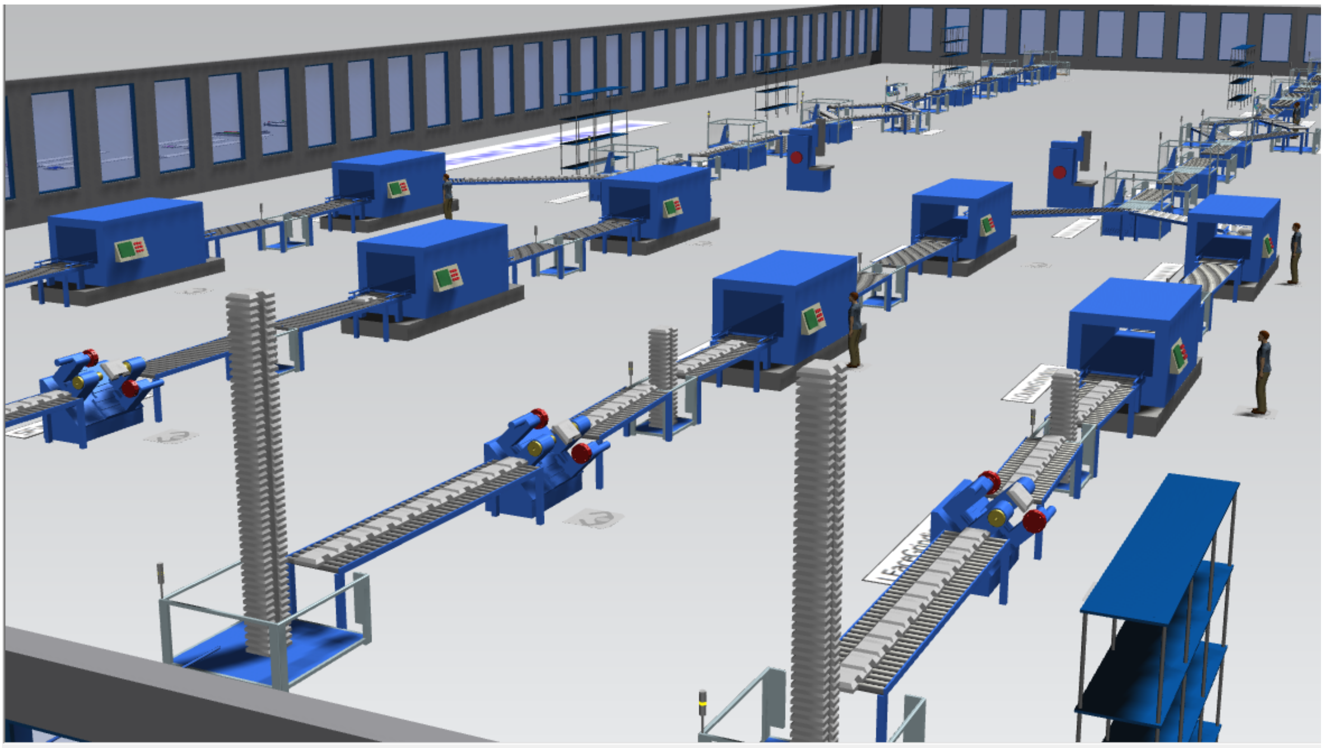

Future manufacturing of midsize bearing

Master's thesis in Production Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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An industrial study on how to design & evaluate a future manufacturing concept using simulation modelling

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Cover: Plant Simulation model of future manufacturing.

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Abstract

A changing market where bearings industry has seen rise in terms of numbers with regards to industries developing and blooming. Opportunities have recently opened in terms of specific products demanding companies to redesign existing production lines in order to meet new production & sales directives. For the forseeable future bearings will have a continuous demand as industries where they are prevalent are either going to remain or even expand. In order to be able to sustain such endeavors the factories must be able to produce and deliver goods in a reasonable time frame to final customer. All this while the industry as a whole is undergoing radical changes terms of acclimatising to Industry 4.0. Further - gadgets, programs and new tools such as simulations have become more and more prevalent in terms of designing current and future production factories, creating better options for evaluation.

This thesis will develop a future manufacturing site using simulation models and evaluate a future production site that currently has no equivalent. The project begun with evaluation of existing production lines working alongside the stakeholding company. As the first hand model had been developed it was verified as credible with regards to producing results similar to existing manufacturing line. By doing so the model was established as a credible model and allowed for trust from said organisation to begin creating a future model as was the final goal of this thesis. Using this future model, experiments were carried out regarding appropriate buffers, batches, setup-, cycle times and product planning with regards to future output in terms of costs. Main takeaways from the project is that information input into existing system will vary widely based on who the contact person is, and thus it is needed to receive a wide base of statements and opinions in order to correctly validate a both credible but also accurate model. Same could be said for developing the future model, defining what the desired output is - beforehand - is of utmost importance as different parties and stakeholders expect different outputs from the project. In terms of the development of the production line it is intended to meet the absolute majority of the future requirements in terms of the proposed investments.

Keywords: DES, Validation, Verification, IRR, NPV, Upscale, Buffers, Batch size, Setup time, Cycle time.

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Best Regards

Asghar Ramezani & Thudor Sonnerup

Gothenburg, June 2021

Terminology

Cycle times(CT) - is the time it takes to complete one task
Project Manager(PM) - is the responsible person for the project thesis
Setup time - is the time it takes align a specific machine/process for the incoming product details allowing production to start
Discrete Event Simulation(DES) -creates models of the system and its operation using discrete sequences of events based on time
Product Family(PF) -is a word used for the same type of product but with different measurements and surrounding features- main principles remain the same
Manufacturing Site(MS(1-2)) -is an abbreviation used for different manufacturing sites
Product(P(1-3)-S/L) -is an abbreviation used for different products manufactured on site and their respective size, S for small and L for large

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1
Introduction

In the following chapter the background of the thesis, aim of the project, specification of the issue under investigation, delimitations and brief background will be presented.

1.1 Background

One of the major issues within manufacturing as of today is calculating, investing and producing based on forecasts- especially long term ones for changing business climates. The demand is ever changing and markets are dynamic, making it even more difficult as a supplier to produce whilst still remaining profitable, achieving sustainability targets and developing organisation. Specifically it is difficult to adjust these long term forecasts in an era where trends such as Industry 4.0, Automation and Digitalisation have come to rapidly change the playing field.

Regardless of these harsh conditions, SKF remains a top competitor within its industry and is always looking to further develop its business areas. For this specific case they intend scaling up a product considerably in terms of both produced parts and demand, while slashing manufacturing costs. However, there is a considerable upside to the to the roller bearing industry for the coming years with the renewable energy businesses increasing exponentially and SKF are heavily linked to many of them - most notably wind turbines [1]. Recently joining the "Renewable Energy 100 initiative attempting to provide a carbon neutral organisation by 2030 - earlier than the absolute majority of manufacturing industries, SKF can clearly be said to take the energy initiative seriously [2].

One of the biggest issues that manufacturing companies face currently is to produce varieties of products in order to satisfy customer needs [3]. Manufacturers solve this problem by producing various models of the same products, which requires different manufacturing equipment, assembly tools, or new set up in machines which is another issue that the company also has to face. [3] The issue could be solved by producing the products in different production lines which is hard to justify financially, thus the products needs to be produced in the same production line which creates a number of manufacturing challenges [3]. One of the main challenges is addressing the high costs of manufacturing. This thesis in collaboration with SKF intends to analyse and identify the current situation of their bearing manufacturing of P1. Further creating a new production line intending to provide a future solution allowing for bigger quantities produced.

SKF is a Swedish founded company in Gothenburg that develop, design, and manufacture bearings, seals, and lubrication systems. The Gothenburg plant are currently producing three types of PF in their factory site located in Gothenburg - Product1(P1), Product2 (P2), and Product3 (P3). The focus of the thesis is only regarding the production of inner- and outer rings of P1, shown in figure 1.1. P1 has a large number of variations based on sizes, functionality, accessories etc. that is offered to different customers. P1 is currently manufactured in two production lines where (MS1) is entirely dedicated to P1L and the (MS2) production volume is split with 1/3 P1S and 2/3s P2. The issues for manufacturing of P1 mainly stem from frequent changeovers and low production volumes. Over time this has rendered P1 to have an increased product cost and thus invoking on their customer segments creating a downward sales spiral.

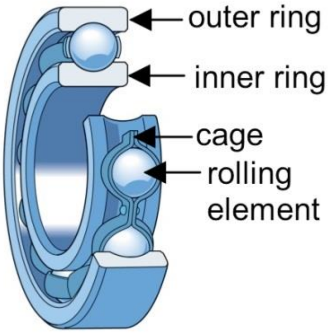

Figure 1.1: Main components of the roller bearing (SKF)

1.2 Aim

The aim of the project is to address a common manufacturing domain issue. The goal is to create a new manufacturing site that increases throughput rates & limits costs. For this specific case its supposed to decrease the production costs for future production of a product with the main purpose of decreasing the overall manufacturing cost in order to increase the demand and sales numbers of P1. Except for decreasing the production costs, there are further requirements and desired traits for future manufacturing of the product. The list also includes, shortened lead times, and also increasing flexibility in production as a requirement. This will be done by:

- Analysing the current situation with the aim of identifying the factors that affects the production costs which will allow to design an experiment and test these factors in the current state in Discrete Event Simulation (DES) tools.

- Developing a new production line with DES in Plant simulation and suggesting a new future scenario that increases the output of P1 and decreases the production costs which eventually allows for higher flexibility in production.

1.3 Problem Definition

Producing more than 40 different models of the same product family(PF) in the same production line -and with an ambition to further increase the number of variants within the PF - has created a number of challenges for the MS1. These challenges include -most notably - a higher number of changeovers per year in order to produce different variants of the product, leading to losing production hours. Simultaneously the machines are getting older which has led to a high failure rates during the up time of production. Another factor that have also affected the production of P1 is that the ambition to upscale the production and increase demand has increased rapidly in the last few years and SKF is planning to scale up the production and sale of P1 several hundred percent. All these factors have led a current state of P1 that several flaws, namely:

Table 1.1: Factors of current state P1

Double the desired production cost
Small batch sizes and frequent changeovers
High leadtime to customer
Too few variants

Thus to investigate the issue regarding the production of P1 and a developing future scenario for the production, the following research question has been proposed:

- *What are the factors that affect production cost in manufacturing of P1?*
- *How to optimize these factors with the purpose of decreasing the total cost of P1?*
- *How should future upscaling stages be evaluated?*
- *What further measures can be taken for the total manufacturing surrounding P1 in conjunction with reducing the production costs?*

1.4 Delimitations

The project intends to only address the manufacturing of rings for P1. No other sequences will be taken into account for P1 except the ring itself, no considerations will be taken for material purchasing, holder rings or sales & aftermarket. The thesis work will revolve around P1 but as it currently shares manufacturing domains with P2 in MS2 some of the presented work will also inevitably come to affect the manufacturing of P2. The simulations will come to use ring measurements as basis for calculating cycle times in order to simulate production flow and thereafter use approximate tools where needed. It will ultimately not evaluate the system end-to-end but just the system withing the manufacturing domain of P1. As P1 also comes to replace P2 in certain applications it would be of interest to see the impact of such a strategy, however no such study will be presented here.

2

Theory

In the following chapter the theory behind the chosen methods are explained. The chapter consists of error identification, production, financial analysis and Discrete Event Simulation (DES).

2.1 Production

Cost factors within production will be processed and further analyzed. Ultimately used to design an experiment enabling us to study the behavior of new models with various machine conditions.

2.1.1 Setup

According to Maynard's engineering handbook [4] setup is defined as the process when an operator changes the production conditions from producing product A to the condition needed to produce product B. The process includes stopping the production after previous product and preparing the machines and other conditions for the of start the next product. The internal activities include the activities which cannot be performed while the machine is running for instance changing a cutting tool. The external activities are defined as activities which can be performed while the next product started and machines has started such as organizing the tools and cleaning the machine equipment which is not used anymore [4]. The setup activity index is an indicator which measures how fast a line can setup the production of the next order, the activity index is visualized in table 2.1 [4]. The setup activity index will be used to design various experiments in the simulation of the production chain for the setup of new machines for the future production of P1.

Table 2.1: Setup Activity Index, Kjell B. Zandin (2001)

The activity and the work needed	Points and Activity time
No tooling changes are required anywhere in the line	0 points (Setup time: 0 sec)
Automatic changeover by pushing a button	1 point (setup time 0–1)
One touch to remove previous tooling and install the next	2 points (setup time 1–3)
Positioning with an alignment fixture	3 points (setup time 1–3)
Tightening bolts is required	20 points (setup time 2–3)
Test production is required	50 points (setup time 2–3)

2.1.2 Cycle Time

Patel & Shah (2014) define cycle time (CT) as "the time necessary to accomplish a certain task or activity at each well-defined station"[5]. CT is one of the most important manufacturing terms for increasing the overall output, affecting cost base and lead times. [5]. The appropriate methods to reduce the CT depend on the industry, and is more often than not a compromise between setup times and CT on machine processes.

2.1.3 Buffers

Storage areas within a production line are called buffers, (Chomnawung, 2016) elaborates on their purpose being to make processes in the production line more independent by making them less prone to unreliability -such as blocking, starvation and setup times - of other processes in the production chain. The prevention of unreliability to some extent will allow for production upstream and downstream regardless of production stops in certain process until the buffer either runs out or the recovery of stopped production process is addressed. (Ouzineb,2018) states that in order to prevent delays it is important to allocate a correctly sized and placed buffer.[6] [7]

2.1.4 Batch sizes

The batch size is the number of units produced before changing the setup. This parameter has a strong impact on the inventory levels that the company needs to keep. Reducing batch sizes will result in lower inventory levels, a surge in production flexibility and -frequency. Burcher (1996) states increased flexibility translates to ease of planning, and that lower inventory levels will help display bottlenecks in the manufacturing domain. In order to successfully reduce the batch sizes - a low set up time is the most integral part of the remainder of the production chain. On the contrary -larger batch sizes will allow for a smaller share of the total setup time calculated on each product, making it cheaper to produce. [8]

2.2 Discrete Event Simulation

Simulation can defined be as experimenting and designing a model of a real operation system with the aim of gaining knowledge about the behaviour of the system or evaluating various strategies for the production system [9]. Simulation can be used as a method to address complex systems and separate flows while still providing clear overview[10]. When specific factors are changing DES can provide clear-cut models and analysis of the situation[10]. Simulation is used to experiment with new designs, different machine capabilities, and requirements ahead of implementation of a new concept to justify the analytic solutions and prepare various situations[10]. The machine factors that can have a big impact on the new model could be cycle times, changeovers, batch sizes, buffer sizes -which can be elaborated with in DES.

DES also allows to animate complex modern system with the purpose of visualizing the future production plant and learn from different experiments and scenarios without the cost or distraction of an ongoing project[10]. However, there are situations in which DES is not appropriate to use it when verifying a new model, these situation are described by [10] as when:

- The issue can be solved using common sense.
- The problem can be solved by using easier or cheaper methods.
- It is more simple to perform the test directly.
- The simulation costs goes over the investment budget.
- The resources or time are not available.
- System behavior is too complex or cannot be defined.
- There is no trained simulation engineer to verify and validate the model.

Building simulation model requires knowledge from diverse background such as operations, computer science, statistic, and engineering which is one of the reasons model builders and managers faces many technical challenges while building the model [11]. According to Banks, a simulation is successful if it shows sufficient and credible results which can aid decision making [11].

2.2.1 Verification, Validation and testing Principles

The quality and accuracy of a simulation model can be evaluated by performing verification, validation and testing (VV&T) on the model [11]. J.Banks (1998) describes these three methods as following:

Model verification is performed with the aim to assure that the model is interpreted and converted from model A to model B with an accuracy that is accepted by decision maker[11]. Model verification assures that the model is build based on the problem definition which is translated into model specification [11]. "Model verification deals with building the model right" [11].

Model validation evaluates the model behavior, i.e. it assures that the model behaves with a consistent accuracy and in line with the project aim [11]. Hence, the simulated model should be analysed to see if the result of the model is correspondant to the real production system output. While validating the assumptions and how detailed the model is simulated based on the real system should be considered [11]."Model validation deals with building the right model" [11].

Model testing is performed with the aim to find the errors or inaccuracies in the model. The model is tested based on the test data or test cases to evaluate and check that it functions properly and shows an accurate result.

The VV&T process and design of DES needs to be continuously overlooked through the whole lifecycle of the model, changes and alterations needs to be implemented throughout the work in order to prevent unnecessary work [11]. Evaluation of a complete model will also be nearly impossible as most sources of error are interconnected, and thus validation must be analysed towards predefined targets[11]. The credibility of the model should be evaluated and tested based on the aim of the study and requirement specification [11]. Problem formulation is one of the most important step of simulating and affects the acceptability and credibility of simulation results [10].

2.2.2 Design of Experiments

The next step after verifying and validating the code and the logic of the model is to design and perform experiments to improve the constraints of the system [12]. The experiments were designed mainly with the purpose of identifying the constrains i.e. bottlenecks and optimizing the utilization of the system. The experiments were designed and conducted based on the theory of constraints developed and introduced by Goldratt (1990) [13] and includes the following steps:

1. Identify the System's Constraints.
2. Decide How to Exploit the System's Constraints.
3. Subordinate Everything Else to the Above Decision.
4. Elevate the System's Constraints.
5. If in the Previous Steps a Constraint Has Been Broken, Go Back to Step 1.

