Test station	Products to repair flow [%]
23	[redacted]
25	[redacted]
29	[redacted]
32	[redacted]
36/37	[redacted]
39	[redacted]

Table 4.5: The percentage of products that would go to the repair flow after each of the test stations

Energy Consumption

The data used to estimate the energy consumption of the future production was based on information from the current production. The machines that would be used in the future production were the same types that were being used in the current production, although the number of machines would be higher in the future production. As mentioned in section 4.1.1, the parts of the production considered regarding the energy consumption was the [redacted], the [redacted] and the [redacted]. In the future production these stations would be 24, 31/34/38 and 36/37. Their respective power consumptions were estimated to be the same as in the current production.

The [redacted], station 24, had a total power of 6 kW, and in the future production there would be three of these ovens. The [redacted], station 31/34/38, had a total power of 6.3 kW and it would be one oven in the future production. The [redacted], station 36/37, had a total power of 15 kW and in the future production there would be three of these machines. The result of the total power consumption per year for these three processes will be presented in section 4.2.3.

Scrap and Average WIP

The cost of the scrapped products would depend on in what stage in the production the products where before entering the repair flow. The reason why the cost of the scraped products in the future production was based on historical data of the current production was due to the products being similar. Consequently, the values of the products in the future production would be similar to the values of the products in the current production. Therefore, it was estimated that the scrap costs in the future production were the same as in the current production. Table 4.6 shows the cost depending on what station the products where on prior to the repair flow. The total cost and WIP of the future production will be presented in section 4.2.3. The cost shown in the table is based on the costs in the current production. The costs are here paired together with the stations in the future production.

The average WIP was gathered from the simulation model, and the value of the WIP in the future production will be presented in section 4.2.3.

Workers in Production

Station before repair flow	**Part**	**Scrap cost [SEK]**
23	C card	[redacted]
	P Card	[redacted]
25	C card	[redacted]
	P card	[redacted]
29	C card	[redacted]
	P card	[redacted]
32	C module	[redacted]
	P module	[redacted]
36/37	Unit	[redacted]
39	Unit	[redacted]

Table 4.6: The scrap cost for each product, depending on where it was prior to the repair flow in the future production

There were nine workers that would work in the future production, and they would have the same shift times as in the current production. The shift would be from 08.00 to 16.30 with 30 minutes lunch at 11.00, and two breaks between 09.00-09.20 and 14.00-14.20.

From Interview A, it was given that the nine workers were planned to work within the future production. They were also going to be assigned to different stations within the production. The workers and their respective stations of responsibility is presented in table 4.7.

Worker	**Group**	**Assigned stations**
1	1	23, 24, 25, 36/37
2		
3		
4	2	26, 32, 39
5	3	27, 30, 31/34/38, 33, 40
6		
7		
8	4	29
9	5	35

Table 4.7: The nine workers and their corresponding groups and stations they were assigned to

Since the future production was in the planning phase, and thereby not implemented yet, literature was studied in order to find relevant information regarding workers in production. Below, the information gathered from literature is connected to the scope of this project, meaning the future production of the company.

Ergonomics at the workplace was stated as one of the main factors influencing the workers well-being within production, and this included both physical and cognitive ergonomics. The physical ergonomics would include ensuring that the workers can perform the tasks while maintaining a good posture. To ensure that the workers have the preconditions to perform their tasks in a good posture, tools can be used. The tools should also be designed to meet the need of every worker. Adding to this, the physical ergonomics could also be affected by reiterative work, meaning that the worker has to do the same tasks over and over again.

Moving on to the cognitive ergonomics. It was pinpointed that the more complex the tasks are, the more important the cognitive ergonomics is. Complex tasks could mean that the worker has to process more information, increasing the workload mentally. The workload could also be, as the word indicates, the amount of work a worker has to do. It could be affected by the setup of the production, meaning that some workers may have more tasks than others. It could also be affected if the different needs of the workers would not be met. Something that could affect the needs of an worker is expertise, which can vary from person to person. The workload on the workers in the future production was gathered through the simulation model, and will be presented in section 4.2.3.

4.2 Simulation model

The creation of the simulation model was a big part of the project and was divided up into several steps. The first model that was the conceptual model which was followed up by a base model that in itself was divided into different versions. The last step was the creation of the experiments performed within the model to get results to be used later in the project.

4.2.1 Conceptual Model

The first model that was created was a conceptual model. The conceptual model was based on the VSM handed to the project group in the beginning of the project together with discussions with the company. The conceptual model can be seen below in figure 4.4. The model gives an overview picture of the production and how the material will flow through the production.

As the scope of the project and master thesis was not the entire production but instead station 23-40, the rest of the stations were not included in the conceptual model. The triangles in the model represent the start and end of the production flow in the model. The arrows represent how the material and the product is moved within the production flow, that is, how the material is physically moved within the production. The rectangles represent the different stations. Station 28 is colored red since it is an outsourced process.

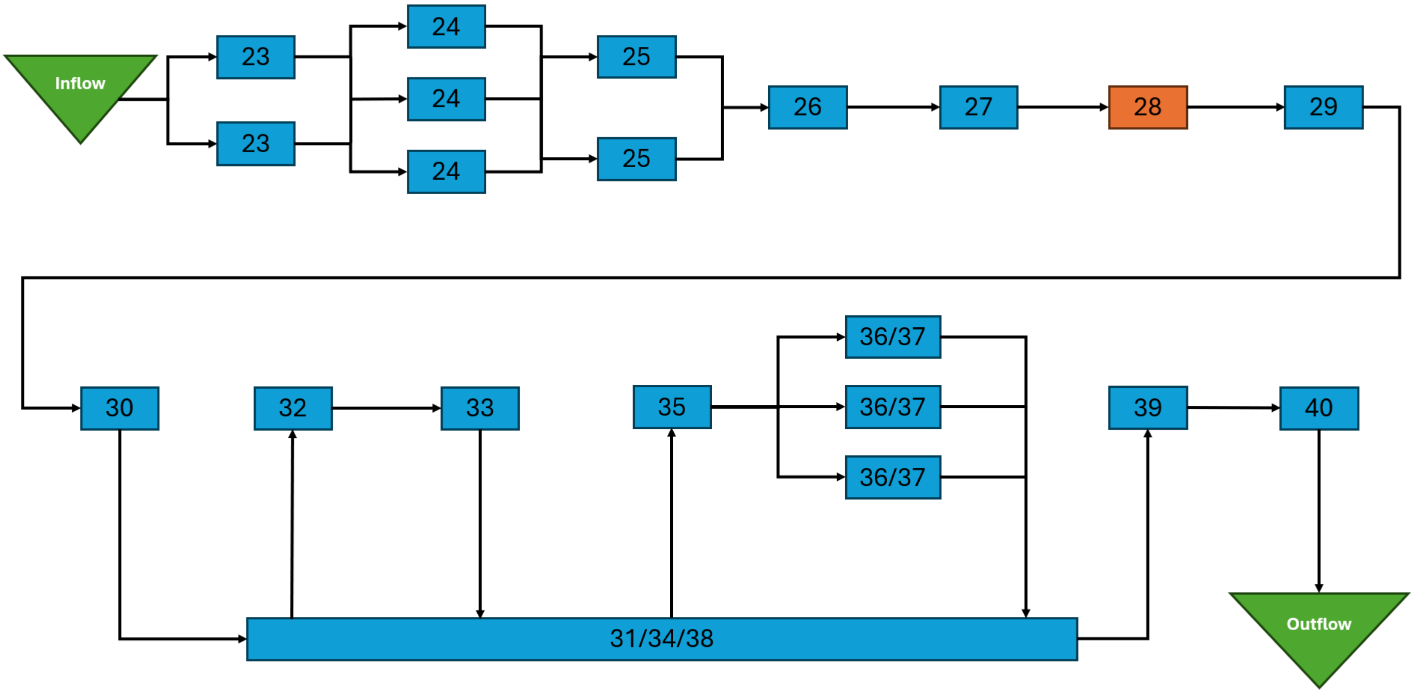


Figure 4.4: Conceptual model of the future production

4.2.2 Base Model

Two pictures of the finished model can be seen in the figures 4.5 and 4.6 below. These pictures represent two different models of the future production. However, the only difference of the two models are the layout. The first model layout, figure 4.5, follows the conceptual model. That is, the products in the model goes in a straight line from start to finish. It was considered easier to follow this model flow compared to the second model by the members of Interview B. The second model is instead arranged as much as possible according to how the future production will look like, which is visualized in figure 4.3. As the layout is different the path the workers take to the different stations are different, but this is where the differences stop. The "straight" model was created first based on the conceptual model, Interview A and Interview B, while the second model was created after all settings on the first was correct and verified by the company.

