

TIME STUDY AND FLOW- SIMULATION

Current and future analysis

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Certificate of Authenticity

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Abstract

Discrete-event simulations are increasingly being used to solve problems and to aid in decision making which are proving useful in the manufacturing industry. The main aim for this thesis was to compare the current production line and how implementing changes for a future state as a supporting basis for making the decision.

The theoretical framework focused on the Lean philosophy merged with simulation-based methods. The simulation model was build using the collected data. A time study was conducted in order to verify the process and setup times since these were only estimated at the time. Two simulation-models were built for the current production line and the future state. The future state was based on the current one since no changes in the process and setup times would be made during the two simulation-model. Experiments were then done to compare the different states, one with batch and the other single-piece flow. The parameters were set on equal terms and the compared values were throughput (TH), lead-time (LT) and work in process (WIP). The conclusion drawn from the results is that the future state would be more efficient.

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1.Introduction

This chapter contains an introduction of the company background and more specific about this project. Information about the problem description, aims and objectives with extent and delimitations included. The last part is the importance of how to connect it with the sustainability perspective.

1.1 Background

Carl Erik Josef Nyberg (C.E.J.N) is the founder of the company CEJN AB. In 1955 he designed and patented a revolutionary quick connect coupling that overcame many of the shortcomings of previous designs. Today CEJN is a leading global niche company providing innovative quick connect solutions. Initially their product was made for compressed air, but now also includes other features such as breathing air, hydraulic oil and fluids. The international head office is located in Skövde, Sweden. Worldwide CEJN has 550 employees with five production facilities and 17 sales offices around the globe (CEJN, 2019). CEJN has a wide variety of products, for this thesis CEJN's breathing air coupling is used as seen in figure 1.



Figure 1. Breathing air coupling (CEJN, 2019)

1.2 Problem description

The company has decided to change the production layout for the current process for assembling of breathing air couplings. As for now they do not know how much affect it will have and want to know the current throughput of the process and how changing the process will affect the throughput, among other things. The idea is to use both semi-automated and manual stations with a single-piece flow. Making the product finished from start to end instead of doing half of the product and put it into buffers with possible long queue time.

One positive side effect they hope to improve with a future state layout is resolving some quality problems they got with the breathing air coupling. With the current production line there are several things that can generate quality problems.

1.3 Aims and objectives

The main goal of the project is building a simulation model of the breathing air coupling production line to identify the throughput of that line with discrete-event simulation. This will create a basis for supporting the decisions of the wanted changes in the process line for breathing air couplings. The company wants a more efficient production line with higher throughput and minimize the quality problems, as much as possible.

The objectives are:

- Identify the current process flow and value stream for the breathing air coupling.
- Do a time study and verify the data.
- Make a simulation for current and future state with help of the collected data.
- Measure the throughput, lead-time and work in process of the different states according to new plan and compare the results.
- Conclusion with a supporting basis with discrete-event simulation in order to show if they should make the changes.

1.4 Extent and delimitations

The project and simulation will cover one type of product which has many similarities to other products. The reason is that products that are “Make to Order” will not be included since it is a small portion. Which could also in the end be positively affected. Many of the ingoing parts are used for a variety of other products which makes the inventory larger than needed for one product.

- There will not be any major changes for the operations since the product still has to be assembled the same way.
- Many of the quality issues are with handling and will therefore be resolved in the future state and no suggestions for improvements will not be made in this project.
- In the machine simulation, those times that machine is busy with other products is not considered, since this is something irregular for the current state and based on demand.
- No calculations for cost of the different states will be made.
- Focus of the value stream mapping will be mainly on the current flow during the production.
- Delays that are due to planning priorities will not be included since it is irregular.

1.5 Sustainability

One important goal with production in today's society is sustainability. To aim for an energy saving production with low emissions and still maintain a high utilisation of the resources. Apart from environmental sustainability there are two other factors that has an influence, which are economy and society. The economical aspect involves things such as development, profitability and future investments. On the society part involves things such as working environment and equality. Several connections of ethical and legal aspects can be made to the already mentions keystones in sustainability (Hjelm, 2013).

Näringsdepartementet (2016) predicts that focus on sustainable production is a good goal for the industry. To increase the resource efficiency from an environmental perspective that generates increased value creation and better competitive production on the market. At the same time also get

a higher output on recycling and lower the emissions. According to World Wide Fund for Nature (WWF) for a sustainable development it must permeate the whole society on a global level. Which is something WWF are illustrating in figure 2 how everything is connected together and effects each other.



Figure 2. Illustration of sustainability (WWF)

Toyota is a company that has succeeded creating a culture that permeate the whole company for a sustainable future. Leaders are getting taught to do right from start. Both towards the company, employees, and customers and for the society (Liker, 2009).

Parament (2008) describes an important change for today's economical sustainability, how the consumers are reacting. Both consumers, media and government have a greater concern for the environment and that this view will not change. The importance of the social sustainability and how the employees can affect this. If the employees are happy and shares the same values as the organisation, they will automatically spread a positive word about the organisation. If a company is known to work hard for a sustainable future it will have a snowball effect and will gain more consumers according to Parament (2008).

There are tools for manufacturing companies that would benefit the environment. Doing a digital simulation of a production line makes it possible to calculate how much raw material would be needed and make right choices from the beginning without unnecessary redesigns. Other things such as the transport systems could also be utilised the same way. This would contribute to use minimize resources and maximize the efficiency (Naturvårdsverket, 2018).

2. Theoretical framework

In this chapter the theory behind the study is covered. Relevant concepts and terms that are used in the project as starting points are explained here. With the intention to increase the knowledge for the reader and with the help of literature create reliable conclusions and results of the project.

2.1 Lean Production

Lean production is coming from the Japanese automobile industry. The Toyota Production System (TPS) is the ground for Lean production which is more commonly known as just Lean (Liker, 2009). Jacobs (2009) defines Lean as a set of designed activities that are integrated in order to achieve producing using minimal inventories of raw materials, work-in-process, and finished goods. To work with Lean includes a philosophy of the bigger picture. A production that is constantly moving with a single-piece flow through a value adding process with a pull system that is defined by the customer orders (Liker, 2009).

According to Liker (2009) the most important about Lean is not to implement all the specific tools that Lean provides. It is more important that the company leaders continuously invest in the employees to build a culture of continual improvements. Lean is not an activity or project to implement over a short period of time. This is something Liker (2009) took notice of when studying other companies for several years and many failing to emphasize the philosophy of Lean. It is something that is never finished and there is always room for improvements to be made.

2.2 14 principles in Lean Production

There are 14 ground principles for Toyota Production System (TPS) and "The Toyota Way" described by Liker (2009). The principles include the tools and techniques that would define TPS. The principles will be used as a ground for related questions in the project.

1. Base decisions on long term philosophy, even at the expense of short-term financial goals.
2. Create a continuous process flow that brings up the problems to the surface.
3. Uses a pull system to avoid overproduction.
4. Level out the workload.
5. Build a culture where stopping to fix problems so that quality is right from start.
6. Standardised tasks as foundation for continuous improvements and employee empowerment.
7. Use visual controls so no problems are hidden.
8. Only use reliable and thoroughly tested technology that supports the employees and processes.
9. Develop leaders that really understand the work, lives the Toyota philosophy and teaching it to others.
10. Develop exceptional people and teams that follow the company philosophy.
11. Respect the extended network of partners and suppliers by challenge them and help them to improve.
12. Go and see with own eyes to understand the situation better.
13. Make decisions slowly and in consensus, thoroughly consider all options, implement quick.
14. Become a learning organisation through relentless reflection and continuous improvement.