2.3 Financial Analysis

The goal of the simulations is to suggest a viable future production line for the P1 components. To evaluate the feasibility for SKF to make the suggested investments & changes in their production a financial analysis is carried out.
Investing in machinery is a costly operation and will require funds to be allocated over long time into the new manufacturing site of P1. Allocating resources should result in increased productivity and potentially lower operating costs, but also depreciation of said resources over a time frame [14] - in SKF's case 14 years. Whether the allocation of resources is financially well motivated or not can be seen in terms of Net Present Value & Internal Rate of Return. Net Present Value can be calculated following the formula presented in Figure 2.1 and is a tool suited to deem an investments net revenue over its active lifetime. [15]

$$NPV = \sum_{t=0}^{n} \frac{NCF_t}{(1+r)^t}$$

Where NPV = net present value; NCFt = net cash flow generated by innovation project in year t; r = discount rate.

Figure 2.1: Formula for calculating NPV

(Belli, 1998) states Net Present Value is useful in terms of calculating investment costs in relation to yearly returns and interest rates over time, however this model does not account for risk of the investment [15]. The formula has been further developed to accord for risk levels in the equation suiting this investment, with a risk taken into accord as an up scaling of sales based on forecasting and prognostics but no established sales. This secondary model portrayed in Figure 2.2 takes into accord the variables of Figure 2.1 and is adjusted for the time to obtain a realistic value of the investment and overall better cases including risk. [15]

$$rNPV = \sum_{t=0}^{n} \frac{CF_t R_0}{(1+r)^t R_t} + \frac{R_0 CF_{n+1}}{(r-g)(1+r)^n}$$

Figure 2.2: Formula for calculating NPVr

In the formula of Figure 2.2 , respective variables of Zizlavskys (2014) model of calculation are clarified in comparison to Figure 2.1 [15].

- *R0* equals the probability of successfully finishing development
- *Rl* represents the probability of period t to taking the product to market
- r is the discount, similarly to 2.1
- n is the last period of time for which costs and revenue is accrued.
- g is representing growth rate

Onwards, Berk et al. (2019) describes Internal Rate of Return (IRR) a useful tool for analysing profit on investments. [16] The purpose of it being to assert whether an investment is profitable or not, but not in actual numbers- but rather in percentages. Internal Rate of Return can be calculated following the formula presented in Figure 2.3 and retrieves percentage on the actual investment. [16] By including a sensitivity-analysis, the IRR method analysis sees increased application areas, providing the worst- & best-case scenarios for different interest rates.[16]

$$NPV = 0 = \sum_{t=0}^{n} \frac{C_t}{(1 + IRR)^t}$$

Figure 2.3: Formula for calculating IRR based on NPV

3
Method

In the following sections the methods that will be used to successfully carry out the project are presented subsequently.

3.1 Assessment

Initiating the project will be done following the assessment method described by (Margerison, 2001) : A Practical Guide - following the four steps [17]:

Collection, Analysis Diagnosis, Feedback & Discussion

As for the *data collection* the existing personnel should be heard for their views, opinions and previous conceptions regarding the overall state of P1, they will be interviewed and their opinions will be taken into accord as a step in the data collection. The interviews will be done in semi-constructed fashion allowing for answers to the questionnaire but also allow for personal pivot in relation to the subject.[18] Besides the interviews the internal existing documents of the company will be collected and taken into accord. Later turning to the *analysis diagnosis* of the assessment where data taken into perspective in relation to the existing project and contemplating on how to use it further, ultimately resulting in a workshop. The *data feedback* stage consisting of presentation of data accrued in relation to the analysis needs presenting to project team in order to process it and prepare for the last step of the assessment sequence. Lifting the process and the external party findings compared to previous conceptions will be the final stage, opening up for a *discussion* in order to bridge miss conceptions and different ideas to the existing problem and possible solutions.

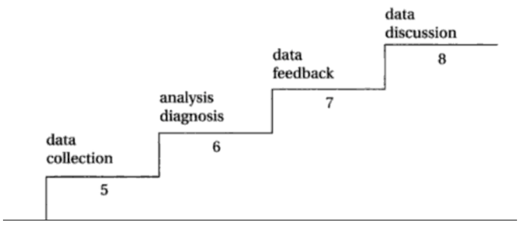

Figure 3.1: Assessment method in - Managerial Consulting Skills: A Practical Guide

3.2 Simulation methodology

The aim of the project was to evaluate current manufacturing practices of P1, propose new alternatives in accord to SKF's internal stakeholders, corresponding to risk analysis of each alternative. Thereafter propose a new production line for the future production of P1 in total in which the P1L from MS1 and the P1S parts created in MS2 are included in the same manufacturing line. Hence, after evaluating a number of simulation models, it was decided to use Siemens Plant Simulation, considering ongoing collaboration between Siemens and SKF. Plant simulation is mainly used by industries with the aim to improve the production performance, simulate and explore different production scenarios. The flowchart visualized in figure B.3 shows a standardized scientific approach developed by J.Banks(1998) for simulation studies[11], the approach was adapted to fit the purpose of the thesis. The approach consists of three main steps: Preparation, Model building & Validation and Analysis.

3.2.1 Preparation

The preparation step as visualized in the flowchart in figure B.3 consists of 5 step the problem formulation, defining the project plan, data Collection, model conceptualization, and learning the software -Siemens Plant Simulation.

An initial *Problem formulation* was described by the PM at SKF which was modified and adapted to also address the academic interest and the limitation of the project. The problem definition as well as the purpose of the project is defined in chapter 1.3

The Project plan is a proposal to with the purpose of the project, a proposal model intends to answer the research questions [11]. The proposal should consists of a description of various factors that needs to be investigated, the Gantt-chart (Appendix 4), and the needed resources for the simulation [11]. Thus, a number of initial scenarios were suggested to SKF out of which one was chosen to build the future manufacturing model which can be seen in figure 4.1 ˙

Model Conceptualization is a matter of creating an abstract model of said concept. It is created by several mathematical and logical in relation to the components involved in the system. Construction of a complex model is not considered vital as it will add considerably to the time consumed for the study and completion of it without adding quality to the project. Rather the concept model should start as a simpler one with room to grow and expand in details, processes and components needed- adding continuously to the complexity of it -but only with inputs desired. Involving the client in the creation process is of utmost importance as it will provide better results in terms of quality for the model and increase confidence from their side towards the final model.[11]

Data Collection Accumulating the needed data from internal pre-made documents and pre-studies of those allowing for further knowledge within the field and most importantly the specific case and its scope. The needed comprehensive data was gathered through quantitative data to get a deeper understanding of the production process of P1. Additionally, qualitative data will be gathered through literature studies and research interviews, these methods are further discussed in Chapter 3.3 .[19]

3.2.2 Model Building & Validation

The model building step as visualized in the flowchart of figure B.3 consists of 4 different steps: translation, building, verification, and validation. The aim of this step is to define, build and visualize the model, which later can be verified and validated.

Model translation
The conceptual model that was suggested to the PM was built and coded in Plant Simulation with the purpose of verifying and validating the model. The current model was built according to the gathered data and the production layout of current manufacturing. It is of utmost importance to gather the right data during the model building[11]. It is important to verify the model after each step during to insure that the logic of the model is corresponded to the real operation system.
The*verification* step is necessary in order to ensure that the simulation model is working properly and according to the real world operation system [11]. "*Validation* is the decision of whether the conceptual model is an accurate representation of the real system" [11]. Thereafter, the statistic results and production behaviour of the current model was compared to the statistics of the real system to verify the model. The results were then verified by the PM at SKF.

3.2.3 Analysis

The Analysis step as visualized in figure B.3 consists of 5 different steps building the future model, experimental design, production runs and analysis, and documentation and reporting. The gathered data was used during the course of building the future model and experimenting.

Once having a future model - based on previous steps - established, several different deviations to this model were elaborated upon in accordance with the PM. This in order to visualise broader changes based on differences in numbers on different variables. The PM suggested 10 separate concepts of the production line that were worthwhile evaluating, once having settled on one specific concept it was the base model for future experiments.

The *experimental design* is an important step for the decision maker, in which different scenarios can be designed based on experience, collected data, as well as investment budget [11]. The experiments can then be applied to the simulation with the sole purpose of comparing the different scenario outputs[10]. DOE can be used for sensitivity analysis, optimization, and validation of a model [11]. Considering the factors of Table 1.1 that affects the state of P1, it was decided together with the PM to design the experiments solely from the factors or adjacent topics that affects the production output. These factors includes- cycle-time, setup-time, batch sizes, buffers, bottlenecks and production planning. The Plant Simulation is used to perform the experiment with the purpose of identifying the optimal factors for the future production of P1. Thus a number of experiments were designed to perform on the future model production.

Experiment 1: Optimization between Cycle- & Setup times

The objective of this experiment is to identify the optimal relation between cycle-time & setup time the production. The balancing of cycle time and setup time will be done in relation desired production schedule on SKF's behalf. The future cycle time for the products was calculated by using a size-dependent mathematical model. The generated cycle-times were verified by the PM so the values are within the limits of real cycle-time. Setup times were varied in relation to cycle times following the Table 2.1 as longer setup times allowed for shorter cycle times and vice versa generating a desired scenario.

Experiment 2: Number of Operators

For this experiment the objective was to identify optimal number of operators on one production line and subsequently on two - the entire production chain. By grouping the operators within both production lines the idea was to receive a higher working-% on operators rather than having assigned operators to each specific production line. By evaluating the number of operators in the production line it would result in optimated output for the number of operators, and allowing for evaluation of the correct number of employees per shift for the maximum output per employee and total output. Reaching an optimal level visualises where productivity per added employee is lowered once having added too many, similarly output is increased considerably per increased operator when too few.

Experiment 3: Buffers in the production
As described in 2.1.3 buffers are a tool for correcting production processes and allowing production to proceed regardless of individual interruptions. By elaborating on correct amount of buffers and space in said buffers one could see where performance was increased by larger or more buffers, and where the total output not affected. Resulting in an optimization of buffers in relation to order quantity and frequency. However, once the output of the production line was not increased the extended buffers serve no purpose and thus the optimization came in play. After discussions with the PM it was decided upon ensuring batches at least covered 1 hours of stopped production and thus it will serve as minimum buffer size in the experiment.

Experiment 4: Production Planning
The aim of this experiment is to find out right production plan and a balance between the batch sizes and frequency of orders.It is - in terms of the production chain - cheaper to produce big orders as the setup time gets divided by a larger amount of products, however the cost for keeping them inventory increases dramatically. SKF has a relatively lean, minimalist philosophy in terms of their inventory levels and thus they can not be increased all too much - but could serve as a topic of discussion. Running the experiment with differently sized batches allows for a total estimate of costs for producing the articles but also storing them.

Experiment 5: Bottlenecks & Scaleability As the financial analysis was based on a single model of future scenario, there was a clear cut bottleneck designed in order for further scaling with limited costs. By allowing a specific machine in the early sequence of the production chain serve as a bottle neck the process became easier to analyse and also to further develop. By running "experiment manager" in the future manufacturing simulation it allowed for a tool in designing a clear bottle neck of the production chain, providing an option for up scale in a future state of production while limiting expenses.
As for *Building current model* it was built in plant simulation with the purpose of both visualizing the production flow as well as performing the experiments in a dynamic system. The model was built by using both the default system in the software and coding some more detailed parts (Namely importing, exit strategies and product handling). However, the model, machine specification, cycle-times, and the material flow was predefined before starting the model building. The model was modified and improved with more details during the course of building the simulation model, a 2D-sketch of future manufacturing model is visualized in figure 4.1.

For *Production runs and analysis* the primary purpose is identifying parameter values that optimize some system performance measures. Some of the inputs will be random within a certain range, giving randomised outputs on the results. Thus simulations will produce independent observations but no pattern can be produced from each individual observation, rather the distribution will be different from time to time producing a range where the results lie within the interval. The output analysis will not be compared to other designs or simulation experiments, nor will reducing variance be a topic of importance. The analysis intends to present an optimal expected performance, by defining the range of work for given variables. In order to optimize performance of the system it needs to be robust enough to overlook noise in valuation.

Documentation and reporting is final step in the simulation model, particularly if the decision maker needs to perform further experiments on the model and to understand how the model is operating [11]. The result of the analysis and experiments should be reported clearly and different step of the simulation needs to be described, if other analysts needs to use the model again [11]. The HTML report is a function in Plant Simulation that allows to document all the necessary result from the model, thus the result of the simulation model was generated after each experiments. This was done to easily compare different simulation results, some examples of the HTML report is visualized in Appendix C.

3.3 Data collection

3.3.1 Organizational Documentation

Besides the other informational sources in the process the work will revolve and take support in pre-existing data accrued by internal personnel in the SKF organization. Existing files of data on manufacturing, sales, organizational roles, visualisations etc. will be used next to the other process steps. Serving as a tool for supporting the process and checking it for validity and giving a reference to future solutions.

3.3.2 Literature Research

In order to allow for a better understanding of the scope of the thesis the first period will be spent conducting literature research in order to understand potential problems of their current manufacturing further and also general manufacturing practices. The literature findings intend to add up to the previous experience of the workers and also debunking incorrect ideas filling the role as a partial proof of concept.

3.3.3 Interviews

During the course of the project there will be several interviews conducted with internal working personnel within the SKF organisation with different backgrounds yet connected and affected to the P1-project. The purpose of the interviews will be to get a historic perspective of why the current manufacturing regime is in its current form and provide improvements for future. The different background in this specific case being Sales, Process Controlling, Production Technicians, Process Development, Supply Chain & Logistics. Interviews will be conducted in a semi-structured manner -see A.1 -and thus both provide answers to relevant questions but also provide personal insight on the matters as the questions are open ended and allows for further elaborating. [18] The interviews will gather qualitative data in order to compliment the total thesis work, which will serve as a good counterpart to the otherwise overall quantitative work. The method for electing interviewees will be purposive sampling out of the assigned P1-project group, this in order to receive as many inputs as possible regarding the current manufacturing situation of P1. Interviews started with the PM and was later on conducted throughout the group, interviewees were chosen by the PM. Election of interviewees was based on the idea of branching the departments and roles as much as possible in order to provide a facetted perspective of the situation.

The table 3.1 is constructed to show their respective roles and department and ultimately visualise the spread of their respective areas of interest.

Table 3.1: List of Interviewees

Role	Department
Project Manager	Production Development
Product Manager	Business Development
Demand Manager	Supply Chain
Financial Controller	Finance
Financial Controller	Finance
Head of Purchasing	Purchasing
Head of Manufacturing	E-Factory
Head of Manufacturing	D-Factory

Interviews were done solely online through communication software except for the one with the PM which was done on site. Notes were taken simultaneously as the interviews progressed but were also recorded in order to be able to replay the sequence. [18]

Given the different nature of the interviewees line of work the results of the separate discussions came up very different in terms of the open end of the interview. Some providing a broader sense of the situation whereas others provide specifics on certain topics.

3.3.4 On-site Study

A number of on-site study visits of the current production lines were done to further investigate the process, get a deeper understanding and collect information specific to SKFs production lines much needed in order to develop alternative scenarios for the production of P1. Next to the site-studies of the manufacturing domain, the project conducted a workshop with relevant employees of different business areas all corresponding to the P1- project in its current form but also with regards to future development.

In order to ensure the analysis of the project having an independent and critical approach towards the project regardless of previous data and analysis done beforehand from the company's side the project will create and work with respect to an internal working sheet, seen in A.2. The sheet elaborated on parametres pre-decided of the project that were deemed relevant. Thereafter they were valued ranging from a 1-5 - with 5 being the most relevant, and 1 being the least relevant - in order to use them in upcoming simulation and/or financial analysis. Whereof those relevant ultimately were used as basis for creating the first iteration of simulation model for the future state.

3.4 Financial Analysis

An assessment of the economics surrounding the project was done with regards to existing, future and simulated values. The current state acting as a worst case scenario and future serving as a best case scenario with the simulated results landing somewhere in between. The results were calculated using both the NPV & IRR analysis in conjunction with SKFs internal project calculations sheets.
The risk of the suggested scenarios was taken into consideration for the discussion but estimating it correctly was deemed to be an obvious risk and thus the risk calculated NPV-scenarios were scrapped from results but included in the discussion the form of risk assessment.

4
Results

Following chapter will contain the results found from this study, where the simulations will be a main part of the focus -specifically addressing credibility and in a latter stage costs. It will include creation & evaluation of each stage (current and future).

4.1 Interviews

Interviews were conducted to determine the aim and limitation of the project. A number of issues have been identified with today's manufacturing methods. Identified issues listed below are the main reasons why costs have increased on the inner and outside ring of Product1 (P1):

- *Low volumes*
- *Frequent setup changes of the machines*
- *Wide product range*
- *Low efficiency on machines*

Low volumes sold -and therefore produced - have over time led to high degrees of fixed costs in relation to the flexible costs of the products. Similarly the *Frequent setup changes of the machines* have been a result of low ordervolumes, in conjuction with SKFs policy regarding keeping warehousing as low as possible.
The SKF production of P1 is heavily linked to their existing product range of P2 as they are ordered together described in 1.1. Therefore the P1 product has to correspond to the existing range of P2 that is far wider due to higher volumes, which also adds to further frequent setup changes.
The problem with the current manufacturing was further amplified by low efficiency levels on existing machinery.