The different stations are programmed with the correct attributes to represent reality as much as possible. All stations have been given the correct time interval, most often normal distributed, of how long it takes to perform the operations at that station. Some stations also needed set up time and even recovery time. These settings were also added to the stations. On some stations the different operations needed specific times that could not be integrated with other times. For example, some test stations had operations that was first performed by an worker, followed up by tests done by a machine without the need for a worker and lastly finished by some operations managed by a worker. The solution was to set the time where the worker works at the station as the set up time and recovery time depending on if

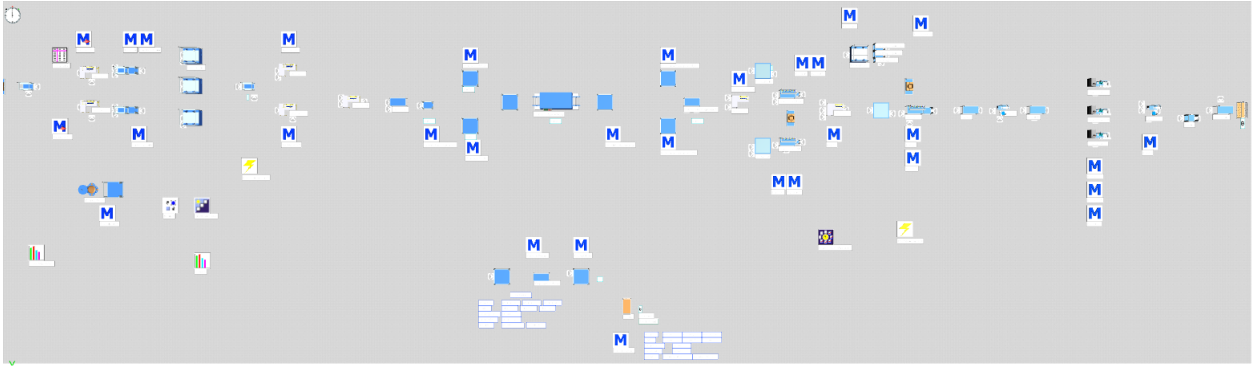


Figure 4.5: Picture of the model where the layout is similar to the conceptual model

the operations where intended to be done before or after the tests. The times of the operations where a worker was not needed was set as the main processing time. The figure 4.7 is an example of how the different settings and attributes can be seen for a station. The times have been masked due to confidentiality.

As has been mentioned in section 4.1.2, some products going through the different test stations will be concluded to be outside specifications and sent to the repair flow. The repair flow in the model is represented by two buffers together with one station and one drain for scrap. This part is not represented in the VSM or conceptual model, but was instead added in retrospect, when the need for a repair flow was surfaced. The repair flow was integrated into the model to the side of the main flow. If a product would be sent to the repair flow, it will need to be able to be sent back to the test station that sent it in the first place. This was solved by giving all products that go through the test stations a variable that changes its value based on the test stations. For example, if a product went through test station 1, the value of the variable would be set to 1 and when it comes to the next test station, test station 2, the variable would be set to 2 and so on. This variable would then be checked after the product was done in the repair flow-station and based on the value of the variable the destination would be set to bring the product back to the correct test station. As mentioned in section 4.1.2, [redacted]% of all products that go through the repair flow will be scrapped. If a product should be scrapped or not was decided by having another variable that would be randomized to be a random value between 0-100. If the variable were to be the value [redacted] or lower, the part would be sent to ”scrap” and scrapped and not sent back to the test station. To keep track of what kind of parts and how many from each stage in the production passed through the repair flow, counters were added to give an insight into the amount. This was done similarly for parts sent to scrap to keep track of how far they moved in the value chain before being scrapped.

Special objects called ”Method” was used in the project to help the model represent how the production would act in reality as much as possible. One such method was used when deciding which of the [redacted] ovens at station 24 parts should be sent to, depending on what type of part it was and how the occupancy of the ovens were.

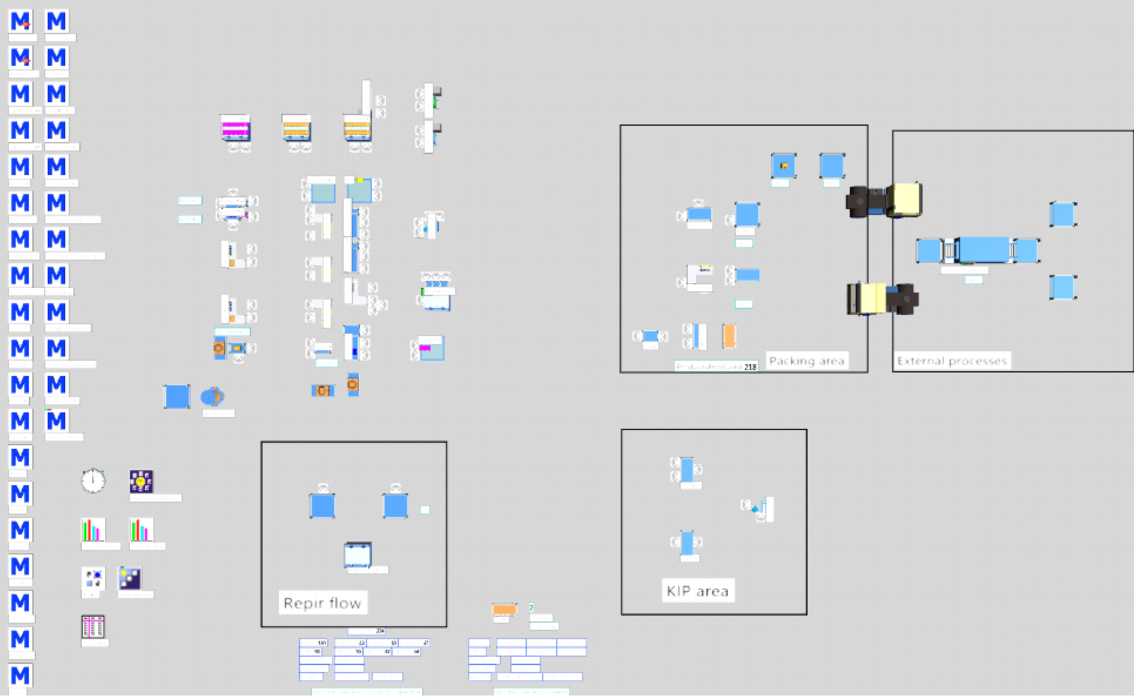
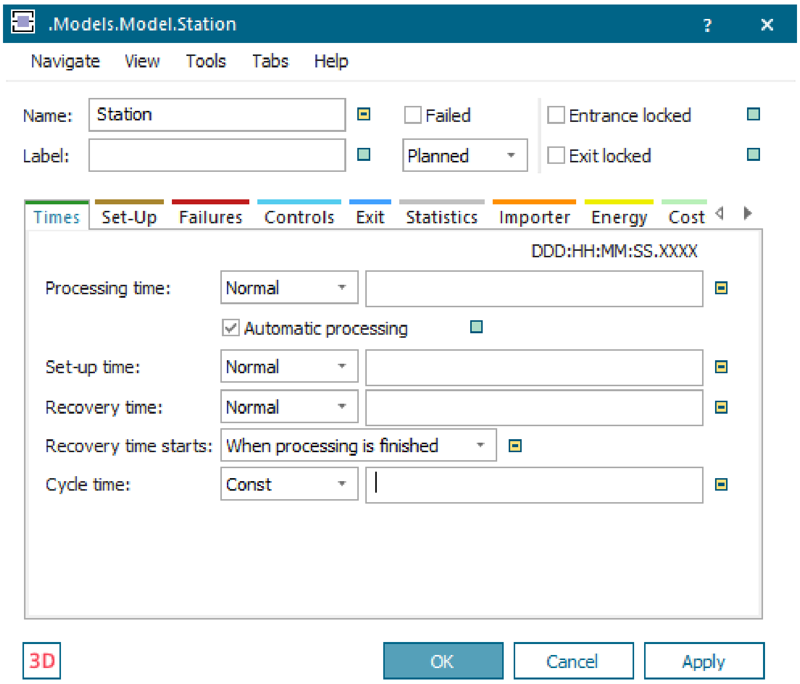


Figure 4.6: Picture of the model where the layout is according to how it could look like in reality

In reality, this decision is made relatively easy by the worker moving the part to the oven. An oven needs to contain [redacted] parts before starting its operation which means that for example the worker should prioritize continue filling up an oven that is half full over an empty oven. Another important aspect is that two different types of parts cannot be in the same oven. Which means that worker cannot put part P in an oven with part C already inside it, even if the oven containing part C is not full. The order of which the oven should be prioritized are, 1. half full oven with the same part, 2. empty oven, 3. if none of the oven are available, such as full or occupied by another type of part, wait at the buffer. The method that help solve this problem is divided into two methods in the model, one that checks the status of the ovens and one that sets the destination for the parts going to the ovens. The methods are called ”CallEnter24” and ”Enter24”. Both methods can be found in Appendix D.