2.3 Seven wastes

Heizer (2017) presents Lean as something that supply the customer with exactly what the customer wants when the customer wants it without creating any waste and through continuous improvement. Companies that are using Lean aims for perfection with no bad parts, no inventory, only value-added activities and no waste. Activities that are value adding are defined by the customer. Any activity the customer does not want to pay for would be a waste. Heizer (2017) describes the seven different wastes in Lean operations.

- Overproduction: Producing more or earlier than the customer demands becomes a waste. Liker (2009) also mentions that this will contribute in a negative way to other form of wastes such as take up inventory space.
- Queues: Heizer (2017) mentions that this would include idle time which would mean a lot of waiting time where nothing is done which does not add any value.
- Transportation: Moving material between workstations or plants and handing it more than once would be considered a waste.
- Inventory: Work in process (WIP), unnecessary raw material. Finished goods and excess operation supplies add no value and are wastes.
- Motion: Movement of employees or equipment adds no value for the customer.
- Over processing: All work that is performed on a product that customer does not want to pay for is waste.
- Defective product: Rework and scraps are waste. Also returns with warranty claims.
- Unused creativity: Liker (2009) describes an eight waste that is sometimes added and mentioned along the seven wastes. It aims to use the creativity of the employees and their knowledge.

2.4 Throughput

Heizer (2017) defines throughput as the rate that products move through a process. It is well known that critical processes are subject to the rule that time is money. A customer that has to wait longer is more likely to switch to a different vendor. Storing material in inventory for longer periods adds a higher investment cost. Often critical processes are depending on limited resources which results in bottlenecks (Jacobs, 2009). Heizer (2017) mentions manufacturing cycle time which is the time between the arrival of raw materials and the shipping of finished products. One technique that could increase the throughput is a pull system. The concept of pull system is that material is being produced only when requested and moved to where it is needed just as it is needed. Lean standards with pull systems use signals for production and delivery request. The concept is used both within production process and with suppliers. This gives smaller batches with material that are pulled through the system thus removing inventory and waste. Furthermore using the pull system concept leads to reduced clutter which brings up problems and continuous improvement is emphasized. With less inventory the investment in inventory and manufacturing cycle time are reduced. Heizer (2017) also points out the opposite, which would be a push system that is pulling material to next production process regardless of timeliness and resource availability.

Jacobs (2009) mentions some other suggestions that would help reduce throughput time without purchasing new equipment, these suggestions would also have to be combined with appropriate ideas.

1. Perform activities parallel, since most of the process operations are performed in a sequence. That will result in a longer throughput time when all the steps with transport and waiting time between are counted. By using a parallel approach throughput time can be reduced with up to 80 percent with better results according to Jacobs (2009).
2. Change the activity sequence. Products, documents and information is something that often goes back and forward between different departments or machines. This is something that could be more efficient if the sequence could be altered to only have to do it once (Jacobs, 2009).
3. Reduce interruptions. Jacobs (2009) means that process could be performed with large time intervals. Improved timing in processes could save a lot of time in throughput for example management should be aware of deadlines when preparing results of purchase orders.

2.5 Time studies

Time study is taking a time sample of an experienced worker's performance for a specified task and use it as base for setting a standard time. Time study were originally proposed by Frederick W. Taylor in 1881 (Heizer, 2017). According to Harrison (2011) companies that do time-based initiatives often has a lot to benefit from it. Opportunities to reduce cost is one of the key elements when using a time study. Improving productivity through identifying non-value-added time and eliminate it. Tasks that are still necessary will have lower costs such as reduced quality costs since the overall lead time will be reduced. With reduced time between an error being made and the problem being detected the less impact it has.

In order to decided what is a fair day's work from an employee a standard time for the different tasks has to be set. By doing a time studies this standard time can be set. In order to do a fair and detailed time study the work has to be standardised. An accurate establishment of time standards make it possible to increase the efficiency of the process. Before a time study is made there are certain requirements that has to be met to get correct results. It should be an experienced operator of the station and they should be notified beforehand about the study. It is important that the work is done in an average pace when measured. Not too fast and not too slow, average for the best performance factor. The work should be verified that it is following the standardised method (Freivalds, 2009).

2.5.1 Snapback method

Snapback method uses a stopwatch that resets after every measured cycle. This method is good to use for longer cycles. With the snapback method it is easier to immediately insert the readout of the stopwatch into the observed time without having to do any calculations thus eliminating potential errors. How many iterations needed can easily be decided since elemental values can be compared from cycle to cycle thus making it easy to spot if it is similar or vastly distributed times. There are some disadvantages with this method such as removal of individual elements from the operation. It is also harder to measure shorter cycle times less than 0.04 minutes. One process of the snapback method that can cause error in the calculating is when the overall time has to be verified by summing the elemental watch readings (Freivalds, 2009).

2.5.2 Continuous method

A great advantage with continuous method is that the resulting study presents a complete recording of the whole observation period. The operator can see that all elements of the observed period are

recorded, even unexpected delays. This method is also better adapted to record shorter cycle times less than 0.04 minutes with a longer period right after since the stopwatch is never rested. The time study operator can then write down the remembered break point time for the short cycle after hand on when the longer period comes. Disadvantage with continuous method are the calculations that has to be made afterwards. Subtractions of the consecutive readings has to be made in order to determine the correct elapsed time for each element. This causes extra steps and are prone to error in the calculation (Freivalds, 2009).

2.5.3 Predetermined motion-time data systems

Predetermined motion-time data systems sums up data from tables of generic movement in order to measure the time of an operation. The most common used are Methods Time Measurement (MTM) (Jacobs, 2009). Freivalds (2009) furthermore explains different levels of MTM. By using a predetermined time system values for motions and tasks are already set and with the help of the table it is possible to calculate standard time and cycle time. Depending on how detailed the results should be there are different levels of MTM tables. The most detailed would analyse every movement such as grasping or the most basic would sum the whole process in one handling motion. Advantages with this method is that started times can be calculated before the equipment are in place. But in order to perform the study with accuracy vast expenditure of time is needed.

2.6 Simulation

Simulations models is something that has been around for a long time but with more recent are increasingly, being used to solve problems and to aid in decision making. Using simulation-based optimisation is a powerful tool to analyse and help the decision making process of a production. Building a simulation model requires necessary data which could be a time-consuming task. Another problem with this process could be if there is no standard on how to collect the data it might be done differently from person to person which in the ended will give wrong data. Sometimes it is not possible to gather the necessary data and therefore an estimation for some of the data has to be done. The goal with a simulation model is in the end to make a copy of the model and implement it into the production. Using known data that is as close to identical as the real process is the ideal. Since the model can be useful and used for further improvements (Bärring et al., 2017).

Today's global market gives a lot of opportunities for companies. It also goes hand in hand with greater competition around the globe. One of the industries that are under huge pressure are the car manufactures. According to Bokrantz et al. (2015) in order to gain competitive advantages car manufacturer need to adapt quicker to meet high and rapidly changing customer demands. One way to gain this small and valuable advantages is to implement fast development of flexible, high performance and cost-effective production systems. An important tool to establish and achieve that statement would be to use discrete-eventsimulation (DES). It is important to collect high quality data compared to just collect a lot of data that are either measured wrong or not necessary for the outcome of the simulation.

