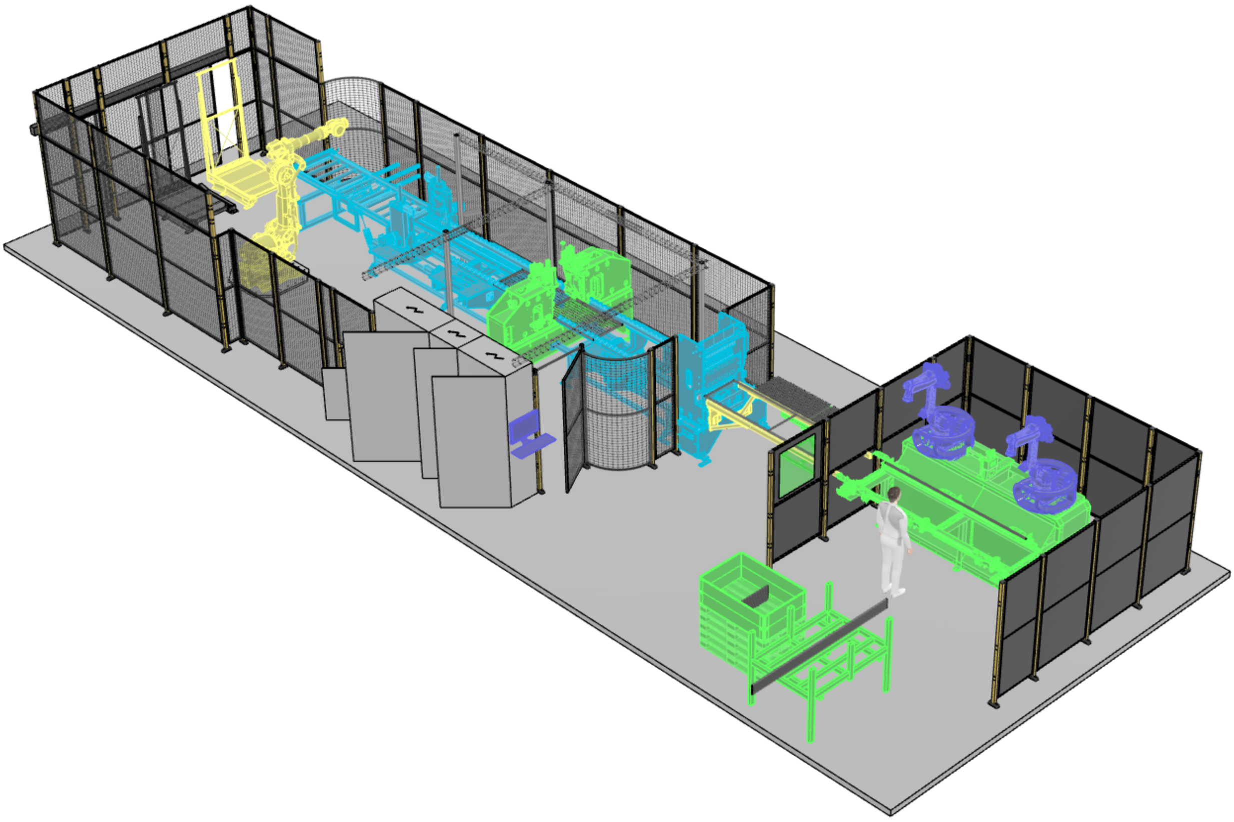

Discrete Event Simulation using DELMIA

Production optimization for small and mid-sized enterprises using the DES software DELMIA

Master's Thesis in Production Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022
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Master's thesis 2022

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Cover: Snapshot of the Axelent AB production line X-line3 in DELMIA *Factory flow simulation.*

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Abstract

In today's industry, cost-efficient processes are key to maintaining a company's profitability and competitiveness. With the technological enhancement in industry, simulation software has proven to be a quick and cost-efficient method of virtually observing and analyzing processes. This enables the conduction of analysis and testing, without interfering with the actual operation. This thesis aims at evaluating how discrete event simulation (DES) software, with practical use in DELMIA, can aid in performing improvement work of a production line, as well as determining the resource demand to use DELMIA for small and mid-sized enterprises (SMEs). To evaluate the practical use of DELMIA in industry, the production line X-line3 at Axelent AB was replicated and analyzed. Interviews and stopwatch time studies, along with an improvement generation phase, resulted in various improvement proposals for the production line. Results of using DELMIA to implement the improvement proposals show that a proposal of fully automating the line as well as adding a fixture and adjusting machine parameters will create the largest throughput increase of 283 %. The proposal focuses on elevating constraints, and whenever a new constraint was identified, the process was iterated until a satisfactory result was achieved or until limited by outside factors. The study shows that DELMIA and DES software are great tools to provide statistics to gain an overall view of a production station, line, or entire factory, which can create value for SMEs in their processes.

Keywords:
simulation, simulation software, DELMIA, DES, production, improvement, SME.

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Gustaf Malmsjö & Joel Nilsson, Malmö/Värnamo, June 2022

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List of Abbreviations

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

3DXML	3D file format developed by Dassault Systemés
AC	Alternating current
CAD	Computer Aided Design
DELMIA	Digital Enterprise Lean Manufacturing Interactive Application
DES	Discrete Event Simulation
MFDC	Medium frequency direct current
NC	Numerical Control
PLM	Product Lifecycle Management
PPR	Product, Process, Resource
SME	Small and medium-sized enterprises
X-line3	The third production line in Axelent AB's factory

1 Introduction

With the growing awareness for sustainability in manufacturing industries and today's market demands for new and enhanced variants, the need for readjustment in the industry is increasing. Companies must face the challenge of a reduced time to market and strive to maximize production rates and identify constraints, also known as bottlenecks. Many smaller companies have facilities or resources that do not fulfill present or future requirements, and a solution to fine-tune the performance of production systems, and conduct feasibility and performance studies is therefore required.

Companies need a solution that will help them to accommodate the changes in production lines to meet the demands of the market and eventually create efficient production systems. Rather than building a new facility or production line, optimization of the present facility is often a superior alternative. This is where Discrete Event Simulation (DES), and software like DELMIA, could be useful to define, simulate, and analyze multiple production scenarios to understand the behavior of the system or evaluate various improvement strategies (Ingalls, 2011).

This master thesis project is a collaboration between the Chalmers University of Technology, Axelent Solutions, and Axelent AB. Using the software DELMIA, an evaluation regarding simulations for optimization will be conducted. The simulations will include various improvement proposals for Axelent AB to potentially use to improve their facility. This chapter aims at describing the background of the project and the expected outcome.

1.1 Background

One of the reasons why requirements are not met is because there is a need for a larger capacity than what the production line was constructed for. At Axelent AB, there is a production flow through the factory consisting of a combination of old and new machines, where most of the production is automated. Axelent is interested in improvements to the production line referred to as X-line3, and it might be required to change the design of the layout, machine, or functions to make any improvements. The X-line3 needs a productivity increase and is to be relocated in the near future, which allows the implementation of improvements when the machine has downtime due to relocation.

Axelent AB offers a complete safety concept for machinery in industry and warehouse environments, consisting of modular mesh panels, called X-Guard, and accessories, see Figure 1.1. The Axelent AB head office is located in Hillerstorp, Sweden, where all product development, production, storage, and packaging takes place (Axelent AB, 2022c). The production line X-line3 is in Hillerstorp and produces smaller variants of the X-Guard mesh panel (Axelent AB, 2022a).

Figure 1.1: *Example of mesh panels from Axelent AB (Industridraperier, 2022).*

Axelent Solutions is an affiliate of Axelent AB, offering solutions in Product Lifecycle Management (PLM) and software development as well as consulting services for product and production development (Axelent Solutions, 2022). They are partners with Dassault Systèmes, which has various software in their portfolio, some of which are: DELMIA, Solidworks, and CATIA. These software are part of the cloud-based platform 3DEXPERIENCE, described as a collaborative business platform (Dassault Systèmes, 2022b). It has an unified interface and centrally store data from all software, enabling collaborative work between the software and users. These software are used at many large companies, such as Scania, Volvo Trucks, Husqvarna, and Thule. Since Axelent Solutions are partners with Dassault Systèmes, both using and providing the software, they are interested in exploring how DELMIA could be used in small to mid-sized enterprises (SMEs) with limited resources, for production simulation and optimization, since many of their customers are within the definition of SMEs.

DELMIA is a software for modeling and planning of industrial production (Dassault Systèmes, 2022a). It helps connect the virtual and real-world in a 3D environment to plan, visualize, analyze, optimize, and simulate production in a collaborative way. DELMIA enables manufacturers to gain insight into the production, to clearly understand how much is being produced and how well the manufacturing flows, making it easy to evaluate and improve manufacturing efficiency. Depending on the scenario, DELMIA provides plenty of different roles with associated applications.

Discrete Event Simulation software is a tool built on stochastic mathematical modeling. The power of DES is the ability to mimic the dynamics of a real system, which even many high-powered optimization models cannot take into account. This ability to mimic the dynamics of the real system gives DES its structure, function, and unique way of analyzing results (Ingalls, 2011).

1.2 Purpose

The purpose of the thesis is to explore the usefulness of DES software, such as DELMIA, towards analyzing and improving the production at SMEs. In addition, Axelent Solution seeks sufficient knowledge and experience in using software, such as DELMIA, to be able to promote its usefulness and come off as a serious contender. A case study carried out at Axelent AB focusing on the X-line3 will constitute a basis for an evaluation of whether DES software is suitable to find improvements and optimize production for SMEs, expanding the current research of the usefulness of DES software.

1.3 Aim

The thesis aims to formulate a recommendation to Axelent Solutions regarding the usefulness of the 3DEXPERIENCE software DELMIA and DES for SMEs. With the use of DELMIA, it also aims at finding improvements to the production line X-line3 at Axelent AB in order to create additional value.

1.4 Research questions

This thesis intends to investigate and answer the following two research questions. The first research question is a slightly more limited interrogation directed towards industry firsthand, evaluating the suitability of DELMIA for production simulation, especially focusing on SMEs with limited resources. The second research question is broader and focuses on DES, with the practical use of DELMIA for the improvement work of the X-line3, but also comparison and research of other DES software to contribute to the development of generic knowledge of modern DES software for SMEs.

- How is the *Factory simulation engineer* role in DELMIA suitable for assisting small and mid-sized companies in production simulation, and how resource-demanding is it to use?
- In what ways could Discrete Event Simulation software assist in analyzing and improving a production line, such as the X-line3 at Axelent AB?

1.5 Delimitations

As there are some limitations to the project, the list below presents a few selected delimitations to frame the project:

- The project aims to be presented after a 20-week period, at the end of May 2022, with a final report and oral presentation.
- The thesis will evaluate the *Factory simulation engineer* role along with its associated applications; *Plant layout designer*, *Factory flow simulation*, and *Equipment design*, not DELMIA in its entirety.
- The visual appearance of the equipment will be provided by CAD models from Axelent Engineering, but depending on the availability, simplified representations of the equipment may be modeled.
- The visual animation of the model is not to be prioritized, therefore removing the programming of robotic movements.
- In the case of absent or unmeasurable data, suitable assumptions will be made based on personal experience and that of the Axelent personnel.
- The focus will be on the improvement of the X-line3, and not on the upstream or downstream operations and material handling. The functions of simulating vehicles will therefore not be included.

2
Theoretical framework

The three main areas for the study, which defined the framework for the project, were DES, SMEs, and DELMIA. The following chapter describes the theory of these three areas, as well as earlier research within the framework.

2.1 Discrete Event Simulation

DES is a method which creates dynamic stochastic simulation models which follows time, where every event has their own process and timestamp (Sakr et al., 2021; Barrett et al., nd). In DES, the system's state gathers information from the entities within it, such as products or resources, and the state is updated based on the different events and its timestamps (Sakr et al., 2021). Between these events there is no changes in the system and can thus directly go into the next event, which may trigger generation of new events to be processed by the system (Barrett et al., nd). The simulated model is then run many times in order to generate a distribution of the results to be thoroughly analyzed and presented (Fahl, 2017).

Due to its ability to analyze many scenarios, DES is used in several ares, such as production, logistics, mining, and health care. It can help companies react or analyze their systems in a cost-efficient way and gain a full insight of their systems. The use of DES speeds up investment decisions since it provides useful information to be used as decision support (Martínez et al., 2020). According to Fahl (2017), there are several benefits of DES, some of which are:

- What if analyzes, used to simulate different scenarios to be able to make reliable comparisons without investing too many resources.
- Uncertainties and occasional events is easily programmed and modified.
- Using the simulated model to train new staff, or create new stations which is not yet physically built.
- Can function as investment support due to its ability to model complex and expensive systems, such as complete production lines or infrastructure.

2.2 Small and medium-sized enterprises

Small and medium-sized enterprises (SMEs) are well represented as more than 99 % of Sweden's companies are in these sizes. To be defined as an SME, the companies are required to have less than a certain amount of employees and turnover or balance sheet total. Small companies are to have less than 50 employees and a turnover or balance sheet total of less than € 10 million. A medium-sized company has an upper barrier of 250 employees and is required to have lower than € 50 million in turnover and less than € 43 million in balance sheet total (European commission, 2022).

According to Martínez et al. (2020), the enterprises worldwide that currently seek innovation and competitiveness are represented by more than 90% of medium-sized enterprises. There has arisen the interest in adopting new technologies and methodologies among SMEs for the purpose of competing and innovating their products with the adoption of the fourth industrial revolution (Industry 4.0) in large enterprise.

The new technologies introduced by Industry 4.0 have in recent years intensified changes in industry, especially in its economy. Increased adoption of technologies has had a positive effect on the growth and development of SMEs, however, common factors have been identified that limit the investing of technologies and methodologies related to Industry 4.0. The problem is due to the lack of effective decision-making among SMEs when designing, evaluating, analyzing, and modifying strategies and changes to product or operating processes (Martínez et al., 2020)

2.3 DELMIA

In January of 2000, Dassault Systèmes created the DELMIA brand, addressing the digital manufacturing domain, including digital process planning, robotic simulation, and human modeling technology. The name DELMIA is an acronym for Digital Enterprise Lean Manufacturing Interactive Application. It was formed under a unique brand after Dassault Systèmes' acquisition and consolidation of Deneb Robotics (robotics), EAI-Delta (process planning), and Safework (ergonomic simulation) to provide the manufacturing community with e-solutions to create, monitor, and control agile distributed manufacturing systems (Dassault Systèmes, 2000).