Let’s first look at the method that checks the status of the ovens. When a part is added to the buffer ”Pre24”, method ”CallEnter24” will be activated. It will check the ovens occupancy based on the criteria, ”are the ovens full?” and ”does the ovens contain parts and are they not the same type as the part?”. The criteria are also checked in the order that they were written. The reason is because of the prioritization order described above. If there is an oven available the method will call on the second method, ”Enter24”. Before ”Enter24” sets the destination it checks the ovens again and sets a wait timer of 30 seconds. This is done in case a part is already on route to an oven and being the last part before making it full. If ”wait” was not there the destination could be set and a worker tasked to carry the part would carry it to the ”unavailable” oven. The worker would be stuck standing at



Name: Station
Label:
☐ Failed
Planned
☐ Entrance locked
☐ Exit locked
Processing time: Normal
☑ Automatic processing
Set-up time: Normal
Recovery time: Normal
Recovery time starts: When processing is finished
Cycle time: Const

Figure 4.7: Generic time setup for one of the stations

that oven until it was done and emptied, which is not how it would happen in reality. Important to note is that it was decided that one of the [redacted] ovens (Station242) should be a designated oven for the C-parts and the other two for the P-parts. This means that the methods does not need to check which type of parts occupies the oven. The parts that are not needed are commented away in the methods. However, if the plan would change again and there is no designated oven for the parts the parts in the methods meant to check the part-type can be ”uncommented” in the methods.

In the simulation model of the future production, 27 other ”Methods” were further implemented. They were constructed in a similar way to the methods described above. The reason for using these methods in the simulation model was to create the intended behavior of the future production. Some methods are copies of each other with some small differences, like which station they are connected with.

Another part of the model is the workers. As has already been mentioned in section 4.1.2 the number of workers in the future production flow will be nine and divided into groups depending on which stations they are working with. How and where the workers are supposed to work are decided with the help of the ”WorkerPool” and the ”Broker”. In the ”WorkerPool” the workers were defined in the groups they belonged to. This was done by defining a group/worker and what task that group/worker had before specifying the amount of workers belonging to that worker group. In figure 4.9 the settings can be seen. The reason the ”Job” task and the ”Transport”/”Trans” tasks are separate is because at some stations some workers only ”work” at the station while another worker from another worker group moves the part. By having the tasks separated, one can make sure that the workers only

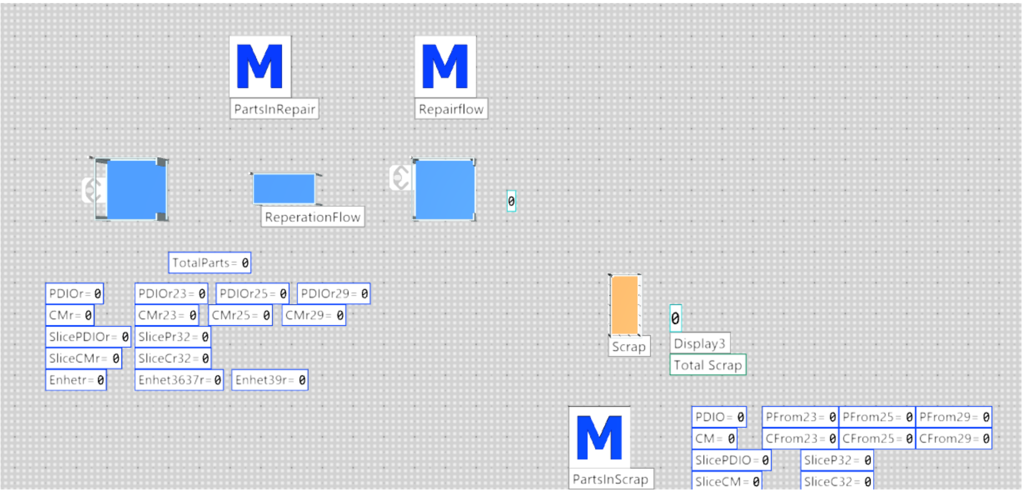
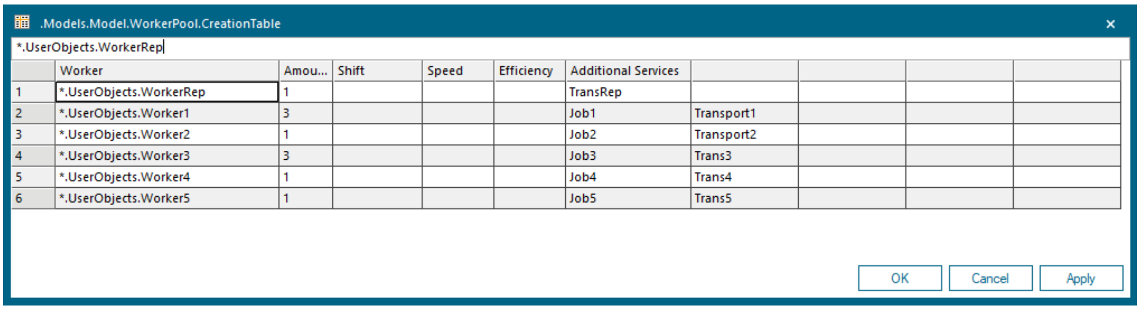


Figure 4.8: Overview of the repair flow used in the model

do the tasks they are meant to do.


.Models.Model.WorkerPool.CreationTable

*.UserObjects.WorkerRep

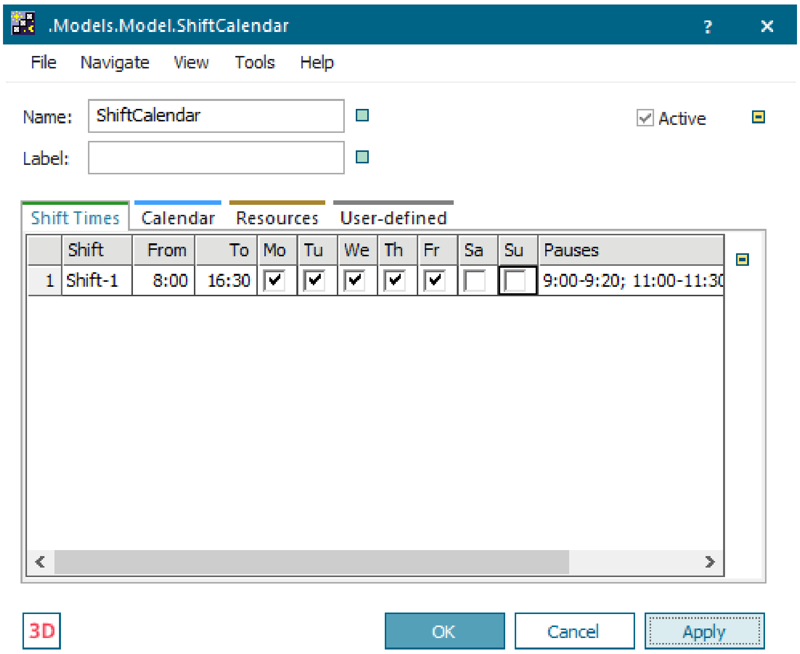
	Worker	Amou...	Shift	Speed	Efficiency	Additional Services				
1	*.UserObjects.WorkerRep	1				TransRep				
2	*.UserObjects.Worker1	3				Job1	Transport1			
3	*.UserObjects.Worker2	1				Job2	Transport2			
4	*.UserObjects.Worker3	3				Job3	Trans3			
5	*.UserObjects.Worker4	1				Job4	Trans4			
6	*.UserObjects.Worker5	1				Job5	Trans5			

Figure 4.9: Settings of the ”Creationtable” from the ”WorkerPool”

The times and shift the worker work with is set up by the ”ShiftCalendar”. In figure 4.10 the settings can be seen. Apart from the workers, most stations are also set to be dependent and work after the shift. The exceptions are the stations that can work independently or semi-independently from a worker. An example is station 28 that is outsourced and not in need of a worker working at the station. This was done to give a more accurate representation of the utilization of the stations when creating for example the utilization-chart over the production. These charts will be presented in section 4.2.3. The other stations not linked to the shift are, stations 24, 28, 36/37 and the 31/34/38.