The data can be everything from production data to layout planning. As Nåfors et al. (2017) implies that making a realistic 3D model of the layout will give an accurate model during planning. This will help the process progress faster since everyone will have the same mental model in their mind. This will allow for quicker implementation and accurate evaluation of changes and improvements.

2.6.1 Discrete-event simulation

According to Banks (2005) discrete-event simulation (DES) is the modeling of systems in which the state variable changes only at a discrete set of points in time. Simulation technology is an important tool for planning, implementing and operating complex technical systems (Bangsow, 2010). Banks (2005) points out that simulation is a helpful tool and increasingly being used to solve problems and to aid in decision making. Simulation of complex systems makes it possible to test and decide different strategies, experiment and visualise changes that otherwise would be too much of a risk.

Discrete-event Simulation (DES) brings many advantages although it is still a relatively new field for many companies who recently started to use it more frequently. Barlas & Heavy (2016) mentioned that gathering data and the process of input data management is a time-consuming and costly for simulation projects. Studies show that data collection could take up to 40% of the project time due to the manual work. A suggestion to reduce this time would be by implementing a tool for automatic data collection. Having an automation of the process gives a lot of potential and would be extremely beneficial.

2.6.2 Value stream mapping

The term value stream was coined by James Womack, Daniel Jones and Daniel Roos in 1990 when launching their book, *The Machine that Changed the World*. A value stream is the sequence of activities required to design, produce and deliver a good service to a customer. It includes both the material flow and the information flow. There are many different ways to do value streams and what to include on them and also an organisation can have multiple value streams over different flows. Value stream maps offer a view over how the work flows through the entire system and are different from process maps in many ways. The first thing is that value stream maps provide a way to establish a strategy for making improvements. Which is the most commonly thing a value stream mapping is looked at, a workflow design tool. The value stream mapping could also identify non-visible work such as communication. The feature with value stream mapping is with the visualisation it brings clarity to not only understanding the value and non-value flow but also gives everyone a clear picture about the value stream of current state and the possibility to make a future state that everyone agrees on (Martin, 2014).

3. Method

This chapter aims to explain the methodology used in the thesis work. The method forms the workflow in order to achieve the aims and objectives of the problem.

3.1 Chosen method

The project will be based on Banks 12-steps for a simulation study as shown in figure 3, since the projects results will be drawn from simulation-based optimisation. All the steps will not be included separately in this thesis since the scale of the project would be too big. Some of the steps will counted together if only a small part of that step is taken into consideration.

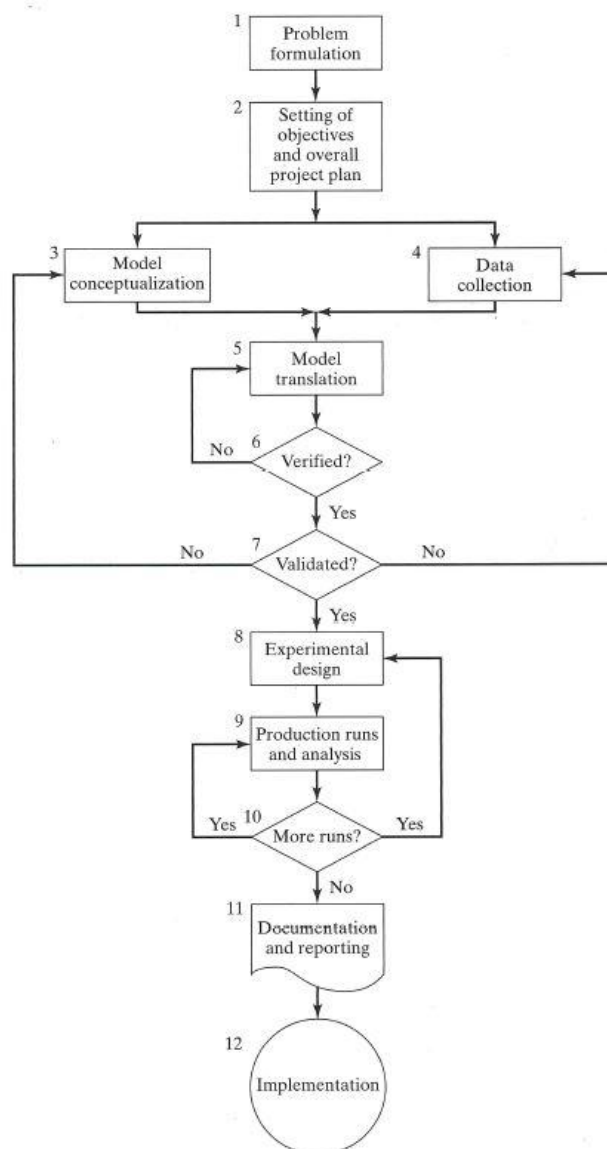


Figure 3. Steps in simulation study (Banks, 2005)

3.2 Current situation analysis

Starting the project with looking at the current situation and to a study in order to comprehend the problem. Together with the company the problem description was evaluated, which lead to the aim

and objectives of the study. Along with the goals, delimitations was set in order to keep the project scope within the time frame and to give results of the asked objectives. Moving on to the next step was to set a project plan for how to execute the study and present the results. The timeline of the project was already set, the goal here was to try and determine how long time needed to complete each step in order reach the final results.

To comprehend the problem fully, why the company wanted to make the changes of the production line it was important to be familiarised with the system that are going to be studied and how they wanted to make the changes for a future production line. To get a better understanding of how the process is built up and how the order starts a simple value stream map was made to get an overview of the information flow. This created a better picture of how the whole process looked like. With the information from the company why and what they wanted to be done within the project a literature study was done of previous work in similar projects.

3.3 Data collection

Data collection focused on data needed for a valid simulation model. The objective was to compare the current and future state. First observations were made for the process with the help of the team leader at the production explaining all the steps. Data for process- and setup times was given from CEJN for the current state. The data given was only an estimated, therefore a time study was made in order to verify the given data.

Other means of data collection was done throughout the process. Apart from the time studies conducted, an interview with the operators was done. This was to get a better understanding on what the operator things about the different stations. The interviews involved interested parties, both in management and operators which lead to a complete picture of the process, which was useful when building the layout of the model.

3.4 Simulation model

The next step in the project plan was to build a model of the given data. To get started with this phase first a process-flow overview model was constructed. This was used to get an overview of how the model should be built. After verifying the process-flow and the collected data the model for the current production line was built with the help of the program software Tecnomatix Plant Simulation. When the model was finished it was once again verified and validated to ensure it suited the expectations of the company. Once the simulation model for the current state was verified, the production line for the future state was built. The future state was based on the current state but some changes was made and the model had to be verified again.

It was now possible to proceed with the objective to compare the both different states. Several experiments were made with the given and collected data. Comparing the current and future state of the production line and get results that gives better insight of the process for the involved parties. The experiments conducted were after completion analysed and documented in the report.

The last step for implementation of the simulation-model was not done since the project scope was only to compare the different states and help as a basis for making the decision.

4. Execution

This chapter describes how the previous steps presented in chapter 3 were implemented into the project. Describing each step from current situation analysis until the actual creation of the both simulations models used to compare the throughput, lead-time and work in process.

4.1 *Current situation analysis*

This would also be seen as the planning phase of the project. Which played a crucial role for building a thesis work in the given time lapse. Here the problem description together with aims and goals for the project was set. The company had their ideas of suitable problems that would be useful. Although there was no clear plan how to proceed or execute the said questions. Together with the involved parties at the company and the student a meeting was set up to go through the problem description and come up with a suitable project plan.