Table 4.1: Summary of workshop

Topic	Description	Relevance/Scope?
Frequencing	*How often batches are produced*	Yes
Volumes	*Sheer quantity*	Yes
Machines	*Deciding cycle-,resetting times and failure rates*	Yes
Distribution Keys	*Economic tool for distributing costs*	No
Market Shares	*Sales level in relation to competitors*	No
Outsourcing/Inhouse	*Production within the company or buying from external*	Yes
Automation Degree	*How much manual labour is required*	Yes
MTO/MTS-Handling	*Manufactured to order/stock*	Yes
Full Chain (Suppliers, Customers)	*Entire production chain from final customer*	No
Product Quality	*Level of product in relation to requirements*	No
Offered product variances after demand	*Acquiring costs after generated revenue*	No
Separation of production	*Producing parts in broken & separate lines*	Yes
Warehousing	*Levels of articles kept in storage*	Yes
Buffers	*Number or articles kept between machines in production line*	Yes
Eliminate process steps	*Removal of processes*	Yes
Merged workers pool	*Less personnel needed*	No
Shared interface	*Lower threshold for using systems*	No

4.2 Workshop

The results of the workshop from the two separate groups eventually resulted in a long list describing future cases and specifics in where a change/improvement was needed. Some *types* will inevitably be more important to a future state factory than others, however the table is presented without internal weighting. The Table4.1 is presented with a judgment of whether the type is relevant and also within the scope for the specific thesis further laying the foundation for the *internal working methodology* in what areas to address.

- Frequencing , during the workshop the concept of *frequencing* was brought up as it has been overlooked due to it being previous manufacturing standard in terms of simplifying the warehousing process and having continuous production of article types.
- Volumes were unanimously agreed upon to be the very biggest factors in terms of needing adressing. Increasing volumes would allow for different order planning entirely.
- Machines, the separate workgroups agreed that current machinery used for manufacturing P1 -and most specifically P1L- are in for an improvement. Stating cycle-, resetting times, automation degree and failure rates.
- Distribution Keys, were mentioned as a useful tool to calculate costs differently and allow for up scaling once investments, new production routine, market shares all were addressed. However, has no fit within the thesis scope and will not therefore be addressed further for development.
- Market Shares is a future topic, where the idea is to scale the production and take further shares eventually lowering fixed costs per article produced. It is not included within the thesis scope nor a manufacturing topic thus will it not be addressed further.
- Outsourcing/Inhouse was mentioned in terms of outsourcing entire process steps or low quantity products to external thirdpartys. Allowing for ease of scheduling remaining products and/or processes in manufacturing. Such a

decision needs evaluation but is not within the limits of the scope and hence is excluded.

- Automation degree will result in lower amounts of manual labour and is of high importance within the manufacturing setting to the outcome of the future state model. Will also effect the setup,- and possibly -cycle times in manufacturing and is therefore of utmost importance to evaluate and is within the scope of the thesis delimitations.
- MTO/MTS-Handling needs revision due to MTO's having reoccuring patterns making them in for a change to MTS's. Change of handling of certain MTO's to MTS's would result in allowing for a more longterm order planning and shorter lead times to customer at the expense of higher warehousing degree.
- Full Chain in terms of the entire project needs to regain credibility for P1,towards both suppliers and customers regarding the P1-investments being done. Previous endeavours have failed to address the current state and thus drained the suppliers and customers resources in relation to P1. It is outside the thesis scope handling SKF relations towards suppliers / customers, however a part of creating a credible solution for P1 involves a thorough basis -which can involve said thesis work.
- Product Quality was suggested to allow for having lower material costs where the current product was "too good" for its application. Would however require separate production for the same product with different materials and thus invoke on ease of order planning negatively. Attempting to change such a measure is however far outside the scope of the thesis.
- Offering Variants after demand could be a tool in upscaling to postpone costs for production tools to ensure there is demand covering parts of tools cost before having to deliver orders alike.
- Separation of production aimed at the possible manufacturing options could be separated into more or fewer alternatives addressing *small*,*medium*and *large* ranges or possibly even further distinguished ranges. This compared to their -as of today-*small* and *large* production ranges on different sites. Also allowing them to overlap in breakpoints of intervals remedying unexpected interruptions to some extent. The separation of production lines for different ranges and/or attributes was an interesting idea that could potentially come into play when modelling and researching possible costs and payoffs for the future state and was considered within the scope and was further considered.
- Warehousing degree was lifted as a tool of removing frequent changeovers and thus lowering frequency in production. Allowing for bigger batches, eventually raising capital tied up. Decision regarding warehousing is outside the scope for the thesis but would eventually allow for easier order planning in manufacturing setting and is therefore included.
- Buffers being increased between production processes would remedy the occasional material shortages that historically have occurred and smoothen the production curve preventing eventual downtimes. The sizing of buffers needs addressing and is within the realms of the scope.
- Eliminate Process Steps was brought up as an experimental idea where the stage of InnerGrinding could be extended in favour of removing the Honing

stage within the process and some quality on the surface of product. It could have some future implementation but as for today's low volumes and demands on high quality products is not a feasible solution nor was it addressed further.
- Merged Worker Pools could be done to a further extent, cutting down costs on white collar workers and production technicians with a shared site and project group for P1. Was however not considered a major stakeholder in addressing the future manufacturing and was also not within the manufacturing route.
- Shared Interface in future manufacturing settings would allow for relocation of workers and less of a threshold for learning a new system when recruiting new personnel, thus gaining revenue faster. Implementation of shared interface on new machinery is however not included within the scope of the thesis and will therefore not be adressed further.

4.3 Simulation

Internal working methodology An internal working sheet was created for identifying, analysing and deciding upon which factors to simulate in the model. The internal working sheet was based around previous internal data of SKF regarding the topic, On-site studies, Literature researches, Interviews and the workshop, ultimately resulting in a pointbased system ranking the different factors from 1-5 in terms of their believed impact on the simulation itself.

An initial conceptual model (figure 4.1) was deigned based on the current model and the machine specification that was provided by the project manager, the machine specification can be seen in table 4.2. The cycle-time of the products is size dependent, thus as mentioned in section 3.1.1 , the cycle-time was calculated based on a mathematical and logical model. However, The cycle time of the smallest and the largest product are assumed based on the existing machines in the market and the experience of the project manager. The cycle-time of the involved products can be seen in Appendix B.1 which is visualizing the large range and Appendix B.2 that visualize the cycle time for the smaller range.

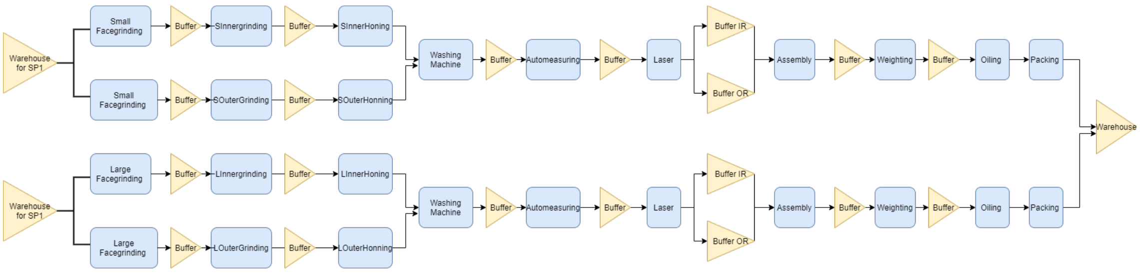

Figure 4.1: Conceptualized model (SKF)

Table 4.2: Machine specification

	Setup time	Cycle time	NM. Resources	Task
FaceGrinding	1 min	1 minute	1	Measuring
Grinding	30 min	Size dependent	1	Setup, measuring
Honing	30 min	Size dependent	1	Setup, measuring
Washing machine	1 min	30 seconds	0	
Automeasuring	1 min	Size dependent	0	
Laser	1 min	30 seconds	0	
Assembly	1 min	Size dependent	2	Assembly
Weighting	1 min	30 seconds	0	
Oiling	1 min	30 seconds	0	
Packing	15 min	30 seconds	1	Setup

Current State

It was agreed upon with the Project Manager that the simulation of the "Current State Model" was to be simplified to only regard the MS1 and exclude the MS2 due to its split between in product catalogue and also in order to remove the fact of split production lines between different material families. Another simplification of the process was to only include chosen parts of the total order planning that were supposed to represent an average in terms of cycle-, resetting times, fail-rates, and order planning to receive similar results without complicating the model far too much. Material families for P1 were grouped together as their respective times were considered a somewhat presentable average of the reality.

The Current state was created solely on the MS1 with the upcoming years production plan as a tool for evaluation. It intended to resemble current manufacturing in terms of looks and number of machinery. For the current state model the PM and researchers agreed upon creating double articles for every article as MS1 otherwise is producing several inner rings of P1 and several outer sample in batches subsequently. This decision was also inherited from future manufacturing settings where inner rings and outer rings are produced independently of one another to enable lower internal buffers and more continuous throughput in assembly.

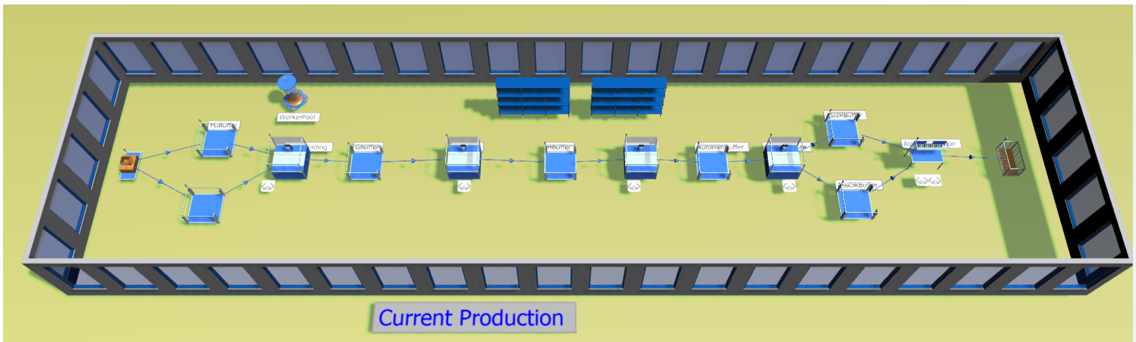

Figure 4.2: Current state production flow (SKF)

The evaluation of current state merely attempted at resembling -or as close as possible to- resemble the existing manufacturing routine in order to provide a valid model to ensure further trust for future models. It was agreed upon for the models final values to resemble the actual production within a 5% error acceptance limit on all processes - as some potential estimates were not exact. The "Current State"-model production output and the machine statistics are visualized in figure 4.3.

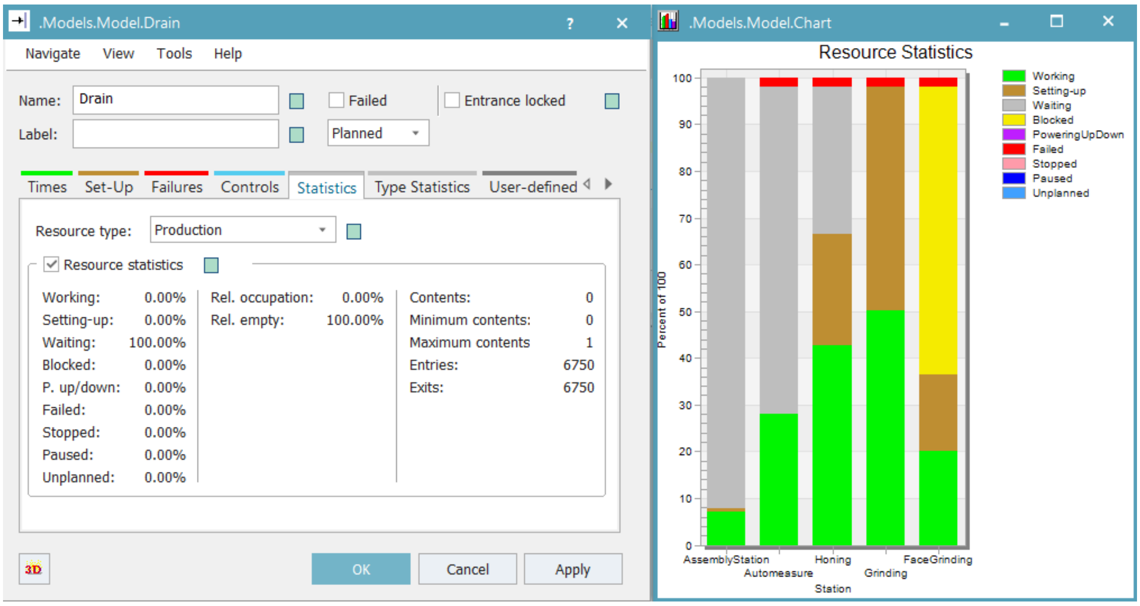

Figure 4.3: Current state production flow output of MS1 and machine statistics

Future State

The simulation of the future production model were designed and simulated in two different model where in the first model production flows and worker pool were separated and in the second alternative the two manufacturing sites are combined to use the same worker pool. The models are visualized in figure 4.4 and 4.5, respectively.

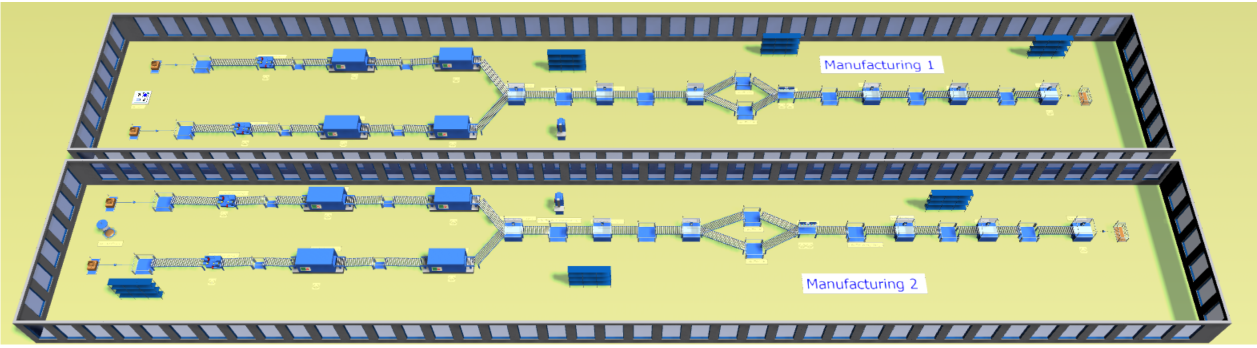

Figure 4.4: Alternative 1, Separate Manufacturing sites (SKF)

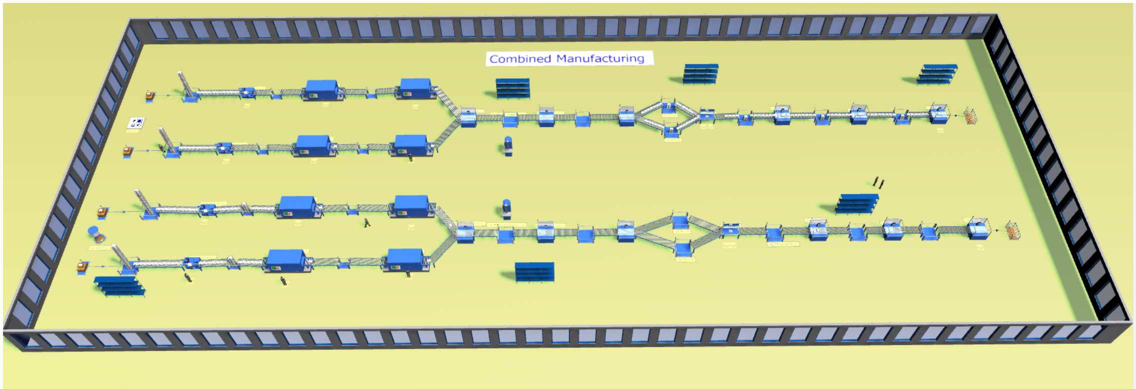

Figure 4.5: Alternative 2, Combined Manufacturing sites (SKF)

The main goal of using the simulation program for screening a future scenario is to optimize the production flow as much as possible theoretically. The following experiments were designed to optimize different function of the future production scenario. The result of the experiments are then analyzed and the best possible outcomes are chosen for different upscale alternatives in "Final state".
As for the experiments and further evaluation of future state the results came out as following:

4.3.1 Experiment 1

Consisting of experiments of ideal role distribution, individual or shared worker pools and number of workers.

-Optimal Role Distribution-experiment

The results of the role distribution experiment in experiment 1 states that ideal role distribution is 6 free operators to all tasks with 5 & 4 respectively allowing 1 & 2 operators to be tied to the assembly station solely, as seen in Figure 4.7.

