Improving the packaging line at SES creative

A simulation study

Bachelor thesis Industrial Engineering & Management

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Preface

Before you lies my bachelor thesis, called: “Improving the packaging line at SES Creative: A simulation study”. It was written in order to complete the bachelor of the study Industrial Engineering and Management at the University of Twente. I was able to perform my research at SES Creative in Enschede and for that I would like to thank them.

I would like to thank my supervisor from the University of Twente, Ipek Seryan-Topan, for her support. With her knowledge and advice, she was able to steer me in the right direction from the start. At the feedback sessions she always took time to help me, which I much appreciate.

I would also like to thank my company supervisor, Pascal Elslo, for his support and guidance. He made me feel welcome in the company and provided me with valuable insights during our feedback meetings and gave me the freedom to execute the project my own way. Furthermore, he was always available to answer questions when needed.

Of course, I would like to thank the colleagues from SES Creative. They provided me with help, information and coffee whenever it was necessary. Everyone in the company that I needed for something was always prepared to help me and everyone was always very interested in my project.

Lastly, I would like to thank my family and friends for their support.

I hope you will find this thesis an interesting read.

Tijmen Zandbergen, August 2019

Management summary

SES Creative is a toy company that manufactures a wide array of educational toys. The packaging for all their products is done by themselves. Most of the products are packaged on the packaging line. Packaging the products costs a lot of time and it is the last step in the manufacturing process before a product can be shipped. By reducing the time that it takes to do the packaging, SES will be able to handle orders more flexibly. In this assignment, I will create a simulation model of the packaging line and this will help me to improve the throughput of the packaging line.

In the first part of the project, a lot of information is gathered about the packaging line itself and about optimization techniques and methods. With all the information that is gathered, the station speeds were determined. Then it was found that there are two bottlenecks in the packaging line. The first bottleneck is the product packing station. This is the bottleneck on slow orders. The second bottleneck is the shipping box packing station. On faster orders, this becomes the bottleneck.

The data that was gathered was used to construct a conceptual model, that describes what the input values are in the model, how the data is handled by the different stations and what the output data should be. In the conceptual model it was decided that the output values that will be gathered are the number of errors that occur per 100 products, the total amount of downtime and the total number of products manufactured over a three-hour period. Once the conceptual model was done, the model was implemented in Tecnomatix Plant Simulation. After it was implemented the model was validated by using observational methods and the resource statistics of the software. Then, the model was verified by using software testing methods and by calculating the necessary number of replications the model needs for the output data to be reliable.

Experimentation and conclusions

With the model implemented, validated and verified, the experimentation phase could start. In the experimentation phase it was decided to conduct six different experiments in which buffer sizes, the number of products per shipping box and the number of workers were varied. Furthermore, the performance of the packaging line when the shipping box packing was automated and the influence of having an extra worker to make sure supplies never ran out was explored.

The experiments showed two possible improvements, one with automation and one without automation. By automating the shipping box packing, the throughput would be increased by 0,60% on slow orders and by 5,89% on fast orders. Next to that, automation would mean that on slow orders one worker less is needed and on fast orders, two workers less are needed. The downside of automation is that it requires a big investment. The improvement without automation shows that increasing the packaging unit to 12 could increase throughput by 4,53% for fast orders, but it would decrease throughput by 0,69% for slow orders. Furthermore, by increasing the buffer size after the gluing machine to 22 the throughput on fast orders could be increased by 2,89%. This was not tested for slow orders. An improvement that can be done in both the automation and non-automation situations is having a worker that refills supplies before they are done. This reduces downtime and can increase throughput by 9,75% for slow orders and by 14,13% for fast orders.

Further improvements that can be done in the packaging line are process based. Currently, there is not a good feedback system in place that the workers or operators can use. Packaging instructions are being used that the workers must follow, but they are not able to adjust these in any way. These packaging instructions can be used as a feedback system for how products should be packed and what starting speed should be used per product. Furthermore, by assigning a difficulty level to each product that must be packed, the number of product packagers could be planned more efficiently.

Recommendation

Finally, recommendations are given. The recommendations are given for both the discussed situations The first one with automation, the second one without. In the case that there is enough budget available for automation, the recommendations are:

1. There should always be a worker that has enough time to refill supplies
2. An investment of maximum €125.000 should be done to automate the shipping box packing.
3. The packaging instructions should include the difficulty of the part and the box folder speed.
4. The packaging instructions should be used as a feedback tool to evaluate orders.

In the case that there is not enough budget available for automation, the recommendations are:

1. There should always be a worker that has enough time to refill supplies
2. The buffer after the gluing machine should be increased to 22.
3. The packaging unit should be increased to at least 8.
4. The packaging instructions should include the difficulty of the part and the box folder speed.
5. The packaging instructions should be used as a feedback tool to evaluate orders.

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Abbreviations

PU: Packaging Unit

TOC: Theory of Constraints

OPT: Optimized Production Technique

DBR: Drum Buffer Rope

HAL: Hand Activity Level

TLV: Threshold Limit Value

NPF: Normalized Peak Force

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1 Problem identification

In this chapter, an idea is given about what the project will look like. An introduction to the company itself and motivation for the research is given. The problem that has to be solved and the problem-solving method are stated. Finally, the reliability of the research and the deliverables are discussed.

1.1 Introduction to SES Creative

SES Creative develops and manufactures more than 400 different educational toys that are fun, safe and helps the development of kids between the ages of 1 to 10. In a world where digital technology is rapidly developing, SES makes sure that there's a world outside of computers for kids to play with. They were founded in 1972 and moved to Enschede soon after. Ever since the factory in Enschede has been the only one they have. All of the processes throughout the development of the toys take place here. Some of the most popular toys that SES has developed are Beedz and Hammer tap tap.

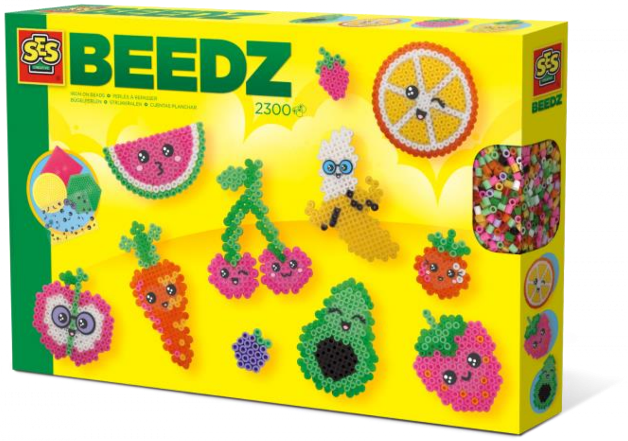

Figure 1.1) A SES-Creative product

1.2 Motivation for the research

Ever since the rapid increase in e-commerce, the market has been changing. Less orders will be shipped to physical stores and more to web shops. Web shops don't want to have the same high stocks as the physical stores used to have, so the shipment size has decreased drastically. This, in combination with the high seasonal demand of the toy industry makes it that SES has to become more flexible to meet the customers preferences. One of the things SES is doing to become more flexible is developing more semi-finished products that can be stocked more easily due to more manageable shape and size. By doing this they don't have to manufacture the complete product anymore when an order comes in. Right now, SES is focusing on how to decrease the time from semi-finished product to shipment. One of the things that has been done is that they have improved the packaging line. Last year they went from 5 packaging lines to 1 packaging line with the same output. At the moment this packaging line is still not always running at capacity, so SES is looking to further develop this part of the process. In this project we'll be focusing on improving the new packaging line, so that SES can become better at meeting more flexible demand.

1.3 Problem context

Through observation a couple of problems have been found that are related to the packaging line. First of all, the machines are having downtime. The boxes that have to be packed have packaging instructions and people on an assembly line follow these instructions to fill the boxes. Sometimes however, the instruction is suboptimal, or people make mistakes. This can cause the box to get stuck on the assembly line, or it can cause the box to not close properly.

Secondly sometimes orders are left unfinished and have to be finished the next day, which causes extra setup time. Sometimes, when the shift is over people will go home, even when the order has almost been finished. The next day, this order has to be finished first and has an extra setup time. It also causes a delay in the planning. This could be an indication of low motivation.

Thirdly there is only a small amount of data that is being used to make the planning and configuration for the packaging line. Data about the packaging line is available, but it either is not being collected, or it isn't being analyzed.

All the problems that have been found have been modeled in the problem cluster (Heerkens & van Winden, 2012) that can be found in figure 1.2. The end goal that we want to achieve is to be able to keep up with more flexible demand. Currently, the packaging line still has room for improvement in terms of efficiency. The inefficiency is being caused by downtime, suboptimal configurations and long setup times. The downtime is mainly caused by packaging mistakes and incorrect machine configurations. The long setup times are caused by orders that are left unfinished and by suboptimal planning. Finally, we end up with the three possible main problems. Firstly, there might be problems with the packaging instructions. Secondly, the small amount of data that is available is not being used efficiently. Lastly, there is a possible motivation issue causing the employees to not always finish the order on the same day. The last problem however is not measurable enough to consider, therefore it has been marked red.

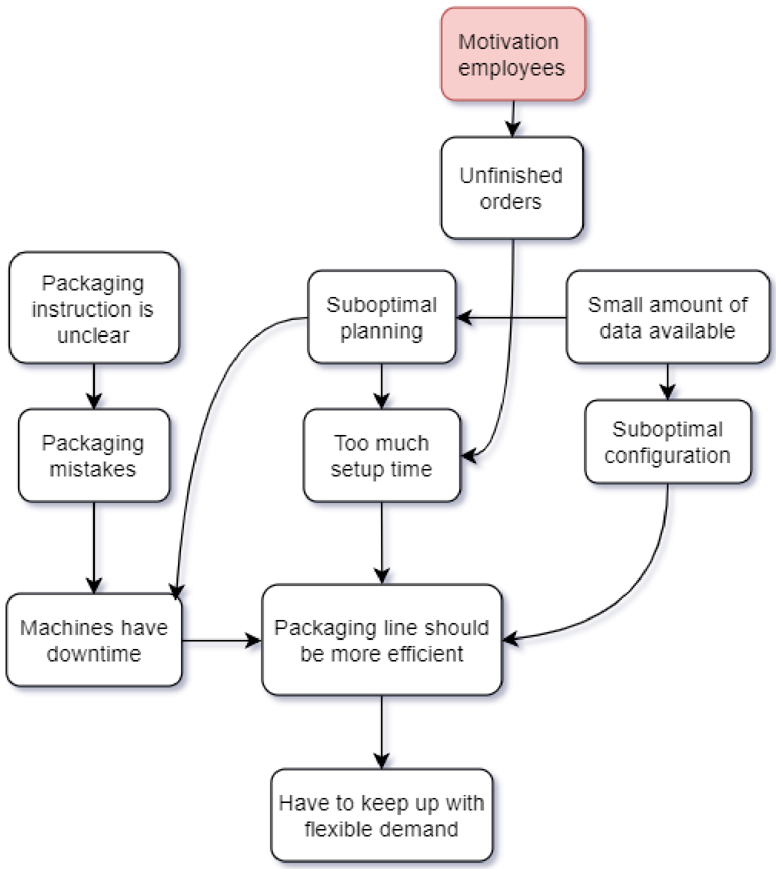

Figure 1.2) Problem cluster

1.4 Core problem

Out of the three problems mentioned above, we'll choose one core problem to solve. This will help us to narrow down the scope of the project. The problem with the packaging instructions is highly specific, because every different toy has its own packaging instruction. Furthermore, it's a difficult problem to make measurable. As stated before, the problem that employees are not motivated enough is difficult to measure as well, but it's also difficult to say if this problem even exists without doing any extra research. The data problem definitely exists and it is a measurable problem. The only data that is being stored at the moment is the throughput of the packaging line. This means that the source of the problem is that there is not enough insight in the packaging line, because there is not enough data available. If we could collect more data about the packaging line, we can get more insight in to what happens and we will be able to improve it.