DELMIA is an integral part of the Dassault Systèmes 3DEXPERIENCE platform and is often referred to as the manufacturing arm. It provides solutions to leverage the virtual world of modeling and simulating with the real world of operations, thus providing complete solutions to value network stakeholders. The virtual experience of the factory production in DELMIA enables analysis, from the impact of design to determining how to meet demands. Before actual resources are committed, bringing together processes, equipment, and people to create a lifelike virtual reality of the manufacturing in DELMIA may determine the best approach to manufacture. Proving out plant level considerations and material flow in the early stages of product and production development enables concepts to be analyzed, and corrective actions taken to minimize cost and waste. Virtual twin technology, such as that of DELMIA, has thus proved to be a valuable tool in enabling a more sustainable focus in manufacturing (Shaw, 2021).

The framework for the thesis is on the DELMIA role *Factory simulation engi-*

neer, which use the applications *Factory flow simulation*, *Plant layout designer*, and *Equipment design*. The application *Factory flow simulation* is developed as a DES software, while the other two are used as design tools to support it.

2.3.1 Plant layout design

The application is used to create the layout of the user's factory. It allows for easy use of existing 2D drawings to create their corresponding 3D version. The application has features that make the user able to use standard CAD models made from other software and place them in the factory. These parts can be placed and positioned with the help of various snap tools to easily align them with other geometries or objects. Additionally, the parts can be generated into resources to acquire certain characteristics such as NC machines, conveyors, or workers, which then can be programmed to possess certain behaviors and functions (3DS Academy, 2016b).

2.3.2 Equipment design

The application enables the definition of virtual mechanical devices within the 3D work cell layout, such as robots, NC machines, and conveyors for planning, simulation, and feasibility studies. For robots, the application enables control of positions, travel limits, and safety zones. The conveyor settings enable the definition of speed, friction, guides, and conveyor networks. The definition of these parameters makes the simulation more accurate (3DS Academy, 2016c). After properly defining the resources, they can be used for simulation purposes in *Factory Flow Simulation*.

2.3.3 Factory flow simulation

The application provides the user with the possibility to define and validate the behavior of a station, a production line, or a complete factory. This is enabled through defining product flow between resources, adding activities such as loads or transfers, but also adjusting the duration of activities, defining the behavior of workers, and setting buffer sizes. This gives the user a wide toolkit to be able to fill their factory with all the details it contains. When the factory is complete, the simulation tool allows access to detailed statistics of the product flow behavior. These statistics can for example be regarding product throughput, utilization rates of resources, or waiting times. The statistics can then be used to analyze the factory's performance (3DS Academy, 2016a).

The creation of a factory flow is built on flows between zones, which are specific points defined either on a resource for a product to be handled (product zones and decision zones), or near a resource to specify the position of a worker (resource zones), see Figure 2.1. The zones can later be equipped with an activity which allows specification of the action of a resource or a zone, such as transforming, buffering, or loading to resources and in and out zones. These are shown in Figure 2.2 and are displayed on the zone when defined. A flow consists of one or many of these different zones and activities.

Symbol	Name	Description
	In-zone	It is the start point of a factory flow
	Out-zone	It is the end point of a factory flow
	Product zone	It is the point set on resources to handle products by resources.
	Resource zone	It is the point near a resource where a worker is located to handle a product.
	Decision zone	It is the point set on a conveyor where a resource executes an activity on a product when that product reaches the zone.
	PnF Decision zone	It is the point set on a Power and Free conveyor to load, unload and route products.

Figure 2.1: *Factory flow simulation zones (3DS Academy, 2016a)*

Symbol	Name	Description	Resource	Zone
	Create	It allows you to define a create activity for a product to an in zone.	-	In zone
	Dispatch	It allows you to define a dispatch activity for a product to an out zone.	-	Out zone
	Buffer	It allows to specify a buffer time to an activity.	Storage For example, a pallet	-
	Transfer	It allows to transfer the product from one location to another.	Transfer For example, a conveyor	-
	Transform	It machines open or closed pocket with or without inner island.	Transform For example, an NC machine	-
	Load	It allows to load a products into a machine.	Machine	-
	Unload	It allows to unload a products into a machine.	Machine	-

Figure 2.2: *Factory flow simulation activities (3DS Academy, 2016a)*

2.4 Earlier research

Literature study of earlier research formed a base for the proceeding of the thesis. The following section presents findings from scientific reports and articles regarding DES, some with conjunction to SMEs. Several earlier theses focusing on DES were also found which work relevant for this thesis is presented.

2.4.1 Scientific articles

An earlier case study by Martínez et al. (2020) was a collaboration between the Mexican School of Engineering and Sciences and a Mexican SME in the automotive sector, aimed at showing how SME's productivity and profitability is improved directly from the decision-making process using DES. In order to improve the productivity of the process, proposed scenarios were simulated through the DES software Plant Simulation Tecnomatix by Siemens.

The plant productivity of 84 units per month was low compared to the SME target of 100 units per month. Bottlenecks in the workstations of the lamination area had been detected due to bad management, and targeted specifically for productivity increase. Three scenarios were generated regarding quality, reliability, and profitability. The scenarios were combinations of added continuous production flow, involvement of additional 8-h shifts, and lead time reductions. The estimated productivity improvement of the third scenario reached 89.9% with respect to the simulated real situation, reaching not only the targeted 100 units, but rather 152 units per month.

The findings was that with DES, it was determined that the SME was 16 units short of the goal due to lack of productive time in its process, affecting the profitability in addition to the waste of non-productive processes. The information obtained by use of DES led to the value creation and generation of viable alternatives for the future of the SME, impacting on profitability. The conclusion was that by working with DES, time and costs can be reduced, regardless of business or production type.

Sulistio and Hidayah (2017) undertook an SME producing craft bags in Indonesia, where the company had success in a marketing program which increased demand. To be able to satiate the demand, production targets went up to 60 units a day, which was difficult for the SME to keep up with unless working overtime.

From 30 work days observations, the results were that the current production rate was about 45 units per day. Building a simulation model using the software Flexsim showed the bottlenecks, and could assist in finding alternatives to improve productivity. Sulistio and Hidayah (2017) concludes that DES is a useful tool for SMEs due to assisting in finding alternatives to increase productivity, and subsequently, reduce the number of resources.

2.4.2 Chalmers master theses

Much similar to this thesis work, the purpose of Bernérus and Karlsson (2016) was to investigate the software platform 3DEXPERIENCE to determine whether the customers of the consultancy firm Prodtex will have use for it. However, the focus was a bit broader on evaluating the platform 3DEXPERIENCE, and for large enterprises rather than SMEs. Toyota Material Handling was used as a representation of a large enterprise, and its factory simulated to validate 3DEXPERIENCE from a real-word scenario. Although, with set delimitations, the evaluation was limited to applications directly related to the *Factory simulation engineer* role in DELMIA.

The evaluation showed that 3DEXPERIENCE excels in categories such as visual aspects, efficiency, modeling assistance, and user support. However, the platform was shown to lack in categories such as financial and technical features, statistical features, and environmental consciousness. To address its suitability for large enterprises, the conclusion was that there are other software matching the demands just as well as 3DEXPERIENCE, but with better environmental sustainability aspects.

3DEXPERIENCE did not support the demand of sustainability features in large enterprises such as Toyota Material Handling.

Lindskog and Lundh (2011) investigated the possibility of assessing environmental product footprint using DES. They found that the simulation of real world dynamics using DES could help determine a product's environmental footprint and studied a factory belonging to an SME, producing machined metal parts for Swedish industries. The factory consisted of several resources and was modeled in 3DCreate from Visual Components to be studied. To investigate the possibility of using DES for environmental assessment, the simulated results were compared to Simplified Life Cycle Assessment (SLCA) using the same input data.

The study showed that simulation using DES gave similar results as SLCA regarding power consumption and Global Warming Potential (GWP) emissions, however, some limitations in gathered data contributed to differences between the DES method and the SLCA method. In some cases, data was derived from interviews with operators and in other cases had estimated. The study concluded that the greatest benefit with using DES instead of a static method was that the dynamics makes it possible to generate different emission values for different products. This enables analysis of the production stability and finding sources in the system with high emissions that could be improved, similarly to bottleneck detection. Whether or not to create a simulation model was discussed with the conclusion that if a simulation model already exists, the time consumption of adding of environmental parameters is not that high. Creating a simulation model solely for environmental evaluation purposes might not be beneficial due to its time consumption.

For simulating, the thesis discussed that it could be hard to simulate human behaviors because every worker behaves differently. The level of graphical representation was furthermore discussed to may have been too high, and leaving out graphics could have made the process faster.

2.4.3 Lund PhD thesis

A PhD Thesis done by Randell (2002) focused on the subject of DES and discussed the reasons why its not used as widely for developing processes, as it is on solving current problems. This gave simulation a reputation of being a cost driver in analysis of the systems instead of being seen as a benefactor.

Randell (2002) reviewed four cases with different goals and targets. Results of the cases described the uses of DES, in its ability to reach the targeted goals as well as the ability to develop methods to be used in the analyzed factories. It could identify and elevate bottlenecks in not yet constructed factories and recommend layout changes to further elevate secondary bottlenecks. In the first case, Randell (2002) mentions that the savings the project would bring the company could alone pay for the project, including new computers, software, and education costs.

The second case resulted in a halt due to lack of accuracy in simulations due to complex errors, which the systems of 2002 could not cope with. Randell (2002) mentions that more potent and powerful computers would be able to cope with these issues.

For the third case, the task was to develop and test a method for developing DES models in a heterogeneous environment, as well as reduce lead times by 25% and increase throughput with 25%. Due to the lack of data, the requested parameter increases could not be met, and Randell (2002) points out the problem with not having accurate enough input data. Randell (2002) found out that there was a increased need for structure with a higher number of developers. When several people worked on the same project, the files would change names, change revisions and the method would get lost without notice and would then complicate the project.

The fourth case needed a new system to be verified in order to know if the system was able to handle a specific capacity. The simulated results could identify and elevate the primary, and a secondary bottleneck and could determine that buffer capacities were sufficient but could be reduced. From the simulated results, work procedures could be made. Randell (2002) mentions the learnings from the third case was to have a good structure when working with several developers in order to make the organization more smooth.

3
Methodology

The proceeding of the project was through a systematic framework, following the steps of the structure tree in Figure 3.1, visualizing the important steps of the process. Based on the project purpose. research questions were developed, as presented in section 1.2. To obtain sufficient knowledge to address and answer the questions, chronological and iterative proceedings through the theoretical framework, research, data collection, and evaluation led up to the final recommendation.

The following sections describe the undergone steps and methodology used in more detail to get enough grounds to be able to sufficiently answer the research questions.

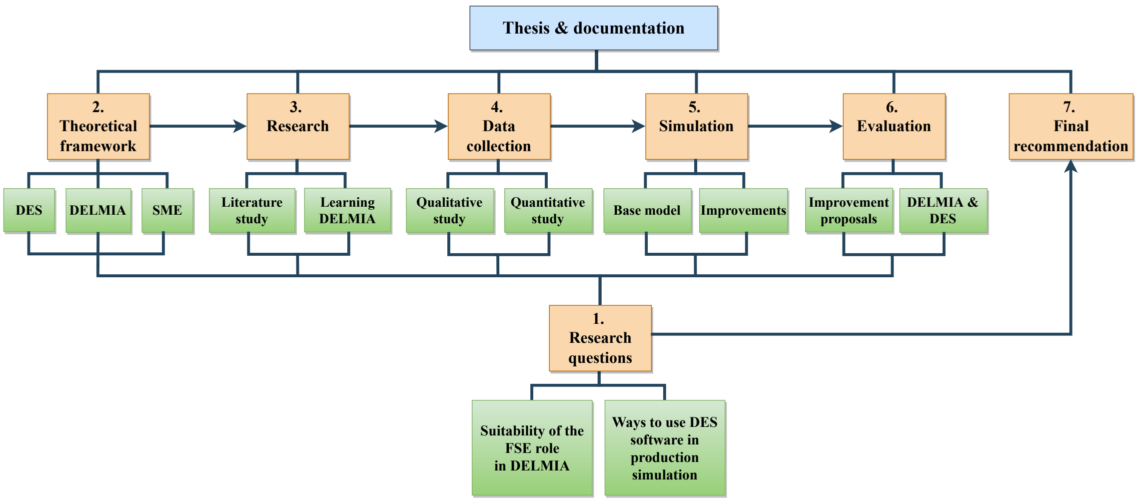


Figure 3.1: *Structure tree.*

3.1 Theory and research

To obtain knowledge about the subject and simulation software, a theoretical framework was established and research conducted using literature and online learning modules. This was necessary in order to discover what previous knowledge existed and understand what to consider through the project in order to answer to research questions.

3.1.1 Literature studies

To gain an understanding of the topic of DES, DELMIA, SME, relevant literature, research papers, and similar studies were sought after and investigated. With the help of academic search portals, such as Scopus (2022) and Chalmers Open Digital Repository (2022), a literature study was completed with keywords such as DELMIA, DES, Production Simulation, and 3DEXPERIENCE. For evaluating simulation software, earlier experience from the course *Simulation of production systems* from Chalmers (2020) was used as a reference, as well as further research papers about similar software and projects. These were foremost used to answer the second research question regarding DES.

3.1.2 Understanding of DELMIA

In order to proceed with the project and begin modeling, a general understanding of the DELMIA applications *Factory flow simulation*, *Plant layout design*, and *Equipment design* was required. To learn how to use and navigate the 3DEXPERIENCE platform, the Dassault Systèmes learning platform, EduSPACE (2022), was used as a foundation for learning, accessed through Chalmers student licenses. Specifically, the learning module *Perform as a Factory Simulation Engineer* was carried out to validate the behavior of a working station, a production line, and a complete plant. The course also taught how to simulate production flow with rework and repair configuration and identify and eliminate bottlenecks. However, the submodule of understanding of DELMIA was a continuous process throughout the project, and one of the key modules for answering the first research question.

Dassault Systèmes help web page, 3DS User Assistance (2022c), was used throughout the project to gain an understanding of the details of functions in DELMIA.

3.2 Data collection

To ensure the data input used in the simulation was valid, data collection was done before starting the simulation process. Having access to collected data helped verify the simulation to the actual times of Axelent's production, as well as the basis for upcoming improvements.

The form of both qualitative and quantitative study methods was chosen, resulting in interviews and respectively a stopwatch time study. Prior to the data collection, an analysis of the production line was performed to give a detailed assessment of the different operations to make sure the data collection covered every step of the line. This included activities such as manual operations, set-ups, maintenance, disturbances, and operator break time. This also gave the possibility to look for opportunities for method improvements simultaneously as learning the operations (Zandin and Maynard, 2001).

3.2.1 Interviews

To obtain a deeper understanding of the production line, interviews were held. They were done with the two operators of the line and the plant manager, who had been part of constructing the machine. To make the most of the interviews, the form of a semi-structured method was used, to ensure that if a question proved to be more relevant than first believed, it could be further expanded into more detail.