4.2.3 Experiments

Through experiments with the help of, for instance, the ”Experiment Manager” the Warm-up time could be decided together with the number of observations necessary to get a reliable result. The warm-up time was set to 224 days and was based on the figure 4.11. As shown in figure 4.11 the number of parts being produced fluctuates until around 196 days. This means that after 196 days the output can be considered



Name: ShiftCalendar

Label:

☑ Active

	Shift	From	To	Mo	Tu	We	Th	Fr	Sa	Su	Pauses
1	Shift-1	8:00	16:30	☑	☑	☑	☑	☑	☐	☐	9:00-9:20; 11:00-11:3

Figure 4.10: The "ShiftCalendar" and its settings

as stable. 224 days were chosen to have a margin to the unstable part of the graph. The number of observations was decided based on the confidence interval given by the experiment manager. 40 observations gave the confidence interval 218.225 ± 0.84 which was deemed sufficient for this experiment.

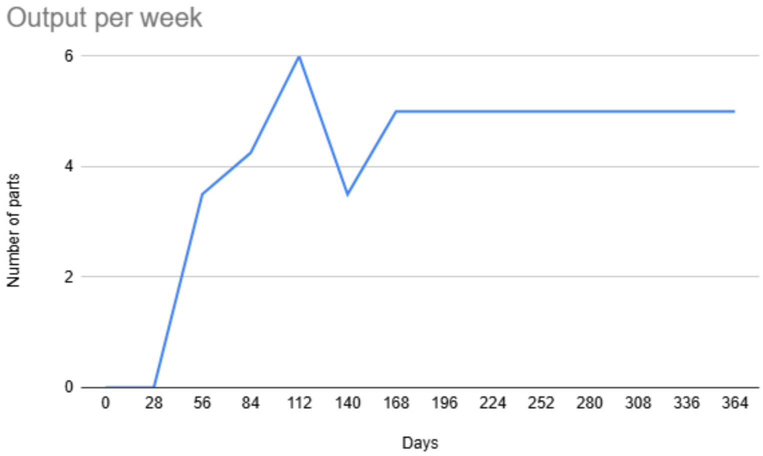


Figure 4.11: Warm-up diagram

By running the Experiment manager the following results was presented. The number of finished products that the company should be able to produce during an interval of 44 weeks, which is the amount of weeks that the company produces during a year, was 218.225 products, which give a throughput of 4.96 products per week. The average number of scrapped products during the 44 week interval was

6.582 products. The distribution of where the scrap came from can be seen in table 4.8. From the distribution the cost of the scrapped goods could be calculated. The cost can be found in the same table, table 4.8. The cost come from table 4.6 where a finished unit is estimated to be the same value as a product from station 39. The total number of WIP in the production was 140 parts distributed over the whole production flow and in different stages of sub assemblies. The distribution and estimated value of the WIP can be seen in table 4.9. Added together, the different sub-assemblies of the unit together with the units still in process gives the total average number of units in process to be 28 units.

Station	**Part**	**Scrap [Amount]**	**Total cost [SEK]**
23	C card	[redacted]	[redacted]
	P card	[redacted]	[redacted]
25	C card	[redacted]	[redacted]
	P card	[redacted]	[redacted]
29	C card	[redacted]	[redacted]
	P card	[redacted]	[redacted]
32	C module	[redacted]	[redacted]
	P module	[redacted]	[redacted]
36/37	Unit	[redacted]	[redacted]
39	Unit	[redacted]	[redacted]
Total cost			[redacted]

Table 4.8: The amount of scrap and total cost for each station. Check table 4.6 for individual cost per part.

Part	**Amount**	**Value of each part [SEK]**	**Total value [SEK]**
C card	[redacted]	[redacted]	[redacted]
P card	[redacted]	[redacted]	[redacted]
C module	[redacted]	[redacted]	[redacted]
P module	[redacted]	[redacted]	[redacted]
Unit	[redacted]	[redacted]	[redacted]
Cumulative value of WIP			[redacted]

Table 4.9: The WIP, in the future production, with corresponding values

With the help of the Experiment manager different charts could be created, such as a resource statistic chart as well as a diagram of the energy consumption and service statistics of the workers. The resource statistic chart can be seen in figure 4.12. The service statistics chart can be seen in figure 4.13, showing a percentage of how much time the workers spends working, waiting and so on during the simulation period. The time when they are free, not at ”work”, is not included in the figure. Finally, the chart of the energy consumption can be seen in figure 4.14. The total energy consumption in a year was concluded to be 305 232.2 kWh. This means that the annual energy consumption per product is 1 398.7 kWh.