The objective as a whole was to create a basis for supporting the changes of the production line for breathing air couplings. On this production line there was several values that had never really been measured. Measuring these values and comparing them for the current production line and for the future production they wanted to implement was the main goal. The current process and setup times were only an estimated value. Therefore a time study was required in order to verify the current data for process and setup times. The company required that following values were to be compared in the simulation model:

- Requirement 1. Throughput per hour (TH), measure and compare the both states.
- Requirement 2. Lead-time (LT), measured results for both states.
- Requirement 3. Work in process (WIP), measured results for both states.

4.1.1 Understanding the process

Having the objectives set next thing was to get familiarised with the process as much as possible for the upcoming task to build the simulation model. Observations in the production line and look around the production to get a bit of more understanding of the process was used. Furthermore interviews were conducted for being able to understand the whole picture of the process and what goes on before and after the production line. How the orders are decided and executed.

4.1.2 Interview

Interviews were conducted at the company with several different parties that were involved in the process. This was done to understand the material and information flow more in depth in order to create a simple value stream mapping for the upcoming task and get a better understanding of the whole process flow. Here it became clear that they were relying on having inventory of raw material and finished products. The information between suppliers and customers were mainly electronic. The resource planner explained that most of the orders were “Make to Order”, hence the needed inventory. They only had one variant of the breathing air coupling they were continuously making for a period of one year at the time. The orders were printed out and handed to the team leader. From here it was not clear how long the product proceed in the process. They have estimated times for each operation and a due date for when the product is needed to be finished. But between this there could be one day up to several depending on the demands of other products that had to be finished first.

With the new information behind the process of the production, observations are again done in the production line. This time mapping all the operations and talking with the operators about the processes. It was clear that there was no standardisation among the operators. They had specifications of how to do it and how the product is assembled but everyone did it their own way.

4.1.3 Data collection

Not all the data was measured and as part of the project objectives was also to produce some of that missing data. This meant a time-consuming task was at hand in order to gather as much data as possible for building the simulation model close to the real-world system as possible. Some estimated times for the process at setup times was taken from CEJN's database which is shown in table 1. The process and setup times were calculated and added together.

Table 1. Process and setup times for breathing air coupling

Operation Number	Quantity	Process- and setup times (hours)
OP10	500	3,06
OP20	500	1,73
OP30	500	1,28
OP40	500	7,16
OP50	500	1,75

Because this was only an estimated time, a time study was made to verify the given times. The choice of study fell on the snapback method using a simple stopwatch. The operator was informed about the study and asked to proceed as normal while doing the operation. During the time study there were at least two different experienced operators for every station to make the times more reliable. In the end the times measured were similar to the estimated time.

The availability data for each operation was missing and assumptions for that were made and set to 95 percent.

4.2 Process description

The process contains of five different operations. These operations are also included in other different products. This is irregular since the demand decides which product the resource planer will make an order for first. This was a simplification made when making the simulation model since the project scope did not take into account the other products.

An overview of the process flow as seen in figure 4 was made to help visualise the products movement and when validated also used as a base for the simulation model.

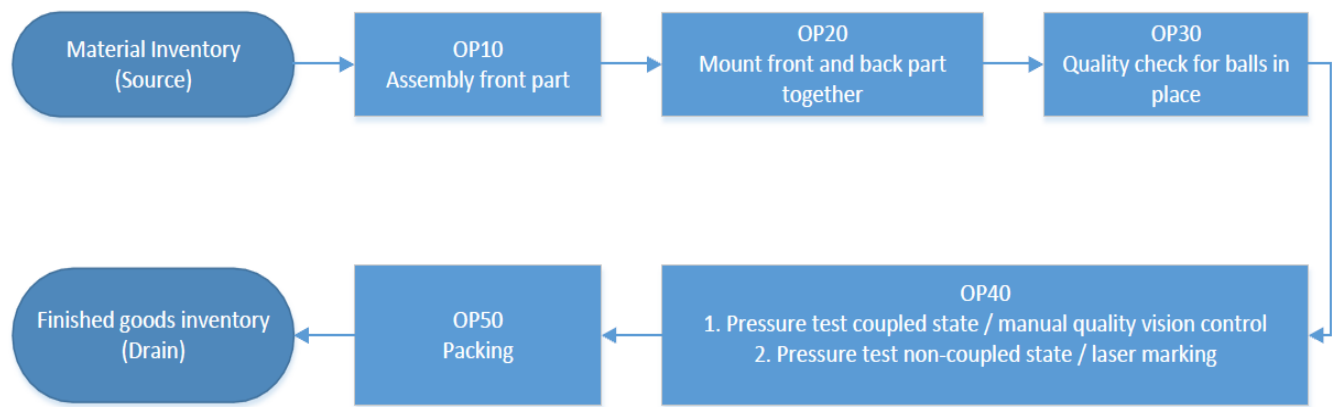


Figure 4. Process-flow overview

4.2.1 Operation 10 – Assembly front part

This is the first station where the operator picks the raw material. This operation includes several smaller components that are assembled. It is important that all the parts are assembled correctly. One of the components that easily can be overlooked when moving the part is the balls. If one ball is missing the coupling this not function properly under high pressure. The finished parts are then stored in a buffer until the batch is done. The finished batch is then moved to a storage that is together with all the different products that have a similar structure or it is directly moved to the next operation (OP20). The parts are moved manually on a large tray with the help of a lift device.

4.2.2 Operation 20 – Mounting front- and back part together

A semi-automated station where the operator does the initial work with entering the back part on the front part and then loading the machine. This machine is also included in several other different products hence the large storage that is set before this station. All the finished parts are put into a box on wheels where the operator either place the box in buffer or if the next operation (OP30) is free it will manually be moved and processed there.

4.2.3 Operation 30 – Quality check for the balls in place

This operation was recently implemented due to quality problems with the breathing air coupling. This is also the station that is the furthest away from the other stations. At this stage the assembly of the product is finished and it is only the quality check and packing left this step was added extra in order to only control so that all the balls are in place. Before this was only done as a manually check when during the assembly. The station is semi-automated and with the help of a machine that the operator uses can detect whether a ball is missing or not. When finished the product is moved to the next operation (OP40).

4.2.4 Operation 40 – Pressure test, quality vision control and laser marking

A semi-automated station where the operator can load one entity at the time. First is the pressure test in coupled state and at the same time a vision quality control is done manually. Depending on the batch size all the entities goes through the process first. When everyone is done it starts over again with a pressure test in non-coupled state and laser marking at the same time. Afterward the entity is put into a buffer and manually moved to the packing station which is operation 50.

4.2.5 Operation 50 - Packing

Packing station for the all similar products. The packing is done manually and usually the buffer here is build up before the products are starting to get packed. When packed they are moved to the finished goods inventory with a forklift, independently from the process.

4.3 Simulation model

The simulation model is based on the data collected in previous work. The process-flow in figure 4 shows the basic behavior of the model. The collected data as described in 4.1 was added into the model. As stated earlier the model includes the journey of one entity and its behavior in the production line along with some simplified assumptions. The scope of the project was to compare the current state of the production line and a future state that the company wanted to transition into. Therefore two different models had to be constructed. Both models have the same basis from the data collected. Such as process times, setup times and availability are not changed. The major changes of the production are going from a batch of 500 to instead use a single-piece flow.

The production line only includes one worker per shift which is also reflected in the model. The workers all have the same attributes, which means they work equally fast and precise. The shifts are regulated via a shift calendar which is updated with the correct work hours and breaks included.