1.5 Goal

The goal of this research is to find a configuration that will improve the throughput of the packaging line. For different groups of products, there might be different bottlenecks. So, it's important to find out what type of product groups are being processed in the packaging line. The eventual goal of increasing the packaging speed will be that SES will be able to meet more flexible demand.

1.6 Methodology

Before we start with the methodology, we'll have to define the main research question. The research question that we will try to answer at the end of the project will be:

"*How to improve the packaging line of SES in order to keep up with the flexible demand?"*

To be able to answer the main research question, several sub questions will be defined. A problem solving methodology that is based on the Managerial Problem Solving Approach (Heerkens & van Winden, 2012) will be used to strucure this project.

Together with SES we've decided that simulation is a good tool answer our research question. Before being able to make the simulation however, we'll have to make a proper analysis of the packaging line. First, further on in this chapter, we'll look at the layout of the packaging line and what variables are involved. Then in the literature research in chapter 3, we will look at what the literature has to say about improving manufacturing lines. In chapter 4, additional data about the specific stations in the packaging line will be collected that will help us with defining the input of our model. Afterwards in chapter 5, we'll see at what the conceptual model for the simulation should look like. In the next step in chapter 6, the implementation, verification and validation of the model will be done. Then experiments will be done in chapter 7 and finally an advice will be given about the configuration of the packaging line in chapter 8. For every phase of the methodology described above, sub questions will be defined that will help to answer the main research question.

Phase 1: Current situation analysis

The first step in the problem-solving approach will be to collect information about the current situation. We need to know about the lay-out of the packaging line and the variables that are involved. We also need to know what different products there are in the packaging line and how the current performance of the line is with these products. The main question and sub questions that have to be answered here are:

What does the packaging line look like now?

- **a.** *What is the lay-out of the packaging line?*
- **b.** *What are the variables of the packaging line?*
- **c.** *What is the current performance of the packaging line?*
- **d.** *What different types of products are there?*

These questions will be answered by conducting interviews with people that are involved in the packaging line. Also, information will be gathered by observing the packaging line.

Phase 2: Literature study

In the literature study we'll be looking at what can be found in the literature about improving packaging lines. First it is necessary to learn about what simulation is and how it works. An important part of this is how to detect where the possible bottlenecks are. We'll also need to know more about manufacturing line optimization methods. Since workers do not have a fixed working capacity, it is useful to look at methods of how to estimate worker speed. Then we'll need to know about the restrictions and assumptions that apply to the found methods so that we can decide if they are a good fit for SES. The research question and the sub questions for this part will be:

What methods are suggested in the literature to improve manufacturing lines?

- **a.** *What is simulation and how is reliable data obtained?*
- **b.** *Which methods for detection of bottlenecks are suggested by literature?*
- **c.** *Which methods for assembly line optimization are suggested by literature?*
- **d.** *Which methods for estimating the speed of workers are suggested by literature?*
- **e.** *What are the preconditions, assumptions and restrictions of the found methods?*
- **f.** *Which methods are a good fit to be used to improve the packaging line of SES?*

These questions will be answered by conducting a literature study to find sources. Then the found sources will be scored for relevance and goodness of fit.

Phase 3: Data gathering

To be able to define the input values for the conceptual model, more data than just the general data that was gathered in phase 1 is necessary. In the literature research, new methods to collect data will be found and these will be applied in this phase. Furthermore, estimations of failure durations and worker capacities have to be done. It has to be decided what data needs to be acquired and what methods will be used to obtain it.

What additional data is necessary to construct the model?

a. *What methods found in literature are helpful to obtain more data?*
b. *What observations needed to estimate model inputs?*

These questions will be answered by doing more in depth observations at specific stations of the packaging line.

Phase 4: Conceptual model

Before the conceptual model can be made, we'll need to gather some information about what data will be used and what we'll do with this data. We'll need to know what the input and output data for the model will be. To make sure that the model will do what we want it to do, we'll have to set requirements as to what the model's functionality should be. We also need to decide on what assumptions and simplifications to make in the model. The research question and sub questions to answer here are:

What will the conceptual model of the packaging line look like?

a. *What will be used as the input data of the model?*
b. *What KPI's should be the output data of the model?*
c. *What should the requirements of the model be?*
d. *What assumptions and simplifications will be made in the model?*

These questions will be answered by conducting interviews. Together with SES we will have to decide what simplifications and assumptions are reasonable to make so that we end up with a model that is a simplified version of reality but is still an accurate representation of the packaging line.

Phase 5: Implementation, validity and verification

In this step we'll have to find out how the model can be implemented in such a way that it gives the information that we want and, in a way, that the information is correct. The requirements that are set in the conceptual model must be checked so that we know for sure that all the functionality is implemented in the model. The data that is found has to be compared to data gathered from the existing packaging line so we can check if the simulated data is accurate. The research question and sub questions that we'll answer are:

How can a valid and verified model be implemented?

a. *How can the model be implemented?*
b. *How can this model be verified?*
c. *How can this model be validated?*

These questions will mainly be answered by trial and error. The simulation has to be programmed and through trial and error we'll find out what works and what won't work. The verification of the system will be done by checking if the functionality of the model meets all the set requirements by the conceptual model. The validation will be done by comparing the generated data to the actual data gathered by the packaging line.

Phase 6: Experiments

When the experiments will be conducted it's important to think about what experiments are relevant to conduct. When the experiments are done the results should be stored in correct way and they should be used to calculate the KPI's that we want to evaluate. The research question and sub questions that will be asked are:

Which experiments will be conducted?

- **a.** *What experiments are relevant to conduct?*
- **b.** *What are the desired results of the conducted experiments?*
- **c.** *What are the results of the conducted experiments?*

Before these questions can be answered, the previous questions have to be answered. When the system is completely implemented and optimization methods have been found, we'll know what experiments will be valuable to conduct and what we would like the results to be.

Phase 7: Advice

In giving the advice we'll have to interpret the results from the experiments. When we know what the results mean, we can decide on a configuration that works best. However, there will be limitations to the model. It will be important to define these limitations and be aware that they exist. The research question and sub questions that will be asked are:

What advice will be given to SES?

- **a.** *What conclusions follow from the results of the experiments?*
- **b.** *What is the answer to our main research question?*
- **c.** *What configuration will I recommend to SES?*
- **d.** *What are the limitations to the model?*
- **e.** *What are the possibilities for future research?*

The answer to these questions will be based on the outcome of the experiment. The experiments will be analyzed and the outcome will be evaluated to create an advice.

1.7 Validity

Validity can be defined as to whether a measure accomplishes its claims (Cooper & Schindler, 2014). Two varieties of validity are considered, internal and external validity. Internal validity asks if the conclusions that we draw truly imply cause. External validity asks if an observed causality is generalizable. Both these forms of validity are highly important to this research.

By checking the results on internal validity, we will have a critical view of the results. It will be important to not jump to conclusions when it comes to finding bottlenecks. We should ask ourselves if the found bottleneck is the bottleneck, or if it's possible that there are more variables that we aren't able to measure accurately. To ensure that this project is internally valid, it'll be important to work thoroughly in the problem analysis phase. We'll have to get a complete list of all the variables in the packaging line and we must be aware of the variables that we cannot influence.

The external validity in this project will check if the results that we get are generalizable for other products or product groups. One of the simplifications that we'll work with is that the products will be categorized. This generalization will mean that we'll lose some of the more product-specific data. To ensure that the results will still be externally valid, we'll have to beware of overgeneralization. In this project we'll have to be careful not to group products together that aren't comparable. Just like with the internal validity, we'll have to be aware of this in the problem analysis phase.

1.8 Reliability

Reliability is the matter of whether a technique, applied repeatedly to the same object, yields the same result each time (Babbie, 2010). According to that definition, simulation is a reliable way of gathering data, because the program won't decide by itself that it'll generate data differently. However, it is important that I keep running the simulations with the same settings. In the experimentation phase I will probably run different experiments with different settings. These settings shouldn't change too much in between experiments so that they will still be comparable. To ensure reliability of this research we must beware of changing too many variables at the same time in the experimentation phase.

1.9 Limitations

The research will focus on the packaging line. The production process and the warehousing before the packaging won't be analyzed. The warehousing and shipment after the packaging process will also not be analyzed. The duration of the simulation will be limited to one order at a time. Not all the individual products will be tested, instead, a categorization will be made to specify different types of products, depending on variables such as box size and the packaging complexity.

1.10 Deliverables

At the end of this project, the following products will be delivered:

1. An analysis of the performance of the current packaging line will be given. This analysis will show how the different stations perform and could give an idea of where improvement is possible.
2. A simulation model that shows how the packaging line would perform with the proposed optimization methods. The data that will be generated from the simulation will show how much improvement of the packaging line is possible.
3. An advice will be given on the new configuration of the new packaging line. This advice will include how to set the variables of the packaging line for each product group. It will also include a discussion and possible future research.

2. Current situation analysis

To get a good idea of what is going on at the packaging line, more general information about the packaging line will be given. This chapter will review what the packaging process looks like and what type of products are being made. It will discuss the different stations of the packaging line and explain how they work. Furthermore, it will give an idea about how data is collected and the reliability of this data.

2.1 The packaging process

Packaging is done in a flow-shop system. In a flow-shop system, the products move in a sequential order that is fixed. So there is no way for a product to skip a station or move backwards. The floor plan of the packaging line can be found in figure 2.1. The first station in the top left corner of the picture, marked blue, is the box folding machine. This machine folds the box that the separate parts of the toy will go into. Next, it puts the box on the assembly line. On the assembly line there are workers, marked red, that each have one or several parts to put in the box while it keeps moving forward. The box continues on the assembly line and goes to the gluing machine, marked purple. The gluing machine glues the borders of the box and folds to close it. After the box is glued, the assembly line puts it in a buffer. From this buffer there are usually two workers, marked green, that put the boxes in a shipping box. Once the shipping box is full, they close it and put it through a taping machine. Here it will go into another buffer. The same workers that pack the shipment boxes are responsible of getting the boxes from this buffer and putting them onto a pallet. Once the pallet is full, one of these workers takes it to the storing location and gets a new pallet.