Scenario:	Workers= Setup/Measuring/Assembly + Assembly	Total worker	Shift	Investments	Produced P1S	Increase P1S	Produced P1L	Increase P1L	Total produced
Current	-	22	-	-	46000	1,00	6000	1,00	52000
Experiment 1	6= 5S/M/A+1A	16	2	100	135502	2,95	24699	4,12	160201
Experiment 2	6= 4S/M/A+2A	20	2	100	135825	2,95	24404	4,07	160229
Experiment 3	6= 3S/M/A+3A	24	2	100	117385	2,55	24124	4,02	141509
Experiment 4	6= 5S/M+1A	28	2	100	21175	0,46	21275	3,55	42450
Experiment 5	6= 4S/M+2A	32	2	100	21172	0,46	21284	3,55	42456
Experiment 6	6= 6S/M/A	32	2	100	141189	3,07	24633	4,11	165822

Figure 4.6: Exp. 1 -Role distribution Output

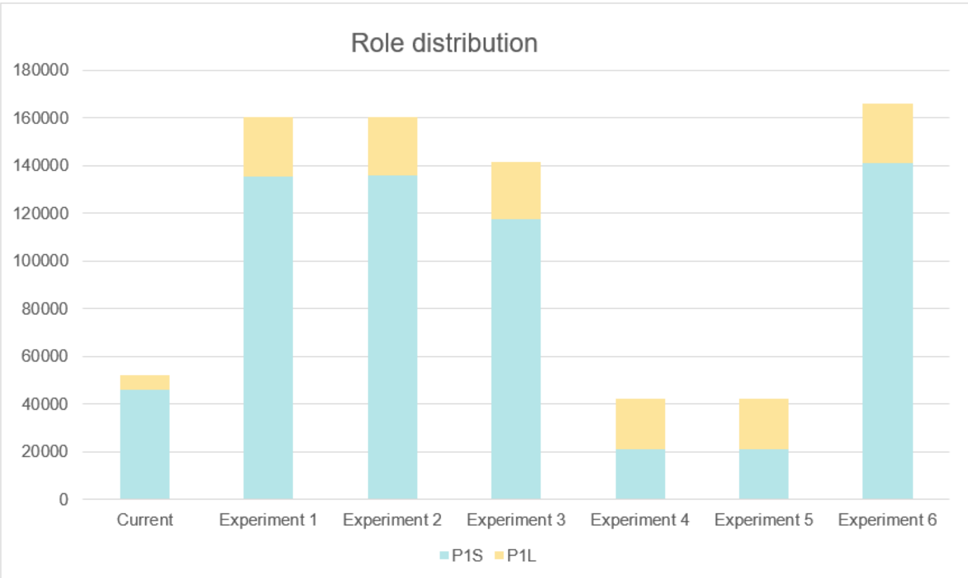

Figure 4.7: Exp. 1 -Role distribution Chart

-Optimal worker pool scenario & number of operators experiment

The results of the comparison between individual working pools per production line was outperformed by the combined worker pools for both lines and thus will be the preferred option as seen in Figure 4.8 & Figure 4.9 respectively. The number of operators experiments results can be seen in Figure 4.10.

Scenario:	Workers= Setup/Measuring/Assembly	Total worker	Shift	Investments	Produced P1S	Increase P1S %	Produced P1L	Increase P1L %	Total produced
Current:	-	22	-	-	46000	1,00	6000	1,00	52000
Experiment 1	4S/M/A	16	2	100	124000	2,70	24069	4,01	148069
Experiment 2	5S/M/A	20	2	100	131222	2,85	24239	4,04	155461
Experiment 3	6S/M/A	24	2	100	140269	3,05	24243	4,04	164512
Experiment 4	7S/M/A	28	2	100	129988	2,83	24256	4,04	154244
Experiment 5	8S/M/A	32	2	100	132674	2,88	24699	4,12	157373

Figure 4.8: Exp. 1 - Single Line Production Output

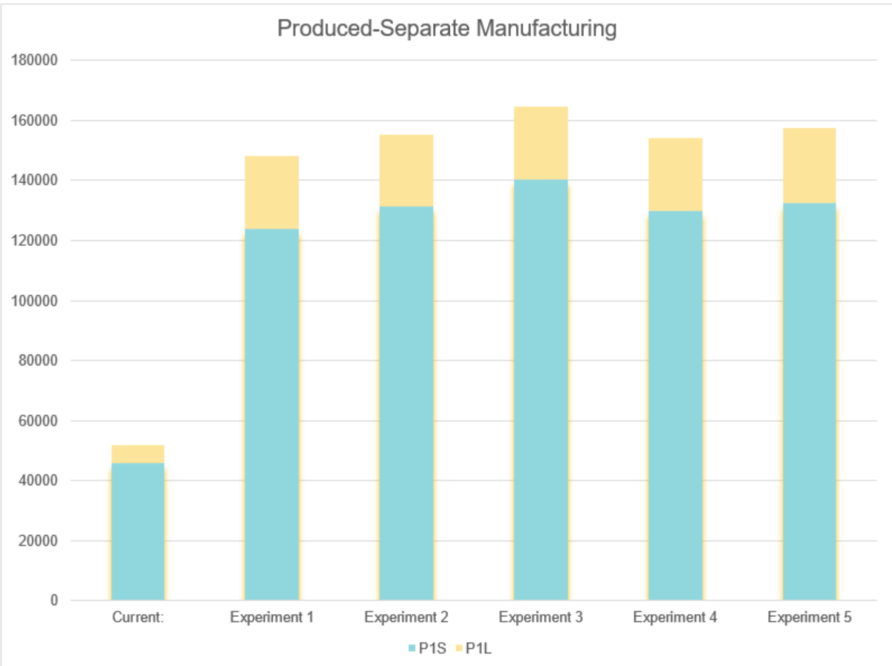

Figure 4.9: Exp. 1 - Single Line Chart

-Worker Occupation Experiment

Allowing workers to be increased as in experiment of Figure 4.10 provides statistics for occupation on workers based on amount of operators and also machine availability. Results can be seen ranging from approximately 85 % to 55% - depending on amount of workers- in Figures C.1-C.5

Scenario:	Workers= Setup/Measuring/Assembly	Total worker	Shift	Investments	Produced P1S	Increase P1S %	Produced P1L	Increase P1L %	Total produced
Current	-	22	-	-	46000	1	6000	1	52000
Experiment 1	4S/M/A	8	2	100	90599	1,970	23025	3,838	113624
Experiment 2	5S/M/A	10	2	100	130735	2,842	24363	4,061	155098
Experiment 3	6S/M/A	12	2	100	141189	3,069	24633	4,106	165822
Experiment 4	7S/M/A	14	2	100	139258	3,027	24699	4,117	163957
Experiment 5	8S/M/A	16	2	100	132558	2,882	24699	4,117	157257

Figure 4.10: Exp. 1 - Combined Line Production Output

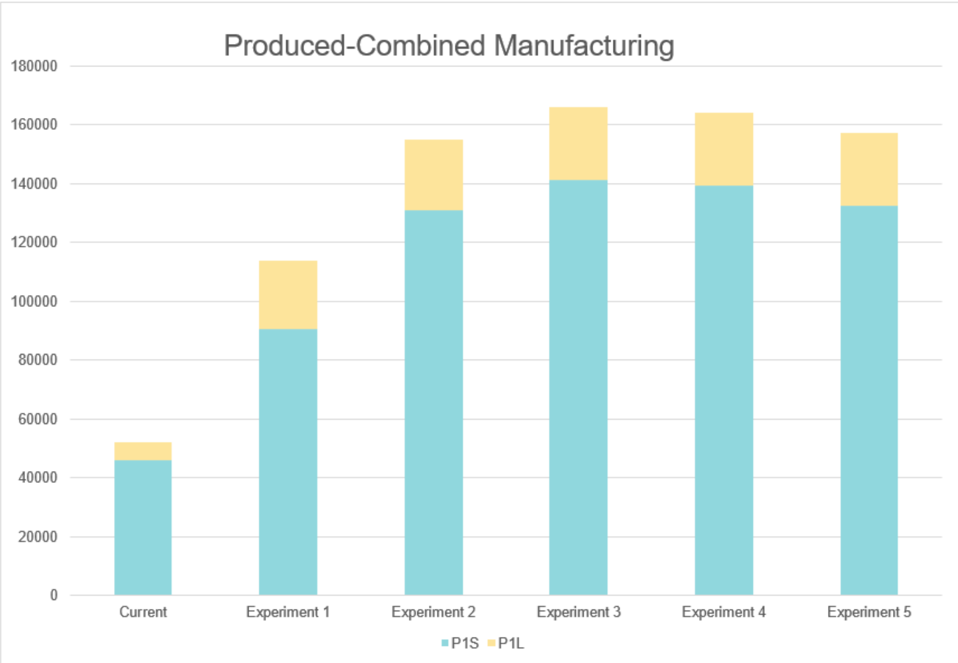

Figure 4.11: Exp. 1 - Combined Line Chart

4.3.2 Experiment 2

Comparing the results it provides clarity in the 30 minute setup time alternative outperforms the 90 minute setup as seen in Figure 4.13 & -4.15 respectively. Thus it became the basis for the future model final concept.

Scenario:	Worker=Setup/Measuring/Assembly	Total Workers	Shift	Investments	Produced P1S	Increase P1S %	Produced P1L	Increase P1L %
Current	6S/M/A	22	-	-	46000	1,00	6000	1,00
Upscale 1	6S/M/A	12	2	100	146933	3,19	24633	4,11
Upscale 2	6S/M/A	18	3	100	219894	4,78	36855	6,14
Upscale 3	6S/M/A	24	4	100	258417	5,62	43797	7,30

Figure 4.12: Exp. 2 - 30 min Production Output

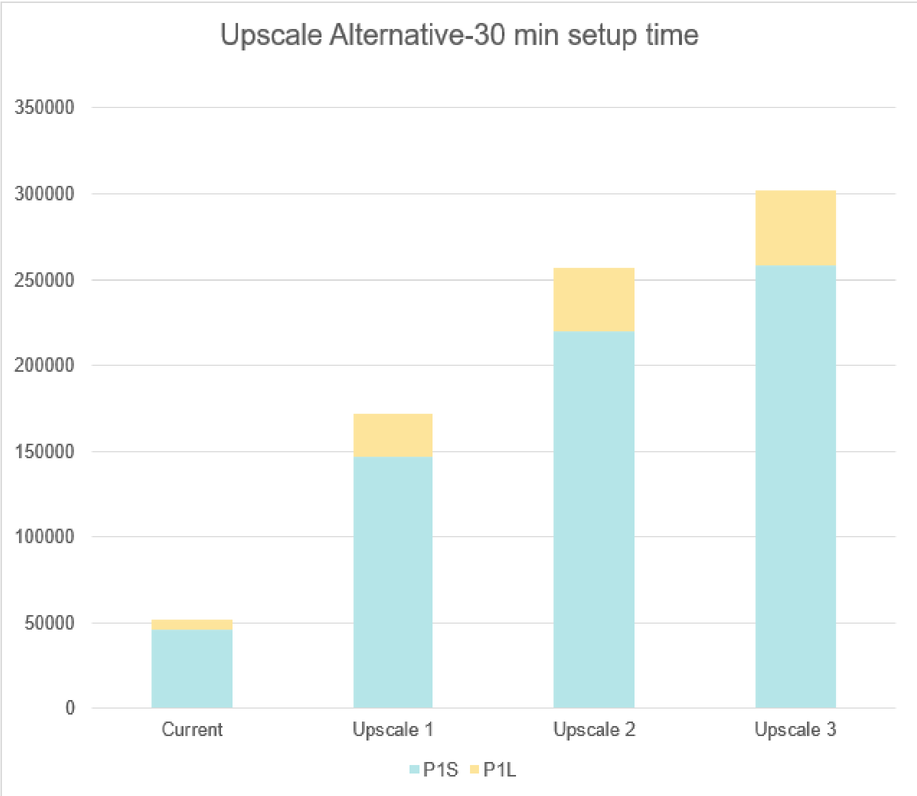

Figure 4.13: Exp. 2 - 30 min Chart

Scenario:	Worker=Setup/Measuring/Assembly	Total Workers	Shift	Investments	Produced P1S	Increase P1S %	Produced P1L	Increase P1L %
Current	6S/M/A	22	-	-	46000	1,00	6000	1,00
Upscale 1	6S/M/A	12	2 (3600 h)	100	133821	2,91	21232	3,54
Upscale 2	6S/M/A	18	3 (5400 h)	100	200336	4,36	31888	5,31
Upscale 3	6S/M/A	24	4 (6400 h)	100	238290	5,18	37837	6,31

Figure 4.14: Exp. 2 - 90 min Production Output

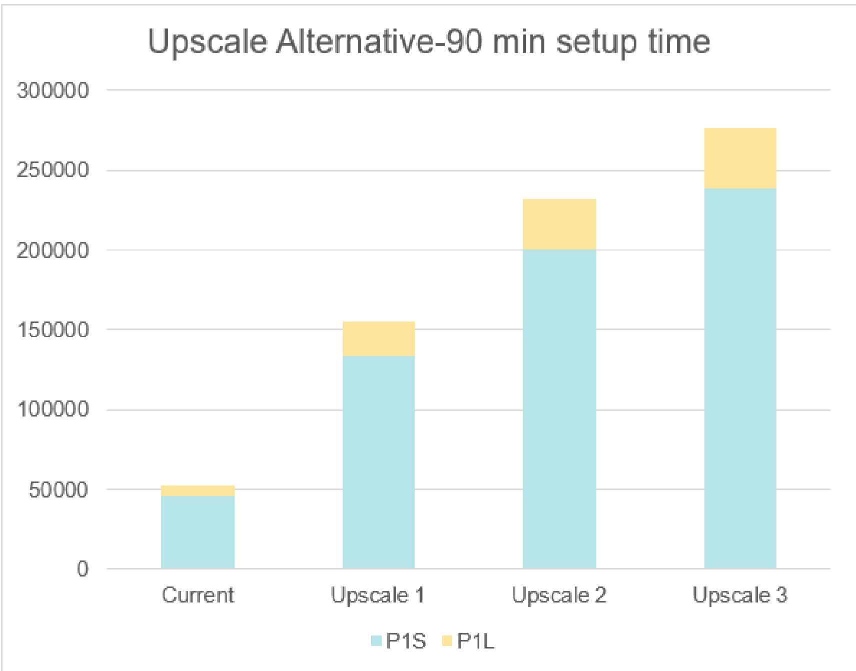

Figure 4.15: Exp. 2 - 90 min Chart

4.3.3 Experiment 3

The results gathered from experiment 3 were regarding performance in relation to buffers. For P1S the highest production output was received in *Experiment 5* with a buffer size on production bottleneck of 50 pieces. For P1S the highest production output was received in *Experiment 1* which also served as the internal minimum buffer size with both results on display in Figure 4.16 & -4.17.

Scenario:	Buffer sizes (P1S)	Buffer sizes (P1L)	Workers= Setup/Measuring/Assembly	Total worker	Shift	Investments	Produced P1S	Increase P1S %	Produced P1L	Increase P1L %
Current			-	22	-	-	46000	1	6000	1
Experiment 1	10	10	6= 6S/M/A	12	2	100	121792	2,65	24633	4,11
Experiment 2	20	20	6= 6S/M/A	12	2	100	124733	2,71	24626	4,10
Experiment 3	40	40	6= 6S/M/A	12	2	100	139095	3,02	24613	4,10
Experiment 4	50	50	6= 6S/M/A	12	2	100	141189	3,07	24637	4,11
Experiment 5	100	100	6= 6S/M/A	12	2	100	142856	3,11	24615	4,10

Figure 4.16: Exp. 3 - Production Output

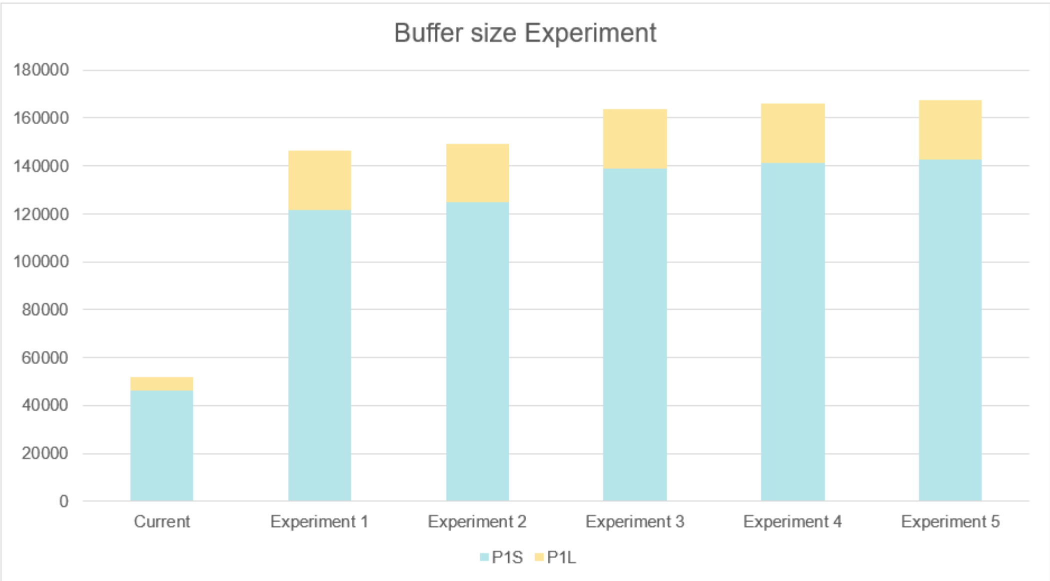

Figure 4.17: Exp. 3 - Chart

4.3.4 Experiment 4

The batch sizes were tested in order to visualise ideal batch size for the future production line. From Figure 4.18 & 4.19 the P1S can be seen to have an ideal batch size with a 50% increase. As for P1L the ideal batch size was similarly increasing the current batch size with 100%, however the differences here were marginal.