In order for the simulation model to correctly represent a real-world system the model must be verified and validated. First of when doing the process of verification and validation was to check all the parameters and logical structure behaved correctly. A very important step of the process is to make a steady-state analysis and replication analysis. The main purpose of this is to determine when the simulation reaches a stable state and desirable accuracy. This was done separately for both the current and future state simulation models.

4.3.1 Current state

The simulation of the current state was built after how the production line looks right now at the company. The simulation model as seen in figure 5 represents how the products is processed with the included buffers, stations and movements.

Table 2. Replication analysis current state

Output	Confidence Interval	Num replications used	MEAN	STDEV	Confidence interval (Standard error)	Relative precision	Absolute precision	Number of simulations needed
TH	0,95	10	13,10	0,316	0,23	0,02	0,262	7,455
LT	0,95	10	123081	1764	1261,89	0,02	2461,620	2,628
WIP	0,95	10	1001,3	29,48	21,09	0,02	20,026	11,089
TH	0,95	20	18,30	0,41	0,19	0,02	0,366	5,508
LT	0,95	20	122371	2763	1293,12	0,02	2447,420	5,583
WIP	0,95	20	994,90	28,93	13,54	0,02	19,898	9,261

The replication analysis in table 2 shows the number of simulations needed when using 10 and 20 replications calculating with the mean value and standard deviation (STDEV) of throughput (TH), lead-time (LT) and work in process (WIP). The mean value is around 1000 since there are two batches of 500 in the production while 500 are in a buffer. The number of simulations needed for the output WIP with 10 replications was not okay since the value was over 11. Therefore the calculation with 20 replications was made and for TH, LT and WIP the results deemed to be good with 20 replications used.

4.3.2 Future state

The future state simulation model is based on the current as mentioned earlier in 4.3. There was no certainty from the deciding team at the company on how they wanted the future state to look like. One thing they wanted to implement was using a single-piece flow instead of batches. The future state simulation model is shown in figure 7 which simulates an optimised production line that reflects the stakeholders' expectations. With all the stations closer to each other to minimize the workspace and keeping a flexible single-piece flow going.

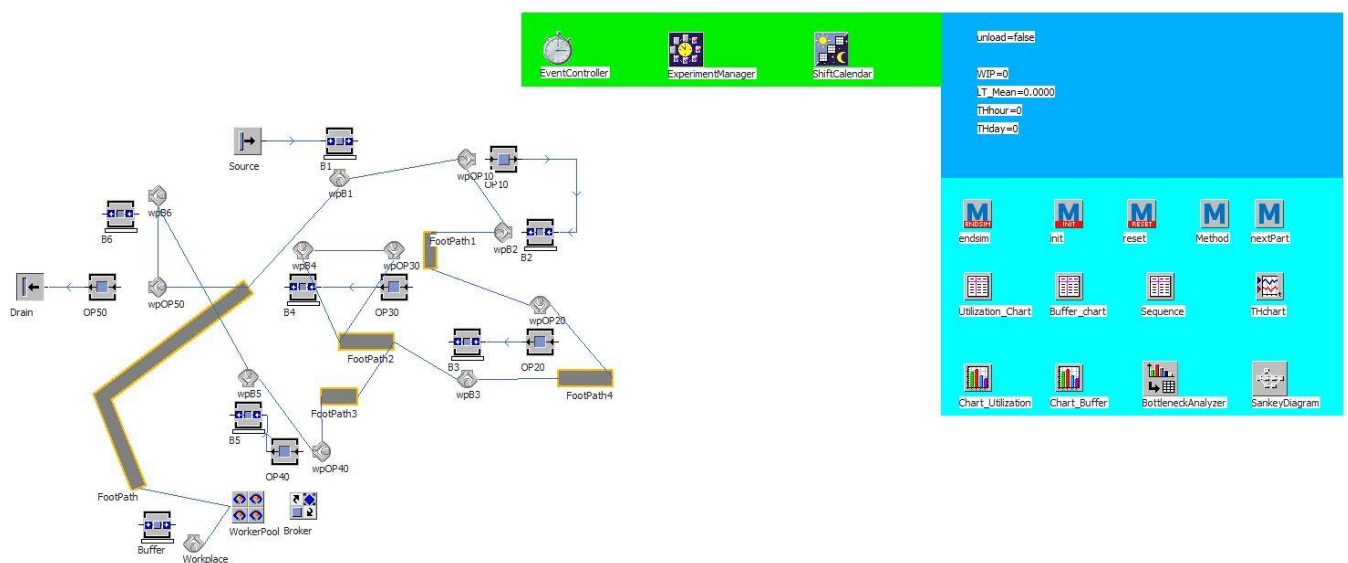


Figure 7. Simulation model future state

Since some changes had been made which led to a new verification and validation process for the future state. As seen in figure 8 the steady-state analysis shows that the simulation reaches a stable state after approximately 50 days as well. In order to keep the consistency between both simulations model the same warm-up time was set, which was 60 days. The simulation horizon was also set to 180 days which is the same period as the current state.

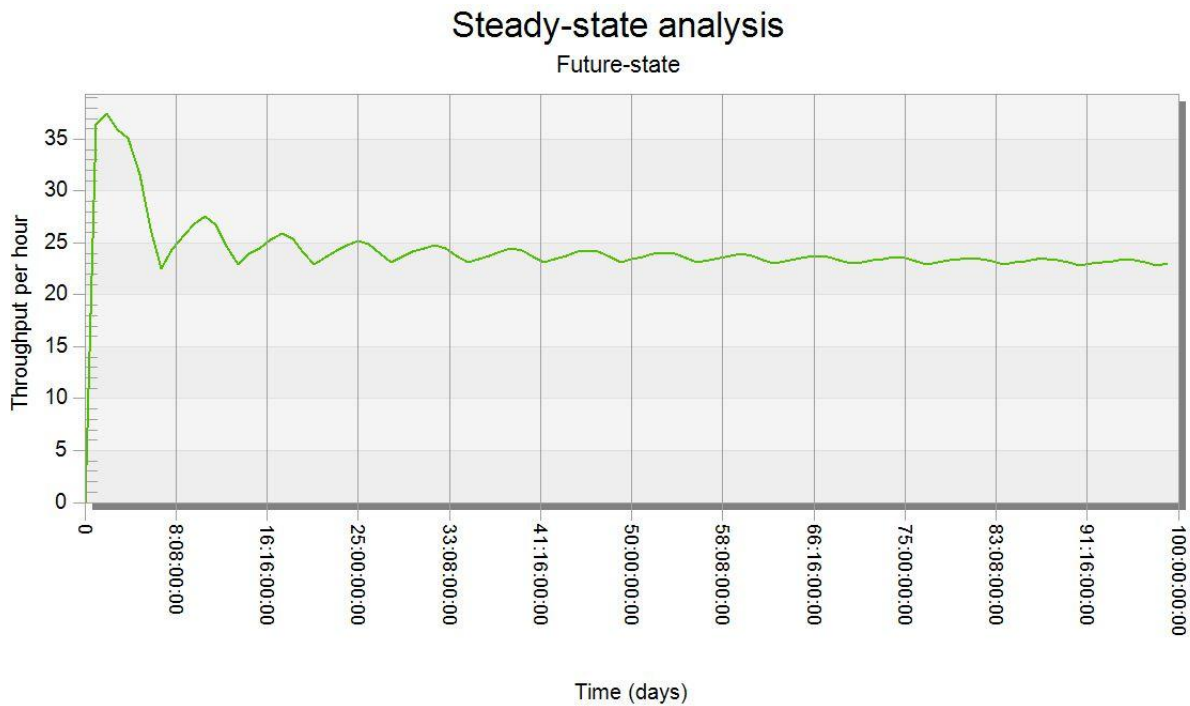


Figure 8. Steady-state analysis for future state

A replication analysis was made for the future state and shown in table 3. Similar to the first simulation model the calculations for TH, LT and WIP showed similar number of simulations needed when calculating with 10 and 20 replications. Once again the calculations with 10 replications were enough for TH and LT but not WIP. Therefore calculations with 20 replications were made and the results showed that 20 replications were enough since it needed 18 simulations for the calculated WIP. In order to get a confidence level of 95%, 20 replications were chosen in the end.