To make sure the operators' responses would be as honest and thorough as possible, it was mentioned that the details of the interviews were only to be used in the thesis work and not shared with managers. In addition, initial conversations were had before the interviews to make the interviewees more comfortable talking about their daily tasks.

3.2.2 Stopwatch time study

To measure the time required to perform the necessary operations at the production line, the operations were closely observed and thoroughly time studied. Dividing the operators' activities into smaller elements was needed to make the correct analysis, as well as make it easier to find improvements. To get an accurate and consistent sample, the operators should be qualified and work at their normal performance level, in accordance with a specified method. In addition, a reasonably high number of observations had to be done so they could follow a normal distribution curve, with some lower and higher-end observations along with a majority grouped in the middle (Zandin and Maynard, 2001, ch.124).

To carry out the time study, a time study form was created, which can be seen in Appendix A. It shows the elements, as well as the different categories the elements were put in. The elements found in the initial analysis were grouped by their manufacturing cell in the production line and further grouped, based on the type of resource which executed the operation. For the study, the form was put on a clipboard so that the order of the elements could be followed throughout the study, and irregular events documented easily. The study was executed with an accurate digital application for Android phones called *Timestudy stopwatch* (Linsener, 2021). The specific application was chosen as it enabled structured saving of the results to be noted down and analyzed after the measurement session.

After the data was documented and analyzed, it was used in the base model simulation in DELMIA for it to behave like the real production line.

3.3 Simulation

This chapter describes how the simulation process in the project was carried out. Using the Theory of Constraints as a reference, the simulation process was carried out in an iterative process. This chapter was used in order to gain experience to be able to mainly answer the first research question, stated in section 1.4, but also used to answer the second research question based on the experience.

3.3.1 Conceptual model

To begin the process of building a base model, a simple, conceptual model was formed. This consisted of operator tasks, machining operations, conveyors, and buffers. The conceptual model was created to help in gaining a quick overview of how the X-line3 functions.

The system includes ten objects, referred to as resources. To start, there is a pair of pallets containing two different sized pipes used to create a frame. These pipes are loaded by the operator into the frame welder, which welds the five pipes into a solid frame. When the welding is complete, the operator pushes the frame into the next station where the mesh is attached onto the frame and is manually spot welded into place with the use of a MFDC-welder. The remaining stations are automated, where the first one is a AC-welder. This machine welds the finals spots of mesh to be attached onto the frame, making it a panel. After many welds, the panel's shape has been changed due to the behavior of metal where it curls due to high temperatures. This is where the Straightener helps the panel to keep its intended geometry by counteracting the natural response to heat as the metal has. Finally, there is a dispatch robot which transfers the finished panel onto a pallet, until moved for painting. The model can be seen in Figure 3.2.

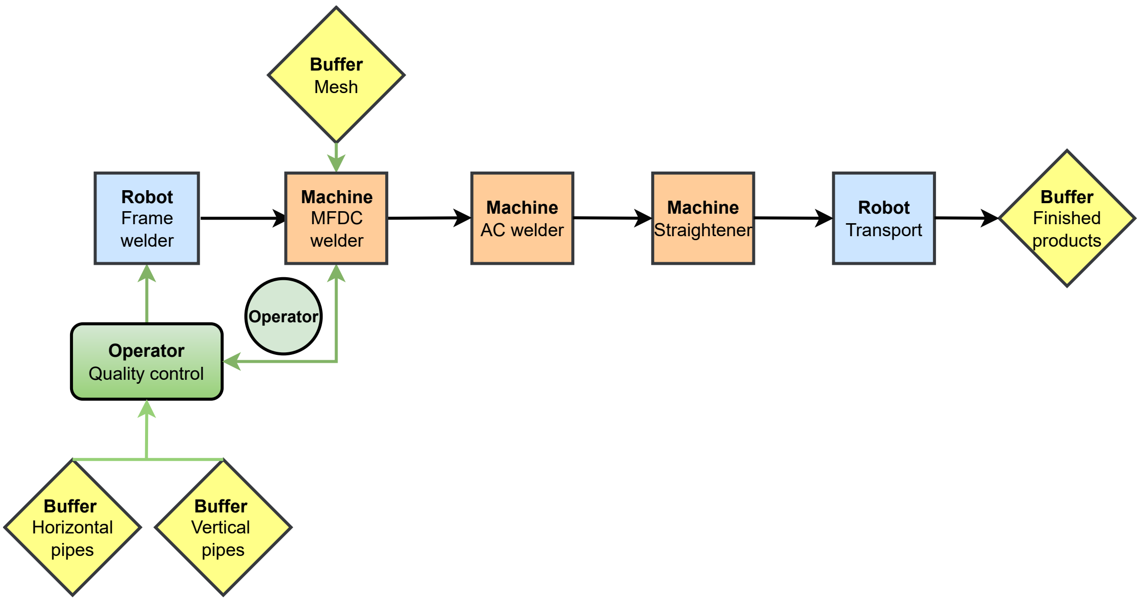


Figure 3.2: *Conceptual model of the X-line3.*

3.3.2 Base model

As mentioned in section 3.1.2, a thorough process to understand the software was required to start the simulation process. The base understanding of DELMIA, together with the data gathered, assisted in building the base model of the X-line3 from Axelent. In this thesis, the base model definition was a replica of the existing production line as it works today. The aim was to achieve the same throughput, with the same tasks and resources, which could later be used as a comparison when implementing improvement proposals. To build the model, continuous troubleshooting was necessary as well as discussions with supervisors and Axelent AB staff.

In order to verify and validate the base model, the approaches and techniques of Sargent (2010) were followed. To verify, simulations were performed continuously throughout the process of building the base model to ensure that any changes were implemented correctly. The verification techniques mainly consisted of studying the model animation as well as printing and viewing information, and to validate the model these values were compared with the measurements from the real production.

3.3.3 Improvements

The performance of a production system is determined by its constraints, also known as bottlenecks. In order to improve the performance, elevating the bottlenecks is therefore necessary. However, the problem in finding bottlenecks is that production systems vary over time, and random events may cause temporary bottlenecks. A system has therefore usually not only one bottleneck machine or resource but a number that causes constraints at different times. Determining the average level of the constraint of a resource over a longer period is for this reason essential. A system might also contain resources not affecting the system performance at all, so-called non-bottlenecks. The primary bottleneck will naturally be focused on in terms of improvements, however, reducing the speed of non-bottlenecks may be another possibility to save money (Roser et al., 2003).

To improve the base model, the five steps of the Theory of Constraints were used to find bottlenecks and then elevate them to optimize the production (Goldratt, 1990). The general process is summarized as:

- Identify constraint.
- Exploiting the constraint.
- Subordinating everything else.
- Elevating the constraint.
- Iterate.

The first step to identify the constraint was done by analyzing the system while looking at the level of utilization of resources, which was chosen as the main method for bottleneck detection. Furthermore, the waiting time for material input, waiting time for resources, and waiting time to output to the next resource were considered (Roser et al., 2003). To exploit the constraint, the goal was to find simple changes with the available resources, which would maximize the level of efficiency the bottleneck had (Rahman, 1998). Before the bottleneck was remedied, the rest of the resources were subordinated. The remaining resources needed to be adjusted and help supply the necessary materials to ensure that the bottleneck is neither starved nor blocked to run at full capacity (Rahman, 1998). After significant changes have been made to the constraint for it to be considered elevated, and no longer limit the system, there forms another one to be the new limiter of the system (Goldratt, 1990). When then the new constraint has been identified from the breaking of the one prior, the process has to be iterated until a satisfactory result has been achieved or until constrained by outside factors, such as limited implementation and investment possibilities.

3.4 Evaluation

Whether DES, and software like DELMIA, is suitable for production simulation, and the improvements of X-line3 are considered sufficient, was determined by evaluating the results. With results that were potentially not satisfactory, additional research on new improvements was carried out and implemented in the simulation for verification. The sub modules in Figure 3.1 of "Improvements" and "Improvement proposals" were therefore performed iteratively in order to come up with the best variants. The evaluation gave arguments to help answer both research questions.

3.4.1 DELMIA & DES

The evaluation of DELMIA was based on the practical use, results, and literature search. Continuous documentation of the DELMIA user experience throughout the project was the major basis for the evaluation. After evaluating the suitability of the *Factory simulation engineer* role in DELMIA, other DES software was looked at briefly and compared with DELMIA to conclude some similarities and differences among DES software. With sufficient knowledge regarding DES, through the practical use and literature study, the use of the software as a tool for production simulation was evaluated.

3.4.2 Improvement proposals

Among the improvement proposals, some may be substantially better than others in different areas. To evaluate, proposals were compared among factors such as productivity increase and bottleneck elevation. The financial results of the final improvement proposal were then simply calculated along with a discussion of its plausibility.

3.5 Final recommendation

Based on the outcome of the evaluation, recommendations were formulated to answer the Research questions. With an evaluation of the *Factory simulation engineer* role in DELMIA, based on the user experience and analysis of its functionality, the first research question was answered through an evaluation regarding its strengths, weaknesses, and resource demand. After investigating possible improvements of the X-line3 using DELMIA, and evaluating DES software through literature studies, the potential use of DES software for manufacturing industry and SMEs was assessed and the second research question answered.

4

Simulation model realization

The following chapter describes the model creation in DELMIA, which was the major foundation for evaluating the suitability of DELMIA. It includes the process through the different applications, evaluation of the base model, as well as generation and implementation of improvement proposals.

4.1 Creation of the base model

To create a manufacturing context, containing products, processes, manufacturing systems, and physical resources, a Product, Process, and Resource (PPR) Context was created in the *Plant layout design* application. After creating PPR Context, a *manufacturing cell* was inserted. By using existing CAD files from Axelent Engineering, the parts of the X-line3 production cell were imported into the cell. As some of the existing CAD files were out of date and incomplete, downloaded CAD files from GrabCAD were used as a complement (GrabCAD, 2022). The machine guarding was updated using the Axelent SnapperWorks tool based on measurements taken, and imported into the PPR Context (Axelent AB, 2022b). Following was a process of defining and generating resources, such as *Machines*, *Robots*, *Conveyors*, *Storage*, and *Worker* among the vast amount of CAD-parts. Using the Layout tools, the resources were arranged and juxtaposed using the Snap tool to fit as in the drawings. With the use of the *Equipment design* application, the creation of mechanical logic and kinematics were made for the conveyors.

After completing the basics in *Plant layout design*, a structure had been created which needed to be filled with purpose using the *Factory flow simulation* application. First, a *Factory flow* was defined with products in order to create the production flow. This flow was connected through the resources, together with the creation of their corresponding *Activities*, such as welding or transportation. Material flows from outside the line were added to complete the product flow, see Figure 4.1.

The activity duration, measured from 5.1.2, was included to make the simulation model further resemble the real model. *Working cycle management* was used for the operator's tasks to make sure its activities were performed in the correct order. The working cycle included walking between operations, material quality control, loading, and enabling resources to begin their tasks. For additional operator activities, a schedule was created in the *Shift* function to follow the daily routines of operators with scheduled breaks and similar activities. The *Working cycle management* function and part of the *Shift* function are shown in Figure 4.2.

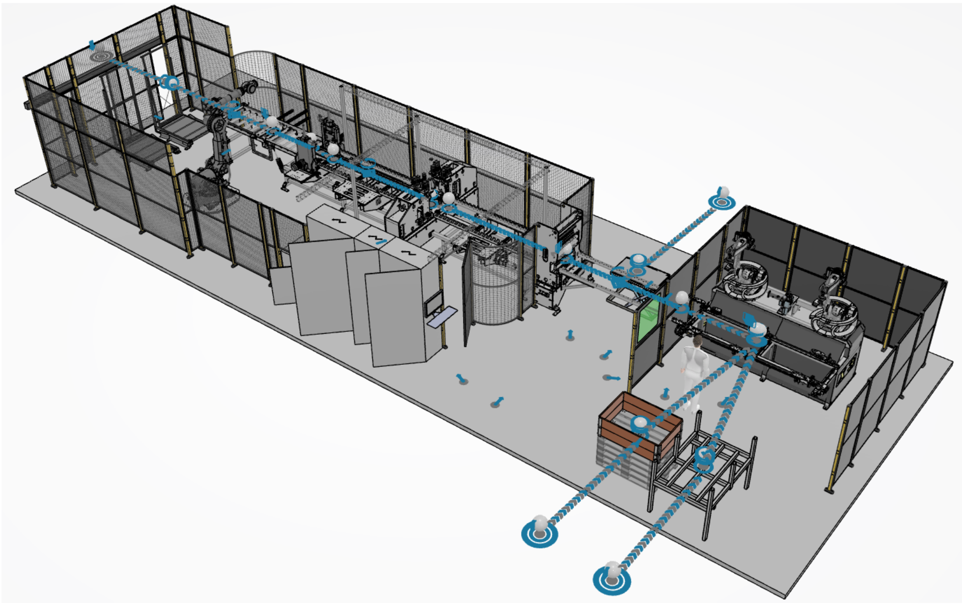
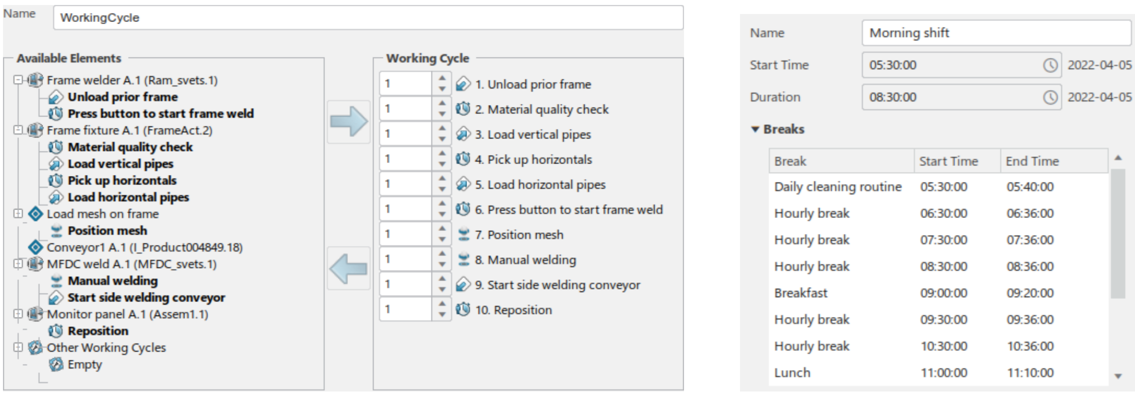


Figure 4.1: *Base model layout.*



(a) *The Working cycle management function.* **(b)** *The Shift function.*

Figure 4.2: *Operator activities.*

4.2 Evaluation of the base model

While creating the base model, it was continuously simulated to verify that new implementations or changes were working correctly, both operationally and visually. The simulation enabled a trial-and-error approach and a visual tool for finding flaws or errors. Highlighting of resource states was one analysis tool displaying whether states were *Idle*, *Processing*, *Waiting for input(s)*, or *Waiting to output(s)*, as shown in Figure 4.3. The set of colors used for displaying different systems states during simulation is shown in Figure 4.4a (3DS User Assistance, 2022b). When a resource is clicked, simulation charts with detailed information appear as shown in Figure 4.3

regarding states, work in progress, utilization, and total produced, see Figure 4.4b (3DS User Assistance, 2022a). Continuously verifying the model finally resulted in a model with all operations in order and with accurate times and states.