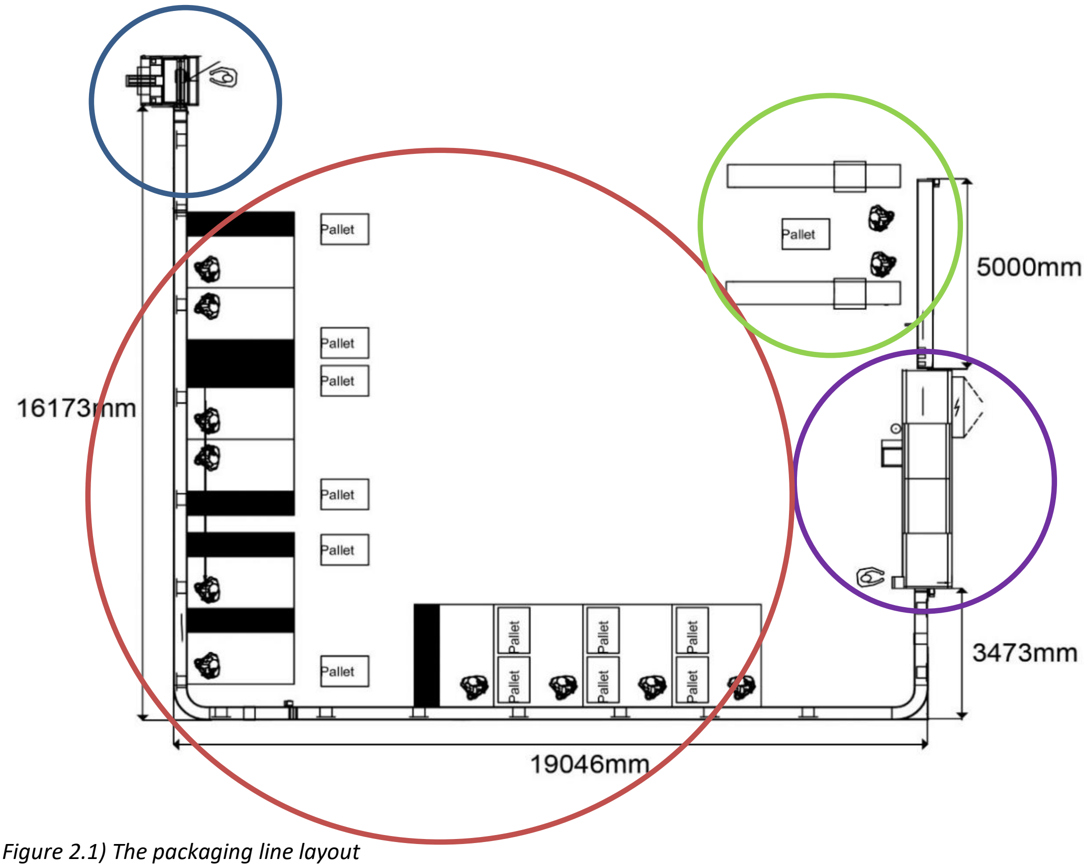

Figure 2.1) The packaging line layout

2.2 Products

A finished product consists of a folded box, the parts of the toy with the instructions and the glue to close the box. Per product, the box size, amount of glue that is used, the amount of parts and the parts itself can be different. The amount of glue that is used is small enough to make it a negligible part of the process, so only information about the other three components will be gathered.

Seven different box sizes are being used and there are three different base sizes and three different height sizes. These seven sizes are made with the use of three molds. Two of these are adjustable in height, the final mold has a fixed size.

The amount of parts that will go into the box can vary strongly. It is decided completely by the product development department. Simple products have almost no parts and it is not uncommon to have more than ten parts in one box with some of the more complex products.

There are a lot of different parts that can go into the product. Some products belong to a series of products and, therefore, are very similar. Other products are highly specific. Since the parts are being put in the box manually, the size, shape, weight and the amount of experience the worker has with the part strongly influence the speed of this process.

2.3 Packing instructions

When a product is developed, a packaging instruction is made. The packaging instruction contains information about out of which parts the product consists. It gives a list of the parts and the quantity of that part that should go into the box. In addition, the instruction tells in what order the parts should be packed and if special placement in the box is necessary. Sometimes parts can shift around or easily fall out of the box. In that case, the packaging instruction can say that this part should be packed first, so that other parts will keep it in place.

When during the packaging process a fault in the packaging instruction is noticed, there is not a real feedback system in place. When a problem is determined, people tell their supervisors until it is a widely known problem, then the supervisor has to communicate to the person responsible for making the packaging instructions that something has to be changed and then it will be changed. An example of this is of a situation where ten wooden sticks had to be added to a product. The workers noticed that counting ten sticks is too time intensive. Since the sticks are really cheap, it was decided that it was easier to just grab a bunch of sticks and throwing them in, so that it always would be at least ten sticks. This was a commonly known problem that did not get solved. When the workers were asked why they did not do it in the adjusted way, they said that the packaging instruction said to do it the old way and they should always follow the packaging instruction. This means that the packaging instructions are in place, they are being used, but they are not being adjusted efficiently.

2.4 Station descriptions

In the next section, the characteristics of the stations will be discussed one by one. We will talk about what the station exactly does, how fast it does it and how many errors can be expected. An overview of the processes involved can be found in figure 2.2.

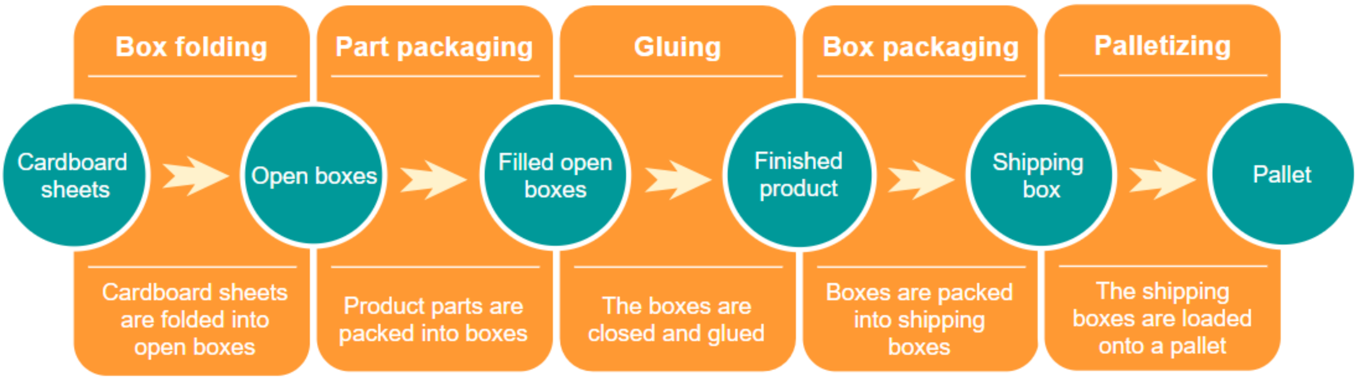

Figure 2.2) The packaging process

Station 1: The box folding machine

As input the box folding machine gets sheets of cardboard with pre-creased lines where the box should be folded. These sheets have the final design of the box printed on them already, so the sheets are specifically used for one product. The machine gets one of the sheets and uses a press and a mold to shape the box. Then it puts the box on the assembly line. The maximum throughput of this machine according to the specifications is 60 boxes/minute. However, it has been measured to have a throughput of 66 boxes/minute, so this is the value we will use.

Malfunctions in this machine can occur when the sheet is wrongly aligned to the mold. However, after proper calibration and testing, this never happens. In practice, this machine will only give an error when the sheet supply is depleted. Whenever an error stops the assembly line, this machine will keep working for four seconds to clear the exit.

Station 2: Product packaging

To put the separate components of the toy into the box, a series of workers on an assembly line is used. Each worker puts in one or more parts into the box, depending on how easy it is to grab it and fit it into the box. Packing several products is significantly more difficult than packing one product. Because of the wide range of products, throughput varies a lot in this station. The lowest measured throughput is 21 boxes per minute and the highest observed throughput is 40 boxes per minute. Since the speed at which the parts are packed varies strongly, different levels of difficulty should be identified. In order to get an estimation of the work speed in this station, extra research will be done in the literature study.

On very difficult parts multiple workers will put the same part into the box to double the throughput, but that usually depends on if there is a spare worker available. If the speed of the assembly line is too high, or the workers can't keep up for another reason, a button is available to stop the entire assembly line. Another way that this station can cause an error is when a part is put over the edge of the box. This will cause the gluing machine to not be able to close the box and it will malfunction.

Station 3: The gluing machine

When a box enters the gluing machine, first the machine will fold the box to close it and it will glue one side of the box. Then it will turn the box 90 degrees and it will glue the other two sides. The machine uses a vacuum to keep the boxes from moving around on the conveyor belt too much. This is especially necessary for the lighter boxes. Boxes that have heavy products in them can have a lower vacuum setting. Boxes must go through this machine one by one. If two boxes enter the machine while touching pull a space between them and glue them individually

Changing the settings on this machine is very complex. When the speed changes, the gluing time has to be manually adjusted to this very accurately. Therefore, this machine is always operating at 90% of its maximum capacity. This gives it a throughput of about 54 boxes per minute.

The gluing machine can malfunction in several ways. The most common reason for malfunctioning is that the box is not packed correctly, and an object will prevent it from closing. This will cause the box to get stuck in the machine. When a box gets stuck, it has to be removed before the machine can be started again. The machine can also malfunction when the vacuum is set too low. This will cause the box to move around in the machine and can cause it to get stuck as well. The last way that the gluing machine can malfunction is when the glue is depleted. This usually doesn’t happen, because before it is empty an alarm light will give a signal and it will be filled before the supply is completely empty.

Station 4: Shipment box packaging and palletizing

The conveyor belt that carries the boxes out of the gluing machine always runs at 100% of the maximum speed. It puts the boxes in a buffer that has a size of 10 to 15 boxes. The size of the buffer depends on the product size. There are four different sizes of shipping box sizes. These fit either 4, 5, 6 or 8 finished products. Two workers get products from the buffer and put them in shipment boxes. When the box is full, they push the box through a box closing machine and it will be put in another buffer with buffer size 8. From here the boxes are stacked on a pallet by the same worker. Most workers have a routine of how many boxes they pack before they stack them on the pallet. Through observation it is determined that after every four to six boxes, they are stacked on the pallet. When the pallet is full, one of the workers will move it away and will get another pallet. Malfunctions occur when the workers cannot keep up with the output of the gluing machine. When the buffer after the gluing machine is full, the entire packaging line will stop. The buffer is considered to be full when a sensor is blocked for four seconds. In the meantime, the machine will keep gluing boxes and will empty the machine before pausing. When the sensor that measures if the buffer is full for is free for another four seconds, the line will start running again.

2.5 Extra worker

Sometimes, there are extra people available on the floor. If, for example, one order needed 7 people and the next one needs 6, there is an extra person available. When this happens, this person is either used to double the capacity of one of the parts or to fill supplies. When this worker is used to fill supplies, no malfunctions occur because of a lack of supplies. So the amount of errors will be much lower. This worker can also help to load the shipment boxes onto the pallet. This increases the capacity of the workers packing the shipment boxes, because they don't have to move from their spot to put the boxes on pallets anymore.

2.6 The operator

The operator is responsible for changeovers between orders and to adjust during the order to manufacture at maximum speed. The setup time can vary quite a lot, depending of what the next order is. When the box size is the same, no adjustment is needed except for changing the input. There are adjustable parts for the box folding machine that allow for a short setup time, because there are only some adjustments. In other cases, parts must be swapped. After this setup is done, it is tested and some of the successfully folded boxes are used to test the gluing machine. The gluing machine must be adjusted if there's a new box size. When it is adjusted it needs to be calibrated. If the weight of the boxes is different, the vacuum has to be adjusted. In total, this takes about 15 to 20 minutes.

When both machines are adjusted for the new product, the correct information will be filled in for the measuring system. During all these processes, the workers should have enough time to get supplies for the new order. When the order starts, usually the operator has an idea of how fast the packaging line can run for that product. For products that don't have a clear starting speed, it will start at 45%. When there are a lot of errors, the operator will decrease the speed. If there aren't a lot of errors, the operator will increase the speed. Adjustments are usually made in steps of -5% or + 5%. The speed at which an order can be handled depends greatly on the amount of people that are packaging and their experience with the component that they are packaging.