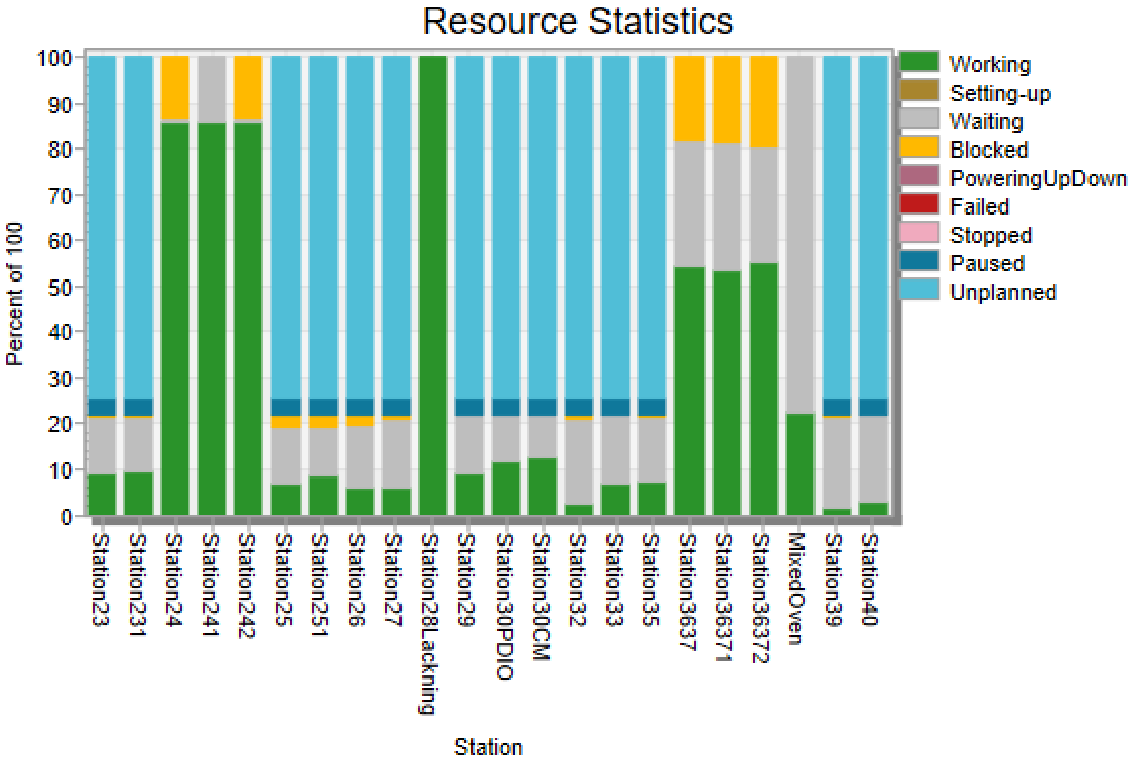


Figure 4.12: Resource Statistics of the future production

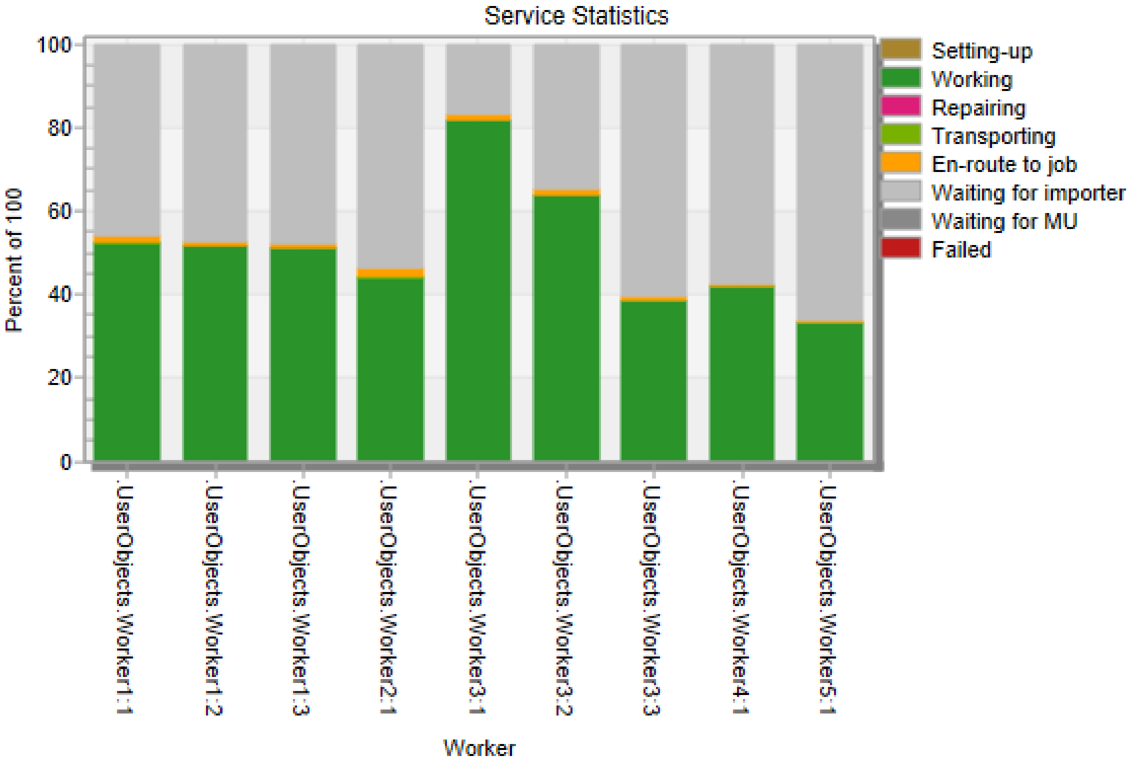


Figure 4.13: Service statistics of the future production

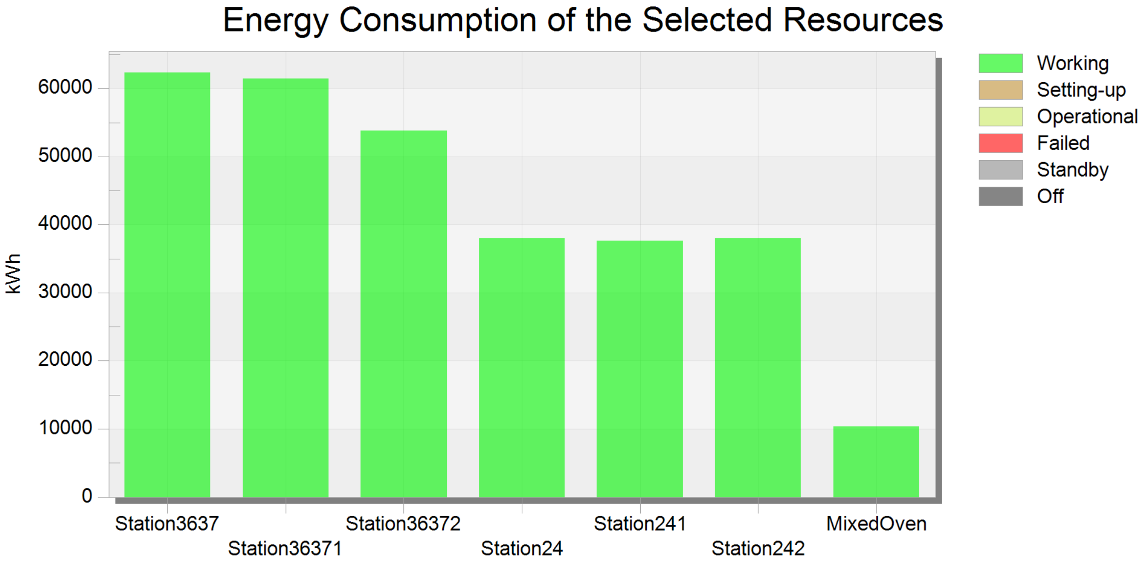


Figure 4.14: Energy consumption of a part of the future production

5

Discussion

In this chapter, the results and answers to the research questions will first be discussed. Later, the methods used will be reviewed. This chapter will be finished with a discussion about future research that could be performed within this area.

5.1 Answers to research Questions

The aim of this project has been to create a simulation model of the future production flow at the company Beyond Gravity. Alongside the aim two research question has been a part of the scope during the whole project. These questions will be answered and discussed below.

5.1.1 Research Question 1

How can creating a simulation model help a company transitioning to a new production?

Before the project was started, the existing data about how the future production would look like and work consisted mostly of a VSM together with layout suggestion. This gave the company a picture over how the output could look like and how the production would work and interact with itself. However, the problem with this picture is that it represents a perfect scenario. Meaning, a scenario where every operation is finished on the exact time stated in the VSM and where no failure occurs. This scenario would most likely never happen in reality, it is normal that time fluctuates between workers or even each time one worker does the same task or operation. It is also hard to get the failure rate down to zero. With this in mind, the picture the VSM created might give a false picture of how the future production will behave. This creates a problem where the company cannot give an accurate estimation to their customers. This could lead to a scenario where the company cannot deliver in that pace they have promised which in turn could hurt their customer relation and in the long run lose that customer.

Let's now look how a simulation model can come in and help in this situation. If the input to the simulation model is high quality data, it will be able to give a more detailed picture of the future production. A DES model will be able to give an estimate that will more likely represent what the future production will be able to do in reality [8]. This is because the DES model will be able to simulate the randomness of reality. Meaning for example, that the time it take to finish the task on a station will not be the same for any of the parts going through it, emulating the reality in that sense. Also, simulating the failure rate where some product are scrapped before they are finished. By also being able to simulate an indication of how much will be scrapped, the company will be able to take action during the planning phase of the production and work around the scrap to be able to deliver what has been promised to their customer. Another example of helpful data which DES model can provide is the utilization of the different machines and workstations in the production flow. In figure 4.12 the resource statistics of the potential future production flow can be seen. With the help of the figure a conclusion can be taken about which stations is the bottleneck for the current production. In this case the bottleneck is station 28 as it is working more or less all the time, while many of the stations downstream are starved. Another example of potential bottlenecks are the stations 24 and 36/37 on similar basis as station 28. Being able to identify these bottlenecks, a user will be able to find solutions to minimize the bottlenecks impact on the production before the production flow is implemented in reality, which leads to another benefit of using a simulation model.

A simulation model is also helpful in the context of testing out different scenarios and ideas [9] [14] [12]. For example, using different amount of workers or different processing times for machines. The simulation model can act as a playground for engineers planning the production. Moreover, testing out new ideas in the simulation software is cheaper and more time efficient in comparison to doing these activities on a real life system. An example of this is if the company wants to try to add another parallel machine to evaluate if an investment should be made or not. A DES model can easily do this task without costing the company money. A DES model can together with Banks model help the company evaluate, improve and optimize their production. For example DES is a very useful tool when searching for bottlenecks in the production [12] [13].