After verifying the model, validation was made by comparing the statistics to the real production. To receive simulation results of longer times of a day or week, the *Batch simulation* was used.

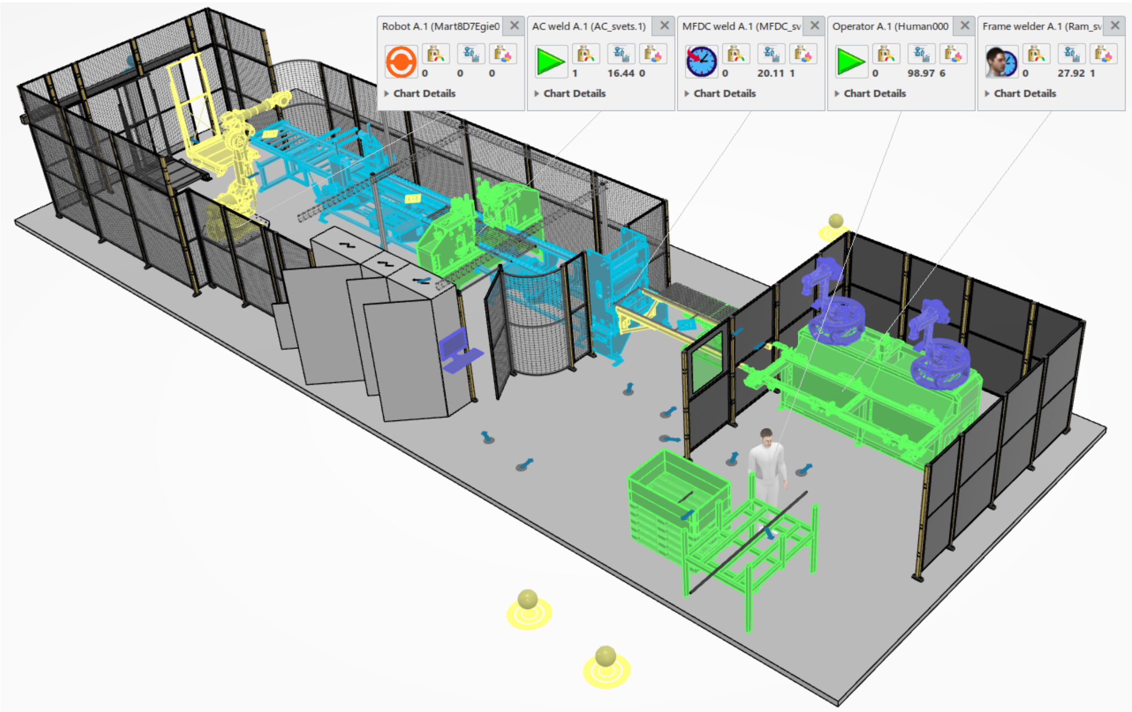


Figure 4.3: *Resource states while in simulation.*

Name	State	Color
Idle		
Processing		
Transporting		
Wait for Input		
Wait to Output		
Failed		
Empty		
Partial		
Full / No Reorder		

(a) *Colors and icons for different resource states.*

Icon	Description
	Number of products handled by a resource or zone.
	Time a resource spend handling the products.
	Number of products already handled by a resource or zone.

(b) *Simulation chart icons.*

Figure 4.4: *Colors and icons used for displaying different states and information of resources during simulation.*

4.3 Generation of improvements

When the main bottlenecks had been detected in the base model, the improvement work of X-line3 began by using the operator interviews and personal observations as the main reference for possible improvements. Brainstorming and simulating, in combination with prior experience from the *Simulation of Production systems* course (Chalmers, 2020), generated plenty of improvement proposals, shown in the list below. The proposals were split into several categories along with the respective improvements. Further description of the improvement proposals are described in Appendix B.

1. Operator activity
   (a) Remove the activity of material quality control
   (b) Remove the activity of material refill and final product dispatch
   (c) Add another operator
   (d) Daily manning around the clock
2. Buffer/material
   (a) Add a buffer after the frame welder
3. Automation
   (a) Automatic loading of frame welder
   (b) Automatic unloading of frame welder
   (c) Automatic MFDC welder
   (d) Full automation
   (e) Full automation around the clock
4. Layout
   (a) Changed orientation of the frame welder station
5. Adding machines
   (a) New loading fixture
   (b) Additional machines
6. Adding machine capacity
   (a) Possibility of processing two products
7. Machine parameters
   (a) Reduced cycle time
   (b) Reduced loading time
   (c) Reduced travel time

Following the Theory of Constraints, once a bottleneck has been elevated, another is created (Goldratt, 1990). The implementation of improvements to elevate the operator bottleneck soon revealed new constraints. Following, a process of iteration began, where the system bottleneck was continuously transferred from one resource to another when elevated.

5
Results

Using the results from the data collection, modeling began and improvement proposals were implemented. The proposals were later evaluated, as well as the DELMIA *Factory simulation engineer* role. The following chapter describes the results of the improvement process and evaluation of how DELMIA and DES software may assist in analyzing and improving a production line with regards to SMEs.

5.1 Data collection

The following section shows the results of the data collection phase of the project, consisting of the interviews and stopwatch time study.

5.1.1 Interviews

When the operators were asked what obvious bottlenecks the production line had, the answer from operator 1 was the side welder machine as well as the manual tasks at the frame welder. They continued to mention that it was the only production line to produce the smaller panels which was a bottleneck for these products in total.

The quality of the pipes was mentioned to sometimes be poor, and make the side welding machine break down due to it not being able to adapt to a poorly shaped pipe. This breakdown could damage the machine and take a considerable amount of time to fix, disrupting the production. One operator mentioned that the frame welder could miss its mark, or weld a hole in the frame, resulting in a need for manual welding. They would then readjust the welding positions to avoid future errors. However, the plant manager commented that a correctly programmed robot should always have the correct position and the source of error is then from elsewhere. This was interpreted as the method or instructions to the operators being inadequate.

For improvements, the operators mentioned making the wrapping and transportation of the pallets with finished products automatic or done by someone else, since it takes a lot of time depending on if there is an available truck or not. It was also mentioned that the loading of material for the frame welder, as well as the unloading of the prior frame, could be done automatically. According to the plant manager, they chose to make it semi-automatic when constructing the machine, as the company did not have the prerequisites to make a large investment in a fully automatic machine. The plant manager mentioned that they had previously tried to use another operator to simulate the process of getting the frame assembled automatically by an additional machine. This resulted in an increased throughput rate for panels with a sparse mesh, but more downtime for operators when producing panels with a dense mesh. This was due to a larger number of welding points for a dense mesh, and a longer cycle time in the side welding, creating a bottleneck in the line. The manager continued that it might be an idea to try out two operators that alternate roles, where one acts as a support, assisting with material handling, and the second one operator the production line. In this way, some downtime could be avoided due to the removal of minor value-adding operations from the main operators' tasks.

5.1.2 Stopwatch time study

From the initial analysis of the production line, 17 different elements for observation were determined. These elements were performed by a mix of operators, conveyors, and machines. The elements were used to collect a total of 30 data samples of the conveyors, machines, and robots, and 40 data samples of the operators' performance. All measurements were done on separate products to get as wide a data sample as possible, following the measurement sheet of Appendix A.

The samples of operations showed a variation in time following a normal distribution, with the manual operations having a larger deviation than the machines. The full results of the time study are shown in Appendix C. As the machines are programmed to perform the same task repetitively, the times are set to have no deviation. However, human behavior results in a standard deviation for the operator tasks for the DELMIA model. The values to use in the DELMIA simulation for the operations were calculated to the average values shown in Table 5.1.

Table 5.1: Stopwatch times.

Element	**Resource**	**Time [s]**	**Std. Dev. [s]**
Unload prior frame	Operator	5.2	1.4
Material quality control	Operator	8.4	1.5
Load vertical pipes	Operator	7.1	2.5
Load horizontal pipes	Operator	9.9	2.8
Start frame welding	Operator	6.2	1.1
Frame welding	Machine	16.8	-
Waiting time	Machine	63.3	-
Load mesh	Operator	9.0	2.0
Position mesh	Operator	5.5	2.4
Manual welding	Operator	15.3	2.5
Start conveyor movement	Operator	2.4	1.1
Conveyor moves panel	Machine	5.8	-
Side welding	Machine	47.0	-
Panel cool down	Machine	4.1	-
Conveyor moves panel	Machine	7.5	-
Conveyor tilts panel	Machine	11.8	-
Robot dispatches panel	Machine	25.5	-

5.2 Virtual modelling & simulation

Based on the outcome of the data collection and the project realization using DELMIA, a final improvement proposal was created.

5.2.1 Base model of the current production line

By creating a PPR Context and importing drawings and CAD models, a base model of the present production line was modeled using DELMIA. It contains the activities of resources within the production line, as well as breaks, working order cycles, and space for a material refill and unloading of the finished products, see Figure 4.1 for the complete model. Batches of one day were set as the standard to save computing power, and decrease wait times for result. Due to the structure of the model with shifts, weekly activities, such as maintenance, were included as shifts of an average time per day calculated from the total time over a week. Running several batch simulations, the base model result showed a throughput of 500 products. The real factory produces 450-500 products each day with intermittent two-shift work.

From the batch simulations, the utilization levels were calculated, see Figure 5.1. The most significant bottleneck was the operator, which has the highest value of utilization in the system. This was mainly due to the manual operations at the MFDC welder and frame weld where the operator currently constrains the system.

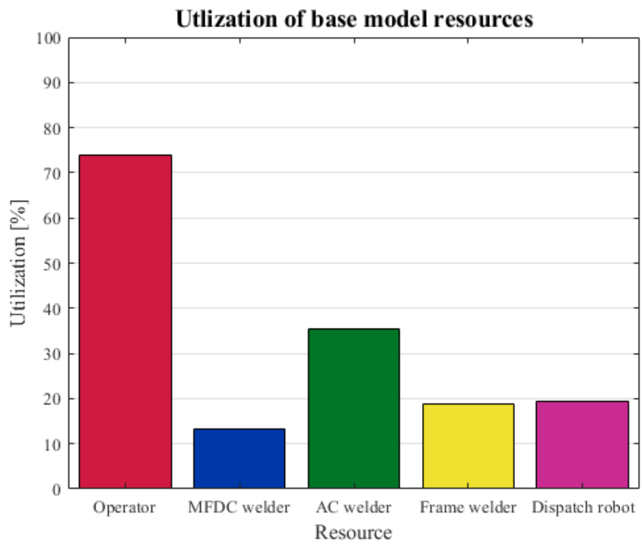


Figure 5.1: *Base model utilization.*

Figure 5.2 shows the level of waiting times for the resources in the system. The waiting times include *waiting for input*, *waiting for output*, *waiting for resources*, and *idle time*. The waiting times indicate how the bottleneck of the operator affects the resources around it, where the bottleneck itself has close to zero waiting time.

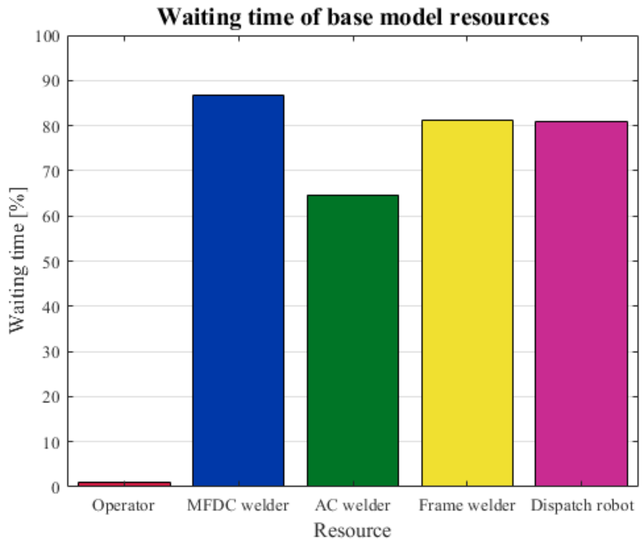


Figure 5.2: *Base model waiting times.*

The takeaway from evaluating the base model was the high load on operator activities, determining the takt of the entire line in the present situation as other resources were waiting. Following the Theory of Constraints, the operator was solely the bottleneck whose utilization had to be equalized with the rest or newly added resources in an improvement process.

5.2.2 Improvement proposals

In order to elevate the bottleneck of the operator activities, an additional resource of loading material was required, either at the MFDC weld or frame weld. This could either be by implementing an additional operator or automating activities by implementing a robot cell. Among all the simulated proposals from section 4.3, only improvement proposals 1c, 3a, 3c, and 3d gave good enough results to be further analyzed and compared by their bottleneck elevation and production output. In Figure 5.3, the bottlenecks are compared and the daily output comparison is presented in Figure 5.4. A full list of how the improvements impacted throughput is shown in Appendix D.

By automating, the question was whether to automate the frame welder or the MFDC welder. As interpreted in Figure 5.3, the implementation of an automatic frame welder eased the operator bottleneck more than the implementation of an automatic MFDC welder. As a result, automating the frame welder increased the output by 73%, in comparison to the 38% increase of automating the MFDC welder. However, as the operators believed the alternative of fully automating the line was the best, the combination was simulated. By implementing full automation, the line may process without interruptions due to human factors, such as breaks. Fully automating the line increased the output by 106%, becoming the reference for the following iteration.