Table 3. Replication analysis future state

Output	Confidence Interval	Num replications used	MEAN	STDEV	Confidence interval (Standard error)	Relative precision	Absolute precision	Number of simulations needed
TH	0,95	10	26,50	0,500	0,36	0,02	0,530	4,554
LT	0,95	10	641,0	7,297	5,22	0,02	12,820	1,658
WIP	0,95	10	5,000	0,224	0,16	0,02	0,100	25,587
TH	0,95	20	26,60	0,503	0,24	0,02	0,532	3,910
LT	0,95	20	639,0	6,995	3,27	0,02	12,780	1,313
WIP	0,95	20	4,950	0,202	0,09	0,02	0,099	18,310

5. Results

This chapter presents the results of the comparison between the current and future state simulation models. It shows if the simulations models have any correlation between each other when it comes to the measured values of lead-time (LT), work in process (WIP) and throughput (TH). A bottleneck analysis was also performed for the stations. Although it was clear which one of the stations was the bottleneck beforehand, here in the results, the percentage of that will be presented.

After establishing a reliable simulation model the experiments took place. Both states have a different production line where the current state is done with pulling batch system that contains 500 entities in each batch. Where the future state only has one entity produced at a time in a single-piece flow system. The results in this chapter will work as a supporting basis if changes should be made in the current production line and what would be the benefits be.

5.1 Lead-time

For the lead-time experiment the same parameters as for current state was first set and measured. The result is shown in figure 9 for the current state. The lead-time should be as low as possible for good flexibility and efficiency. The time period for the simulation of the results was the same and measured over 180 days and lead-time in minutes with nine different benchmarks.

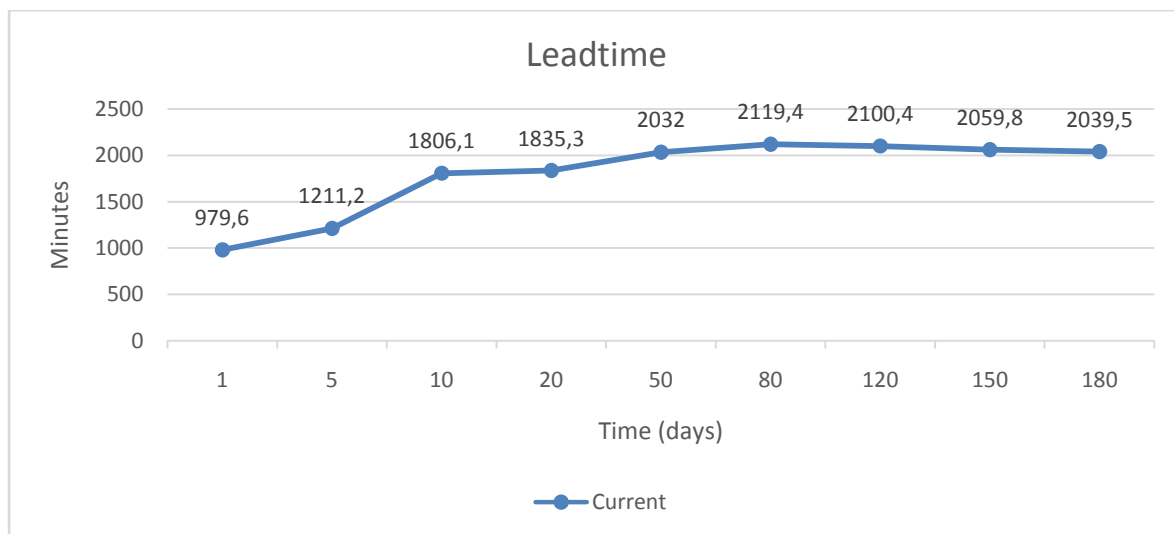


Figure 9. Lead-time for current state

As seen in figure 9 the lead-time starts lower and then raises until the simulation model is stable and starts to plan out. It starts out at 979 minutes which is over 16 hours, peaks at right above 35 hours (2119 minutes) and ends up right under 34 hours (2039 minutes).

For the future state changes were made and single-piece flow was simulated instead. The results for the measured lead-time in the future state are shown in figure 10. The lead-time starts out at 4.1 minutes and ends up at 10.7 minutes this is because of a single-piece flow is used and no batches.

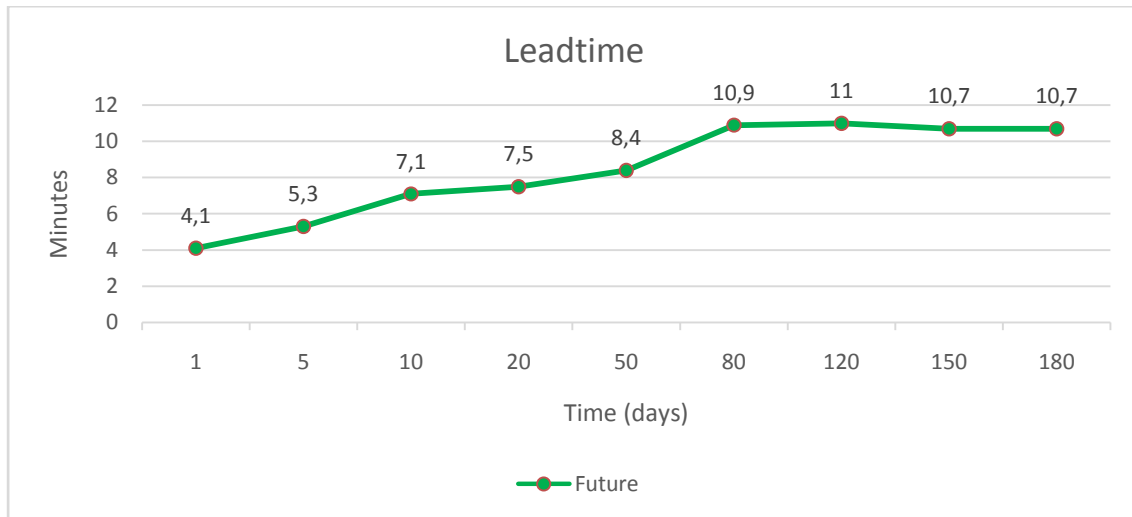


Figure 10. Lead-time for future state

5.2 Work in process

The work in process (WIP) experiment also used the same parameters set in 5.1. Smaller WIP gives a more flexible production line. First, the results for the current state was made, using a batch system. The results are shown in figure 11 for the current states WIP over a period of 180 days.