Scenario:	Buffer sizes (P1S)	Buffer sizes (P1L)	Batch size	Worker	Total Worker	Shift	Investments	Produced P1S	Increase P1S %	Produced P1L	Increase P1L %
Current	-	-	-	-	22	-	-	46000	1	6000	1
Experiment 1	50	10	0,8*current production plan	6= 6S/M/A	12	2	100	140736	3,06	24004	4,00
Experiment 3	50	10	1*current production plan	6= 6S/M/A	12	2	100	142856	3,11	24615	4,10
Experiment 4	50	10	1,1*current production plan	6= 6S/M/A	12	2	100	138191	3,00	24684	4,11
Experiment 5	50	10	1,5*current production plan	6= 6S/M/A	12	2	100	150258	3,27	25606	4,27
Experiment 6	50	10	2*current production plan	6= 6S/M/A	12	2	100	142808	3,10	25517	4,25
Experiment 8	50	10	2,5*current production plan	6= 6S/M/A	12	2	100	138589	3,01	25328	4,22
Experiment 9	50	10	3*current production plan	6= 6S/M/A	12	2	100	138169	3,00	25418	4,24

Figure 4.18: Exp. 4 - Production Output

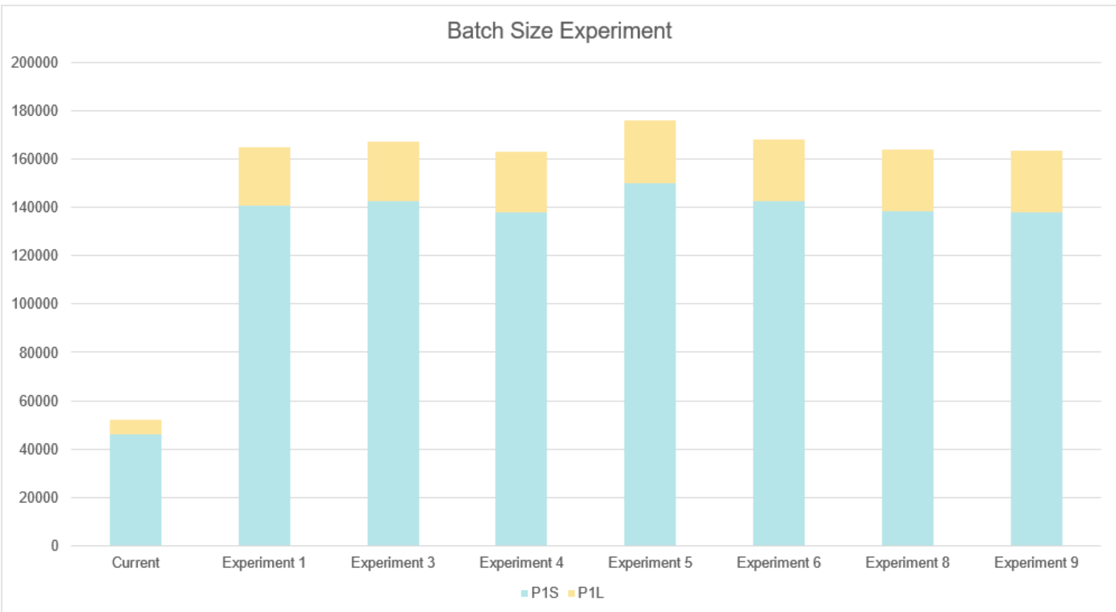

Figure 4.19: Exp. 4 - Chart

4.3.5 Experiment 5

From experiment 5 the bottlenecks of production were designed to be as early as possible within the production line. Serving as a clear indicator of throughput of the entire production system and also as a indicator of where future investments are to be made in order to increase productivity , see Fig 4.20. The total number of passed products can be seen in each respective drain being the same as the bottleneck, verifying that is the case. 4.22 4.21

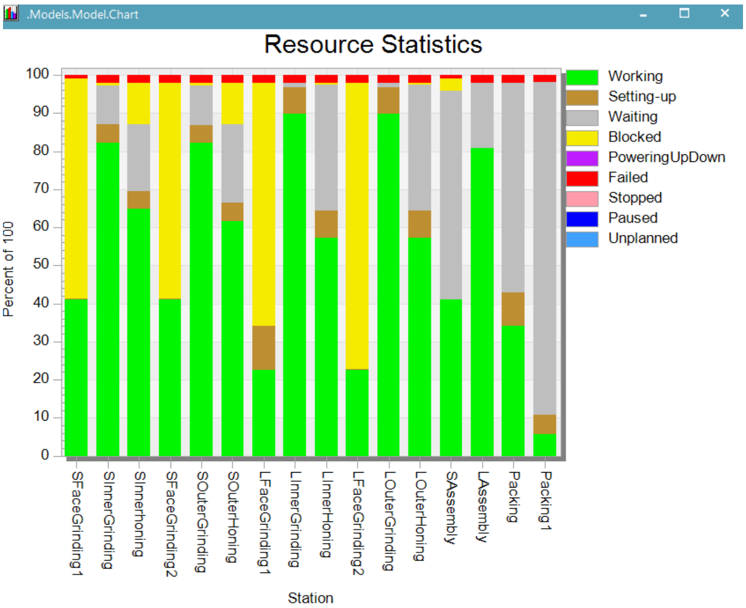

Figure 4.20: Exp. 5 - Process Chart

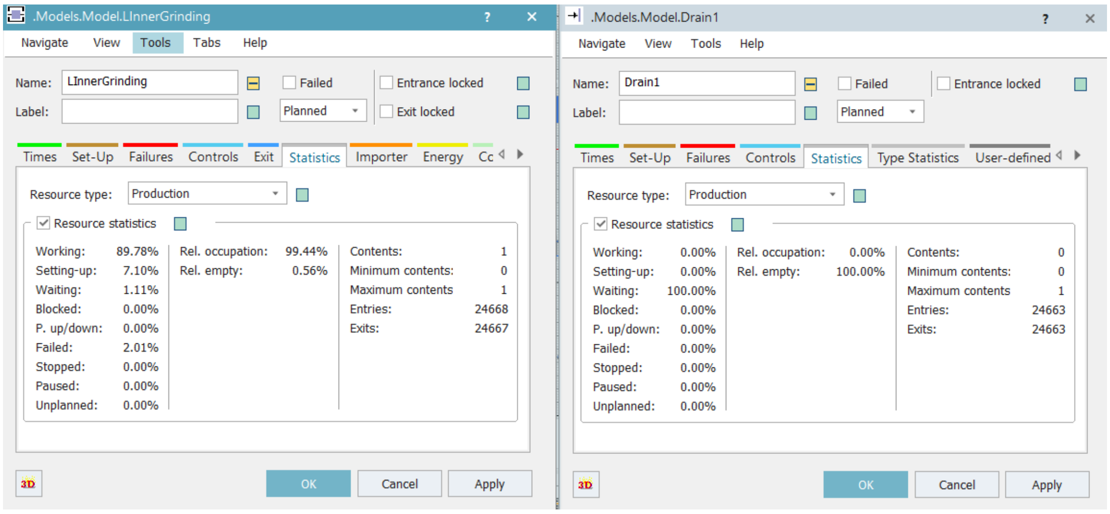

Figure 4.21: Exp. 5 - Large Range Output

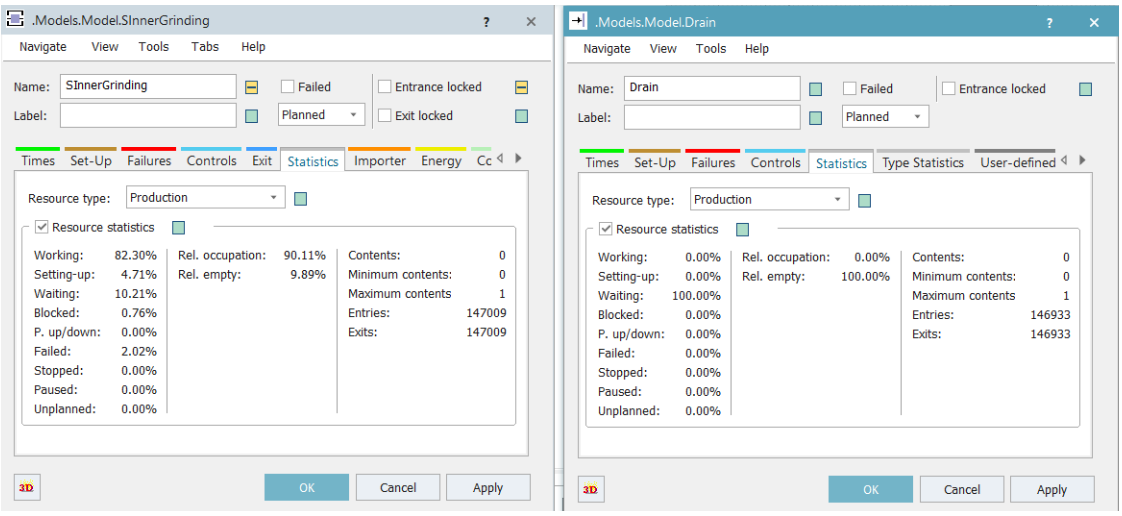

Figure 4.22: Exp. 5 - Small Range Output

4.3.6 Final state

Based off their internal investment calculations for machine types and their respective investment costs, the future manufacturing line total costs would be adding up to a total of 100[MSEK]. Using the starting concept given from PM and including all the findings from the experiments gave the following results presented in Figure 4.23 and 4.24. Results became notably increased, ranging from +52% to 447% for the smaller range and 245% to 531% for the larger range.
The most worthwhile increases -in terms of output and costs- will be chosen and those alternatives will be evaluated using the SKFs internal IRE system for calculating investments profitability.

1st upscale
The chosen first upscale of the future model was *Experiment 1* with 4 workers per shift joint in both production lines producing 50% & 100% bigger batches working 2 shifts. Increasing overall output by 52% & 245% respectively.

2nd upscale
Solely by increasing from 4 to 5 operators in step *Experiment 2* the output significantly increased and helped operators address the *blocked*-state that is prevalent in working with 4 workers. Output reaches 185% & 253% increase respectively in comparison to current manufacturing.

3rd upscale
Third suggested upscale would be *Experiment 7* which provided an increase in overall output of 311% & 428%. It used a higher shift degree so operator costs will increase 50%.

4th upscale
Lastly the 4th and final upscale would be *Experiment 13* with 6 total workers per shift and 4 shifts in total. Increasing the total output of the production lines with 439% & 530% of current state.

Scenario:	Buffer sizes (P1S/P1L)	Batch sizes	Workers= Setup/Measuring/ Assembly	Total worker	Shift	Investments	Produced P1S	Increase P1S %	Produced P1L	Increase P1L %
Current			-	22	-	-	46000	1	6000	1
Experiment 1	100/10	1,5* P1S (current) / 1,5*P1L(current)	4S/M/A	8	2 (3600 h)	100	86535	1,88	22900	3,82
Experiment 2	100/10	1,5* P1S (current) / 1,5*P1L(current)	5S/M/A	10	2 (3600 h)	100	135249	2,94	24274	4,05
Experiment 3	100/10	1,5* P1S (current) / 1,5*P1L(current)	6S/M/A	12	2 (3600 h)	100	142995	3,11	24562	4,09
Experiment 4	100/10	1,5* P1S (current) / 1,5*P1L(current)	7S/M/A	14	2 (3600 h)	100	143710	3,12	24608	4,10
Experiment 5	100/10	1,5* P1S (current) / 1,5*P1L(current)	8S/M/A	16	2 (3600 h)	100	144429	3,14	24574	4,10
Experiment 6	100/10	1,5* P1S (current) / 1,5*P1L(current)	4S/M/A	12	3 (5400 h)	100	128757	2,80	34412	5,74
Experiment 7	100/10	1,5* P1S (current) / 1,5*P1L(current)	5S/M/A	15	3 (5400 h)	100	202627	4,40	36498	6,08
Experiment 8	100/10	1,5* P1S (current) / 1,5*P1L(current)	6S/M/A	18	3 (5400 h)	100	212526	4,62	36808	6,13
Experiment 9	100/10	1,5* P1S (current) / 1,5*P1L(current)	7S/M/A	21	3 (5400 h)	100	213589	4,64	36875	6,15
Experiment 10	100/10	1,5* P1S (current) / 1,5*P1L(current)	8S/M/A	24	3 (5400 h)	100	214657	4,67	36927	6,15
Experiment 11	100/10	1,5* P1S (current) / 1,5*P1L(current)	4S/M/A	16	4 (6400 h)	100	151001	3,28	40183	6,70
Experiment 12	100/10	1,5* P1S (current) / 1,5*P1L(current)	5S/M/A	20	4 (6400 h)	100	241028	5,24	43276	7,21
Experiment 13	100/10	1,5* P1S (current) / 1,5*P1L(current)	6S/M/A	24	4 (6400 h)	100	249555	5,43	43678	7,28
Experiment 14	100/10	1,5* P1S (current) / 1,5*P1L(current)	7S/M/A	28	4 (6400 h)	100	250803	5,45	44371	7,40
Experiment 15	100/10	1,5* P1S (current) / 1,5*P1L(current)	8S/M/A	32	4 (6400 h)	100	252057	5,48	43702	7,28

Figure 4.23: Final State Upscale statistics

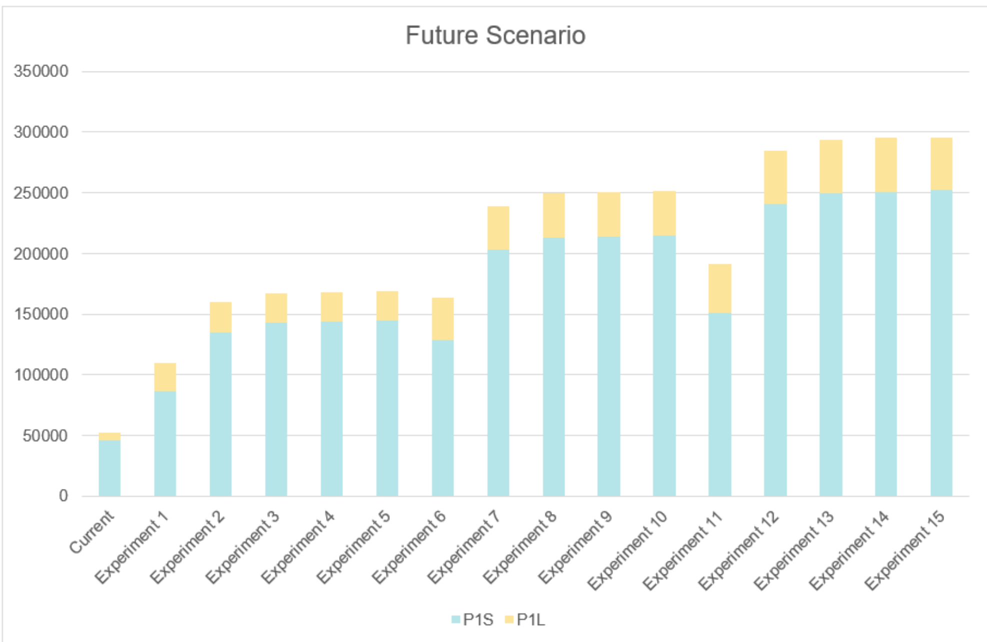

Figure 4.24: Final State Upscale Chart

4.4 Financial Analysis

Financial Results of the simulation scenarios limit scenarios will be presented below in relation to existing costs and future costs with the resulting yields and costs.Scenarios in between outer points are calculated but not presented working as a reference. The chapter presents numbers surrounding the manufacturing state -addressing production cost - and the investment itself with focus on NPV & IRR.

For the ideal production site of the future scenario the model was given by the PM in order to match the data provided by SKF. Production costs were calculated on *Experiment 1 & Experiment 13* -hereby being *Upscale 1 & -4*, seen page below in Figure 4.25 & 4.26. Resulting in a final result on a weighted average of 33 & 17 for *Upscale 1* & *Upscale 4* respectively compared to their previous weighted average of 67.