2.7 Data reliability

Data is being gathered in three ways. There is data that is available through observation, through the administration and data that is being measured by sensors in the packaging line. The data that is available through the administration is reliable information, because the administration provides constant values. The observed data will be an estimation, so it is a form of abstraction. The measured data is the least reliable because of multiple reasons. Firstly, the sensors might not always register what they want to measure correctly. For example, a sensor that counts the boxes that pass by counts two boxes as one when they are touching. Secondly, the data that is being measured is based on highly specific situations. If multiple measurements of the same product had a different number of workers, this will result in big differences. Thirdly, sometimes the operator will make mistakes while filling in the data or forgets to stop the program when the order is done. This will corrupt all the data that is based on the duration of the order. Lastly, since the packaging line is relatively new, there haven't been a lot of measurements yet and the system is still being developed. This means that there is only a small amount of data available and the data that is there includes a lot of test data or data that is gathered using different methods.

Since there is a lot of unreliable data available, it is important to have a critical look at what data can be used. Since the eventual goal is to optimize the throughput of the packaging line, there should be a way of determining the speed of the packaging line. The amount of downtime plays a big role the throughput of the packaging line. So, a reliable way of counting the malfunctions must be found.

Duration of the order is an unreliable factor in the measurements. This means that the found average speed is not useful. However, the program measures at what speed the box folding machine has been running. The box folding machine is the source of the whole process. If the input is 30 boxes per minute, the output will not be higher than 30 boxes per minute. The box folding machine speed therefore gives a good indication of the speed at which the packaging line is running.

To find the error sensitivity it is important to know what happens when the packaging line malfunctions. In case of a malfunction, the box folding machine will always shut down. This means that the amount of times that the box folding machine is started is equal to the number of malfunctions. However, since time is not measured accurately, it is not possible to calculate the number of malfunctions per unit of time. However, the planned order size is known. By using order size, the error sensitivity can be expressed in malfunctions per 100 products.

2.8 Sensor locations

There are four sensors placed on the packaging line. The first sensor is place at the supply of the box folding machine. This sensor measures when the supply of unfolded boxes is almost depleted. Once the supply is depleted an orange flashing light will turn on so that someone can go and fill the supply. This sensor doesn't measure any data that will be saved. The second sensor counts how many boxes pass through and is placed right after the box folder. It is important that there is a space between the two boxes. If two boxes are touching, the sensor will count them as one box. This data is saved as the number of products that is correctly folded and gives the speed of the box folder in real-time. The third sensor also counts the boxes and is placed right before the gluing machine. The fourth sensor is located after the gluing machine and measures if the buffer is full or not. Once the sensor is blocked for four seconds, it will shut down the entire packaging line. No data is stored. This sensor is placed behind the first worker and therefore it also counts how many boxes pass the first worker. This number is an indication if both workers are working at the same speed or not. It doesn't save the data, it only shows the real-time information.

Other data that is being gathered is: total amount of workers, total amount manufactured today, time past, downtime, break time, number of stop buttons, time it was stopped, box folding start ups and average throughput.

2.9 Conclusion

The packaging process itself is a quite simple and straightforward process. The complexity in the system comes from the different products that have to be processed by the packaging line. Another difficulty is the reliability of the collected data. There is reliable data available, but it has to be critically evaluated while it is being used.

3. Literature review

To get a better understanding of how to improve the packaging line, a theoretical background is necessary. We will take a look at what simulation is and how it works, some methods for detecting bottlenecks and resolving them by using line optimization methods. Finally, we will try to get an idea of how to estimate worker speed for repetitive actions.

3.1 Simulation

In the next section, literature about simulation will be discussed. We will take a look at what simulation is and how reliable data can be collected.

What is simulation?

Simulation is a technique that is used to numerically calculate a model by changing input values to see how they affect the performance of the model, given by output values (Law, 2015). A simulation can be terminating or non-terminating (Robinson, 2014). When a simulation is terminating it has a natural endpoint. When a simulation is non-terminating, there is no endpoint, so the simulation can keep running indefinitely.

Three dimensions determine what the type of a simulation is (Law, 2015). A simulation can be static or dynamic. In static, or steady-state, simulations a system is calculated in an equilibrium, which means that time is of no influence on the simulation. In dynamic systems, the results change over time. A simulation can be deterministic or stochastic. In stochastic systems the model contains some kind of probabilistic component. When this is not the case, a model is deterministic. A simulation can be discrete or continuous. In discrete systems, the state of the system changes at certain points in time. In continuous systems, the state of the system is constantly changing and are not triggered by events.

Acquiring reliable data

There are two issues that should be addressed when trying to get reliable output from a simulation, the initialization bias and obtaining sufficient data (Robinson, 2014). The initialization bias applies to non-terminating simulations and terminating simulations that do not start and return to an empty condition. In this case, the simulation needs some time to adjust for the empty state at the start and the first couple of replications have to be removed. In terminating simulations that start from and return to an empty condition, an initialization bias is not necessary.

Obtaining sufficient data can be done in two ways. It can be obtained by a single long run, or by performing multiple replications. A single long run only applies to non-terminating simulations. For terminating simulations, the only option is to perform multiple replications. The number of necessary replications can be calculated by using the confidence interval method (Robinson, 2014). With this method, a value *d* is chosen that will decide how reliable the data will be. This value will be compared to the value of the formula that calculates the width of the confidence interval, relative to the average of all of the replications. Once this value is smaller than *d*, there are sufficient replications. The formula that is used for this calculation is:

$$\frac{\frac{S}{\sqrt{n}} \times t_{n-1,1-\frac{\alpha}{2}}}{|\bar{x}|} < d$$

With:

n = the number of replications

$\bar{x}$ = The mean of the output data

S = The standard deviation from the output data

$T_{n-1,\ 1-\alpha/2}$ = The value from the student's T distribution with n-1 degrees of freedom and with a confidence of 1-α/2

In theory, it is necessary to calculate the number of replications for every experiment. In practice, the number is usually determined for the base model and then overestimated so that it can be used for all the experiments (Robinson, 2014).

3.2 Bottleneck detection

In the next section several methods for bottleneck detection that can be found in literature will be reviewed. Six different methods were found and at the end of the section, a comparison of the found methods will be made.

Turning point method

The turning point method was developed by Li, Chang & Ni (2007). This method is based on the time that stations are being blocked or starved. By calculating where the "turning point" is, this method will find the bottleneck. To find this turning point, the method relies on complex calculations, but an easy method for approaching the turning point would be to see where the difference between blocking and starvation time turns from positive to negative. Furthermore, the sum of both blocking and starvation time should be lower than the sum of blocking and starvation time in the neighboring machines.

This method is very well applicable to flow shop systems, but there are several problems, first of all, it relies heavily on data for each machine. There needs to be a way to find out when a machine is blocked or starved and how often this happens. Furthermore, there are systems in which the turning point method is not able to find the bottleneck at all (Roser & Nakano, 2015).

Bottleneck walk

The bottleneck walk (Roser, Lorentzen & Deuse, 2014) is a method that is not based on calculations, but it finds bottlenecks through observation. Basically, the method consists of walking around and identifying where machines are blocked or starved and checking buffers and inventories. By observing these, it can be decided if the bottleneck will be upstream or downstream. By following the path from both ends of the production line, eventually the bottleneck will be closed in. This system is easy to use and can identify bottlenecks in different kinds of system (Roser & Nakano, 2015). The bottleneck sets rules to in which direction the bottleneck will most probably be. This method is the most effective to identify where the bottleneck will be in complex systems, especially when there's no fixed sequence of machines such as in job shop systems but will work just as well in simple systems. Because in most systems the bottleneck will change from time to time, it is a good idea to perform the bottleneck walk multiple times.

Arrow method

The arrow method (Kuo, Lim & Meerkov, 1996) uses starving and blocking information to point out in which direction the bottleneck can be found. Instead of using starvation and blocking times such as the turning point method, the starvation and blocking frequencies are used. If the blocking frequency is larger than the starvation frequency of the next machine, the bottleneck will be downstream. If the starvation frequency is larger than the blocking frequency of the next machine, the bottleneck will be upstream. The arrow method is specifically designed to identify bottlenecks in serial production lines. However, just like with the turning point method, specific data is required to be able to apply it. Furthermore, when tested it fails to detect all bottlenecks in different kinds of systems (Roser & Nakano, 2015).

Active period method

The active period method was developed by Roser, Nakano & Tanaka (2002). It focusses on the active period of each machine to find a momentary bottleneck. The active period is the period in which the machine is not waiting for parts or materials. The machine that has the longest uninterrupted active period is considered the momentary bottleneck. The machine that is the momentary bottleneck most of the time is considered the average bottleneck. By starting with a momentary bottleneck, this method works even when the bottleneck can shift over time. It is applicable for complex job shop systems as well as simple flow shop systems. When tested by Roser & Nakano (2015), this method detected all the bottlenecks.

Simulation

Simulation can also be used to identify bottlenecks. First a simulation model must be constructed. Then throughput analysis will be carried out to identify where the bottlenecks are. The quality of a simulation model depends on many factors, such as how closely the simulation can appropriate the real world and the skill level of the programmer (Li, Chang & Ni, 2007). Problems of the simulation method are that it's not a flexible method, since every production line needs a new simulation and it has high costs to make a simulation. In general, it isn't efficient to build a simulation model just to do throughput analysis. However, using simulation doesn't exclude other methods. It can be used as a source of confirming the adequacy of another method (Kikolksi, 2016). Simulation models will also be useful for finding ways to remove bottlenecks, because it allows to run experiments without having to do any actual physical testing.

Utilization/Waiting times/Queue length

There are several methods that are based on utilization, waiting times and queue length. A couple examples of these are described by Law & Kelton (1991). These methods are some of the most commonly used ones in the industry (Roser & Nakano, 2015). They work well to give an indication of where the bottleneck could be in simple systems, but when tested in more complex systems, these methods often give an incomplete picture of the situation, or an unclear result. Especially when it comes to systems in which the bottleneck shifts over time, Roser & Nakano (2015) have proven these methods to be inaccurate.

Conclusion

When we look at the found methods, two types of methods can be found, those that apply to static bottlenecks and shifting bottlenecks and those that only apply to static bottlenecks. Since it is likely that our bottleneck problem is located in different stations for different product groups, it is a good idea to investigate methods that are able to detect shifting bottlenecks. Roser and Nakano (2015) state that it is imperative to first detect the momentary bottleneck before calculating averages of the overall effect on the system and that methods that use averages before detecting the bottlenecks are likely to fall short. From their analysis, the active period method is considered the best one for data-rich environments. The bottleneck walk is considered the best method for an observation on the shop-floor. Simulation can be considered a separate type of method, since it's able to use any of the other methods. Therefore, simulation is a powerful tool to use for confirmation of the used methods. In this project, the bottleneck walk will be used to detect the bottleneck, then simulation will be used to validate the bottleneck walk.

3.3 Line optimization

In the next section, literature about line optimization will be discussed. First, we will discuss the theory of constraints, then optimized production technology and finally the drum buffer rope method. At the end we will look at which of the methods are useful for our research.

Theory of constraints

The theory of constraints (TOC) (Goldratt, 1988) was developed to increase throughput of an entire production plant. It introduces the idea that bottlenecks can influence the throughput of the whole production process. By focusing on the exploitation of bottlenecks the efficiency of the plant can be improved. The theory of constraints can be applied by using the five focusing steps. First, the current constraint should be identified. This is will be the process that is limiting the rate at which the goal is achieved. In the second step the bottleneck should be exploited. This means that with existing resources improvements should be made. Thirdly, all other activities should be subordinated to the bottleneck to make sure that they support the needs of the constraint. In the fourth step, if the constraint is still there, actions are considered that can be taken until the constraint is eliminated. In the last step, the process will be repeated.

Optimized production technology

Optimized production technology (OPT) (Goldratt, 1988) is a scheduling tool that differentiates between bottleneck and non-bottleneck processes. By seeing these two as different processes, it makes it clear on what processes the focus should be. OPT follows from the TOC. It follows a set of rules that tell how to manage bottleneck and non-bottleneck resources. These rules state that it is useless to improve capacity on non-bottleneck resources and that the main focus should be on making sure that the bottleneck is always working.