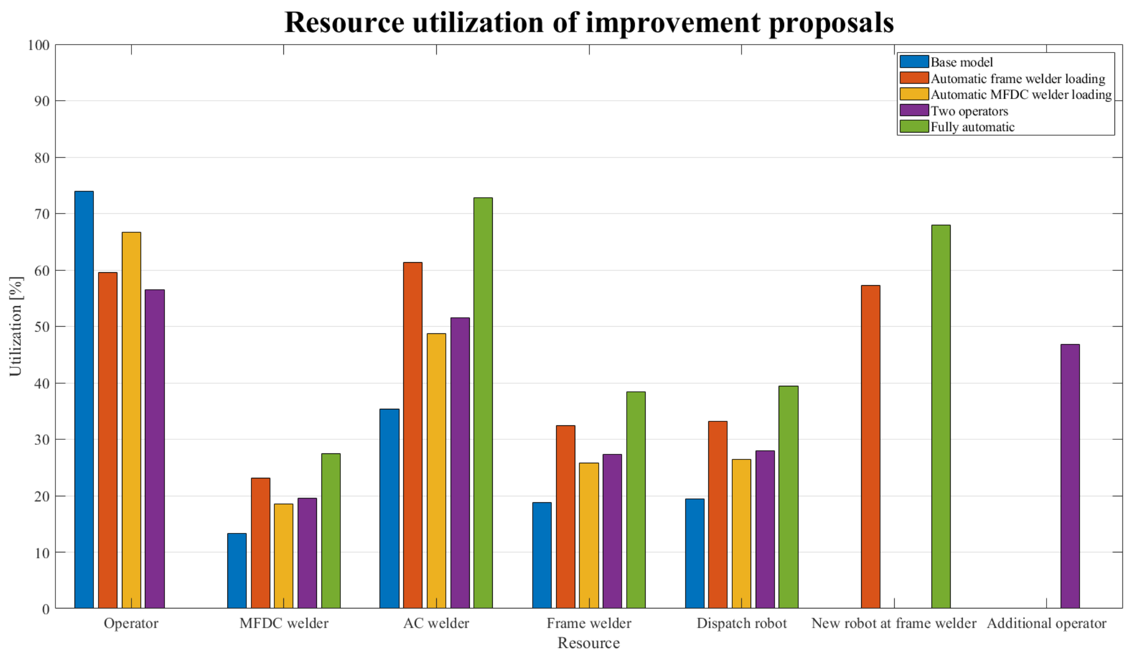


Figure 5.3: *Utilization comparison.*

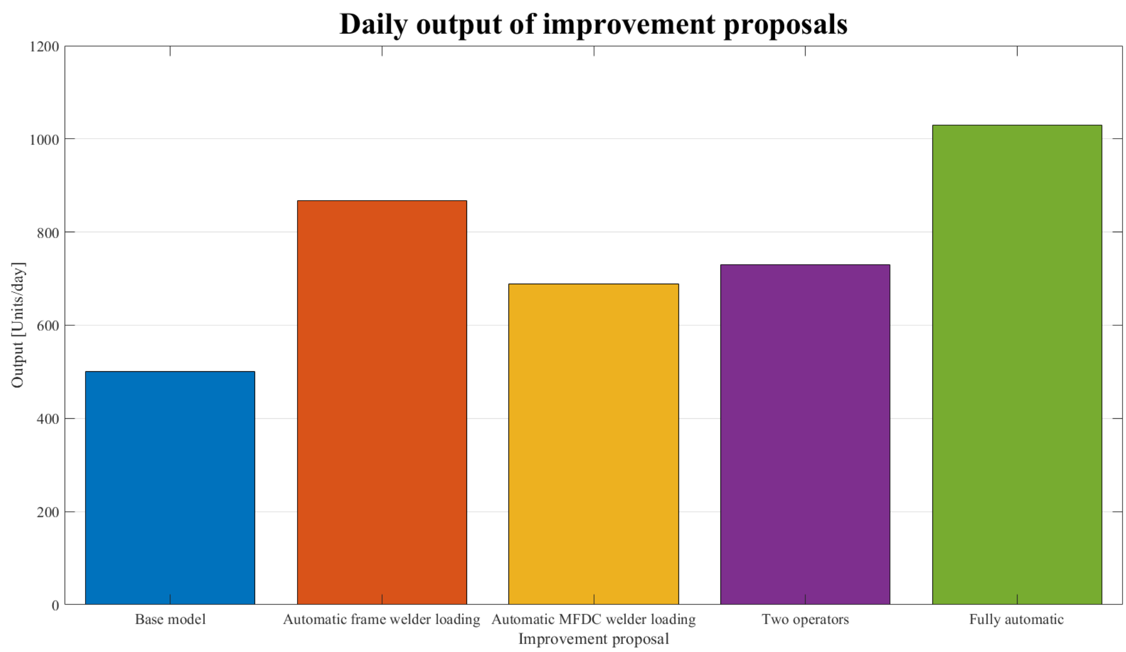


Figure 5.4: *Daily output comparison.*

5.2.3 Iteration & optimization

Following the implementation of a fully automatic line, the new constraint was now the production line's initial frame welder, blocking the loading robot. As the loading fixture was the same fixture used when welding, the loading robot was idle during the welding process. To fully exploit the new bottleneck, a separate loading fixture was added to be loaded simultaneously as the robot was welding, see Figure 5.5 for the highlighted fixture. The proposed solution functions as a pallet change, allowing jobs to be set up on one pallet while processing parts on the other pallet (Haas CNC, 2022). This type of fixture has already been implemented in several other parts of the factory. The fixture increased the output to 153%, creating a new bottleneck at the AC welder.

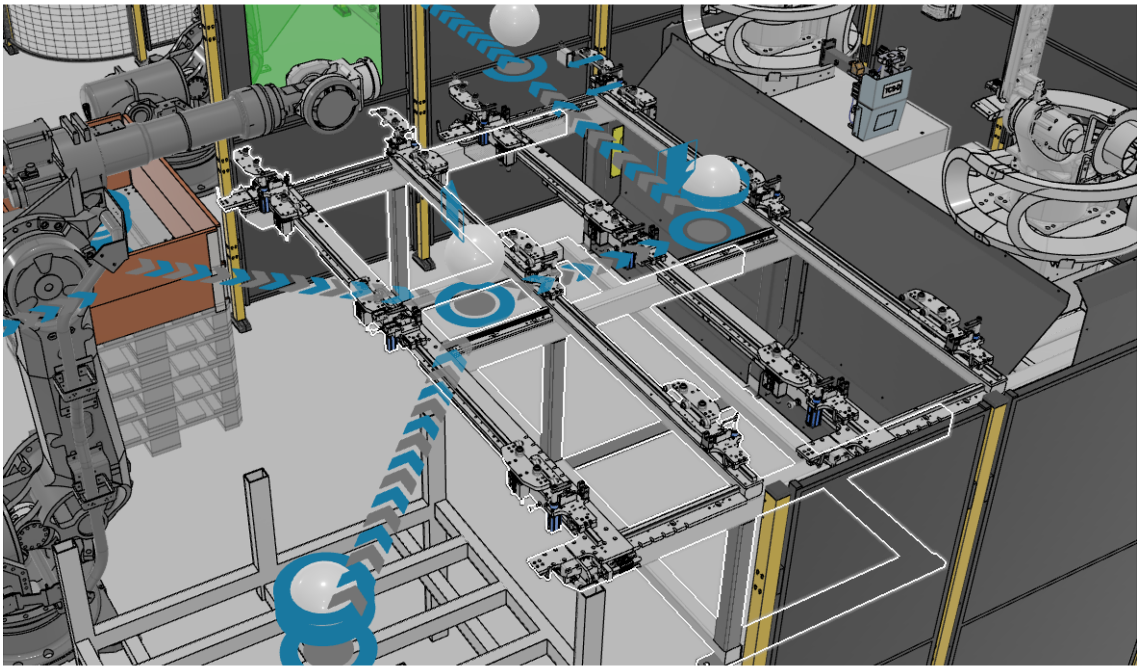


Figure 5.5: *The frame loading fixture.*

Shortening the AC welding time could be done by enabling welding of additional points or increasing the pace. As the current machine parameters are set to comply with the operator pace, there are room for improvements according to Axelent Engineering. Simulating a reduced cycle time of 50% increased the output further to 193%. The new bottleneck was now downstream at the end of the line, blocking the steps before. The identified bottleneck was the final conveyor and the dispatch robot.

By continuing the iteration, decreasing the robot dispatch time by 50%, and increasing the conveyor speed to match the rest of the line, the output was further increased to 283%, creating a new bottleneck at the MFDC welder. As the output increase was already several times higher than originally, the iteration did not continue any further. Continuing any further would possibly require excessive investments. A full list of how the iterated improvements impacted throughput is shown in Appendix E.

Trying to create improvements was useful in building an idea of how well DELMIA could function for an SME. This was needed to be able to answer the first research question, and indirectly, the second one as well, due to the *Factory simulation engineer* role is included in DES.

5.2.4 Final improvement proposal

The final improvement proposal simulated in DELMIA consisted of the following improvements:

- Robot cell to load and unload the frame weld.
- Loading fixture at the frame weld for continuous loading, avoiding blockage.
- Robot cell to load the mesh on the frame.
- Automatic MFDC welder.
- Reduced AC welding cycle time.
- Reduced robot dispatching time.
- Increased final conveyor speed.
- Removal of material quality control.
- Removal of material refill and final product dispatch.

The output was simulated to an average of 1913 units per day with the present intermittent two-shift work between 05:30 and 24:00. A further suggestion would be full automation around the clock as Improvement 3e suggests, increasing output to about 2483 units per day. The final layout is shown in Figure 5.6.

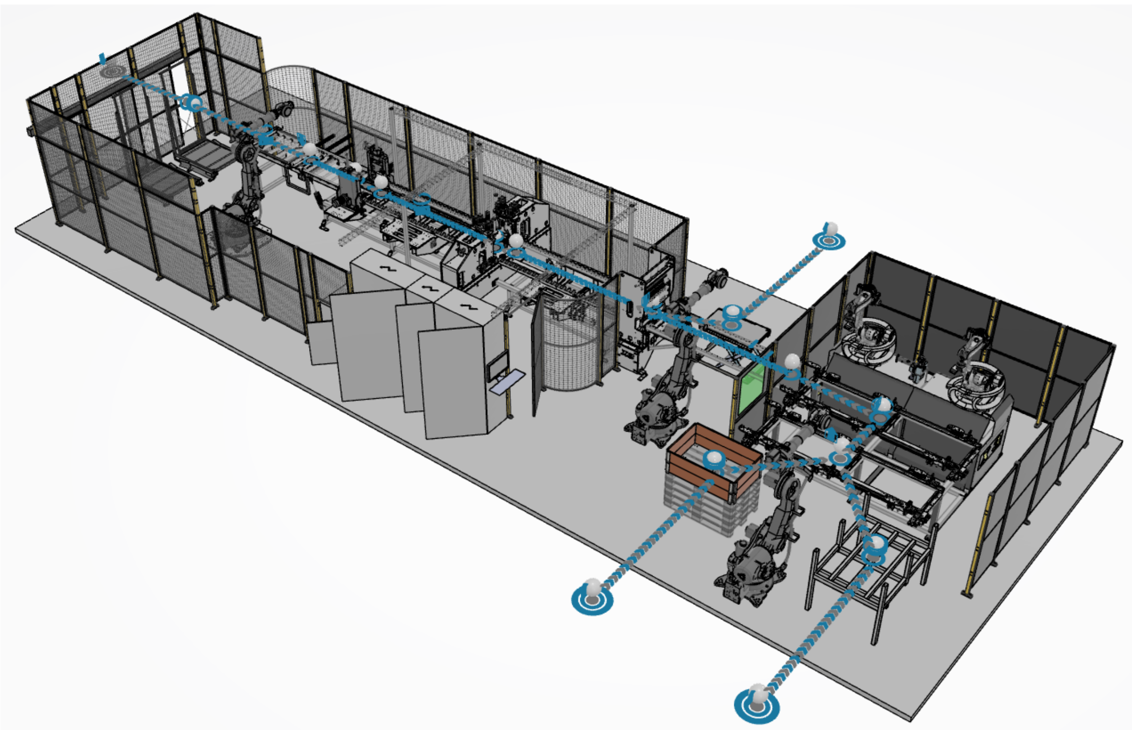


Figure 5.6: *The final improvement proposal.*

5.2.5 Financial calculations

To clarify the impact of the improvement, the results have been converted into a smaller financial calculation. The following list shows the investments required and potential savings by estimations from Axelent dialogue and RobotWorx (2022).
Investments:

- Two robot cells: 2 x 1 500 TSEK
- Loading fixture: 1 500 TSEK
- Automatic MFDC welder: 700 TSEK
- Decreased AC welding time: 500 TSEK
- Decreased robot dispatching time: 150 TSEK
- Increased final conveyor movement: 150 TSEK
- **Total: 6 000 TSEK.**

Savings:

- No requirement of two operators: 2 x 500 TSEK/year
- **Total: 1 000 TSEK.**

In order to give a perception of the payback duration and break-even-volume, a payback calculation and a result analysis with approximated numbers are performed.

According to financial statements, Axelent had a profit margin of 24.4% in the fiscal year of 2020 (Retriever, 2022). According to Axelent, the production cost was 135 SEK per unit, making the approximated sell price 168 SEK, and the margin 33 SEK.

Using the break-even formula, Equation 5.1 (Lantz et al., 2014, p. 172), the payback duration is calculated based on the investment and the increased daily cash flow.

$$\textit{Payback period} = \frac{\textit{Initial investment}}{\textit{Increased daily cash flow}} \tag{5.1}$$

$$\textit{Payback period} = \frac{\textit{Initial investment - Savings}}{(\textit{New output - Old output}) \cdot \textit{Margin}} \tag{5.2}$$

$$\textit{Payback period} = \frac{\textit{6 000 000 - 1 000 000}}{(\textit{1 913 - 500}) \cdot \textit{33}} = \textit{107 days} \tag{5.3}$$

For the result analysis, proportional variable income and cost are represented by linear equations in Equation 5.4 and Equation 5.5 with selling price respectively production cost multiplied by the increase of output volume per day. The point where costs and income are level is called the break-even-point and represents the volume necessary to cover up the costs, here calculated as days, x (Lantz et al., 2014, p. 38).

$$\textit{Costs = 6 000 000 - 1 000 000 + 135} \cdot (\textit{1 913 - 500}) \cdot x \tag{5.4}$$

$$\textit{Income = 168} \cdot (\textit{1 913 - 500}) \cdot x \tag{5.5}$$

As for the pay-back calculation, the result analysis shows a break-even point after 107 days of production, see Figure 5.7.