			Upscale 1	
	Volume increase	52%	245%	1,641304348
	Shift	2	2	2
	Manning	4	4	8
	Channel	U1P1S	U1P1L	Total
	Year	X	X	X
		YTD	YTD	YTD
Account description		Possible	Possible	Possible
Deliveries from production - SC				
Internal subcontracting sold				
Income from production at SC (TSEK)		50153,52704	149929,0158	200082,5428
Direct material - external consumption at SC		−13901,92	−43639,05	−57540,97
Components - SKF manufactured		−5962,96	−7410,6	−13373,56
External subcontracting purchased		0	0	0
Internal subcontracting charged		0		0
Direct material cost incl subcontracting at SC		**−19864,88**	**−51049,65**	**−70914,53**
Material share		−38%	−38%	−0,354426373
Variable wages		−2400	−2400	−4800
Cost for agency people		0	0	0
Shop supplies		−1000	−1000	−2000
Maintenance and repairs		−277	−400	−677
Other variable manuf. cost		−100	−100	−200
Inbound VA services from SLS (central cost)		−66	−66	−132
Invoiced inbound cost		0	0	0
Other Variable Income		0	0	0
Import duties on SKF material		0	0	0
Variable manufacturing costs		**−3843**	**−3966**	**−7809**
Fixed wages		−300	−300	−600
Salaries		−750	−750	−1500
Utilities		−750	−750	−1500
Rent		−53,5	−53,5	−107
Depreciation ATP - production		−3571,428571	−3571,428571	−7142,857143
Depreciation ROU - production		−7	−7	−14
Project costs		−86,5	−86,5	−173
Direct IT costs (central cost)		−317	−352	−669
Common system IT cost at SC (central cost)		−50	−51	−101
Other fixed manufacturing costs		−7783	−7783	−15566
Other income (fixed)		0	0	0
Fixed Manufacturing Cost		**−13668,42857**	**−13704,42857**	**−27372,85714**
Total Manufatuing cost at SC		**−17511,42857**	**−17670,42857**	**−35181,85714**
Inventories adjustment - production		1000	1000	2000
Other incomes / expenses - production		0	0	0
Other Inc/Ex Production		1000	1000	2000
Manufacturing Performance result (TSEK)		**34642,09847**	**134258,5872**	**168900,6857**
				0
MCL		73	45	52
Value added cost level		55	17	26
sold Kg		425600	637000	1062600
Pris per Kg		41	28	33
		1		1

Figure 4.25: Manufacturing cost calculations - Upscale 1

Account description		Upscale 4		
	Volume increase	439%	530%	5,508695652
	Shift	4	4	4
	Manning	12	12	24
	Channel	U4P1S	U4P1L	Total
	Year	X	X	X
		YTD	YTD	YTD
Account description		Possible	Possible	Possible
Deliveries from production - SC				
Internal subcontracting sold				
Income from production at SC (TSEK)		177847,0465	273783,4202	451630,4667
Direct material - external consumption at SC		−49296,94	−79688,7	−128985,64
Components - SKF manufactured		−21144,97	−13532,4	−34677,37
External subcontracting purchased		0	0	0
Internal subcontracting charged		0	0	0
Direct material cost incl subcontracting at SC		**−70441,91**	**−93221,1**	**−163663,01**
Material share		−38%	−38%	−0,362382572
Variable wages		−7200	−7200	−14400
Cost for agency people		0	0	0
Shop supplies		−1000	−1000	−2000
Maintenance and repairs		−277	−400	−677
Other variable manuf. cost		−100	−100	−200
Inbound VA services from SLS (central cost)		−66	−66	−132
Invoiced inbound cost		0	0	0
Other Variable Income		0	0	0
Import duties on SKF material		0	0	0
Variable manufacturing costs		**−8643**	**−8766**	**−17409**
Fixed wages		−300	−300	−600
Salaries		−750	−750	−1500
Utilities		−750	−750	−1500
Rent		−53,5	−53,5	−107
Depreciation ATP - production		−3571,428571	−3571,428571	−7142,857143
Depreciation ROU - production		−7	−7	−14
Project costs		−86,5	−86,5	−173
Direct IT costs (central cost)		−317	−352	−669
Common system IT cost at SC (central cost)		−50	−51	−101
Other fixed manufacturing costs		−7783	−7783	−15566
Other income (fixed)		0	0	0
Fixed Manufacturing Cost		**−13668,42857**	**−13704,42857**	**−27372,85714**
Total Manufaturing cost at SC		**−22311,42857**	**−22470,42857**	**−44781,85714**
Inventories adjustment - production		1000	1000	2000
Other incomes / expenses - production		0	0	0
Other Inc/Ex Production		1000	1000	2000
Manufacturing Performance result (TSEK)		**157535,618**	**253312,9916**	**410848,6096**
				0
MCL		52	42	46
Value added cost level		20	12	15
sold Kg		1229200	1378000	2607200
Pris per Kg		18	16	17
		1		1

Figure 4.26: Manufacturing cost calculations - Upscale 4

4.4.1 NPV & IRR

A potential investment of 100 000 [TSEK] in total, would yield costs, revenue and - provided in a yearly depreciation of 7 % - resulted in following for the smallest and largest suggested upscale scenarios:

	Upscale 1														
YEAR	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Revenue	-	200 082,54	200 082,54	200 082,54	200 082,54	200 082,54	200 082,54	200 082,54	200 082,54	200 082,54	200 082,54	200 082,54	200 082,54	200 082,54	200 082,54
Costs	-	−106 096,39	−106 096,39	−106 096,39	−106 096,39	−106 096,39	−106 096,39	−106 096,39	−106 096,39	−106 096,39	−106 096,39	−106 096,39	−106 096,39	−106 096,39	−106 096,39
Depreciation	-	7 142,86	7 857,14	8 585,71	9 328,86	10 086,86	10 860,03	11 648,66	12 453,06	13 273,55	14 110,45	14 964,09	15 834,80	16 722,92	17 628,81
CapEx	100 000	10 000,00	10 200,00	10 404,00	10 612,08	10 824,32	11 040,81	11 261,62	11 486,86	11 716,59	11 950,93	12 189,94	12 433,74	12 682,42	12 936,07
Free cash flow	−100 000,00	233 381,35	233 331,35	233 280,35	233 228,33	233 175,27	233 121,15	233 065,95	233 009,64	232 952,21	232 893,62	232 833,87	232 772,92	232 710,75	232 647,34
NPV	−100 000,00	192 877,15	192 835,83	192 793,68	192 750,69	192 706,84	192 662,11	192 616,49	192 569,95	192 522,48	192 474,07	192 424,68	192 374,31	192 322,93	192 270,53
NPV (Sum)	**2 696 201,75**														
IRR	**233,36%**														
IRR (NPV)	192,86%														
Corporate Tax :	0,21														

Figure 4.27: NPV & IRR calculations - Upscale 1

	Upscale 13														
YEAR	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Revenue	-	451 630,47	451 630,47	451 630,47	451 630,47	451 630,47	451 630,47	451 630,47	451 630,47	451 630,47	451 630,47	451 630,47	451 630,47	451 630,47	451 630,47
Costs	-	−208 444,87	−208 444,87	−208 444,87	−208 444,87	−208 444,87	−208 444,87	−208 444,87	−208 444,87	−208 444,87	−208 444,87	−208 444,87	−208 444,87	−208 444,87	−208 444,87
Depreciation	-	7 142,86	7 857,14	8 578,57	9 307,21	10 043,14	10 786,43	11 537,15	12 295,38	13 061,19	13 834,66	14 615,87	15 404,88	16 201,79	17 006,66
CapEx	100 000	10 000,00	10 100,00	10 201,00	10 303,01	10 406,04	10 510,10	10 615,20	10 721,35	10 828,57	10 936,85	11 046,22	11 156,68	11 268,25	11 380,93
Free cash flow	−100 000,00	512 959,51	513 009,51	513 060,01	513 111,02	513 162,53	513 214,56	513 267,11	513 320,19	513 373,80	513 427,94	513 482,62	513 537,86	513 593,64	513 649,98
NPV	−100 000,00	423 933,48	423 974,80	424 016,54	424 058,69	424 101,27	424 144,27	424 187,70	424 231,56	424 275,87	424 320,61	424 365,81	424 411,45	424 457,55	424 504,12
NPV (Sum)	**5 938 983,72**														
IRR	**512,97%**														
IRR (NPV)	423,94%														
Corporate Tax :	0,21														

Figure 4.28: NPV & IRR calculations - Upscale 4

Resulting in a NPV-result ranging between 2 500 000 and 6 900 000[TSEK] serving as an indicator of a good investment. IRR for the calculations are ranging between 183 % and 492 % for the smallest & largest upscale respectively.

5

Discussion

In the following section the respective results of the project are summarized and discussed.

5.1 Simulation

The aim of the thesis was to use DES to simulate and calculate the output of the future production line that was later used to conduct the financial analysis with respect to respective up-scaling cost. Thus, a number of experiments were designed and performed on future simulation model based on the utilization method and theory of constraints. The experiments were designed to identify and optimize the bottlenecks of production one by one in order to make it easier to compare the different cases. These bottlenecks were firstly identified during the data collection phase of the project but were later verified by experimenting in the simulation.

One important factor was the cycle-time of processes, which needs to be optimized in the future production state. The cycle-times for the future manufacturing model were firstly assumed based on the existing machines in their World-class production line and for the products were based on a mathematical model (size-dependent). As shown in results, the product output - in terms of numbers - of P1L is always much smaller than P1S which suggest that P1L has higher cycle-time than P1S considering that the other factors are not effecting the output for that specific case.

The current state was used to verify and validate the model and increase the trust in the value of future simulation models, as well as building a small model to see the logic behind the machine statistics. The model was validated by the PM and as seen in 4.3, the bottlenecks of the current state production line was clearly the grinding machine which has the highest cycle-time in the real world operations system.

As mentioned in 1.1 Introduction, P1 is being produced in two separate manufacturing sites. As for the future state it was designed to be simulated in both separate production lines with separate worker pools and combined manufacturing site which uses a joint worker pool.

- Experiment 1
  In the real time production SKF uses workers with different competence levels with the intent of having a mix of both experienced and intermediate/beginner workers in the production. For instance the experienced workers are able to perform all types of jobs such as repair, measuring of the products, setup of the machines and assembly while the inexperienced workers can only perform the assembly or measuring. Another factor that is very important to have in mind is that it takes time to learn the machines and all the tasks, i.e. there is a high cost of training of intermediate/beginner workers. Thus, in the models, a number of experiments were performed to find the right role distribution within the workers. The experiment scenario 6 in figure **??**, clearly shows that if, all the operators can perform all the tasks, the production output is the best with 165822 products produced in total. However, as mentioned it is a hard and time consuming task to recruit or train all the workers with the new machines. Thus, the best choice would be a combination of experienced and inexperienced workers, i.e. experiment scenario 2.

  Optimal worker pool scenario & number of operators experiment were performed with the purpose to show that smaller numbers of operators can be used to produce the same number of products if used in a combined manufacturing site and a joint worker pool. Comparing experiment scenario 3 in respective figure 4.8 & 4.10, it is clear that the combined manufacturing is better alternative, since the joint worker pool can run the production with half number of total operators but have approximately the same output.

- Experiment 2

  The current states bottleneck has a setup time of 90 minutes which is very slow in comparison to the new machines used in SKFs other production lines. Thus *Experiment 2* was performed to show that by decreasing the setup time there is a considerable impact on the production output, which can be seen in figure 4.12 & 4.14, comparing the respective scenarios. The production output will always be greater while the setup time is 30 minutes as cycle time remains unaffected. This experiment was mostly done in order to visualize improvement, as there was no counterpart with regards to cycle time being increased/decreased in relation to setup time.

- Experiment 3

  The buffer size is an important factor to analyse while developing a new production line, considering that a too small buffer can block the bottleneck machines and a too big buffer size can be relatively expensive and difficult task to handle in a running production. As can be seen in figure 4.16, the buffer size for P1L does not have any great impact on the production output after reaching 10 pieces - ensuring it does not block the grinding machines which are the bottlenecks of the production flow. As for the P1S production line, the best production output is while using a buffer size 100, but following reconciliation with PM, 100 was considered too large a number in production considering logistics and material handling. As a rule of thumb in SKF, buffer sizes correspond to around one hour of production for the machine. Considering the material handling and the discussion with the PM, the buffer size for P1S and P1L should be approximately 40 & 10 respectively.

- Experiment 4
  The batch size is important and has a huge impact on the cost of the products, considering the high cost for setup of the machines being divided on the number of products produced. For instance, if the cost of setup is 1000 SEK, and the batch size in P1L is 1, the total cost of setup will be divided on 1 product i.e. the total cost of the product will be an additional 1000 SEK to the total prize. By increasing the batch size to a 100, the total cost of 1 product will be an additional 10 SEK to total prize. The batch size is currently based on customer orders and the production plan includes batch sizes as small as 1. Thus, this factor must to be taken into consideration while planning the production plan. *Experiment 4* was designed with the aim of identifying the ideal batch sizes for the production. As it can be seen in figure 4.18, the ideal production plan for P1S is a factor of 1.5*current batch size and the same goes for P1L. These batch sizes are generally larger than the typically occurring batch sizes in the production of SKF and might not be accepted in order to prevent high inventory costs and big internal buffers. One should establish a "smallest allowed" batch size, potentially responding to buffer sizes within production volumes. Currently SKF are manufacturing very specific low volumer orders in their production, that type of order planning is detrimental for maintaining a high productivity. This would prevent risk for disruptions to be increased drastically as setting up and receiving errors with small batches would stop the entire production flow.

- Experiment 5

  The current state production of MS1 has an evident bottleneck in the grinding machines, seen in figure 4.20. The bottleneck hinders further throughput, however it is useful in terms of serving as a clear cut improvement point for where future investments are to be made in order to increase production further, exceeding more operators and different shift types.

- Final State- Alternative
  The final state suggested is the optimal one in terms of output based on experiments, however some of the areas such as buffers, batch sizes, and worker setup are not ideal based on SKFs current business model and production ideas. Thus an alternative model was created based on 40/10 buffer sizes for P1S/P1L and current batch size the same as the current one. It proved to provide near similar or slightly less production output overall, however it produced more parts for P1L and but significantly fewer for P1S.

Scenario:	Buffer sizes (P1S/P1L)	Batch sizes	Workers= Setup/Measuring/Assembly	Total worker	Shift	Investments	Produced P1S	Increase P1S %	Produced P1L	Increase P1L %
Current			-	22	-	-	46000	1	6000	1
Experiment scenario 1	40/10	P1S (current) / P1L(current)	4S/M/A	8	2 (3600 h)	100	64665	1,41	22395	3,73
Experiment scenario 2	40/10	P1S (current) / P1L(current)	5=3S/M/A+2A	10	2 (3600 h)	100	101318	2,20	21850	3,64
Experiment scenario 3	40/10	P1S (current) / P1L(current)	5=3S/M/A+2A	15	3 (5400 h)	100	141340	3,07	32558	5,43
Experiment scenario 4	40/10	P1S (current) / P1L(current)	6=4 S/M/A+2A	24	4 (6400 h)	100	220193	4,79	41232	6,87
Experiment scenario 5	40/10	P1S (current) / P1L(current)	6=4 S/M/A+2A	12	2	100	132478	2,8799565	23269	3,8781667
Experiment scenario 6	40/10	0,5* P1S (current) / 0,5* P1L(current)	6=4 S/M/A+2A	12	2	100	101932	2,215913	20481	3,4135

Figure 5.1: Final State Production Statistics

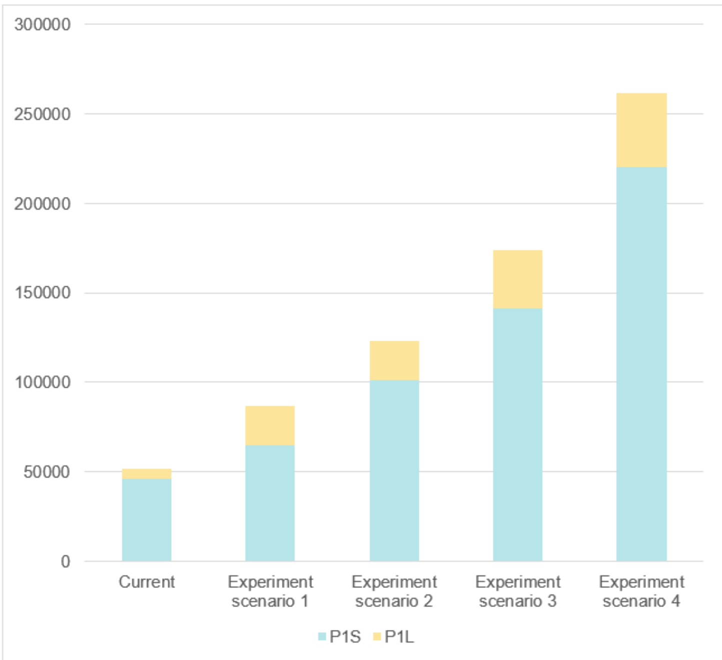

Figure 5.2: Final State Upscale Chart

5.2 Financials

What needs to be kept in mind when discussing the different methods of analysis chosen from an economic perspective for said investment, is that neither method is a guarantee for profit. Other aspects play in part of the final decision-making, in terms of SKF specifically the business does not change all too rapidly compared to other industries where a 14 year horizon of an investment can make or break a company, making it more of a suitable business proposition. However it is increasingly important to include risk as an element in terms of potential investments. Thus NPVr-method (or other risk adjusted investment calculation-methods) should be implemented as an alternative for SKF in terms of their investment calculations as it could potentially produce other conclusions of where to invest.

5.2.1 Production planning of MS2

Currently MS2 is producing P1(P1S) only 1/3 of its total operating hours. Removing the P1S production from MF2 leaves it with possibility to increase its current manufacturing numbers of P2 with 50% - and possibly more depending on internal directives regarding batch sizes, lead times and inventory levels. As P2 currently is the most profit-yielding product of theirs it would create a potentially substantial upside to creating a standalone system for P1.

5.2.2 Role Distribution

In 4.3.1 - Experiment 1 -the suggested distribution of roles suggested in a manufacturing scenario is suggested to be all tasks spread equally on all operators, such a scenario requires more knowledge - and consequently higher operating costs. The decision of doing so came from when increasing the total number operators on the production line the distribution would be hard to distinguish as the relation of 7 workers is different than the one of 6. It will most likely not be the final scenario for a real time application as the scenario with 4 flexible and 2 assigned assemblers produced at nearly the same pace and is less costly. Which is also why that alternative is included in the final suggested scenario to visualize differences between the two options.

5.2.3 Batch Sizes & Inventory levels

As described in Experiment 3 in 4.3.4 the batch sizes were increased considerably 50% and 100% respectively. This might seem a steep increase and specifically in relation to the P1L, worth noting is that the current production schedule is based on their cycle- & setup times of their current manufacturing state and thus it produces less of each product in order to satisfy customer needs to a higher extent. It might seem contradictory as the currently long cycle- & setup times in MS1 would imply bigger batches, but is in fact currently not the case. Worth noting is that the outcome of the batch size experiment is based on the production schedule using current machinery, which might become of relevance later years.

The reasoning regarding increased batch sizes is solely decided upon from a manufacturing perspective and does not take into accord that inventory levels and warehousing costs would be increased significantly. However it would serve a useful tool for addressing the lead time to customer from ordering point.