Drum buffer rope

The drum buffer rope (DBR) (Slack, 2016) methodology follows from the TOC and the OPT. It uses analogies to find a solution for planning and scheduling problems. DBR says that there is always a process in the plant which is limiting capacity. This limiting process is the bottleneck and therefore, it sets the pace for the other processes as if it is a drum, setting the rhythm. It is important that the drum is not disrupted, so planning behavior has to be focused on exploiting the drum. The buffer is used to protect the drum. By making sure there is a buffer in front of the bottleneck process, the bottleneck station can always be active. The processes in front of the bottleneck should be synchronized to the bottleneck, so that the buffer will remain full, but it won't overflow. This synchronization is as if these processes are tied together and therefore move at the same pace. That is why the synchronization is also called, the rope.

Conclusion

The TOC is a strong basis for improving the packaging line. This iterative concept can be used to keep improving the packaging line over time. However, the TOC does not give any specifics on how to optimize anything. It is more a general method for improving plants. OPT Gives a more specific idea of how to look at bottlenecks and how to work with them, but it still is a very general method that states rules about plant design. As long as these rules are followed, a production system should be working efficiently, but it still only gives a general idea of how to look at bottlenecks. The DBR method gives a more specific solution to the problem. It introduces the idea of buffering and communication between stations to improve the workflow.

For this project, the theory of constraints will be used as a mechanism to detect and solve the bottleneck. The drum buffer rope method will be used in the experimentation phase to analyze the existing buffers and possibly add new buffers to the system.

3.4 Worker speed

In the next section we will discuss literature about how to estimate worker speeds for repetitive action. This will help to get an idea of how fast the workers in the product packing station can work without getting injured. Two methods will be discussed, the OCRA method and the HAL/TLV method.

OCRA

An estimate of average worker speed for repeating actions at a high frequency can be found when looking at the occupational repetitive action method (Occhipinti, 2008). The OCRA method is a complex method for determining how many actions per minute a worker can do without it being hazardous for physical health. The method starts with the action frequency constant of 30 actions per minute and adjusts it depending on the specific movements made and the force used. According to the OCRA method, more that 40 actions per minute can only be done for periods shorter than an hour. More than 40 actions per minute for longer than an hour has too high of a risk of injury.

HAL/TLV

Another method for assessing risk of injury for repeating actions at high frequency is using the threshold limit value (TLV) for hand activity level (HAL) and normalized peak force (NPF) (Latko, 1997). This method uses HAL and NPF to give an upper bound to how fast workers should work. It also suggests an action limit, which gives the recommended work speed. HAL has a value from 0 to 10 that is estimated. When the value is 0, it means there is no activity, when it is 10 it means the worker can only just keep up with the tempo. The NPF is a percentage of how much of the maximum force of a worker is used. This can be measured using specialized tools, but since this differs per worker and is difficult to measure, this can also be estimated. As can be seen in figure 3.1, the general idea of this method is that for actions that require little force, the frequency can be higher than for actions that require more force. Whenever the TLV is exceeded the activity has a high chance of causing injury.

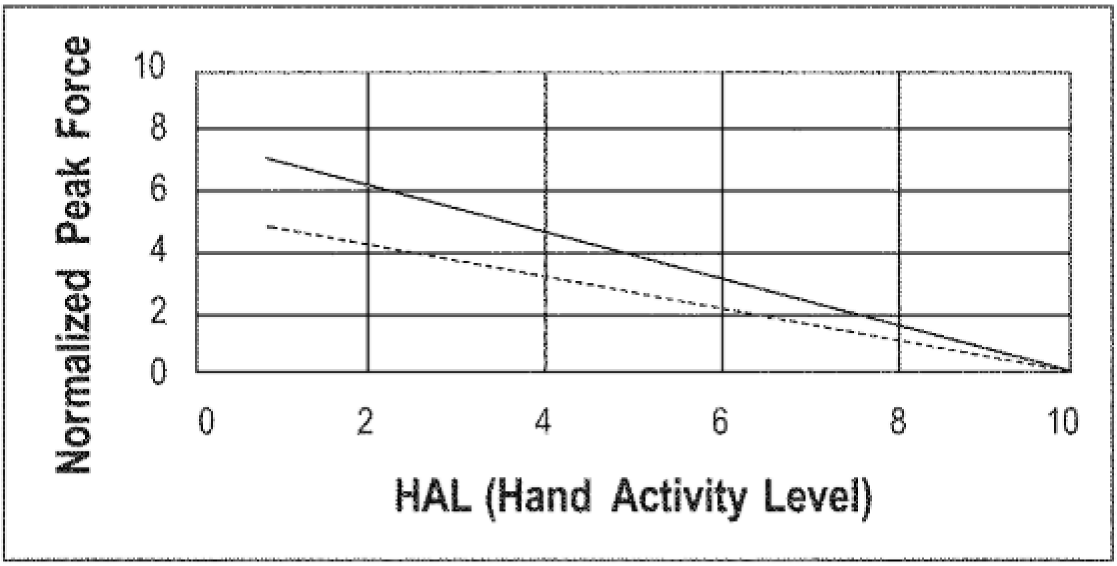

Figure 3.1) HAL/TLV

Conclusion

Both the OCRA method and the HAL/TLV method give good estimates of a maximum limit to how high activity frequency should be. To be able to use the OCRA method fully, specialized knowledge is needed. This knowledge is unavailable, but the action frequency constant can be used to give an indication of average work speed. Furthermore, the upper limit of 40 actions per minute for work longer than one hour can be used. The TLV method relies heavily on estimations and therefore, will not be very accurate. However, it does give a good idea of how action frequencies change when products get heavier. The OCRA method will be used in the data gathering phase, to get a good idea of the working speed of the product packing workers. The HAL/TLV method will be used to visualize at what speeds the workers should be working to not be at risk of injury while running an efficient packaging line.

3.5 Conclusion

Several sources have been found that gave a better understanding of the system and possible solutions. It is clear how simulation can be used to obtain reliable data. This will be useful in the implementation phase. Bottleneck detection methods have been found and the bottleneck walk will be used in the data gathering phase, while it will be verified by the base model of the simulation. Possible solutions for line optimization have been found. The theory of constraints and the drum buffer rope method will be used to construct experiments. Finally, the OCRA method gives a good idea of the maximum speed at which a worker can work without having risk of injury and the HAL/TLV method gives a way to visualize this.

4. Data gathering

In chapter 2, a general idea about what the line looks like has been given, but to get a better understanding of how specific parts of the packaging line work, additional data is needed. The methods that were found in chapter 3 will help with this process. First, data on the bottleneck will be gathered and the bottleneck walk will be used to find the bottleneck. Then the products will be grouped, so that not every product will have to be tested individually. Afterwards, the worker speed for the product packing and the shipping box packing will be estimated. Finally, the duration of failures of the system will be estimated.

4.1 Bottleneck detection

To find what stations could be the bottleneck, the bottleneck walk, as described in section 3.2 is used. In the bottleneck walk, inventories are analyzed to see if the bottleneck is upstream or downstream. This is done multiple times so that it can be detected if there is one bottleneck, or multiple bottlenecks.

During the bottleneck walk, two different situations could be found. The results of these bottleneck walks can be found in figure 4.1. The top row gives the results for the first situation, the bottom row gives the results for the second situation. In the rows, circles and arrows can be found. The circles indicate how much inventory there was. The more colored circles, the more inventory. The arrows indicate in which direction the bottleneck will most probably be. The bottleneck is found where two arrows are pointing at each other. Usually the bottleneck is positioned at the station that has a big inventory which causes the next station to be starved. Another possibility is that the bottleneck is somewhere in between the two stations, for example in transportation.

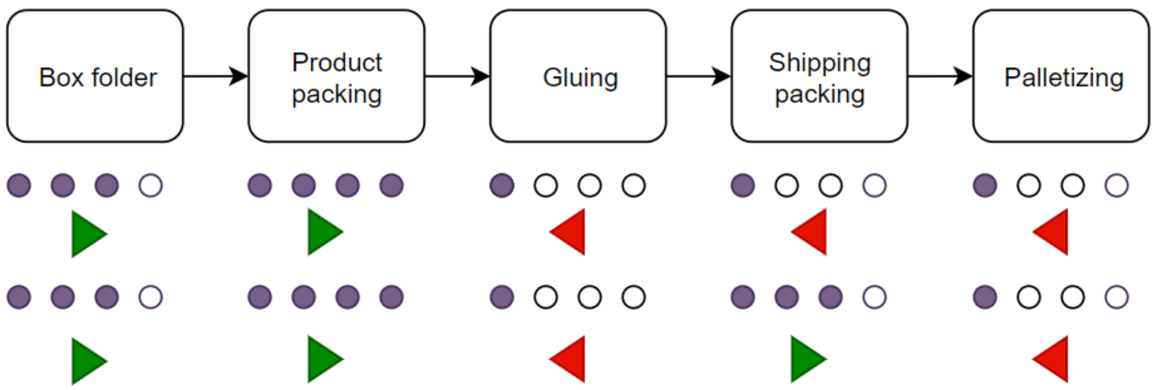

Figure 4.1) The bottleneck walk

In the first situation the packaging line was always running at a low speed, which was usually 50% of the maximum speed of the box folder or less. The box folder always only has a problem with inventory when it is depleted. This causes downtime but it can easily be solved by filling the supply. The product packing was always busy and was never starved. The products they were packing were often difficult to grab or fit in the box in some way. The gluing machine was running at 54 products per minute, but was getting way less than that, so it was starved for a big part of the time. In the shipping box packing and palletizing the workers were able to work slowly. It was obvious that they could work faster if necessary. They were even able to leave their stations for short moments and let the buffer fill up until they were back. Sometimes they would cause downtime because of this, but they were obviously not the bottleneck. Where the two arrows meet in figure 4.1 are the product packing and the gluing machine. Since there is no transportation problem in between these stations, the product packing must be the bottleneck.

The second situation was slightly different than the first situation. It occurred when the line was running at higher speeds than 50% of the maximum speed of the box folder. These speeds could only happen for products that only had simple parts to pack into the box. The box folder was similar to the first situation. It was running at a higher capacity, but still not getting close to the maximum capacity. In this situation it really depended on the type of product if the product packers could easily keep up or not. With some products they were managing, but sometimes having trouble to keep up. For the very easy products, they could easily keep up. The gluing machine was still starved for a big part of the time. At the shipping box packing they were constantly working at these speeds and had no time to spare. Every time a mistake was made, and something took a little bit of extra time, an error would occur. Sometimes an extra worker would be used here to do the palletizing, but even in these situations the shipping box packers always had inventory and they had little room for mistakes. In the results of the bottleneck walk in this situation two bottlenecks can be seen. Firstly, the product packing bottleneck that was also observed in the first situation. Secondly, at the shipping box packing a bottleneck can be found. Especially when the workers would do the palletizing themselves, a lot of downtime was caused here.

For the first situation, the capacity of the workers can easily be measured. The speed at which the box folder can be set and the workers can just keep up is their maximum capacity. However, the capacity of the shipping box workers is not that trivial. The packing of the boxes could be done at a high pace. Sometimes the workers were even starved for boxes to pack. The problem here would be the variance. If some boxes would be slowly packed for some reason, the buffer would fill up and the line would stop. This means that it will not be possible to measure if this is a bottleneck by using the capacity of the workers. Instead, a combination of the capacity and the caused downtime should be analyzed.