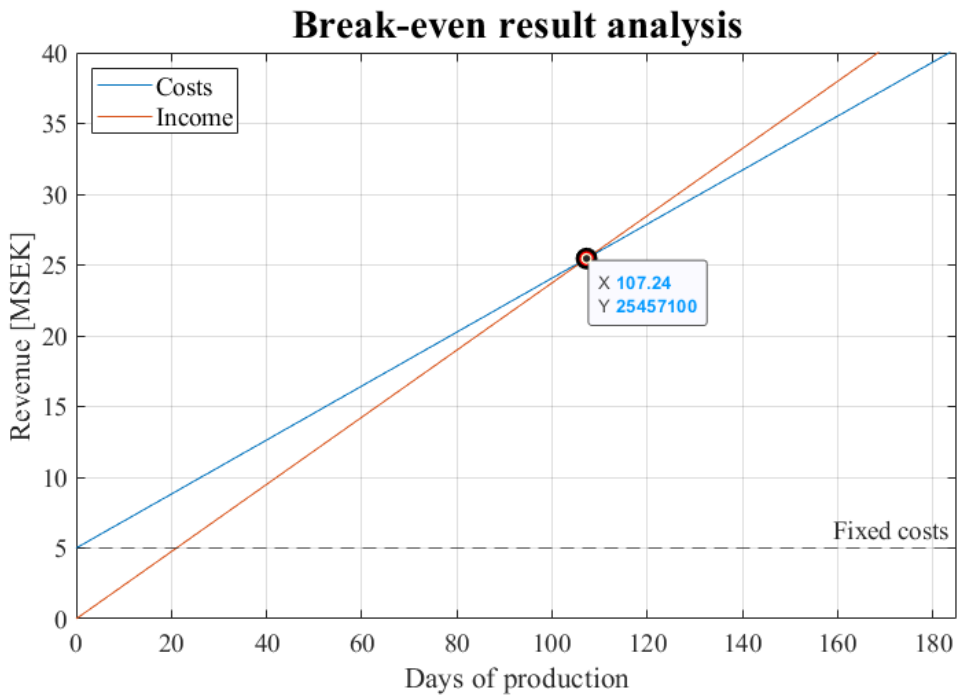


Figure 5.7: *Break-even result analysis graph*

5.3 Evaluation of DELMIA

By analyzing the project process and the results, there was a sufficient basis for evaluating the used applications in DELMIA, and answer the first research question. The following lists shows the strengths and weaknesses of the *Factory flow simulation* role in DELMIA, found by user experience.

5.3.1 Strengths of DELMIA

The following items have been observed to be a positive function using the DELMIA software. They are divided into the following three categories; Flow simulation, Layout and resource definition, and General features, with the first two covering the three applications in the *Factory simulation engineer* role.

5.3.1.1 Flow simulation

- The output result sheet when finishing a batch simulation gives crucial statistics and information to be able to find bottlenecks in the system as well as where to make changes to improve the production.
- The *Resource configuration* panel is an agile tool and adept at configuring activities and resources. It also gathers all activities connected to a certain resource for easy accessibility.

- The Shift function enables the possibility to schedule how resources should behave during longer batch simulations. It can include breaks or pauses to simulate an operator and is a useful tool in order to recreate the real factory system for a production planner.
- The feature *States history* shows a precise distribution of resource states in real-time during simulation. This can be used to identify bottlenecks and resource impact, see Figure 5.8

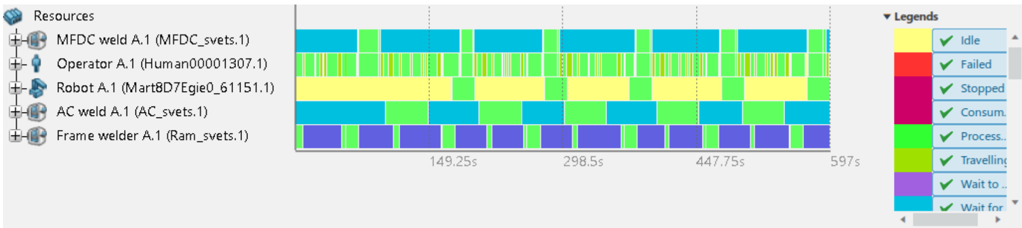


Figure 5.8: *States history.*

- The function *Define part position* makes it easy to place parts at the correct position when performing activities for resources for a better visual simulation.
- Gantt-schedules in NC-machines enables strict control of the sequencing of their activities, see Figure 5.9.

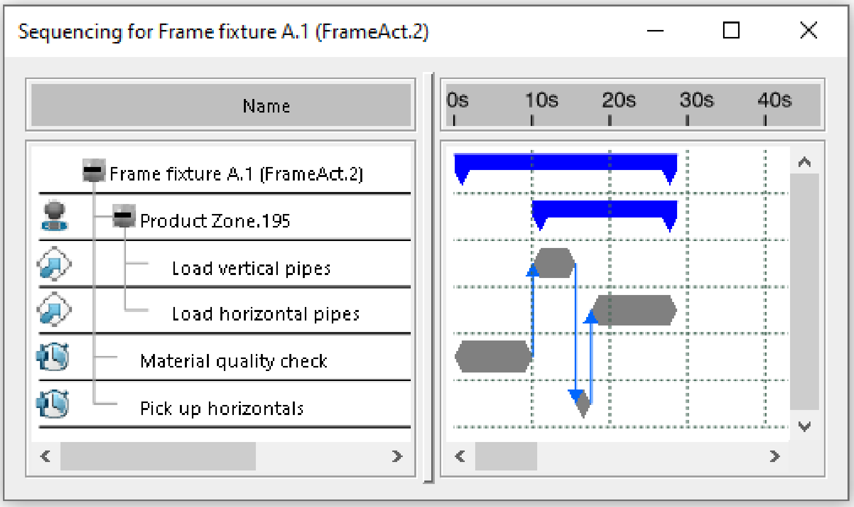


Figure 5.9: *Gantt definition of the frame fixture.*

- It is possible to enable time distributions for activities to make the resources and the model behave as realistic as possible.
- The feature *Record animations* enables easy access to record videos and shorter presentation material of the simulation model to share with potential stakeholders.
- When constructing a flow, a recommended product appears to be added to the flow which eases the process of building a model.

5.3.1.2 Layout and resource definition

- When inserting an existing 3D model of a production flow, the definition of components and resources is simple, and the model is ready for simulation with low resource usage.
- To import CAD or 3DXML files from other sources is simple, which left more time to build the system.

5.3.1.3 General features

- DELMIA offers a great visual representation of a working station, a production line, or a complete plant, enabling easy presentation and understanding.
- Having DELMIA on an On-cloud premise of 3DEXPERIENCE enables easy sharing of files and cooperation between different accounts.
- Easy to change applications within the 3DEXPERIENCE platform. For example, by simply double-clicking a part, an application change occurs to CATIA Part Design which quickly enables product modifications.

5.3.2 Weaknesses of DELMIA

The following items have been observed to be weaknesses in the DELMIA software. It may be missing functions, flaws, or other problems. They are divided into the same categories as in 5.3.1; Flow simulation, Layout and resource definition, and General features, with the first two covering the three applications in the *Factory simulation engineer* role.

5.3.2.1 Flow simulation

- Not able to model stochastic inputs and mimic unpredictable behavior of production resources while using a *Working cycle management*. For tasks to be performed in the correct order, a deterministic approach was necessary.
- Following the lack of stochastic inputs, scheduled shift breaks were used as a solution rather than random need of maintenance, showing inaccurate statistics regarding states.
- Lack of a functional debugger, complicating troubleshooting and verification.
- The set duration of operator transfers and walk paths did not function accurately. To solve the problem, the task had to be unassigned from the operator, assigned to another operator and then re-assigned to the original operator. However, the solution did not stick, making the duration inaccurate and thus not trustworthy.

5.3.2.2 Layout and resource definition

- Unclarity regarding the coordinate systems and part origins, making the layout configuration of resources and the products related to them difficult.
- The robotic kinematics under the Equipment design was complex, including the need for constraints and robotic coding. Simpler visual movements were therefore not easily implemented.

5.3.2.3 General features

- DELMIA has an initial large knowledge entry barrier to be able to work the program, which is enhanced by the lack of deeper describing educational material.
- Missing or inadequate functions required assistance from the developers at Dassault Systèmes. Based on the feedback, updates could then be released. This indicates that the software is yet not fully mature.
- Navigating in 3DEXPERIENCE is complex as well as the way to save or duplicate files. It is hard to understand how the different save options impact the current and future saves.
- The user may experience slow software, especially for opening files and simulating batches.
- Sometimes the DELMIA software freezes which can force a restart, undoing work if not recently saved.
- Recording videos during simulation resulted in large video files in sizes of several gigabytes.

5.3.3 DELMIA resource demand

DELMIA has a high knowledge barrier to pass before being able to navigate the software and its platform 3DEXPERIENCE. Many of the functions in the software lack depth in their description of how they work, and it is often hard to know how to correctly implement them. Fortunately, 3DEXPERIENCE has a large educational website to which one can gain sufficient understanding to perform basic simulations. EduSPACE (2022) includes a multitude of various courses which teaches the user some functions in different applications, such as *Factory flow simulation*, or *Plant layout designer*. However, creating larger, more complex simulation systems, requires some trial-and-error, or a level of deeper knowledge, or some assistance directly from Dassault Systèmes. This can get frustrating for the user, however, the functions offer enough explanation and with some prior experience, users are able to create these systems. The functions' broad programmability can create almost any type of scenario possible, although, these versatile functions can get in each other's way and contradict each other, which makes the simulation stuck.

In addition to the cost of employee education, DELMIA requires licenses. To use the applications in DELMIA, one or more licenses might be required, costing $750 per year and user (3DEXPERIENCE, 2022). Considering SMEs, several licenses might be required and might impact a smaller company's economy, especially in the early stages of learning the software, where little profits can be made. It can, together with the employee education, however, become minor costs when the employee gains enough knowledge and experience to earn back the costs in savings from finding improvements and reducing waste in the processes.

5.4 Evaluation of DES software

Simulation software such as DELMIA is a great tool for companies to use to improve their production, as demonstrated in this thesis. It can help decision support due to its ability to model deviations, errors, and random events during manufacturing (Fahl, 2017). Additionally, simulation software will not impact production uptime since the physical system does not need to stop when performing tests or experimentation with new system configurations (Dimitris, 2020). To have the system running while doing tests, there are cost savings of not needing to shut down production, but also from finding ways to minimize waste from the simulation. Simulation models give a large overview of the system while standing on the production floor does not, comparing activities as well as the resources to find where they should be placed to be most efficient. It also gives easy management of inventory, maintenance, and scheduling from this overview (Wright and Davidson, 2020).

Simulating the results of the model can show valuable statistics to be used as decision support, such as for planning or investments, which could be crucial for an SME with limited resources and risk-taking. Furthermore, visual representation of the results may be useful for promoting specific system characteristics Lindskog and Lundh (2011). For an SME, this may be beneficial in demonstrating value internally, for decision making, and externally, to gain business advantages. To create value for companies, simulation software could be used to gain insight into their production, to find bottlenecks, to find the actual production rates, decision support, and greater control over their production process, which can give competitive advantages (Malec, 2018; Randell, 2002). For example, from the study of the X-line3, it was noted that the quality control of vertical pipes should be placed earlier in the flow, as it was identified as an unnecessary activity for the already high utilized operator. Since X-line3 is considered a bottleneck in the factory, a simple activity such as controlling the quality of a pipe should be placed on a resource that is blocked by the bottleneck to exploit it further.

Another form of value may be the platform used, such as 3DEXPERIENCE which DELMIA and other engineering applications are a part of. It enables users to work independently of each other on the same project, saving time and decreasing communication mistakes when projects are shared between departments.

5.4.1 Strengths of DES

A summary of the most important strengths and value gains of DES based on literature search and user experience is given in the list below:

- Simulation enables better insight of the present system and why a specific phenomenon may occur (Malec, 2018), and is suitable for SMEs by increasing productivity and reducing costs (Sulistio and Hidayah, 2017).
- The visual and pedagogical overview of a simulation would not have been possible in the physical reality (Wright and Davidson, 2020).

- Statistics from DES enables decision support for improvement and investments, as well as management regarding inventory, maintenance, and scheduling (Wright and Davidson, 2020).
- In a capital intensive industry, the possibility to perform "what if" analyzes using DES before they are implemented is an excessive benefit (Fahl, 2017).
- To not disturb the real production system, DES enables virtual analysis and experimentation, reducing downtime (Dimitris, 2020).
- Using DES, the dynamic and stochastic behavior of the real system can be modeled and studied (Fahl, 2017).
- Using a simulated model, new staff can be educated (Fahl, 2017).
- In the simulation, events can be sped up or slowed down. An entire shift can be analyzed in minutes, which enables quick analysis (Fahl, 2017).

5.4.2 Weaknesses of DES

Some major weaknesses or shortcomings of DES are presented in the list below:

- To create a simulation model is time-consuming and requires stochastic skills and an adequate level of experience and knowledge (Fahl, 2017). Learning the software itself might challenging due to the large knowledge entry barrier.
- DES may only be applied if the simulation model replicates the reality to a sufficient level and if the data is of sufficient accuracy (Fahl, 2017; Randell, 2002).
- When having a highly dynamic operation, keeping models up to date may be difficult (Price, 2014).
- The results of a DES only provide estimations for the model outcomes, like numerical mathematical models (Price, 2014).
- Human behavior and decisions naturally deviate and are difficult to model (Lindskog and Lundh, 2011).
- It could be challenging to gain acceptance within the organization if stakeholders are reluctant to change.

5.4.3 Other DES software

Today there is plenty of DES software available. Some software other than DELMIA is Visual Components, Siemens Tecnomatix Plant Simulation, AutoMod, and Simul8. The following list describes the software and briefly compares them to DELMIA:

- Visual Components can plot simulation in a 3D environment, giving the user a view of the whole factory or system. It can also do material flow analysis', layout sketching, robot work cycle planning or, virtual reality, having a high resemblance to DELMIA (Visual Components, 2022). As shown by Lindskog and Lundh (2011) in section 2.4.2, Visual Components may also be used to simulate the environmental product footprint using DES.
- Siemens Tecnomatix Plant Simulation is a 3D rendering simulation software much like Visual Components. It has several functions including analysis tools,

such as bottleneck- and energy analyzer, to be able to optimize the system (Siemens, 2022). Martínez et al. (2020) showed the potential of Tecnomatix in modeling and analyzing productivity and profitability, shown in section 2.4.2.
- AutoMod is, unlike DELMIA, a code-based software with 2D or 3D graphics. It can simulate systems and is less accessible for quick changes in system structure due to it being code base, and require extensive experience to be able to create larger systems (AutoMod, 2022).
- Simul8 is similar to DELMIA in its broad use but produces visuals in 2D. Focusing on simplicity, Simul8 help new users to simulation with low experience levels to start quickly with the placement of resources and products, with a simple UI (Simul8, 2022).

6
Discussion

The following chapter will discuss the presented results and how these were achieved, as well as their plausibility and impact. Considerations and obstacles met during the project and the thoughts on how these were handled are discussed further.