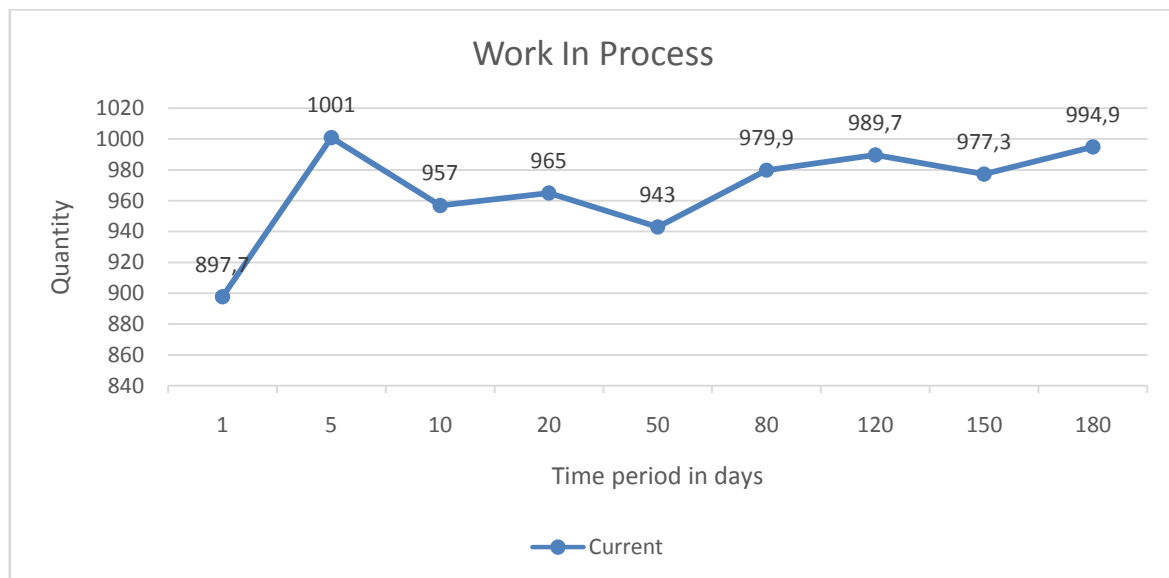


Figure 11. Work in process for current state

The current state has close to 1000 entities in the process since it uses batches of 500 and one batch are processed in a station and another stored in a buffer. Whereas the future state only has four for a period of 180 days.

Results for the future state are shown in figure 12. Work in process for the future state is between three and five entities, this is because the future state are using a single-piece flow instead of batches.

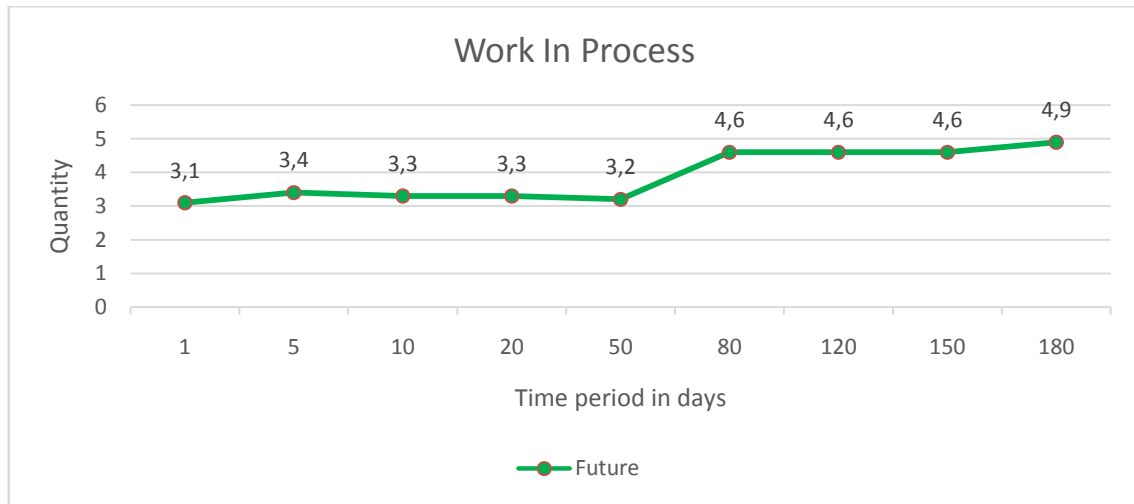


Figure 12. Work in process for future state

5.3 Throughput

With the previous results in mind throughput was then measured and compared between both states. The results of the experiment comparison are shown in figure 13. The blue line represents the current state and the green line the future state. The experiment was conducted through a time period of 180 days starting at day one and continued with chosen benchmarks in order to see how the simulation model behaved during the period and how the throughput per hour changed with time.

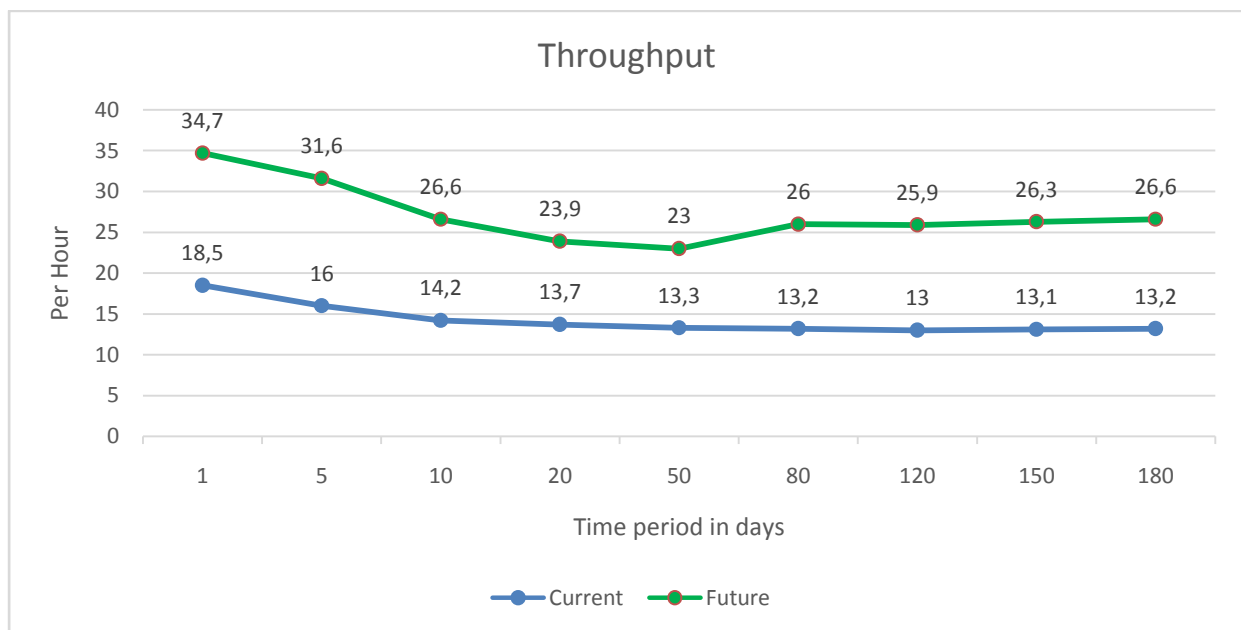


Figure 13. Throughput comparison, current and future state

As seen in figure 13 the peak is in the beginning. Over time the TH will drop and eventually become stable. This shows that the future state had a higher TH overall.

5.4 Bottleneck

Looking into the bottleneck was not a requirement from the company but an interesting experiment. Already from the start it was obvious which station (OP40) took the longest time by just looking at the process times.