4.2 Product groups

When special one-time orders are included, more than 500 different products are being processed by the packaging line. Many toys are discontinued within a year and there are around 80 new products each year, so it does not make a lot of sense to analyze each product separately. Instead, a categorization is made, based on the data that has been collected by SES. However, since the measuring system is relatively new, there are a lot of measuring errors and there is not a lot of data available. Therefore, the available data is critically evaluated for correctness by me and the operator.

Firstly, the decision on what products to omit must be made. According to SES it is not worth it to evaluate products that have a sales forecast of less than 7500, since can be made in one order. Furthermore, there are products of which the parts are being fitted into a plastic frame. These products are a special case, because packaging them takes a lot of precision. Therefore, they are extremely slow products to pack. SES is working on another solution for these products, so they can be omitted in this project.

The speed of the packaging line is determined by the maximum speed of the product packaging workers. The speed at which they work is described as a percentage of the maximum speed of the box folder, because the rate at which the box folder can be configured is the speed at which the product packaging workers will work.

The product packaging determines at which speed the box folder can run. On products that are easy to place in the box, the box folder can run at a very high speed. If there are more difficult products to pack, the speed will be lower. Usually the operator will adjust the speed of the box folder in steps of 5%, so this will also be the interval in which the categories are made. These speed intervals will be used to group the products. The list of groups that are made can be found in table 4.1.

Table 4.1) Product groups

Category	Speed
A	35%
B	40%
C	45%
D	50%
E	55%
F	60%

4.3 Product packing speed

Through observation, three different levels of complexity for the product packaging process have been found. There are products that are difficult to grab or difficult to fit into the box, difficult to grab and difficult to fit into the box and products that are easy to grab and easy to fit into the box. Parts that are difficult to grab can be those that somehow get stuck to each other such as parts with hooks or stacks of paper. Other parts that are considered difficult to grab are when an exact number of units needs to go into the box. Parts that are difficult to fit into the box are usually big or light products that barely fit or easily move out of the box through vibrations of the assembly line. These three levels of complexity will be used to estimate the speed of the product packing process.

According to the OCRA method, repetitive movements with a speed of more than 40 actions per minute for longer than an hour can result in injuries. Since the duration of the shifts is longer than an hour, the workers should never be forced to work at a faster speed than 40 products a minute. The fastest shift that was measured had a speed of 43 products per minute. The only way to reach these speeds is if multiple people will pack the same product and all the parts are simple to grab and simple to fit in the box. We won’t take this situation in account. The slowest shift that was ever measured in the packaging line had a speed of 20 products a minute. Slower than this will also result in badly folded boxes, because the box folder does not work well like this. This was a product that had a lot of complex parts. The OCRA method uses the action frequency constant as a starting point. The action frequency constant has a value of 30 actions per minute. This value fits nicely in between the other two found values. Therefore, it will be used as the speed for the middle level of complexity.

Figure 4.2 shows the HAL diagram. This diagram shows the threshold limit value (top line) and the action limit (dashed line). The blue horizontal line is the force that is necessary to pack the product parts. All the parts are quite similar in size and weight, so a constant value will be used for this. The red zones indicate which settings cannot be used, because they will result in injury or because the machines won’t operate. The yellow zones indicate where the machines can operate and it won’t result in injury, but the workers are not operating as fast as they can. The green zone is when the action limit is reached. This is where the workers should ideally operate to reach maximum efficiency.

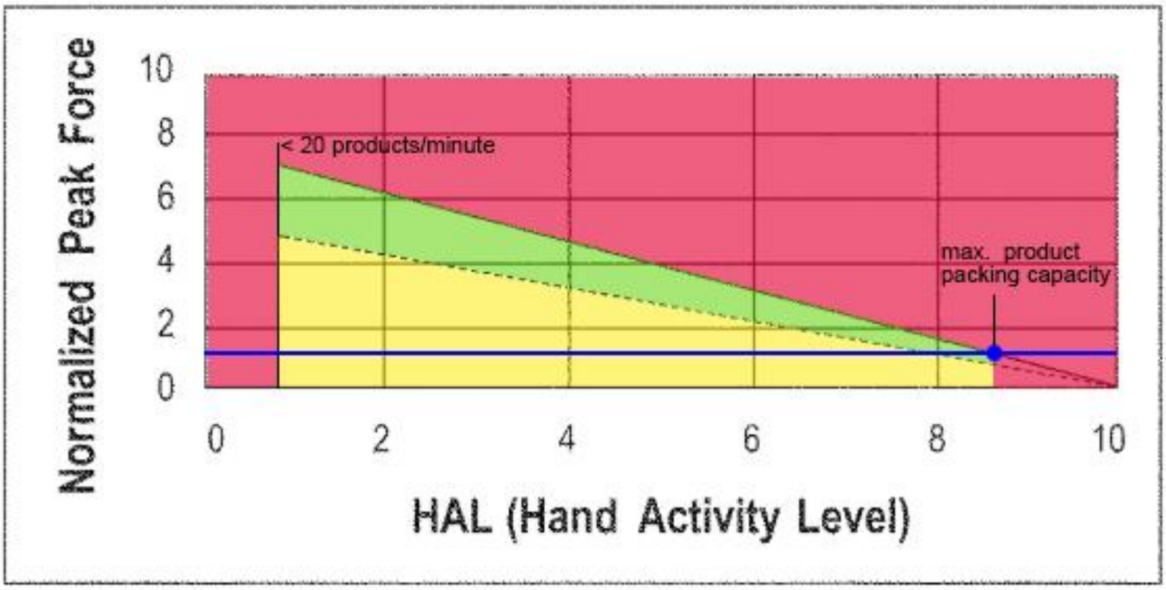

Figure 4.2 HAL/TLV for worker speeds

4.4 Shipping box packing and palletizing speed

To find the speed of the shipping box packing and the palletizing, observations have been done. The first observation is the time it takes to fold one box, pack it and close it. This was measured from the time that the worker would first touch the box he was going to fold until he would touch the next box. The observation has been done 30 times. These observations can be found in appendix A. Afterwards, the software "Easystat" was used to fit a distribution to the data. The distribution that was found is a normal distribution with the parameters μ = 14,467 seconds and σ = 1,432 seconds.

In the second observation, the palletizing speed was observed. Again, 30 observations were done. All the observations could be rounded up to 3 seconds per box. Since all of the observations were this close, the assumption is made that palletizing can be done with a constant speed of 3 seconds per box.

4.5 Failure duration

Three different failures can occur in the system. The supply at the box folder can run out, the product packaging can cause a failure and the shipping box packing can cause a failure. The shipping box failure will automatically be solved by the system itself. When the buffer empties enough, the line will start running again, so for this failure, there does not have to be an estimation of the duration. For the other two failures, we do have to estimate how long they take. Since it is not always predictable when the system will fail, only ten measurements have been done for both types of failures. The observations can be found in appendix A.

When the box folder supply runs out, one of the product packing workers will have to go to box folder and restock the supply. The time that it takes can vary a lot depending on if a pallet with new boxes is available at the box folder or not. Times were measured from 66 seconds to 191 seconds. There does not seem to be a relation between these times, so it is assumed that the failure duration is uniformly distributed between the values 66s and 191s.

When a product packing failure occurs, the workers press a button and the line will stop. Since the line does not immediately stop, the workers will have to fix the products that they could not keep up with. Then they will usually make sure that they open the boxes so that they will have a big enough supply and then they will start the line again. When the delay is small, this failure can be over quite fast. When there is a big delay, the failure takes a lot longer. Times were measured from 31 seconds to 133 seconds. With these measurements there also does not seem to be any relation between the results. It is assumed that the failure duration is uniformly distributed between the values 31s and 133s. These assumptions are quite arbitrary and with more measurements, a more accurate prediction could have been given. However, for now this assumption is realistic enough.

4.6 Conclusion

The bottlenecks have been found, by using the bottleneck walk. There are two situations that have different bottlenecks. In one situation, the product packing speed is limiting the system. In the other situation the worker speed of the shipping box packing is the bottleneck. The products have been categorized based on the speed at which the box folder is running. This resulted in six product categories. Estimates for the worker speeds have been given. For the product packing, boundaries have been found that should not be exceeded by the workers to not risk injuries. For the shipping box packing, a distribution that gives the working speed has been found. For the duration of failures estimates were made by fitting distributions to the observed data. Now, enough data is collected to be to start developing the conceptual model.

5. Conceptual model

In order to be a realistic representation of the packaging line, the simulation needs certain system requirements. These requirements can be grouped into three categories. These categories are abstraction, initialization and validation. For the abstraction it is important that the assumptions and simplifications about the packaging line are realistic. It is not possible to realistically model every detail of the system, so the abstraction that is decided on needs to be well thought out. In the initialization the correct settings and input values will have to be used. The settings and input values should model a realistic scenario. Correct settings will also make sure that the output values are reliable. A valid run length and number of replications will be necessary for this. To find realistic output values validation and verification is necessary to ensure that the simulation does what we want it to do and that it calculates the output data in a realistic way. Lastly, it is important that the output data that is calculated is the data that is useful for the research. This will be enough data to be able be reliable, but also not more data than necessary. How these model requirements are found can be read in this chapter.

5.1 Assumptions and simplifications

In the next section, we will talk about the assumptions and simplifications that will be done in the conceptual model. Assumptions and simplifications are necessary, because it will not be possible to make a perfect copy of reality. In this section we will discuss what the simplifications will be and why they are necessary.

Setup times are not included

Between every two orders some, setup is required. The duration of the setup can be anywhere between almost instantly to about 20 minutes. This depends on how different the previous order is from the next. With smart planning, setup times can be significantly reduced. However, since the simulation will only run single orders, the duration of the setup times is not of importance. Therefore, setup times will be omitted from the simulation.

Failures are modeled as a pause

In the packaging line, whenever a station fails, someone will have to go there to fix the problem. Usually this will be the operator, however the operator is working in different departments of the factory, so he might not be there. Usually when this happens, there is someone else available to fix the problem and to restart the line. When the operator is present, he will adjust the settings if necessary, to prevent future failure. This means that when the operator is there, slightly less failures will occur. However, since this is difficult to measure, we will not model this. Instead, in case of a failure, the machine will shut down for a period and start back up automatically.

No re-entrance

Sometimes it will happen that a product does not get properly packed or the box is not glued correctly. When this is noticed before a failure occurs and the product remains undamaged, the product will be placed back on the line. It also happens that a product is damaged during a failure. In this case a product is rejected. Often when a product is rejected, parts can be re used and will re-enter the system. Since re-entry rarely happens and is of little influence on the performance of the system, the simulation will not have re-entering products.

Moving pallets is not modelled

When a pallet is completely full, one of the shipping box packers will move it out of the way and place a new pallet to load onto. Usually this will be done during downtime and it takes under a minute do this. When the line is running at high speeds there will even be an extra worker available to move the pallets. Since the moving of pallets is of a negligible influence on the system, it is not modeled.

Long failures are not modeled

The duration of failures varies strongly. Some failures, such as filling supplies, have a quite constant duration. Other failures can cause a lot of downtime. In the real system it happens that a certain method to pack the box does not work fast enough, or that settings must be changed during the order. It can occur that for these reasons testing will be done during order. This results in long failures. Since these long failures are always out of the ordinary, they will not be modeled. In the simulation failures will have a maximum duration of 191 seconds, since this is the longest observed failure.

There is an infinite supply of shipping boxes

The shipping boxes will be generated by a source that has an infinite capacity. This means that there always is a folded box ready to be filled. The time that it takes to fold the box before it can be filled is taken into account in the distribution of the packing speed.