With that being said, there may be incorrect results from the simulation model, especially if the input data is not accurate [9] [14]. Therefore it is important to validate and verify the data used to design the simulation model. The simulation model could also deliver biased results if not all possible scenarios of the production system is considered. In this case, it is necessary to have a clear scope of the simulation model, and what the goal with creating a simulation model is. Finally, a simulation model can provide an estimate of the outcome and behavior of a production. However, there is no guarantee that the simulation model will provide exact results or that the results will be useful.

As seen in the result of this thesis, chapter 4, the simulation model developed of the future production at Beyond Gravity was able to predict that the future throughput would be around 4.96 per week. Since it is not possible to make exactly 4.96 products a better estimate is that the throughput will be 4 or 5 products per week. However, the error margin of the simulation model is 0.84 products for a whole year, highlighting the importance of correct data. Even though the ME is low, the result could still be misguiding if the input data is of bad quality or lack backing from reality.

To summarize, creating a simulation model may help the transition to a new production for a company. It can give a good estimation of how the new production will behave and what the output will be as well as give an indication of what the bottlenecks may be. However, it is important that the model is fed with accurate and correct data otherwise it may give a false picture of the new production. It this project the model was able to verify that the company would be able to almost reach its goal, producing 4.96 products per week compared to their goal of 5 products per week. This indicates that the company is on the right path in their planning of their future production. It has also been able to provide the company where bottlenecks exist and where problems may arise, which might indicate that the company needs to make adjustments before implementing their new production.

5.1.2 Research Question 2

How will sustainability aspects in the Triple Bottom Line be affected in this transition?

The simulation model created for the future production has given an initial understanding of the workings of the future state and is able to provide initial insight on sustainability perspectives. The sustainability KPIs the thesis has focused on was energy consumption, average WIP, scrap and workers in production. The model and the results of the simulation, together with data collection about the current production, lays the foundation to the discussion below and answer to the second research question.

The energy consumption in the current production was estimated based on available data to be 36 773.2 kWh per year and 1 935.4 kWh per product. For the future production the consumption was simulated and estimated to be 305 232.2 kWh per year which give a consumption of 1 398.7 kWh per product. When looking at the two results from the current and future production it can be concluded that the yearly energy consumption in the future will be 8.3 times larger than the current production. However, the future production will need 0.7 times less energy per product. This means that the product will in the future become more sustainable from an energy consumption perspective, which could make the product more competitive on the market since the market care more and more about the sustainability aspect of the products they buy. However, as has been mentioned the company will overall consume more energy per year. This will however, from a sustainability perspective, result in a negative impact for the energy consumption part of the sustainability of the company. It is therefor important for the company to make sure they have the capacity for this type of production from the energy perspective. If they don't have that capacity there will be problems in the long run to sustain that type of production.

Moreover, the station 28 in the future production is an outsourced function meaning that there is a long transport to and from the location where the cards are processed. This means that in reality there would be additional energy consumption per product in the future production than what is presented in the above section. However, it was through personal communication from Beyond Gravity recommended not to take the outsourced station 28 into consideration when estimating the energy consumption. Furthermore, to make the current and future production comparable to each other, the stations [redacted], [redacted], and [redacted] were chosen to take into consideration since these processes exist in the current production and would also exist in the future production. Therefore, the energy consumption resulting from this thesis could be interpreted as a result of the in-house processes within the production of an OBC at Beyond Gravity.

Another aspect of energy consumption is the amount of scrapped products. A scrapped product will still be contributing to the energy consumption but only to the point where it is deemed unfit and scrapped. Meaning, if no products were scrapped during the process both the overall energy consumption would be lower and the energy consumption per product. For example, lets say the production needs to deliver 40 products. During the process 5 products are scrapped. However, as the company still needs to deliver 40 products, the production needs to have started the production of 45 products, meaning that at some point in the production 45 products have been processed which will reflects on the energy consumption of the station up to that specific point.

From the economic sustainability perspective the project focused on the amount of produced products, average WIP and scrapped products. As can be seen in chapter 4, the number of OBC products that the current production is able to produce is 19 products per year while the future production should be able to produce 218.225 products per year. This means that the company will be able to produce 11 times more products in the future. Looking at the amount of scrapped parts and products as well, the amount that has been scrapped in the current production is 8 parts. The amount that will be scrapped in the future according to the simulation model will be 6.582 parts. This is positive from an economic perspective as fewer products will be scrapped in the future production, which will lead to fewer economical losses.

The financial loss the scrap generates in the current production lies around [redacted] SEK while the future production scrap might stand for around [redacted] SEK. The difference is not large, however as the future production will be able to produce 11 times more products, the cost of the scrap will be relatively small to the value of what is produced for the future production, compared to the current. From an economical sustainability perspective the future flow may be more sustainable due to the fact that there will be more products produced. Moreover, this thesis does not take into consideration the operational running costs that may increase in the future production.

The two production flows can also, from an economic sustainability perspective, be compared through the average WIP and the tied up capital it represents. The amount of average WIP in the current lies on an average of [redacted] parts or [redacted] units while the average WIP of the future production will include [redacted] parts or [redacted] units depending how you look at it. From this it can be concluded that the future production will contain more tied up capital for the company compared to the current production. The future production will have almost 2.5 times more tied up capital. This could be seen as an economic risk for the company as more money are tied up in the production. It highlights the importance that the production flows as intended without larger disturbances. The reason for the higher WIP is the increase in stations which enables the larger throughput in the production, since the goal is to produce 5 units each week.

It is, however, difficult to draw a specific conclusion if the profit for the company will increase or decrease with the increased throughput and WIP in the future. This is because there are other variable costs in the production, which could be for instance personnel cost that is not accounted for, as that data has not been able to be collected from the DES model due to missing input data. The authors therefore reserve themselves from drawing a sharp conclusion regarding the economic sustainability, instead engaging in a discussion about what the specific results in this thesis could indicate.

On the aspect of social sustainability, clear differences in the workload and working environment of the workers can be seen. The discussion is thus delimited to the discussing the differences of the workers in the current and future production work situation. In the current production, it was stated that they had a lot to do and were often interrupted. The interruption was due to having many projects ongoing at the same time in the production, and priorities shifting, meaning that they sometimes had to leave products half finished in order to finish another product. Moreover, the interruption led to the workers having further difficulties to finish their tasks. The workload was high, leading to stress among the workers. Consequently, this affected the work environment for the workers in a negative way since the feeling of not being able to manage the stress was voiced. Additionally, tools such as microscopes were used in the current production. There was one microscope for each worker and these were personalized and ergonomically set up to fit each user.

In the current production, it was also stated that the work instructions differed in quality. Some were good and clear and some were not. This was voiced as something to improve in the future. There was a need of having all work instructions made in the same way, and written in a way so all workers could understand no matter how much experience they had. The lack in quality regarding work instructions in the current production was considered as something that could affect the workers ability to perform their tasks. It could also lead to mistakes by the workers and further stress, as mentioned in Interview C and confirmed by [7]. Moreover, training sessions were used to ensure that the workers knew how the tasks should be performed. However, these training sessions could take several weeks, especially if the worker was new to the work. As mentioned previously, there were several projects ongoing in the current production that lead to the workers continuously needing to have further training sessions, since new projects may have meant new tasks or operations.

The future production would include nine workers, divided into different groups depending on their assigned stations. In section 4.2.3, the result from the simulation model showed that there would be an uneven workload between the nine workers, and the work groups. There is a big difference between the different work groups where some have an even workload while others have an uneven workload. Since the workload was already stated as an issue in the current production, the risk of uneven workload in the future production indicates that further re-planning or rescheduling of the tasks may be necessary. Having uneven workload among the workers increases the threat of poor cognitive ergonomics [38], including risks of confusion and mistakes [7]. One way to prevent this in the future production could therefore be to make changes in the assignment of tasks to the workers and look over if the amount of workers is sufficient.