The results shown in figure 14 is for the current state analysis and the OP40 is the station working most of the time which is at around 19 percent of the time which makes the other operations waiting for the majority of the time. The experiment was done over a period of 180 days where batches of 500 each were made. Since there is only one worker for this process flow the other stations are bound to have to wait. Since the experiment only includes one product the results for the bottleneck is misleading looking at the production overall. The other stations will most of the time be used for another product when the said station is free.

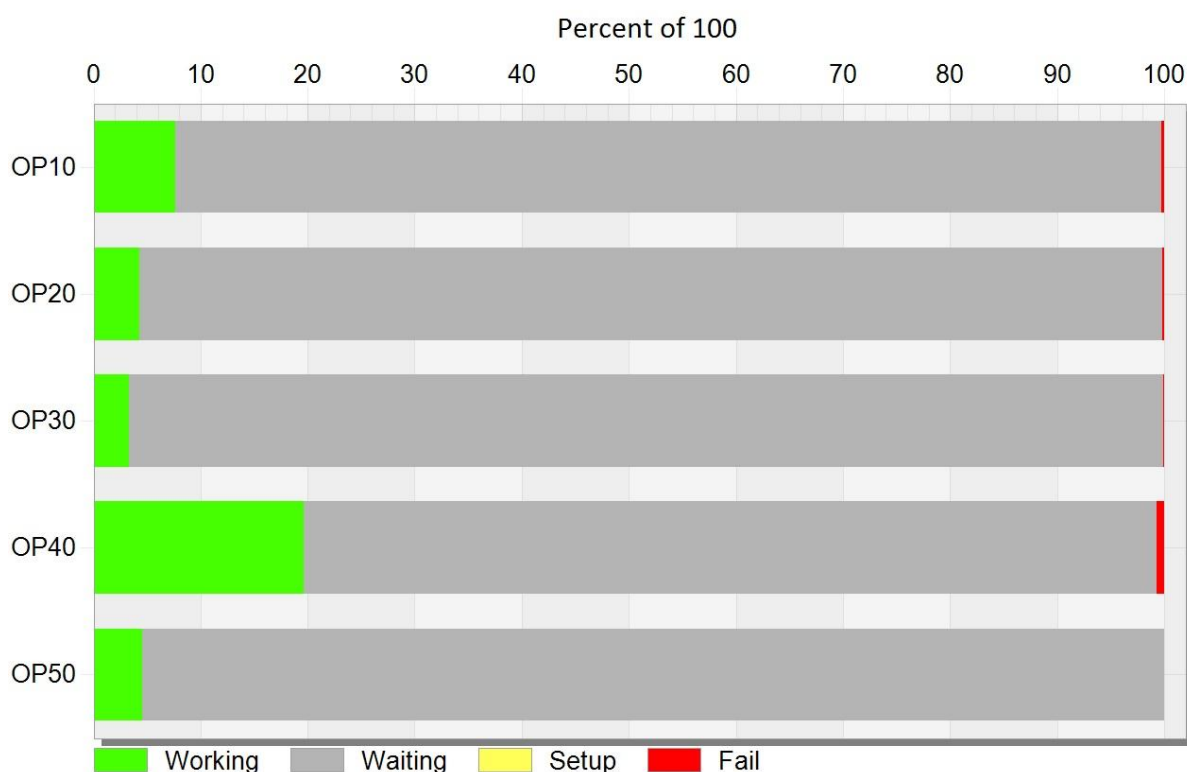


Figure 14. Bottleneck analysis current state

For the future state, the results are shown in figure 15. The bottleneck is still operation 40 but with some changes, the working time as gone up to about 32 percent. This reflects the whole production line since all stations have higher working percentage. Which would make the future production line a bit more flexible. Still there is no fixing the long process time for operation 40. The same also goes for the future state as the current state that the other stations will be used for other products when not occupied.



Figure 15. Bottleneck analysis future state

6. Discussion

The project overall has reached the aim and objectives described earlier in chapter 1.3. Sometimes it was not easy to follow only the objectives. During the project several other interesting questions were lifted. But in order to keep within the project scope and just add a lot of questions and no results, staying within the delimitations described in chapter 1.4 was important.

The simulation model was verified and validated with the given data. But when analysing the results it is still important to be aware of that errors may accrue. The simulation model is only an estimation on how it may look and there are no actually way to completely be sure on how the future production line will look like and behave for that matter. One concern is the fact that the simulation model is based on the fact that the process flow is in a constant production which it is not. This makes the point that the simulation model lacks data that effects the overall system. The simplification and assumptions were necessary for the project to stay within the delimitations and giving comparable results. The results are on equal terms for both current and future state.

Data collection was one of the first things that were time-consuming. This process could have been smoother if all the parties involved in the project had a clearer picture of what exactly the project scope would include and what information is already available. Due to lack of knowledge of the data systems at the company together with a vague knowledge on what kind of data would actually be necessary for the flow simulation model. The data collection process was very inefficient and in hindsight getting a better knowledge about the available data would have helped the project to become more efficient. Also getting a greater extent on the different available data collecting methods would have been helpful.

The project and the results would most likely have benefited from a larger simulation model that would cover more different data inputs. Making that would unfortunately have been too big of a project and time-consuming for it to stay within the project scope and delimitations that were first set. That also reflects on the flow simulation process which is based on only one project. Hence it should be seen more as a basis for further discussion, which is what the objectives were about.

In hindsight the project should have developed differently with the company more involved. As it was now there was not much interest about the project. This was probably because several factors one of them being the inexperience from both sides regarding a study like this. Initially the company was interested but did not really have any project specified. This was the first mistake since it took extra time to come up with something that would suit. Input about suitable projects were also given by the student which might have made the stakeholders take a hasty decision without thinking about necessary resources needed. Another drawback of the project was that the company do not use any type of flow simulation models. Which meant that there was no possible feedback from the involved team at the company or experience about data collection for this intended purpose. In this case I should have involved the supervisor at the university more instead of solving issues on my own which became a time-consuming task sometimes.

Overall the project was interesting and raised new questions that initially were not set in the aim and objectives. During the observations of the project it was also clear that the company had other areas that would benefit more in form of a case study or similar. They are using the Lean concept and a study on how to implement the new production line with a standardisation would probably be more useful. CEJN is not using any flow simulation programs for their production line and there was no indication that they will in a near future. Even though they can see from the results that they are on the right idea, they will not use the flow simulation for further experiments.

7. Conclusion

The main objective of the project was to create a basis for supporting the decision making to change from the current production line for a future single-piece flow production line. In order to do this some requirements were given from the company that they wanted to be compared for the current state against the future state.

- Time study in order to verify the process and setup times.

In order to reach the set requirement identifying the process flow was the key, followed up with data collection and verify the process- and setup times. A time study was made which verified that their estimated process and setup times were correct for the current state. The times were also used for the future state since there were not any changes for the process and setup times.

- Make a flow simulation model and compare results for throughput, lead-time and WIP for the current and future state.

After getting a verified and validated flow simulation model for both current and future state -both states were compared. The results that are presented in sections 5.1, 5.2 and 5.3 gives a clear view of different states and which one is to prefer. Overall the results for the throughput in the future state is better and concludes that CEJN would do the right decision to change if the both states are on equal terms. However in order to make a right decision, there are more parameters to include to get the whole picture of the production and that will require some work to implement. One aspect is the management and how the resource planner would plan the orders and give them to the team leader. It is much bigger challenge to implement a standardised production line with a lot of irregular tasks happening in the process flow.

Overall the results concludes that the better option still would be a single-piece flow since that would make the production more flexible and more efficient in the long run. Another aspect it is easier to find quality problems and immediately correct any issues.

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