Packaging Unit (PU)

The packaging unit determines how many products go in one shipping box. PU's of 4, 5, 6, 8 and 12 are being used. By far the most used PU's are 6 and 8. The PU's 4 and 5 are used respectively 3% and 6% of the time and 12 is only used for special orders, which occur 1% of the time. The PU 6 occurs 62% of the time and PU 8 occurs 28% of the time. Since having to test for both the PU's 6 and 8 will double the amount of experiments that need to be conducted, the PU will be set to 6 for the base model, as this is the most occurring PU. However, since the packaging unit will most probably influence the throughput of the packaging line, an experiment that varies the different PU's will be added in the experimentation phase.

5.2 Input data

In the next section the input data of the system will be discussed. In figure 5.1, a black box model of the conceptual model can be found. This model shows the input and output of the system. What values the station speeds are getting will determine what product group is being handled by the system. Furthermore, the inputs for the system are the sizes of the buffer after the gluing machine and the shipping box buffer, and the error probability of the different stations. The output data that the model will collect is the error rate, which gives the average number of errors that are made every 100 products, the total downtime during the run and the total products that were made over the total duration of the run.

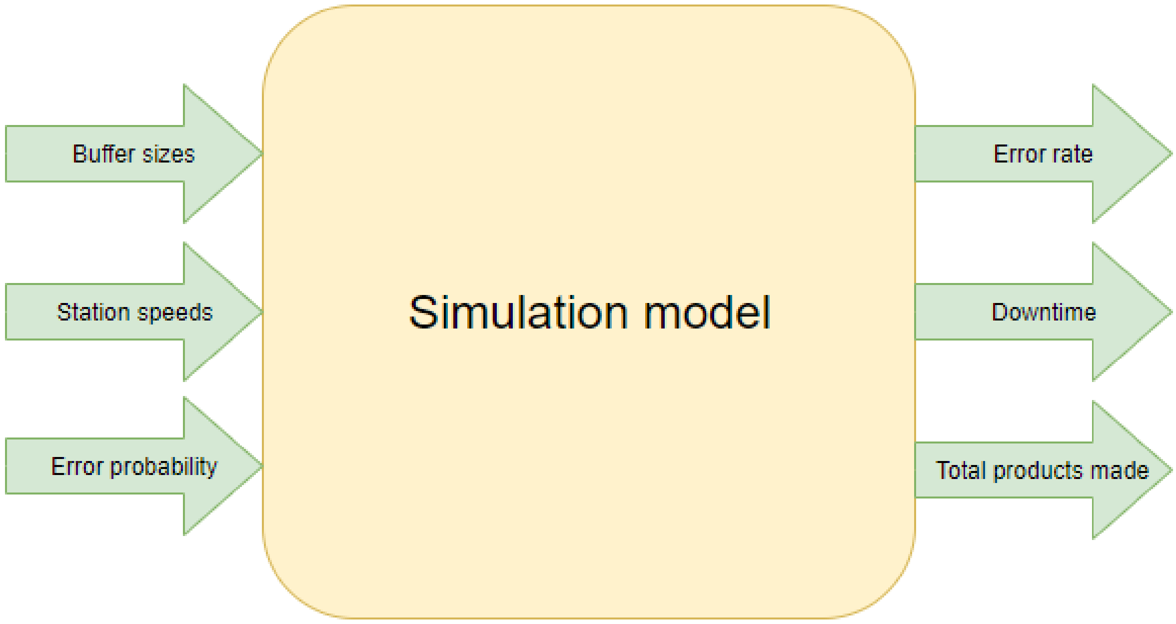

Figure 5.1) Black-box model

Product groups

Since it will take too much time to run the simulation for every possible speed, the categories that were made in section 5.2 will be used for the simulation. It also is not necessary to test all the categories that were made. If the slowest category and the fastest category can be verified and validated then we can assume that the categories in the middle will give correct outputs as well.

Since there are two bottlenecks in the system, experiments will have to be run for both situations. In the situation where the bottleneck is the product packing, the system is always running slowly, so a category with a low speed will be used. In the situation where the shipping box packing is the bottleneck, a category with a higher speed should be used.

The slowest category that has a speed of 35% of the maximum speed only happens occasionally. Therefore, this category is omitted in testing. Instead runs at 40% of maximum speed will be used to simulate low speeds. The highest possible speed that the product packers should work at is at 60% of the maximum speed. This will be used as the fast category. The final product groups that will be used for testing can be found in table 5.1.

Table 5.1) Product groups that will be used

Category	**Speed**
B	40%
F	60%

Buffer sizes

Box folder supply: The exact maximum supply of the box folder is unknown. It can work with a supply of a certain weight, but since the weight of the boxes vary, the exact maximum number of boxes that it can handle as a supply is unknown. When the box supply is filled, a mark is used so that they know until where the supply should be filled, but it usually is not filled to exactly where the mark is. The operator says that usually the number of boxes that can fit in the supply will be around 400 to 600. Since there is no way of knowing how this is distributed, a uniform distribution in between 400 and 600 will be used as the box folder supply.

Shipping box buffer: The buffer of the shipping box packing fits 10 boxes before it blocks the sensor. Once the sensor is blocked for four seconds, the line will shut down. In these four seconds, another four boxes will be added to the buffer. That means that when the buffer is filled with 14 products, the line will shut down. Therefore, a buffer size of 14 boxes will be used.

Palletizing buffer: In the buffer before the palletizing it will fit 8 boxes. However, most of the workers have a routine. They close four boxes and then they walk over to the pallet and they stack them. So usually they do not use the full size of the buffer. From observation it has been found that usually the workers limit the buffer to a size of 4 boxes, so this is the buffer size that we will use.

Workstation data

Box folder: The box folder has been clocked at a maximum speed of 66 boxes per minute. In reality, the speed of the box folder is adjusted to the speed of the product packers. However, if it will be simulated like that the statistics that will be gathered about the box folder would be wrong. Therefore, we will use the maximum speed of the box folder and it will be limited by the speed of the product packers. It is not realistic that the box folder will always be used at the maximum speed, so we will set it at 60 boxes per minute.

The box folder does not break down, unless it is running at extremely slow speeds. Since this should never happen it will be assumed that it only fails when the supply runs out. Other breakdowns do not occur.

Product packing: The previously found product packing speeds indicate that it will be somewhere in between 35% to 65% of the maximum speed of the box folder. Since it was decided that the slowest category will be run at 40% and the fastest at 60%, these will be the values that will be used for the simulation. This comes down to 26,4 products per minute for the slowest category and 39,6 products per minute for the fastest category.

The product packing can cause the line to stop because of two different reasons. Firstly, they can press a button when they cannot keep up with the speed of the line. Secondly, when a product is packed incorrectly it can cause the gluing machine to not be able to close the box and it will cause a breakdown. The assumption can be made that both these situations occur because the workers cannot keep up with the speed of the line. For errors will be made when working under pressure. By using this assumption, there is only one reason why the product packing fails; one of the workers is too far behind.

To model this situation, a delay will be generated that will either be added or subtracted to the total delay. Since a worker will not be able to work ahead of schedule, this delay can only have a positive value. Once the delay get above a certain threshold, the line will stop and the total delay will be reset. During the testing, the value of this threshold must be determined, so that the error distribution will be similar to the actual error distribution.

Gluing machine: The gluing machine has a maximum capacity of 60 products per minute. It is always run at the same speed, which is 90% of the maximum speed. Therefore, the used capacity for the gluing machine will be 54 products per minute. If the gluing machine is set up properly, it will only fail when a product has been packed wrongly. This can occur when an object is sticking out of the box or when an object is too high for the box to close. These failures will be modeled as a product packing error.

Shipping box packing: For the shipping box packing, the distribution that was found in the data gathering will be used. This is a normal distribution with parameters: μ = 14,467 and σ = 1,432. This station will be modeled as an assembly station, since it will group several boxes together and it will put them inside a bigger box. Therefore, a new source to generate shipping boxes will be necessary. The time it takes to prepare these boxes is included in the distribution, so the source can generate shipping boxes at an infinite speed. For the assembly to take place, a worker needs to be at the assembly station, so this station will be modeled with workers that will handle both the assembly and the palletizing.

When the workers cannot keep up with the speed of the line, the buffer will fill and when it is completely full an error will occur. Once the sensor is not blocked anymore, the line will wait for four seconds and then start back up.

Palletizing: The palletizing is observed to be done at a constant speed of three seconds per box. This will be speed that will be used. The palletizing cannot cause an error. During a slow run of the system, there are two worker active that can do both the shipping box packing and the palletizing. During fast runs however, there is often an extra worker that only does the palletizing. For this situation, the worker can stay at the shipment box packing. Then the capacity of the of the palletizing worker is 60/3= 20 boxes per minute, which must be multiplied by packaging unit to get the products per minute. Since this capacity is way higher than the capacity of the two shipping box packers combined, it can easily keep up and it will not be necessary to simulate an extra worker here. It will be sufficient to use a station without workers.

5.3 Output data

Downtime: The downtime says how much time the simulation has been running during an error. The ending value is the total downtime of the order.

Products made: The products made gives the number of finished products that exit the system. The ending value should be the size of the order.

Error rate: The error sensitivity returns the amount of failures per 100 products.

Real-time data: All the KPI's can be monitored in real-time during the simulation. There are also several counters, the supply levels and a variable that gives the delay in product packing.

5.4 The conceptual model

When combining all the data that was gathered, the conceptual model that can be found in figure 5.2 is created. The model gives an overview of the stations that will have to simulated and their attributes. Per station the attributes are the buffer size, the capacity and when it will fail. The buffer size is either given as a constant or as a statistical distribution of the buffer size. The capacity is given in products per minute or a statistical distribution of the number of products per minute. When the station will fail is given as the situation that causes the station to fail, followed by the distribution of the duration of the failure.

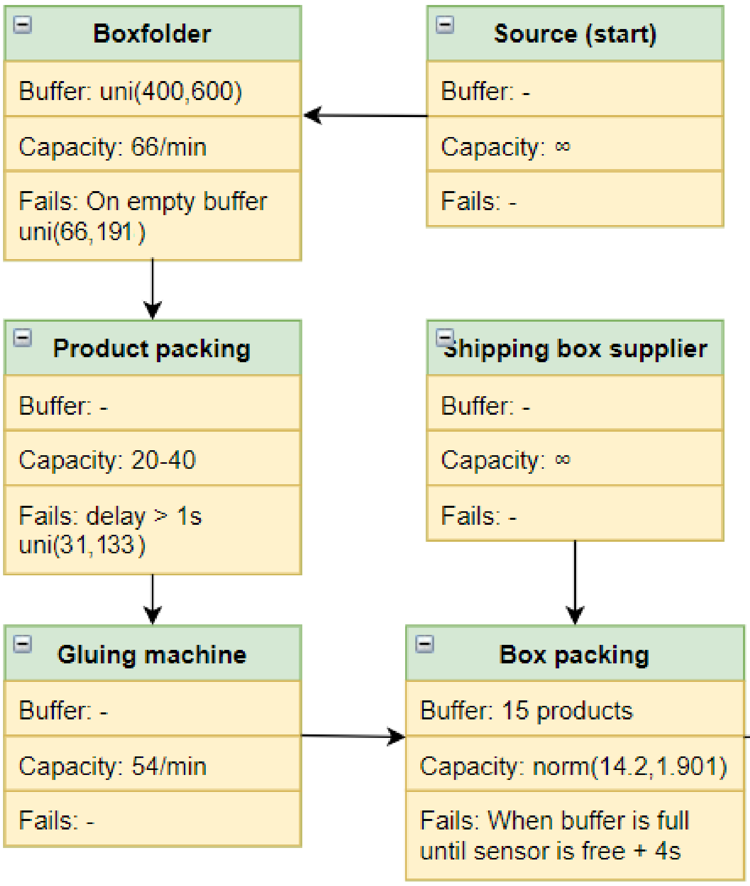

Figure 5.2) The conceptual model

The model has two sources and one drain. The sources are the main source, which is the first station of the model, and the shipping box supplier, which generates the shipping boxes. The arrows in between the stations indicate in which direction the product moves. At the box packing station, multiple products are merged into one shipping box. From that point, one unit is no longer one product, but the number of products that fit into one shipping box. However, the capacity is still given as the number of products per minute. The number of products that fit into one box depends on the packaging unit.