6.1 Data collection

A comparable quantitative study of looking at historical production data was planned in order to have something to compare the collected data to. It could show if the machine has been producing better or worse compared to previously, and might have shown some reason on why it changed. When Axelent was asked if there was any previous or historical data that could be compared, the answer was that the company had a poor production follow-up system and that such data was missing. As the stopwatch time study was thoroughly carried out with a vast amount of samples, the study made for a quantitative result which was approved by Axelent for use in the simulation and improvement work.

When being observed, operators tend to change their performance level, for better or worse. In addition to performing abnormally when being observed, operators might be more focused or make a greater effort in their tasks which might produce fewer errors while working (Zandin and Maynard, 2001, ch.124). It might be hard to know the correct failure rate of products if operators change their way of working when being observed. This makes it hard to replicate the amount of failed parts when historical data is not available, as mentioned above. As a result, instructions were given to the operators to try working at their normal pace during the study.

When performing the time study, obvious skewed data due to the human factor or operation irregularities were removed from the data. Initially, 30 measurements of machine elements and 60 measurements of operator elements were planned, as human behavior deviates more than programmed machines and there were two operators. Interestingly, observations showed the operators working two different methods when loading the frame welder, corresponding well to the difficult experiences of Lindskog and Lundh (2011) for simulating human behaviour. Operator 1 had a material quality control by controlling the straightness of the vertical pips, then loading them. Afterward, the loading of the three horizontals was done separately. Operator 2 did not make the quality control activity and loaded vertical and horizontal pipes simultaneously. Results showed a longer load time for Operator 1 than

Operator 2, as shown in Figure 6.1. However, Operator 2 was having more quality issues resulting in longer downtimes. The work method of Operator 1 was more thorough and therefore used for the simulation. For this reason, Operator 2 was not as observed as Operator 1 either, as the time study standard is supposed to be correct for an operator following the prescribed method and validated in accordance with those specifications (Zandin and Maynard, 2001).

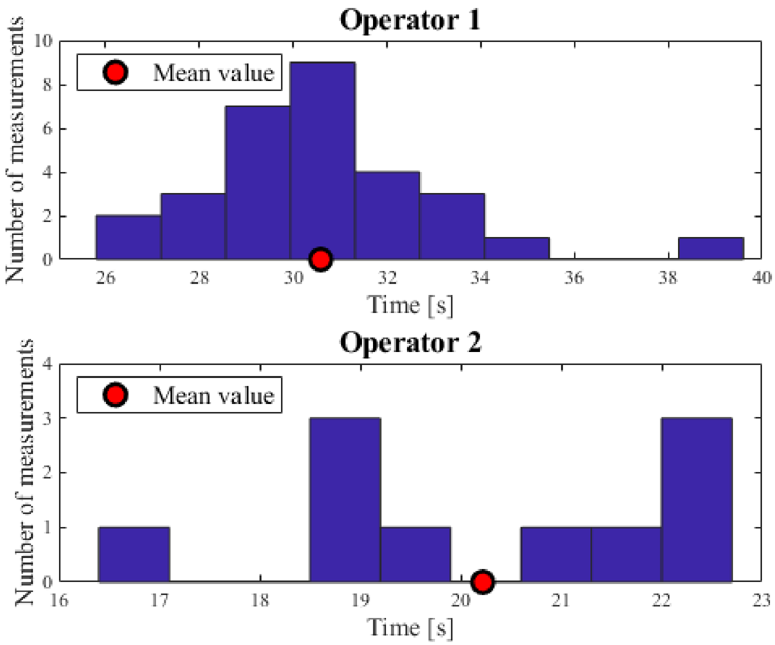


Figure 6.1: *Operator loading time of the frame welder*

For further improvement proposals, the plant manager proposed that making the speed of the machine based on operator piece rate instead of a daily throughput rate would potentially increase throughput. This would, according to the manager, give the operators incentives to work harder due to the increase in wage from producing more. However, the operators stated that not having an incentive pay was less stressful and that they were satisfied with the current state. According to Zandin and Maynard (2001, ch.60), the benefits of incentives are increased production rate, lowering overall unit cost, together with an increased employee earning and motivation. Successful incentive plans are equitable for the employee as well as the company, providing substantial benefits for both parties. Properly designed plans will support the company's operating strategies, encourage teamwork and reward continuous improvement. Although, unions typically resist installing new incentive systems as they are a threat, because they will automate the union's task to raise the wages (Zandin and Maynard, 2001).

6.2 DELMIA

The following chapter will discuss the results of the base model in DELMIA and the obstacles presented when trying to build the system.

6.2.1 Simulation results

To be able to implement the improvement proposals, a valid base model had to be formed. For the throughput numbers to be correct, there was a lot of work to fix minor and some major details, which affected the whole system. Early on, the throughput was about doubled from the real production line, which was derived from too efficient simulated operators. The model would not consider the minor pauses and breaks as the human operator takes, and since being the sole bottleneck, they would greatly increase the production rate. After using the trial-and-error approach long enough, solutions were found that validated the simulation model and achieved the target of 500 units per day.

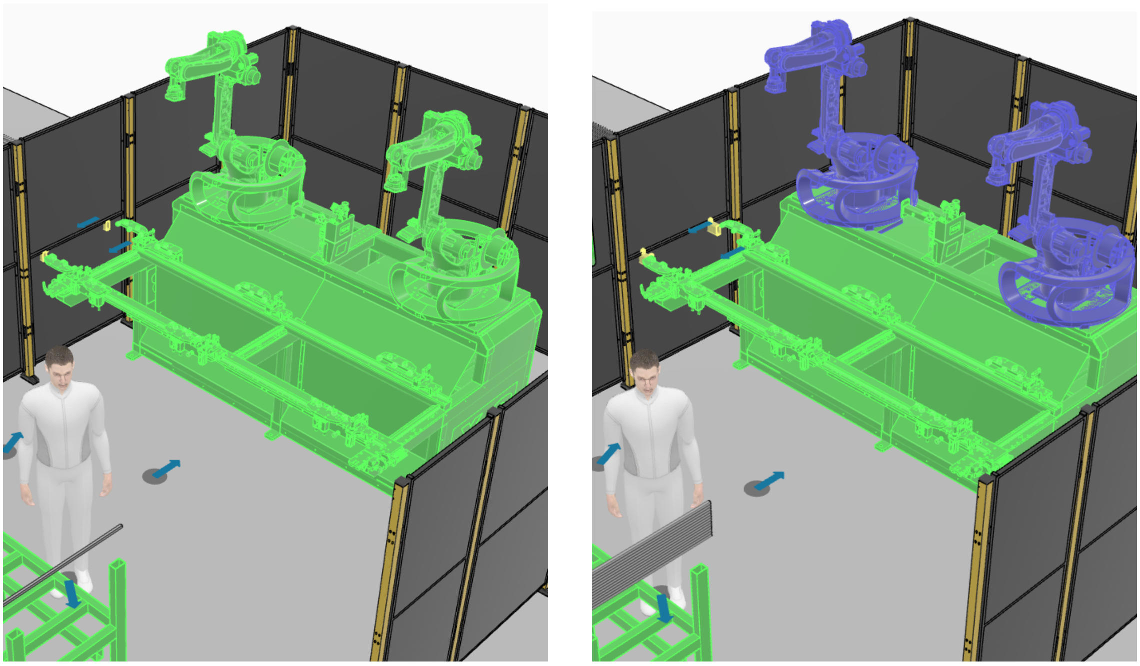
From the time study, the project has focused on one product variant, namely the most standard product Axelent AB offers, W312-220025, at a height of 2200 millimeters and with a mesh of 50x30 millimeters (Axelent AB, 2022a). For products with sparser mesh, it will take a shorter time to weld together the frame and the mesh, which will affect the throughput. Since only one product was simulated, set times were not considered, and would affect the throughput as well.

As the use of *Working cycle management* made it difficult to implement errors and random events, a warm-up time was hard to achieve. This meant that every resource started in steady state, which is not the case in the real system. If implemented in the real system, it would quicken the deterioration of components in the machines, which would lead to errors occurring more often.

Visual aesthetics in the simulations, such as robot arm movements, were deprioritized due to the lack of value it would add to the result. Learnings from Lindskog and Lundh (2011), who discussed their unnecessary high detail of graphical representation, resulted in time spent on more vital areas. Given that there is no client to convince the meaningfulness of a certain type of improvement by a visual presentation, it was deemed better to spend effort on improving the necessary components of the system and analyze the statistics.

6.2.2 Problem-solving in DELMIA

A problem noted in the simulation was whenever the operator performs an activity related to a machine, the state of the machine is set to "Processing". This includes generic activities, such as the quality control of the material at the loading of the frame weld seen in Figure 6.2. This gives wrong statistics in the result sheet, indicating that the machine is processing and having a high utilization when it is actually waiting to be loaded, see Figure 6.2a. To solve this issue, the machine was divided into two NC machines, one fixture for loading and one with the robots performing the welding activity. In Figure 6.2b, the state of the fixture is *Processing* and the robots are *Waiting for resources*, making statistics more accurate. It should be noted that there are still activities in the machines that are incorrect, which somewhat affects the state of the welding machines, but there were no better solutions found.



(a) *Merged frame weld* (b) *Divided frame weld*

Figure 6.2: *Frame weld state*

As simulating irregular activities, such as machine errors or random events, was found non-compatible with *Working cycles management*, these were placed as operator breaks using the *Shift* function as shown in Figure 4.2b. However, the state statistics then show the operator in a break mode when the operator is actually working. Although, the total time of non-processing was deemed the most important and the solution showed to be successful in simulating the daily output.

As mentioned in sections 2.4.2 and 5.4.2, human decisions are difficult to model since the irregularities of decisions cannot be programmed. In the simulation, the operator is given tasks to perform regularly, but there is no room for random events, especially when *Working cycle management* responds poorly to activities outside its list of tasks. As mentioned in 6.2.1, the operators worked too efficiently in the simulation, which gave a better than the normal result. To some extent try to remedy this, a time of six minutes was added each hour for a pause in the operator schedule. In the six minutes per hour pause, there is some of it planned to try to make the simulated operator behave as a normal person would since the simulated operator works 100 percent all of the time until told otherwise. In addition to the extra six minutes pause, an activity of walking to the computer was added into the *Working cycle management*. This was further meant to add to a few seconds per cycle where operators, for example, drink a sip of coffee or check their personal phone.

6.2.3 Comparison to other software

As modeling in DELMIA took several weeks to learn and get familiar with, there was not enough time to learn another simulation software well enough to be able to compare DELMIA. However, through previous experience during the simulation course at Chalmers (2020), AutoMOD had been used and could be vaguely compared with DELMIA. Where DELMIA is a software with a user-friendly interface, with easy accessibility to change and restructure layouts and functions, AutoMOD is based on coding and therefore more demanding in making quick changes. To have any functions, they have to be coded by the user which takes time and has to be considered when further expanding the model, while DELMIA can show how resources interact with each other through panels that hold most of the placed functions. With the previous experience of AutoMOD, the visual simulation was in 2D and did not have any detailed objects, whereas DELMIA made it easy to put together a detailed simulation.

6.2.4 Advantage of 3DEXPERIENCE

Using 3DEXPERIENCE as a platform, Axelent AB could utilize the full potential of the PLM and collaboration capabilities it holds. In addition to the experiences in this project, Bernérus and Karlsson (2016) showed great benefits of this in their evaluation of 3DEXPERIENCE. Rather than a company server hard drive, information could be saved and be available on the cloud. This would increase the transparency and collaboration between departments at the company and the availability of information. Increasing transparency of the process through sharing information can be good to gain understanding and respect of other departments inside companies, as Randell (2002) presented the lack of communication and transparency was an issue in section 2.4.3. For someone from another department, who has not yet seen the value of using simulation, due to lack of experience or reluctance to change, showing the wide range of potential results may convince them otherwise.

6.3 Improvements of X-line3

From the improvement results, the substantially increased output may be questioned. When approaching the simulation and improvement work of the production line X-line3, an analysis was made to detect obvious bottlenecks resulting in starved and blocked machines. The reason was the operator working at a 100% utilization, with several manual operations at the loading of the frame welder and the MFDC welder. This was controlling the pace of the entire production line, as the single operator was not sufficient to keep up the loading at the pace of the other operations. By removing one of these manual operations, a large proportion of the bottleneck was elevated, seen as Improvement 1b, Improvement 3a, and Improvement 3c, increasing the output by 46%, 73%, and 38%, see Appendix D. Some of the specific improvement proposals are discussed in the following section, followed by some considerations and then a discussion regarding the financial calculation.

6.3.1 Considerations of improvement proposals

As the generation of proposals was built on theory and imagination, some proposals were not feasible in reality. Improvement 6a showed to be limited by the size of conveyors and machines. The large frames do not fit more than one on each conveyor, making the improvement unfeasible. For it to be implemented, a total remodeling of the system is required.

Some improvement proposals were not possible to implement individually but required prior implementations. Improvement 5a and 2a can only be used as follow-ups on earlier improvement suggestions. Improvement 5a needs another operator or robot cell at the frame welding station to be functional and Improvement 2a needs an automatic loading and unloading of the frame welder, Improvement 3a and 3b, to be relevant. Because of this, Improvement 2a in Appendix D is a combination of several improvements. However, the implementation of a buffer showed little impact on the throughput and was discarded as a non-value adding improvement.

When iterating the improvement proposal, the resource utilization and wait time were the determining factors for what to implement as the next step to elevate the next bottleneck. Iteration 5, seen in Appendix E, was made after looking at the utilization level where the AC welder peaked, however, it was noted no difference in throughput from earlier. This was due to the waiting times of resources prior to the dispatch robot being high and thus blocking them. By improving the dispatch time a higher throughput was achieved.

The plausibility of the improvement suggestions which included changes in machine parameters was hard to determine. Since there was no historical data about prior levels of improvements on machines or resources, as well as vague answers from the responsible engineers, the parameter changes had to be estimated, as for Lindskog and Lundh (2011), and might have been done too ambitiously. However, changing parameters in DELMIA is simple, and if there is a need to change it further or to analyze optional parameters, it can be done quickly.

The generated improvement proposals are for Axelent AB to be interpreted simply as proposals, improving the present state of the production line regarding output. They have not been optimized and there are additional factors to consider for the implementation of the proposals, such as feasibility, maintainability, cost, and employee education.

6.3.2 Financial calculation

The investment payback duration may seem very short, although, the improvement proposal increases the output by nearly 300%, creating a substantial increase in potential sales volume. Whether there is a large enough market demand is something outside the scope of this thesis. The calculation is furthermore very simplified, with a lack of additional costs related to implementation, interest rates, and education for the employees. Although calculated as such, the implementation of the proposed solution does not necessarily eliminate the two operators. It may rather enable simultaneous work with other operations and simple monitoring of the production line. However, with the implementation of new equipment and technology, education might be necessary to keep the automated production line running.