Moreover, the future production also brings a change of the production layout. This new layout would be a mix between a batch flow and a functional flow, meaning that the product being in work would move in a flow between different stations. This would be a change since the layout of the current production was more of a fixed position where most of the operations were conducted at the two existing work benches. Although, a few activities had to be carried through with the help of ovens and a test machine. Therefore, there will be a quite drastic change of the way the company produces their products, while at the same time scaling up their production. In the context of a new production layout, there may also be a need for training for the workers since the way of producing the OBC will change. From Interview C it was provided that there are training sessions in the current production, and through literature it was given that it is important to give the workers the right preconditions for their work. This includes training sessions, but also having clear instructions. In the current production it was stated through Interview C that the instructions had variations in quality, indicating that the preconditions might not always be in place and bringing the risk of workers making mistakes. The literature emphasizes the importance of work instructions, since it affects the cognitive ergonomics of the worker [39]. Therefore, the work instructions should be constructed in such a way that every worker can understand it, no matter if they are new to the production work or not.

Lastly, one of the tools used at the current production was the microscope. As previously stated, the microscopes were used individually. They were also somewhat difficult to reconfigure between different persons, and this procedure would also be time consuming. As the future production would be a flow where different workers are working on a set of stations, this raises a concern if the use of the microscopes as a tool would be complicated. Another concern is if the workers in the future production would have time to reconfigure the microscopes, as it was not included in the set of operation tasks provided by the company. Having the right tools is important for the physical ergonomics, as it decreases the risk of pain or harm to the body [7]. Therefore, the tools used for the current production should be carefully examined in order to make sure that they will be suitable for the set up of the future production. If the tools are not applicable to the future production, one suggestion may be to consider investing in new tools.

To summarize, the TBL sustainability aspects will of course be affected when going from the current production to the future production. Due to the company limited ability to gather data from the production there has been difficulties to draw any big conclusions about the affects within the environmental and economic aspects. Although, the results indicate that the energy consumption will, in the future production, rise overall but the energy consumption per product will decrease compared to the current production. From the economic perspective, there will be an increase in the throughput of the production. The future production will produce 11 times more products compared to the current production. The scrap cost does not seem to become that different in the future. Although, the scrap cost relative to what is produced will become smaller in the future, indicating a more sustainable economy. The future production will also have 2.5 times more tied up capital, in the form of WIP. This could be viewed as an economic risk for the company, pinpointing the importance of the future production running smoothly without any large disturbances. Finally, when it comes to the social aspect the conclusion is that there will be significant change of the way the workers work in the production. The production will go from a fixed position to a more functional layout where the products move from station to station. One positive consequence is that some workers workload will become more stable, as shown in figure 4.13, meaning less cognitive stress. However, not all workers will have an even workload which might need adjusting and more testing before implementing the future production in reality. Moreover, another consequence might be that a new way of thinking when it comes to the tools used in production, such as the microscopes. There needs to be a way to easily reconfigure a microscope to the workers personal preferences when the worker moves to the next station.

5.2 Discussion on methods

During the project the decision was made to perform two group interviews and one individual interview. The biggest basis for this was due to the lack of time to participate in interviews from the side of the company. Both of the group interviews could for example be performed individually, but due to conflicting calender schedules it was decided to do group interviews as the input from the different participants were needed to get a good picture of the future production. The positive side of having the group interviews was that the participants had the opportunity to interact with each other and discuss their answers, possibly leading to a better understanding. Of course, letting the participants interact with each other could generate bias to their answers. For example, some participants in the interviews were managers which could have influence over the other participants due to power imbalance. Moreover, the participants had different responsibilities within the company as well which also may have affected bias in the answers, since they could have different viewpoints on the subject. However, as described above, the different viewpoints could also be seen as a strength of the group interviews as the different perspectives were mixed, creating a fuller picture of the future production.

When creating the DES model the project team was presented with two different times of the different operations that would be included. Those being planed times and actual times. The planned times was based on estimations from the company, meaning how much time they thought an operation would take based on their experience. The actual times was based on reporting done by the workers themselves. The choice of using the planned times was based on several aspects. One of those being the accuracy of the actual times and how they were measured. The methods that the company used for measuring the actual times was done through having the workers starting the clock when they started a new operation, and stopped by the same when the operation was finished. However, the problem with this method was that activities that were not included in the operations were included in the time measurements, such as breaks or other operations that should in turn been measured on their own. The time it took for the workers to finish different operations did also vary a lot, which contributed to the total time variation. The times were also measured by the workers themselves which could create bias when the workers were reporting or recording their times. Due to time limitations of the project which was described in section 1.4, the project was not able to perform a time study of the different operations. A time study may have given more accurate times that could have been used in the DES model.

The planned times can of course also be subjected to bias from the company, but based on personal communication with the company and Interview B it was decided that the planned times given to the project would give a more accurate picture than the actual times. However, as was discussed in section 4.1.2 to still keep the large variation of times that exist in the current production a relatively large standard deviation, of 20%, was chosen to emulate the time variation. Still, as the existing data may not be as accurate compared to if a time study would have been performed the results given by the simulation model could be considered somewhat biased. If a time study would have been performed, the model could have been able to give an even more accurate result of how the future production would perform. According to Interview B, the initial result from the simulation model together with the input times etc was considered sufficient and gave a good picture of the future production. However, as discussed before, Interview B's participants opinions may have been more subjective to the result presented, compared to if data would have been collected directly in a time study. Meaning that the result from the simulation model might have been more objectively accurate if the input data to the model would have been based on a time study.

The simulation model that was created was according to Interview B a good representation of how the future production will look like. All the times that were used as input for the simulation model, such as operation times for workers and processing times for stations, were verified. It was, during Interview B, concluded that the simulation model behaved the way the future production would behave. Although, as stated previously, a simulation model is a representation of the reality but that does not mean that it is always accurate. However, the simulation model gives the company an indication of important KPIs of the future production, such as finished products per week. The simulation model can also provide information about what areas in the future production that needs to be reconsidered or changed in order for the company to reach their goal of producing five units per week. Additionally, it was only possible to make a simulation model of a part of the future production. This decision was based on the time frame of the project. Additionally, all data that was given during the project has mostly come from personal communication or the interviews done. Due to time limitations there has not been time to perform an new time study of the current production from which the future production times were based on. The project has therefore not been able to objectively verify the data provided by the company.

Finally, this project used the approach of TBL to investigate the sustainability affects of the current and future production. The economic, environmental and social aspects were in this project delimited to scrap, average WIP, energy consumption and workers in production. As already discussed, there were lack of data at the company which influenced all three aspects of the TBL investigation. The result of this is that some aspects were more easily discussed compared to others. However, the data available was processed in a way to make it possible to compare the future and the current production from data points representing examples of all three TBL aspects. Additionally, the TBL is an approach that gives an approximate direction of the sustainability aspects, and may not give an exact result of how it is now or how it will be in the future.

5.3 Future research

This project is limited to only a part of the current and the future production. Therefore, a suggestion for the future research is to investigate more parts of the production, or even the whole production. Beyond Gravity has other products and thereby additional production systems at their site in Gothenburg. This way, an overview of the whole factory system may be provided. Moreover, there might be insights into if or how the production systems affect each other in aspects such as logistics and other finite resources like workers. Adding to this, a question could be how the factory system as a whole is affected when one part of the production is changed, as it has been in this project. It could for example be interesting to see how DES can help optimize the resource allocation in a changing production environment such as it is at Beyond Gravity where the products produced changes often. DES and similar tools could be of great value to a company similar to Beyond Gravity to help manage a changing production environment. A model could potentially give a more accurate picture of how well the production will be able to deliver when changing its production system to handle a new product. Furthermore it could also give an indication where for example potential bottlenecks could appear which can be managed before the production even has started.

Furthermore, during this project, TBL was applied to investigate the sustainability aspects of the current and future production. This was delimited to explore the scrap, average WIP, energy consumption and workers in production. The TBL approach can give an indication on where the company is heading, from a sustainability perspective. However, there may be of interest to use other approaches to investigate the sustainability perspective of the production. It could, for instance, be to make a more in-depth inspection on the ergonomics of the future production, especially since the tools used in the current production might not be applicable to the future production system. Additionally, a more thorough examination of the economic and the environmental part of sustainability could be done to give a more holistic view of the sustainability aspect of the production.

Although, during the time of this project it became clear that the company had an insufficient way of collecting data, which could make it difficult to gain a more in-depth understanding of their production, as well as a higher quality result. Therefore, another suggestion for future research would be to help the company create and implement a new data collection strategy. Furthermore, future research could also examine what type of data that is relevant and needs to be gathered in order to fully understand the complex and ever changing production the company is working with.