5.2.4 Upscale

The initiative of scaling up the production several 100 % will almost always need some sort of investment. This because current cycle- & setup times of existing machinery limit the total output. Thus, new machines are needed and will more often than not come at a hefty investment cost. Even when limiting operative costs to the smallest amount the investment remains sizeable in terms of the current demand and potential revenue. Thus the project from a perspective of risk exposure could be designed for the future production line to be able to handle producing either P2 or P3 besides planned production of P1. This because having a newly installed production line is extremely costly and more or less needs maximum up time. Running on a 2-shift schedule - which is suggested in the first stages of upscale for the final model in this thesis work -would render it with an extensive unmanned time -which is expensive and unfortunate.

The current NPVs and IRRs suggested provide extremely lucrative business opportunities, worth noting however is that they are solemnly based on the prenotion of demand increasing correspondingly, which is a dangerous assumption. If demand was not to increase the opportunities would rather become liabilities for the factory given said investment. They are also based on current prizing strategy which most likely will be removed/reworked as it serves no purpose when manufacturing costs are significantly lowered. This because it currently is an internal way of addressing their currently high production costs of P1. When both of these decisions are taken out of the picture the financial state surrounding the project might look entirely different than as of now.

What can be said tho is that it is evident the production costs will be reduced a tremendous amount as seen in Figure 4.25 & 4.26. A decrease of production costs would eventually allow SKF to internally treat P1 the same as P2 and thus create a sustainable production and pricing environment over long term.

5.3 Third party Relations

Ignoring the outright manufacturing capacity & sales numbers, the project needs a credible foundation covering the entire production chain of the P1 article - this in order to make sure the entire project of up scaling is credible towards suppliers/customers. Previous to this thesis of increasing production of P1 there have been several attempts at lowering selling prices, lowering expenses to suppliers, or selling for a loss- in order to receive more customers. Since the attempts have not been continuous and numbers were not increasing during the shorter time frames the credibility from existing suppliers and customers towards the P1 projects has diminished.
Therefore, before launching this new concept of upscale surrounding P1 it is of utmost importance that the entire proposition is thought through from end-to-end in order to address the many perspectives that could potentially arise from the different stakeholders.

5.4 The role as a consultant

Taking on the role as an external project consultant in a new setting requires fundamental consideration what the role requires. In this setting it would be an external consultant with the mission to advising the client in relation to ongoing P1 project and improve the organizational output. In order to be efficient in the role it is important to accept their pre-existing data and conceptions of existing state. Considering the state of the manufacturing site an opportunity to make a change and assess the problems over time in correct manner. [17]

5.5 Error sources

Current state
The model itself was hard to grasp as cycle- & setup times were merged per product through the entire value adding chain, thus preventing detailed analysis in early phases. Respective times were later separated by percentages of the processing times of machines. This could potentially be an error of validating the current model. However the validation process of the current model was based on reaching an acceptably close scenario and thus a generous error margin was accepted for the current model.

Final Model
Results on smaller range does not increase as much as larger range in early stages with fewer operators, as a consequence of their batch size being increased further and their cycle times are longer and thus do not need as many resets as the smaller range production line and thus it comes more suffering due to lack of operators. As the number of operators increase the availability of personnel for resetting the smaller range production line increases and subsequently its total output.

5.6 Future work

The project intends to provide a starting ground for continuously growing the manufacturing & demand surrounding P1. For such a scenario the *next step* needs continuous addressing beforehand so a concept is planned before reaching such a level of demand that the matter is urgent. For the forseeable future this proposed solution will provide opportunities for upscaling of the production, however with every increase of either operators/shift degree the returns are diminishing. Eventually reaching a breaking point where either creating an automated assembly of P1 or extending the capacity of their bottlenecks with further investments. Specifically the assembly might be worthwhile looking into as it was shown to be the labour-intensive bottleneck within production from the results presented in 4.3.1s *Experiment 1* as all operators always needed extra allocation to assembly. Regardless of scenario such cases are bound to require additional investments, which would require results in terms of increased sales number over long term.

5.7 Miscellaneous

In several of the statistics figures in the result section the current workers are said to be 22. This is the total amount of workers within the MS1+MS2 and is an entirely correct number, the reason for why it was included is that it is the total number of operators within the MS1 & within MS2 the number of operators dedicated to manufacturing P1. It was kept in order to visualise operator numbers within the current manufacturing of MS1+MS2 as a reference for future concepts.

6
Conclusion

The aim of the project was to address a common issue within the manufacturing domain of the P1-production of rings. The goal was to create a new manufacturing site that increases throughput rates & limits costs and optimize the production factors which increased the cost of the products. DES was used to design the new manufacturing model, perform experiments with the goal of optimizing the different parameters and suggest a number of different production scenarios. The statistics for suggested scenarios based on the projects results are visualized in Figure 4.23 and 4.24 and the statistics for desired scenarios from the PM are visualized in figure 5.1. In order to have some framework for the thesis, the following research questions were designed and answered based on the produced results.

- *What are the factors that affect the production cost of manufacturing of P1?*

  In terms of the manufacturing domain the current manufacturing suffers heavily from high discrepancies in cycle-, & setup times on the respective machines and needs redesigning for future manufacturing in order to balance the production line. What could also be seen on the current manufacturing was that batch sizes were too small in comparison the setup times and thus invoked heavily on the overall output. For future manufacturing it is of utmost importance that a system is designed to produce orders aligning with their existing factory. Lower setup times on processes requires less internal buffer and enables smaller batches in production line, allowing for frequency adjustment to customer orders. Their currently long setup times on processes require larger internal buffers and does not handle small specific orders particularly well. In order to produce smaller batches the setup times needs to be aligning with your intents of production scheduling.

- *How to optimize these factors with the purpose of decreasing the total cost of P1?*

  A number of experiments were designed based on the theory of constraints for each factor to optimize each one the factors and combine the results in one final scenario which is presented in 4.23 & 4.24 respectively. The number of operators & their respective role distribution within them played an important part, although the best scenario would be to use the entire workforce for all the different tasks it would require intense training done on employees, which would not be justifiable financially. The setup times were varied and played a big part -as would the cycle times if the possible investment options of machines had a variance within them. The buffer sizes should be kept as low as possible for all the stations except the bottlenecks which are the grinding machines, after discussion with the PM the rule of thumb of having around one hour of buffer for this station. The batch sizes should be as big as the bottleneck buffer size, i.e. 40 rings for P1S and 10 for P1L.

- *How should future upscaling stages be evaluated?*

  This project of up scaling the production of P1 to new levels will ultimately require some sort of investment no matter how the problem is formulated. If an investment is to be made there needs to be a thorough analysis created in terms of expected returns, and required costs for said returns. This in order to guarantee all stakeholders share a mutual goal for the final state of the project, in order to be able to validate the model continuously. Some elements of risk assessment needs adding towards the investment as far as calculating expected revenue over long term and consequently risk exposure to ultimately yield a result in terms of long term revenue and payoff horizon. This in order to correctly address the financial background of up scaling as it is not certain said investment will work. However, the potential upside of the investment seems incredibly lucrative given market demand increase, thus it might become worthwhile nevertheless.

- *What further measures can be taken for the total manufacturing surrounding P1 in conjunction with reducing the production costs?*

  As far as the production output of the expected production lines, it will substantially increase the current output figures given an investment, however it is not certain that the demand of P1 will be increased in terms of market development. Thus the future production lines should be able to handle production of other parts as well during the upscale, namely P2 & P3. By allowing the manufacturing of P2 & P3 to cover the financial risk of scaling up it could suffice as an investment with less risk than originally thought. Same goes for the upscale being done in sequences rather than the entirety at once, in order to limit the investments before any sort of revenue yield is seen, hence preventing higher degrees of risk exposure.

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A

Appendix 1

Question Template

Do we have your consent to record this interview?

1. What is your role and your main responsibilities?
2. How does your **“main responsibilities(eg. supply chain, controlling, sales)”** connect to P1?
3. What would you describe being the most important factors for making P1 successful?
4. From your perspective and coming from your discipline, what are the most important factors for you?
5. How would you deem P1 in terms of the current manufacturing regime in relation to comparable products? -What part of the production do you think needs to be changed?
6. How important is the process controlling for P1(current/future perspective), also in relation to other comparable products currently sold by SKF?
7. How important is the supply chain for P1(current/future perspective), also in relation to other comparable products currently sold by SKF?
8. How important is the sales for P1 (current/future perspective), also in relation to other comparable products currently sold by SKF?
9. How important is the [INSERT DIVISION] for P1 (current/future perspective), also in relation to other comparable products currently sold by SKF?
10. How do you think we can reduce the cost of production in P1?
11. Digitalization and automation of machinery is going to play a big role in the production of products in a fast-paced environment, considering the customer demand, do you think it is beneficial to produce a large number of P1?
12. What are key aspects for a potential investment of new machinery that are highly interesting to you?
13. What percentages do you think future manufacturing needs to exceed in terms of volume produced or demand in order to become profitable with regards to downtime, quality, conversion and uptime?
14. Which requirements does the production planning of a product fulfill to have as low of a downtime as possible? in terms, maintenance (corrective/preventive) of machines, logistics of materials in and out., failures,
15. What are your views on a potential full or part automization for P1? Follow up regarding IoT digital twins etc. in manufacturing.
16. What are your views on the interface of future and current? Do you see potential benefits to having a shared one?
17. How are you looking at the personnel of P1 in the future, could they be merged in production? Could white collar achieve any sort of synergies making that part cheaper/less time consuming?
18. Are there any other clear upsides to the project that you see you’d like to share?

Figure A.1: Appendix 1 -Question Template for internal interviews

The cost value added that SKF use as a factor to calcualate standard cost of a production is being affected by a number of factors that needs to be adressed and analyzed. In order to be able to reduce the VA cost, it is necessary to rank the imporance of each factor.	Impact ratio will be graded from a scale of 1-5 -with 5 being the worst and 1 the best case scenario - and eventually reevaluated after simulations of systems have been done to concur whether assessment was correct or not					
Cost factors	**Impact ratio**	**Changeable**	**Possible to simulate**	Financial Analysi	**How?**	**Difference to previous perception of SKF**
Changeovers	5	Yes	Yes	no	Produce bigger batches, a better planning of the orders and stock for the quarter	The cost of the production will be divided on bigger batches which will decrease the VA-cost
Product Range	2	No	Yes	no	Could potentially be changed but have to be aligned with existing SRB-catalogue	Decreased number of changeovers that can lead to bigger batches in the production
Product Quality	2	Yes	No	no	Can be lowered to fit specific application	Decreased quality compared to the quality of todays products for a certain product families
Buffer size	4	Yes	Yes	no		
Operators	4	Yes	Yes	yes		
Warehousing	4	Yes	No	no	Better planning and separation of MTS/MTO's in a clear cut way	Higher stocks in product families that are sold very little during the year
Automation degree	3	Yes	No	no	Investments needed for new machines,	Automation of manual tasks such as measuring of the rings that can decrease the cycletime
Materials Handling	2	Yes	No	no	Better planning terms of manufacturing line but also warehousing, restructure inhouse/outsourcing	
Lead time	2	Yes	No	no	Enable higher degree of warehousing, new machines, stock at 3rd party suppliers.	Lower leadtime to the customers compared to today
Cycle times	3	Yes	Yes	no	With new machines and lower cycle times, investment needed	Faster production of products taht leads to higher production capacity
Shift-type	4	Yes	Yes	yes	Renegotiate with the union	Changed working-shift which is standard in other industries such as vehicle-production thatt can result in decreasing the production cost
White Colour workers	1	Yes	No	yes	Can be rearranged to new grouping and with synergies of different products working with similiar interfaces.	Decreasing the number white colour staff in positions such as supply chain, production manager, etc.
Product variants	3	No	No	no	Cluster product features in order to reduce deviations, uncertain whether doable	Include several features within one product if possible.
Changeover frequency	4	Yes	Yes	no		
Changeovers time	4	Yes	Yes	no	Better knowledge in their recently changed program (SAP) and bigger batches	Decrease the total number of changeover which leads to lower VA-Cost
Volumes	4	Yes	Yes	no	Increase sales	Leads to bigger volumes in the production and implementing of economy of scale which decreases the total VA-cost
Service/Maintenance	3	Yes	yes	no		
OEE	4	Yes	yes	no		
Scrap	2	Yes	Yes	no		

Figure A.2: Internal Working Methodology Sheet

B
Appendix 2

Name	LFaceGrinding2	LFaceGrinding1	LOuterGrinding	LInnerGrinding	LOuterHoning	LInnerHoning	Automeasuring1	LAssembly
C2228	1:00.2000	1:00.2000	4:00.8000	4:00.8000	2:33.8000	2:33.8000	1:01.5000	3:36.7448
C2230	1:11.1000	1:11.1000	4:44.4000	4:44.4000	3:01.7000	3:01.7000	1:12.7000	4:15.9724
C2234	1:32.9000	1:32.9000	6:11.6000	6:11.6000	3:57.4000	3:57.4000	1:34.9000	5:34.4276
C2238	1:49.2000	1:49.2000	7:17.0000	7:17.0000	4:39.1000	4:39.1000	1:51.7000	6:33.2690
C2244	2:21.9000	2:21.9000	9:27.7000	9:27.7000	6:02.7000	6:02.7000	2:25.1000	8:30.9517
C2326	2:21.9000	2:21.9000	9:27.7000	9:27.7000	6:02.7000	6:02.7000	2:25.1000	8:30.9517
C3034	1:16.6000	1:16.6000	5:06.2000	5:06.2000	3:15.6000	3:15.6000	1:18.2000	4:35.5862
C3036	1:16.0000	1:16.0000	5:06.2000	5:06.2000	3:15.6000	3:15.6000	1:18.2000	4:35.5862
C3038	1:22.0000	1:22.0000	5:28.0000	5:28.0000	3:29.5000	3:29.5000	1:23.8000	4:55.2000
C3040	1:32.9000	1:32.9000	6:11.6000	6:11.6000	3:57.4000	3:57.4000	1:34.9000	5:34.4276
C3044	1:49.2000	1:49.2000	7:17.0000	7:17.0000	4:39.1000	4:39.1000	1:51.7000	6:33.2690
C3048	2:00.1000	2:00.1000	8:00.6000	8:00.6000	5:07.0000	5:07.0000	2:02.8000	7:12.4966
C3052	2:21.9000	2:21.9000	9:27.7000	9:27.7000	6:02.7000	6:02.7000	2:25.1000	8:30.9517
C3056	2:32.8000	2:32.8000	10:11.3000	10:11.3000	6:30.5000	6:30.5000	2:36.2000	9:10.1793
C3060	2:32.8000	2:32.8000	10:11.3000	10:11.3000	6:30.5000	6:30.5000	2:36.2000	9:10.1793
C3064	2:54.6000	2:54.6000	11:38.5000	11:38.5000	7:26.2000	7:26.2000	2:58.5000	10:28.6345
C3068	3:05.5000	3:05.5000	12:22.1000	12:22.1000	7:54.0000	7:54.0000	3:09.6000	11:07.8621
C3072	3:27.3000	3:27.3000	13:49.2000	13:49.2000	8:49.7000	8:49.7000	3:31.9000	12:26.3172
C3076	3:38.2000	3:38.2000	14:32.8000	14:32.8000	9:17.6000	9:17.6000	3:43.0000	13:05.5448
C3080	3:49.1000	3:49.1000	15:16.4000	15:16.4000	9:45.4000	9:45.4000	3:54.2000	13:44.7724
C3130	1:00.2000	1:00.2000	4:00.8000	4:00.8000	2:33.8000	2:33.8000	1:01.5000	3:36.7448
C3132	1:11.1000	1:11.1000	4:44.4000	4:44.4000	3:01.7000	3:01.7000	1:12.7000	4:15.9724
C3136	1:27.4000	1:27.4000	5:49.8000	5:49.8000	3:43.4000	3:43.4000	1:29.4000	5:14.8138
C3138	1:27.4000	1:27.4000	5:49.8000	5:49.8000	3:43.4000	3:43.4000	1:29.4000	5:14.8138
C3140	1:49.2000	1:49.2000	7:17.0000	7:17.0000	4:39.1000	4:39.1000	1:51.7000	6:33.2690
C3144	2:05.6000	2:05.6000	8:22.3000	8:22.3000	5:20.9000	5:20.9000	2:08.4000	7:32.1103
C3148	2:21.9000	2:21.9000	9:27.7000	9:27.7000	6:02.7000	6:02.7000	2:25.1000	8:30.9517
C3152	2:43.7000	2:43.7000	10:54.9000	10:54.9000	6:58.3000	6:58.3000	2:47.3000	9:49.4069
C3156	2:54.6000	2:54.6000	11:38.5000	11:38.5000	7:26.2000	7:26.2000	2:58.5000	10:28.6345
C3160	3:16.4000	3:16.4000	13:05.7000	13:05.7000	8:21.9000	8:21.9000	3:20.7000	11:47.0897
C3164	3:16.4000	3:16.4000	13:05.7000	13:05.7000	8:21.9000	8:21.9000	3:20.7000	11:47.0897
C3168	3:38.2000	3:38.2000	14:32.8000	14:32.8000	9:17.6000	9:17.6000	3:43.0000	13:05.5448
C3172	4:00.0000	4:00.0000	16:00.0000	16:00.0000	10:13.2000	10:13.2000	4:05.3000	14:24.0000
C3232	1:22.0000	1:22.0000	5:28.0000	5:28.0000	3:29.5000	3:29.5000	1:23.8000	4:55.2000
C3236	1:38.3000	1:38.3000	6:33.4000	6:33.4000	4:11.3000	4:11.3000	1:40.5000	5:54.0414
C3972	1:38.3000	1:38.3000	6:33.4000	6:33.4000	4:11.3000	4:11.3000	1:40.5000	5:54.0414
C3984	3:38.2000	3:38.2000	14:32.8000	14:32.8000	9:17.6000	9:17.6000	3:43.0000	13:05.5448
C4034	3:49.1000	3:49.1000	15:16.4000	15:16.4000	9:45.4000	9:45.4000	3:54.2000	13:44.7724
C4036	1:05.7000	1:05.7000	4:22.6000	4:22.6000	2:47.8000	2:47.8000	1:07.1000	3:56.3586
C4040	1:16.6000	1:16.6000	5:06.2000	5:06.2000	3:15.6000	3:15.6000	1:18.2000	4:35.5862
C4060	1:49.2000	1:49.2000	7:17.0000	7:17.0000	4:39.1000	4:39.1000	1:51.7000	6:33.2690
C4130	2:54.6000	2:54.6000	11:38.5000	11:38.5000	7:26.2000	7:26.2000	2:58.5000	10:28.6345