Considering the daily production cost per unit of labor and material, this can be divided into fixed costs and variable costs. Since the fixed cost is divided by the volume, increased production will decrease the fixed cost per unit (Lantz et al., 2014, p. 35). The suggested improvement will therefore not only generate a larger output, potentially increasing the sales volume, but also increase the margin exponentially. However, increased production may result in additional maintenance costs compensating for the average unit cost decrease. The simplification of reality using the linear model has an advantage in its simplicity, however, it assumes the production line produces one specific product and does not include a mix of products, nor does it consider that price and productivity may change with the volume (Lantz et al., 2014, p. 39).

There are some decision situations to consider for the implementation of the proposed improvement, some of which may contribute to separate costs or incomes. Some may be what machine to buy when the equipment is to be maintained or exchanged, whether the equipment should be bought or rented, what capacity for product variants, and what software is to be used. In order to make a long-term profitability assessment, interest rates, depreciation, and planning horizon are also necessary to consider, as well as compensations for risks and downtime (Lantz et al., 2014, p. 155-157). The definite financials are for the company to take into further consideration.

6.4 Project results

The project aimed at contributing to the development of generic knowledge regarding DES and creating an improvement proposal for a production line using DELMIA, evaluating the software for promotion purposes. Whether the improvement proposal is plausible, how the project has impacted Axelent, and how DES is suitable for SMEs is discussed in this section.

6.4.1 Final improvement proposal plausibility

The final improvement proposal resulted in an increase from 500 products per day to around 1913. Whether this is plausible depends on the implementation of the proposed improvements. In order to implement this productivity increase, several changes are required.

The main change is the two robot cells for loading. As the rest of the factory already has automatic loading, this would not seem to be a problem to implement. The same goes for the automatizing of the MFDC welder. The loading fixture at the frame weld might however require some design to be implemented. As Axelent

Engineering has built the X-line3, and most of the other lines in the factory, this should not be an issue to construct. Due to the company's lack of knowledge of their machine parameter optimization, Axelent Engineering expresses that it should be possible to find room for improvements if analyzed as the current parameters are set to comply with the operator pace.

Whether or not the improvement implementation costs approximately 6'000'000 SEK is for the engineering and economic department to determine. With almost certainty, the actual investment would be more expensive, making the realistic payback duration longer than 107 days.

6.4.2 Project impact on Axelent

As stated in the project aim, Axelent Solutions requested confidence in the feasibility of DELMIA in order to be able to promote its usefulness to customers. Given the project results, far larger confidence in the software has been achieved and Axelent Solutions has already started to demonstrate its potential usefulness to potential customers. Furthermore, the affiliate Axelent Engineering was particularly impressed and saw advantages in its ability to test and simulate orders of production lines and machines to show to clients before starting production.

Whether Axelent AB decides to implement improvements based on this project is yet uncertain, however, the general impression was that the results are useful for decision support regarding throughput increase, and DELMIA is a useful tool.

6.4.3 Suitability of DES for SMEs

As presented in chapter 5, DELMIA could be a valuable tool for companies to use to increase their production. Direct proposals has been presented to show in what ways DELMIA and DES could used in order to create value. The project results corresponds to the prior research shown in section 2.4.1 that DES is useful for SMEs for increasing productivity and reducing costs, where SMEs usually has a limited resource pool and non-effective decision-making (Martínez et al., 2020). Randell (2002) shows in multiple cases that DES enables analysis of the system and can provide decision support for SMEs, although, it needs accurate and relevant data to be useful, which this project found troublesome when modeling human behavior.

Fahl (2017) mentions the benefit of using a simulated model to train new staff. For an SME, this may be advantageous due to the limited resources. When performing stopwatch measurements and observing the X-line3, the operators found the simulation useful. The collaboration of a production simulation engineer and operator may be beneficial for creating and analyzing a high qualitative model. This collaborative work may be more intuitive for an SME due to the smaller facilities, closer relations, and the sense of community.

6.5 Ethical considerations

As automation increases, simpler repetitive and physical job opportunities are removed from people and replaced by robotics. As in Axelent's case, two people might lose their jobs due to automation, but will most likely be transferred to another task within the company. When repetitive and physical jobs decrease, more complex, cognitive jobs will rise (Müller, 2020). Automation is great at handling the same tasks thousands of times a day, but cannot fix itself when it needs maintenance, and this is where people step in. More and more jobs will need education in the future when there are further advancements in automation. Then focusing on educating the current workforce to be more able to work in different positions is a necessity when society moves further into Industry 4.0.

From an environmental sustainability point of view, the use of simulation is a valuable work tool in manufacturing, as shown by Lindskog and Lundh (2011). The outcome of Bernérus and Karlsson (2016), however, showed that 3DEXPERIENCE lacked environmental sustainability aspects. Although, simulation can be used early in the product life cycle, saving time, effort, and resources at a later stage (Hosseinpour and Hajihosseini, 2009). Comparatively, a physical test needs to stop production, and invest many resources for a change that might not be beneficial.

7
Conclusion

Throughout the span of the project, simulation software has been researched and evaluated for its use in production simulation with practical use of DELMIA on the production line X-line3 at Axelent AB. The identification of bottlenecks and the implementation of improvement have been thoroughly analyzed in order to answer how the *Factory simulation engineer* role in DELMIA may assist in analysis and improvement.

The result of generating improvements gave a product throughput increase of 283 % through an iteration process of improvement proposals. The investment would, by a simple calculation, reach break-even after 107 days of production. This shows the impact DELMIA can have on SMEs and an improvement like this could be essential to be competitive and meet the market demands.

The use of simulation software enables observing an operation without performing it, resulting in problem-solving possibilities which could lead to cost savings by improvements or waste reduction. Furthermore, the DES software combines problem identification and finding solutions, without interrupting production. However, the time to learn the simulation program is the shortcoming of using DES, therefore being quite resource-demanding. Ultimately, there is a trade-off between simulation time, cost, and possible profits or savings.

To conclude, DELMIA and DES software are great tools to provide statistics to gain an overall view of a production station, line, or entire factory, which can create value for SMEs, such as Axelent Solutions and their customers, in their processes.

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A Appendix A

Time study of regularities in X3 production line				Date:		Operator:			Analyst:			Observation number:		
				Measurement														
Element	Resource	Operation number	Operation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Frame welding	Operator	1	Unload prior frame															
	Operator	2	Material quality check															
	Operator	3	Load vertical pipes															
	Operator	4	Load horizontal pipes															
	Operator	5	Starting frame welding															
	Machine	6	Frame welding															
	Machine	7	Waiting time															
MFDC-welding	Operator	8	Load mesh															
	Operator	9	Position mesh															
	Operator	10	Manual welding															
	Operator	11	Start conveyor movement															
AC-welding	Machine	12	Conveyor moves panel															
	Machine	13	Side welding															
Straightener	Machine	14	Panel cool down															
	Machine	15	Conveyor moves panel															
Dispatch	Machine	16	Conveyor tilts panel															
	Machine	17	Robot dispatches panel															

Figure A.1: *Time study measurement sheet*

B

Appendix B

Operator activity

Improvement 1a refers to allocating the activity of controlling the quality of the material to a step prior the X-line3 due to this production line being a bottleneck in the factory.

Improvement 1b removes the wrapping and transportation of the pallets of finished products as well as the material refill by making it automatic or allocating it within the factory.

Improvement 1c adds another operator to share the activities which the original operator has. The new operator takes the responsibility of the MFDC welder and its associated tasks and the first operator is responsible for the Frame welder.

Improvement 1d adds another shift to the schedule so the production line works around the clock in three shifts.

Buffer/material

Improvement 2a adds a buffer after the frame welder. This is because that the frame welding activities are shorter than the ones at the next station, MFDC welder, and could therefore produce without having to wait to output.

Automation

Improvement 3a automates the load process at the frame welder by adding a robot cell, to make the system less dependable on the operator.

Improvement 3b is a continuation of 3a by giving the robot cell responsibility of the unload activity in the frame welder.

Improvement 3c automates the MFDC processes instead. It adds a robot cell to place mesh on the frame and weld it in place. The operator will then only handle the Frame welder's activities.

Improvement 3d implements improvements 3a, 3b, and 3c to fully automate the production line and remove the operator from the resource pool.

Improvement 3e extends the fully automated production line from improvement 3d to work around the clock.

Layout
Improvement 4a changes the layout of the Frame welder cell to remove the distance the operator has to travel in order to reach every task.

Adding machines
Improvement 5a adds a separate loading fixture for the frame weld, enabling loading of tubes while the machine is welding.

Improvement 5b intend to add additional machines to increase the capacity.

Adding machine capacity
Improvement 6a increased capacity at one machine through the possibility of processing several products simultaneously.

Machine parameters
Improvement 7a aims at reducing cycle time on one machine.

Improvement 7b focuses on reducing the loading duration.

Improvement 7c aims at reducing the travel time of products by increasing conveyor speed.

C

Appendix C

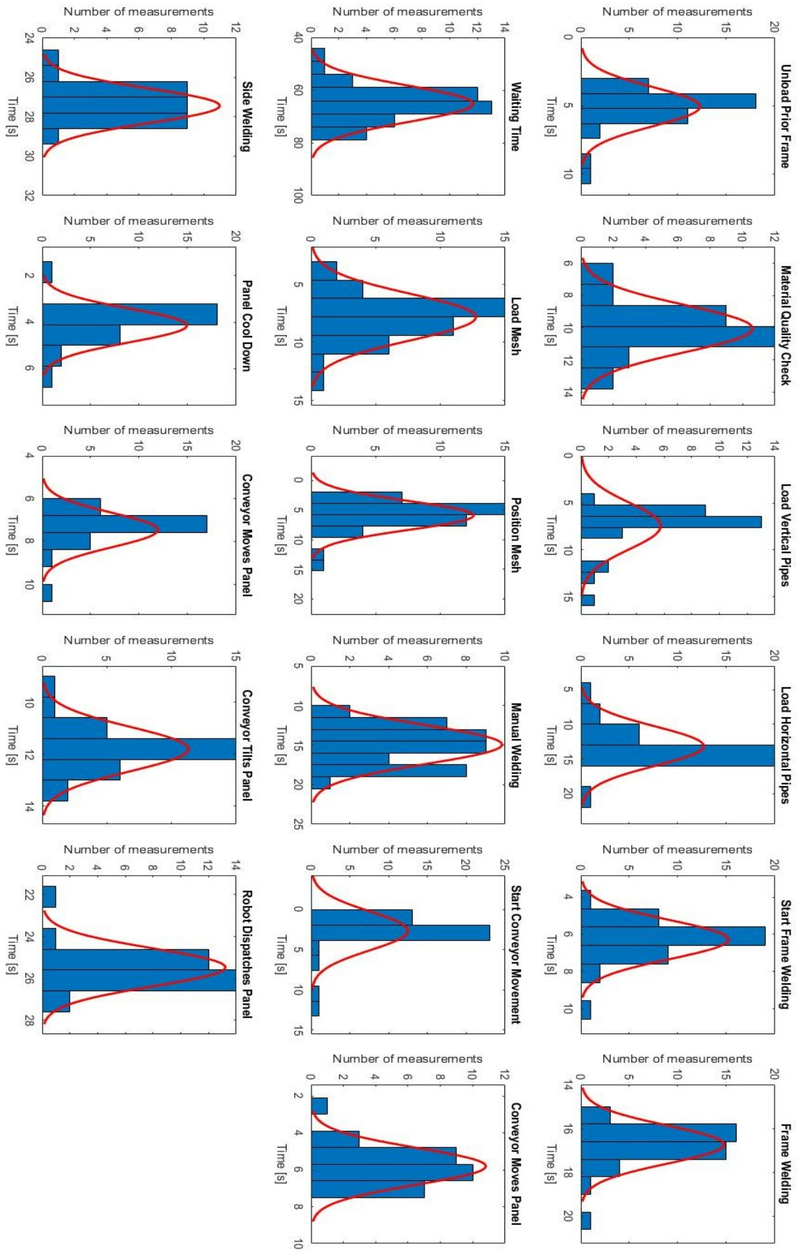

Figure C.1: *Time study measurement results*

D Appendix D

Name	Category	Improvement description	Output/day [Units]	Increase [%]
Reference: Base model			**500**	**0%**
Improvement 1a	Operator activity	Remove the activity of material quality control	**556**	**11%**
Improvement 1b	Operator activity	Remove the activity of material refill and final product dispatch	**522**	**4%**
Improvement 1c	Operator activity	Add another operator	**730**	**46%**
Improvement 1d	Operator activity	Increased daily manning	**672**	**34%**
Improvement 2a + 3a + 3b	Buffer/Material	Add a buffer after the frame welder + Automatic loading + unloading of frame welder	**868**	**74%**
Improvement 3a	Automation	Automatic loading of frame welder	**867**	**73%**
Improvement 3b	Automation	Automatic unloading of frame welder	**536**	**7%**
Improvement 3c	Automation	Automatic MFDC welder	**689**	**38%**
Improvement 3d	Automation	Full automation	**1029**	**106%**
Improvement 4a	Layout	Changed orientation of frame welder station and material pallets	**537**	**7%**

Figure D.1: *Improvement process*

E

Appendix E

Name	Category	Improvement description	Note	Output/day [Units]	Increase [%]
Reference: Improvement 3d	Automation	**Full automation**		**1029**	**106%**
Iteration 1: Improvement 3d & 7a	Machine parameter	Full automation & Reduced AC-weld cycle time	-16 seconds (-33%)	**1095**	**119%**
Iteration 2: Improvement 3d & 5a	Adding machines	Full automation & New frame loading fixture		**1267**	**153%**
Iteration 3: Iteration 1 & 2	Adding machines + Machine parameter	Combining iteration 1 & 2		**1420**	**184%**
Iteration 4: Iteration 1 & 2 + Improvement 7b	Machine parameter	Shorter frame welding loading time.	-5 seconds (-18%)	**1466**	**193%**
Iteration 5: Iteration 4 & Improvement 7a	Machine parameter	Reduced AC-weld cycle time	-23 seconds (-50%)	**1467**	**193%**
Iteration 6: Iteration 5 + Improvement 7a	Machine parameter	Reduced robot dispatching time	-5 seconds (-20%)	**1648**	**230%**
Iteration 7: Iteration 6 + Improvement 7a	Machine parameter	Reduced robot dispatching time	-10 seconds (-40%)	**1881**	**276%**
Iteration 8: Iteration 7 + Improvement 7c	Machine parameter	Reduced conveyor travel time (tilt and speed)	-6 seconds (-50%) & 0.3 m/s increased to 1.0 m/s	**1913**	**283%**
Iteration 9: Iteration 8 + Improvement 3e	Automation	Full automation around the clock		**2483**	**397%**

Figure E.1: *Iteration process*

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