6

Conclusion

This project was conducted with the aim of creating a simulation model of a part of the future production of OBC at Beyond Gravity, and investigate how it would affect the sustainability factors through a TBL approach. Two research questions were created; *RQ1: How can creating a simulation model help a company transitioning to a new production?* and *RQ2: How will sustainability aspects in the Triple Bottom Line be affected in this transition?*.

The project created a DES-model of the future production in two variants, one were the layout was based on the VSM-flow, meaning the products move from left to right in the production system, and a second were the layout was according to one of the proposed layouts by the company. It was concluded that the layout had a very small impact on the output. The model was verified and validated by the company and deemed to be a good representation of the future production flow.

The simulation model created of the future production resulted in 4.96 products produced per week, which is close to the goal set up, by Beyond Gravity, to produce 5 products each week. This result indicated that the company was on a good way to reach their goal, but to make sure that they reach it some adjustments in the plan of the future production might be necessary. Therefore, creating a simulation model was helpful for the company, since the performance of the model provided insights that may have been impossible to gain without a simulation model. Moreover, these insights are valuable to get beforehand of implementing the new production, instead of implementing the production and realizing that something is not right. Thereby, creating a simulation model can assist a company in the transition to a new production. It should, however, be remembered that the simulation model is not a direct translation of the reality, but more an estimate to mimic it.

The sustainability aspects will be affected by the transition from the current to the future production. For example, the total energy consumption will increase for the company while on the other hand the energy consumed per product will decrease. The amount of WIP will increase with the move to the future production which will include more tied up capital in the production. It is therefore important that the future production will run according to plan. The scrap cost in the future production will become relatively small to the value of what is planned to produce, indicating that Beyond Gravity may be moving towards a more sustainable economy. From the social perspective, there will be a big difference in the ways the workers operate in the future production. The workload and work-balance will shift and it will be important for the company to recognize the problems that may arise with this. The tools used will also need careful consideration to avoid affecting the ergonomics of the workers in the future production.

The goal of creating a DES model of a part of Beyond Gravity's future production has been reached. Furthermore, both research questions has been answered in a sufficient way. Due to time restriction, the scope of the project was limited. Therefore, there are several further perspectives that could be examined in the future. It would be of interest to include the whole production in the DES model, to get a better overview of the performance of the production and what is affecting it. More in-depth investigation in the economic, environmental and social aspects of sustainability could be conducted in order to get a better understanding of what the company needs to do to enhance their sustainability. Lastly, a new data collection strategy at the company may be of interest.

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A

Interview A Questions

If nobody needs help before step 35, is there still going to be an inspection point at step 35 or will step 35 not be “used”?

Buffers? Do they exist? Where are they located in the production flow?

Where can the instructions to the stations be found?

How many operators are in the production flow? How do the operators move between the stations?

Kitting? Where is it done? How much time is needed? Which stations need kitting?

CM-cards. What are the process times on the different stations?

PDIO-cards. What are the process times on the different stations?

Do you have any sustainability data that can be used? For example, People, Planet Profit.

The data that is needed are:
- Cycle times and associated standard deviations
- Failure rate or MTBF
- MTTR
- Set-up times
- Arrival times for material and how large the batches are
- Production schedule, when are you going to be producing?
- Energy consumption for stations and tools
- Do tools need to be exchanged, in that case how often?
- Scrap rate and when is it decided a product should be scrapped?
- Where are the products tested?

Are you able to provide this information?

What data are you not able to provide?

What data can you provide now and what can you provide at a later date?

B

Interview B Questions

The Participants were shown the different worker groups and how it looks like when they work

Now when you know where the workers will operate, does this coincide with how it will look like in reality?

Is there any worker group that does not coincide?

Now when you have seen how the workers operate, do you think the way of working is correct and similar to the way you work in reality?

Are there any places where the model differs from reality?

The participants were shown the different times used as input to the model in batches of two or three

Based on your experience of building similar products, are the times used as input reasonable?

Are there any times that are not reasonable? Why? What should it be instead?

Here the focus switched to the buffers in the model and their capacity

Is there anywhere where there are any buffers missing? Where in that case? What capacity should they have?

Is the capacity of the existing buffers reasonable, or correct? Is there any change needed? Where? What should the capacity be instead?

The participants were showed some preliminary results such as output and resource statistics

Now when you have seen some of the results. How do you feel about it? Is the model still reasonable?

Is there anything that you feel should be changed to emulate reality more?

C

Interview C Questions

How do you work in production today?

Do you work in a line-production, or do you work on a whole product at one workplace at a time?

Are there any support functions available? For example, Kitting or Andon system.

How many kinds of products does a worker work with today?

How high is the workload?

Do instructions exist?

Are the instructions easy to follow? Why/why not?

How do you work with the instructions? Are they always used, or do you work from memory?

What is the stress level?

Do you have the time to finish what you are doing, or can you be interrupted? Explain and give examples.

Is it easy or hard to make mistakes? For example, during assembly is it possible to assemble a part in the wrong way? Can you use the tool in the wrong way? Give examples.

How do you work to be able to see what you are working with? When working with, for example, circuit boards?

D

Methods ”CallEnter24” and ”Enter24”

D.1 CallEnter24

```
//var Random : real
var muname : string  // Name of current MU in station

muname := @.name  //Get name of MU

/*
While mu does not have a destination check station24 and station241 (
   ↪ Ovens designated for P-parts)
*/
while @.destination = void
       wait 30
               //Wait 30 sek to give time for potential PDIOs already
                  ↪  on their way to ovens, to arrive, avoid
                  ↪ overfilling ovens
               if (Station24.NumMu = 9 AND muname = Station24.mu.name
                  ↪ ) OR (Station241.NumMu = 9 AND muname =
                  ↪ Station241.mu.name)
                      wait 30
               end

               //If both oven are both full or ovens contain MU that
                  ↪ are not the same as the MU in the buffer (in
                  ↪ this case P-parts)
               if (Station24.NumMu = 10 AND Station241.NumMu = 10)
                      waituntil Station24.NumMu = 0 OR Station241.
                         ↪ NumMu = 0
               elseif Station24.NumMu > 0 AND Station241.NumMu > 0
                  ↪ AND muname /= Station24.mu.name AND muname /=
                  ↪ Station241.mu.name
                      waituntil Station24.NumMu = 0 OR Station241.
                         ↪ NumMu = 0
               end
```

```
        &Enter24.execute //execute submethod to get mu destination
end

@.move //Move mu to its destination
```

D.2 Enter24

```
//var PartName : string
var muname : string  // Name of current MU in station
//var Random : real
muname := @.name //Get name of the part

//Random := z_uniform(1,1,100)

/*
Check what type of MU it is (P or C).
Checks the status of the ovens,
1. does station24 or station241 contain the same type of MU as MU in buffer but are not full? --> Set destination to that oven
2. Are one of the ovens are already full or both are empty? --> Set destination to an empty oven

Station24 have priority over Station241
*/
if muname = "PartPA"
    if 0 < Station24.NumMu AND Station24.NumMu < 10 AND muname = Station24.mu.name
        @.destination := Station24

    elseif 0 < Station241.NumMu AND Station241.NumMu < 10 AND muname = Station241.cont.name
        @.destination := Station241

    elseif Station24.NumMu = 0
        @.destination := Station24

    elseif Station241.NumMu = 0
        @.destination := Station241

    else
        waituntil Station24.NumMu = 0 OR Station241.NumMu = 0
    end
```

```
elseif muname = "PartCA" //Code not used as C-MUs have a
   ↪ designated oven (Station242)

if 0 < Station24.NumMu AND Station24.NumMu < 10 AND muname =
   ↪ Station24.mu.name
       @.destination := Station24

elseif 0 < Station241.NumMu AND Station241.NumMu < 10 AND
   ↪ muname = Station241.cont.name
       @.destination := Station241

elseif 0 < Station242.NumMu AND Station242.NumMu < 10 AND
   ↪ muname = Station242.cont.name
       @.destination := Station242

elseif Station24.NumMu = 0
       @.destination := Station24

elseif Station241.NumMu = 0
       @.destination := Station241

elseif Station242.NumMu = 0
       @.destination := Station242
else
       waituntil Station24.NumMu = 0 OR Station241.NumMu = 0
          ↪ OR Station242.NumMu = 0
end

end
```

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