Figure B.1: The cycle-time for the P1L

Name	SInnerGrinding	SOuterGrinding	SFaceGrinding1	SFaceGrinding2	SOuterHoning	Sinnerhoning	SAutomeasuring	SAssembly
C4032	1:30.0000	1:30.0000	45.0000	45.0000	1:07.5000	1:07.5000	45.0000	45.0000
C4030	1:20.0000	1:20.0000	40.0000	40.0000	1:00.0000	1:00.0000	40.0000	40.0000
C4028	1:23.0000	1:23.0000	41.5000	41.5000	1:02.2500	1:02.2500	41.5000	41.5000
C4026	1:11.0000	1:11.0000	35.5000	35.5000	53.2500	53.2500	35.5000	35.5000
C4024	1:11.0000	1:11.0000	35.5000	35.5000	53.2500	53.2500	35.5000	35.5000
C4022	1:13.0000	1:13.0000	36.5000	36.5000	54.7500	54.7500	36.5000	36.5000
C4020	1:03.0000	1:03.0000	31.5000	31.5000	47.2500	47.2500	31.5000	31.5000
C2215	57.0000	57.0000	28.5000	28.5000	42.7500	42.7500	28.5000	28.5000
C2216	58.0000	58.0000	29.0000	29.0000	43.5000	43.5000	29.0000	29.0000
C2217	1:00.0000	1:00.0000	30.0000	30.0000	45.0000	45.0000	30.0000	30.0000
C2218	1:04.0000	1:04.0000	32.0000	32.0000	48.0000	48.0000	32.0000	32.0000
C2220	1:05.0000	1:05.0000	32.5000	32.5000	48.7500	48.7500	32.5000	32.5000
C2222	1:12.0000	1:12.0000	36.0000	36.0000	54.0000	54.0000	36.0000	36.0000
C2226	1:31.0000	1:31.0000	45.5000	45.5000	1:08.2500	1:08.2500	45.5000	45.5000
C2314	59.0000	59.0000	29.5000	29.5000	44.2500	44.2500	29.5000	29.5000
C2315	1:02.0000	1:02.0000	31.0000	31.0000	46.5000	46.5000	31.0000	31.0000
C2316	1:09.0000	1:09.0000	34.5000	34.5000	51.7500	51.7500	34.5000	34.5000
C2317	1:09.0000	1:09.0000	34.5000	34.5000	51.7500	51.7500	34.5000	34.5000
C2318	1:15.0000	1:15.0000	37.5000	37.5000	56.2500	56.2500	37.5000	37.5000
C2319	1:21.0000	1:21.0000	40.5000	40.5000	1:00.7500	1:00.7500	40.5000	40.5000
C2320	1:21.0000	1:21.0000	40.5000	40.5000	1:00.7500	1:00.7500	40.5000	40.5000
C3024	1:15.0000	1:15.0000	37.5000	37.5000	56.2500	56.2500	37.5000	37.5000
C3030	1:26.0000	1:26.0000	43.0000	43.0000	1:04.5000	1:04.5000	43.0000	43.0000
C3224	1:28.0000	1:28.0000	44.0000	44.0000	1:06.0000	1:06.0000	44.0000	44.0000
C3120	1:07.0000	1:07.0000	33.5000	33.5000	50.2500	50.2500	33.5000	33.5000
C4120	1:14.0000	1:14.0000	37.0000	37.0000	55.5000	55.5000	37.0000	37.0000
C4122	1:18.0000	1:18.0000	39.0000	39.0000	58.5000	58.5000	39.0000	39.0000
C4128	1:44.0000	1:44.0000	52.0000	52.0000	1:18.0000	1:18.0000	52.0000	52.0000

Figure B.2: The cycle-time for the P1S

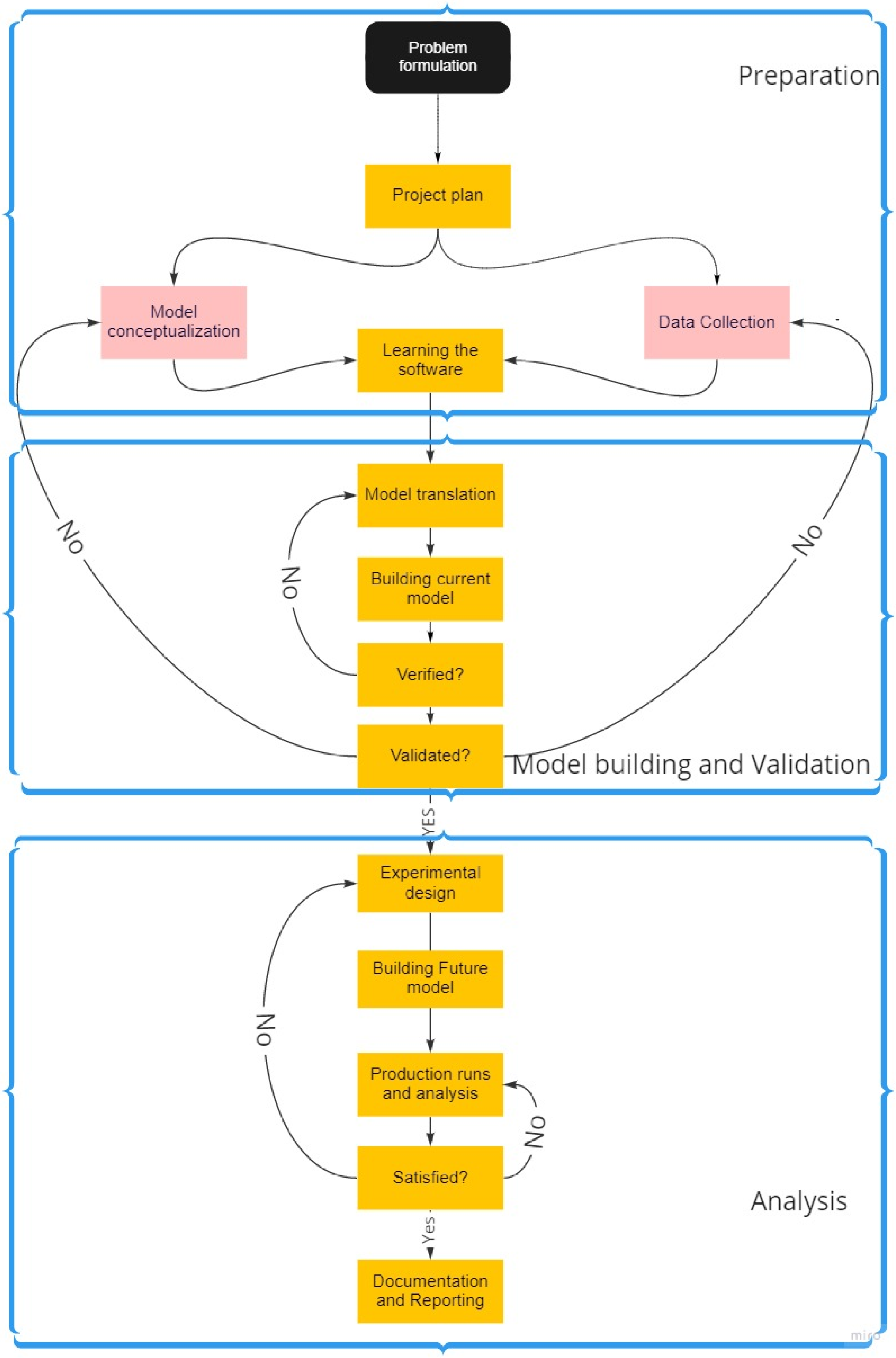

Figure B.3: Methodology for the thesis project based on Banks model [11]

C

Appendix 3

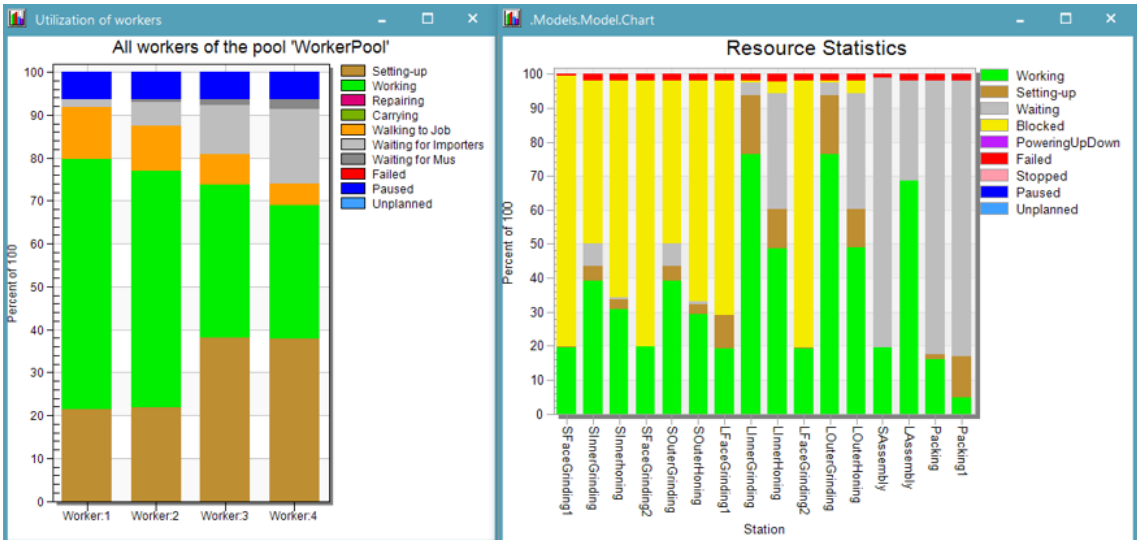

Figure C.1: The worker and machine statistics with 4 worker

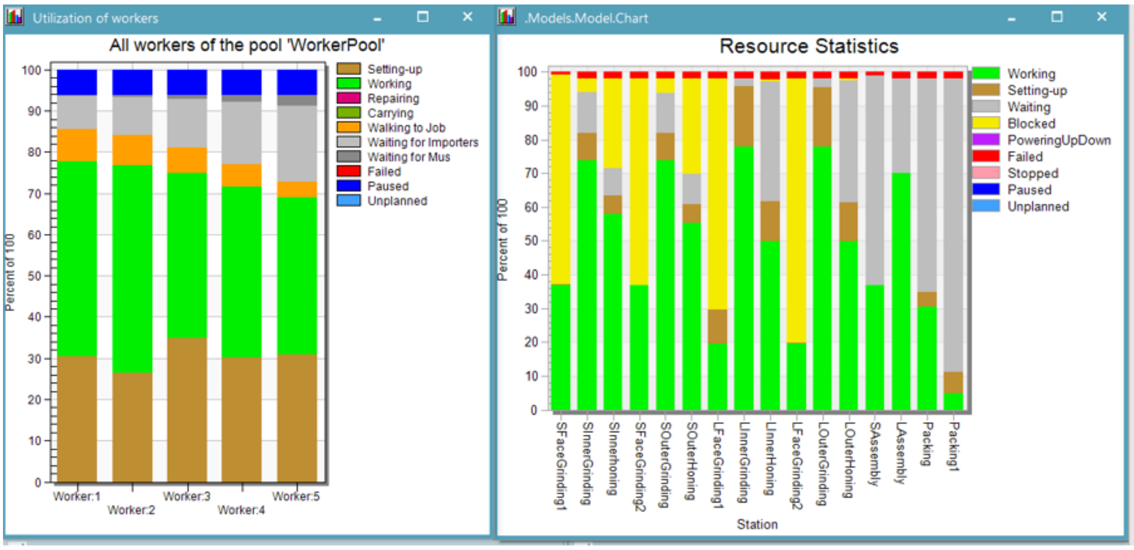

Figure C.2: The worker and machine statistics with 5 worker

Figure C.3: The worker and machine statistics with 6 worker

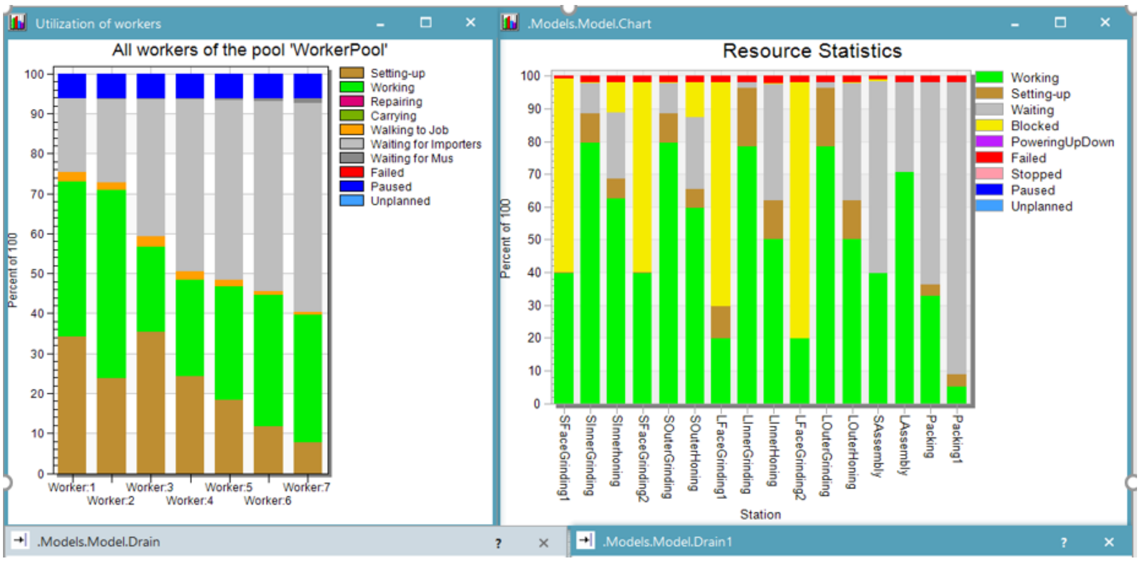

Figure C.4: The worker and machine statistics with 7 worker

Figure C.5: The worker and machine statistics with 8 worker

D

Appendix 4

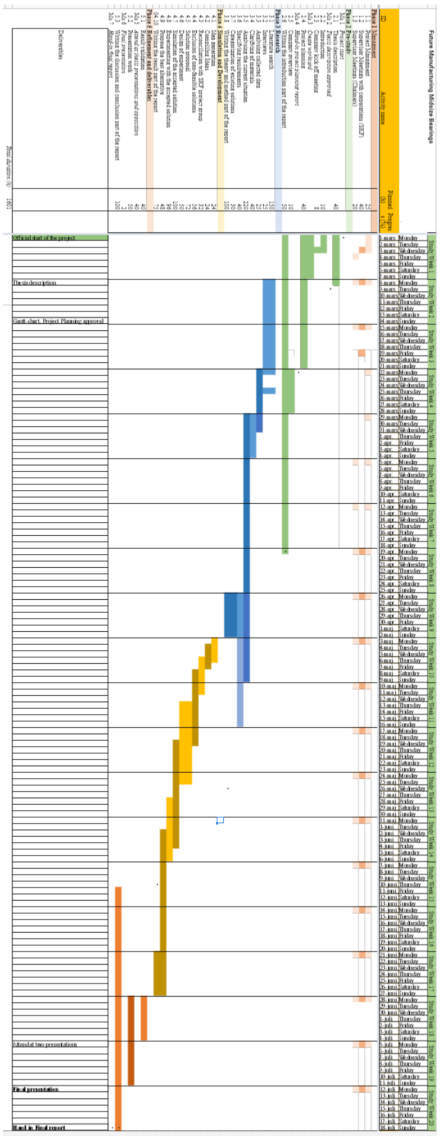

Figure D.1: Gantchart

The project name	Future manufacturing midsize bearings		
Background	SKF is a swedish founded company in Gothenburg that develop, design, and manufacture bearings, seals, and lubrication systems. They are currently producing three types of bearing families (these three families can be called product1(P1), product2 (P2), and product3 (P3)) which are intended to satisfy different customer needs. The focus of the thesis is only regarding the production of P1. P1 has a large number of variations based on sizes, functionality, accessories etc. that is offered to different customers. P1 is currently manufactured in two production lines, the issues in manufacturing of P1 mainly stem from frequent changeovers and low production volumes. Over time this has rendered P1 to have an increased product cost and thus invoking on their customer segments creating a downward sales spiral.		
Project owners	Thudor Sonnerup and Asghar Ramezani		
Users	SKF		
Timeframe for execution of the project	Beginning		End
	February 2021		*July 2021*
Documentation received by			Date 2021-02-25
			Asghar & Thudor
Handling of documents	Main folder:Googledriv and Report Overleaf/LaTex		
Appendices	Asghar Ramezani and Thudor Sonnerup		
Other			

Figure D.2: Project scope

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