At the end of the model a drain is simulated that has an unlimited capacity, no buffer and it never fails. That means that once the box is stacked onto a pallet, it is out of the system and this is where the system stops. Since we decided to not model the moving of the pallets, this is modeled as a single pallet that has an infinite capacity.

Now that the conceptual model is constructed, we can look at how to implement, validate and verify the model.

6. Implementation, validation and verification

In this chapter we will look at how the implementation of the model is done and how it can be verified that the model is correct. First, we will see what the simulation model looks like. Then we will look at the different phases that the model goes through. Finally, we will look at the verification and validation of the generated data.

6.1 Implementation

A top view of the simulation can be found in figure 6.1. The main source is marked with a green circle and the drain is marked with a red circle. The source is placed right next to the box folder. From the box folder a line runs to three stations to the right. These three stations model three product packagers. From there, the line continues and has two curves. After the second curve the gluing machine is modeled and after the gluing machine the buffer. From here The line splits up into two assembly stations where the shipping box packers are modeled. After the shipping box packing, there is another buffer and afterwards the palletizing station. After the palletizing station, the boxes go into the drain.

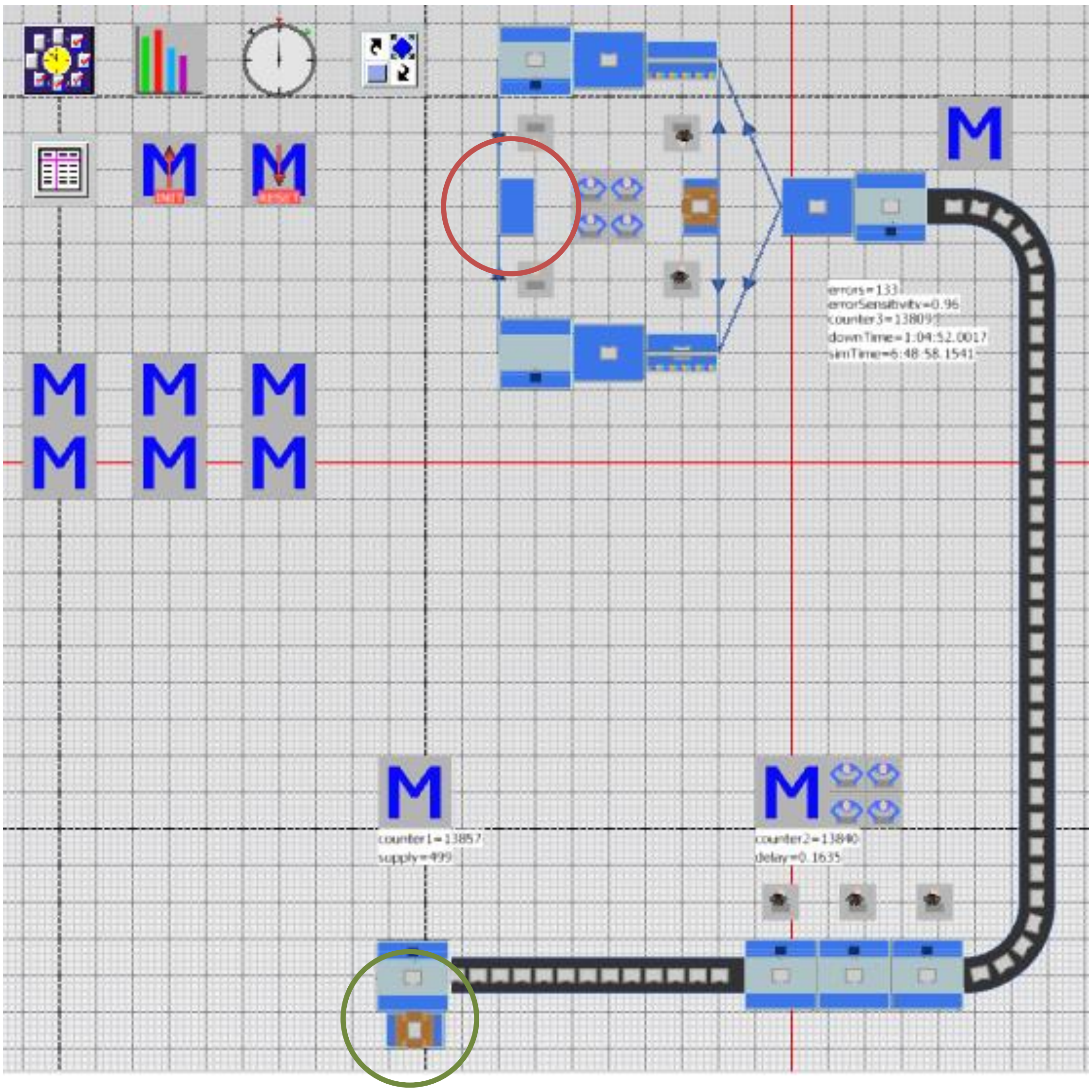

Figure 6.1) The simulation model

On the top left of the image four controllers can be found. The first one is the experiment manager. This controller runs the experiments that need to be conducted. Next to that is the chart. The chart collects data on the different stations and gives information about their performance. Next to the chart is the event controller, which runs the actual simulation. Finally, there is the broker. The broker assigns jobs to the workers in the simulation.

In the row under the controllers, three initialization controls can be found. The first one is the table file which is used for the data input. Next to it is the initialization method which will assign the input values to the correct stations. This method also checks the input data so that wrong input cannot be given. The last method is the reset method. When a simulation is done and is reset, the reset method will make sure that all the variables will get their initial values.

Throughout the simulation several methods can be found. To the left, a block of methods can be found that control the shipping box packing, the palletizing and the corresponding buffers. At the box folder and at the product packing there are two methods that control the box folder errors and the product packing errors. Right in front of the gluing machine there is a method that controls the sensor that counts the products.

In several locations in the simulation variables can be found. The main variables can be found in the top right. This is where the output data is kept. During runtime these variables can also be checked. Both the box folder and product packing methods have two variables that track the line activity. Based on what is measured in the line, the methods control the error rate.

Initialization phase

In the initialization phase all the workstation input is loaded into the correct stations. The correct work speeds, buffer sizes, failure sensitivity and order size are loaded. The input is checked for correctness, so that any typing mistakes are caught. By changing the input, the desired scenario can be selected.

Run phase

During the running phase, the simulation is making the products. How the products pass through the packaging line can be monitored and how the variables change can be seen during runtime. The event controller can be used to speed up the simulation or to slow it down. By running the simulation really slowly, the activities in the simulation can be analyzed in detail. By running the simulation faster, the end results can quickly be checked. This functionality is convenient during the testing. When the simulation has finished the order, the simulation is ended, and the final value of the variables is used as the output values.

6.2 Validation

For the model to be valid, we will have to be able to prove that the model that we built is the model that we wanted to build. In other words, does the system behave correctly? As discussed in the literature study, we will be using white-box and black-box validation for this.

For the white-box validation, we will have to check if every part of the system behaves in the same way as the actual system does. This was done by analyzing real-time output data, and by doing visual checks. The real-time data could be analyzed by running the simulation next to the order that was running at the packaging line at that moment. By adjusting all the input data to be the same as the current order, the stations in the simulation were expected to behave similarly. Analyzing real-time output helped to test if the distributions gave realistic values.

By doing visual checks a lot of the behavior of the simulation can be determined. Visual checks are useful to see how the products flow through the system. The most attention was paid to the box shipping process, since there are moving workers there and the stations can have different behaviors depending on the situation.

The black-box validation does not care about the internal working of the system but wants to check if the system as a whole behaves correctly. This was done in two ways. Firstly, by comparing all the orders of one day to a simulation of the same orders. Secondly, by using the resource statistics of the simulation model and comparing these to the found results during the bottleneck identification.

In comparing the simulation to the actual data, the results would not always be accurate since a lot of abnormalities would occur in the real system. Often the data gathering system would keep running through the break for example. Then we would have to estimate for how long the workers were taking a break. Because of these abnormalities, it is difficult to say if the model is valid based on these observations. What can be said is that the simulation shows similar behavior and after estimated corrections, the observations all came within a 15-minute timeframe of the observed orders. However, because of these estimations, these results might not be reliable.

When the resource statistics of the simulation software is being used, the validity of the model is shown in a more reliable way. In figures 6.2 and 6.3, the utility of the stations can be seen. From left to right, the bars show the box folder, the product packaging, the gluing machine and the two shipping box packaging stations. In the diagram on the left, the system can be observed running 40%. On the right, the system running at 60%.

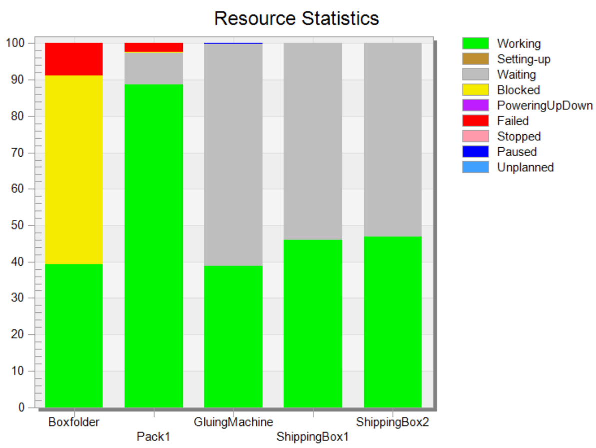

Figure 6.2) Statistics at 40%

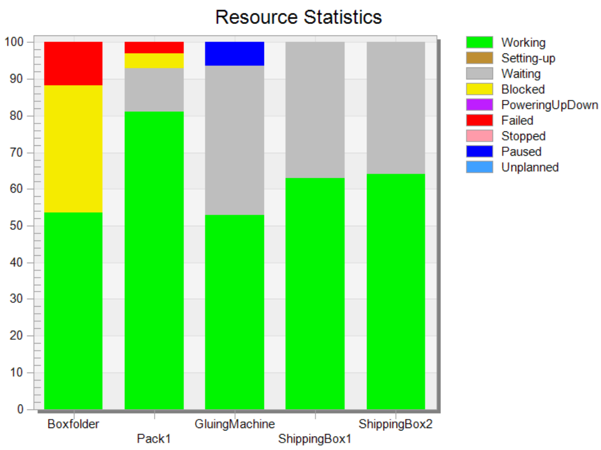

Figure 6.3) Statistics at 60%

When the system is running at 40%, the graph shows the product packaging station to have the highest utility. The station before it is often blocked and the station behind it is often starved. This indicates that the product packaging station is the bottleneck.

At 60% of the speed, it is less obvious where the bottleneck is. Product packaging still has the highest utilization, but it has gone down a bit. According to the bottleneck walk, performed in chapter 4, the shipping box packing should be the bottleneck now. It has gone up slightly, but it does not have the highest utilization, so there must be another explanation. In the model, the shipping box packing is modeled as a worker that handles both the packing and the palletizing. However, since Plant Simulation does not gather resource statistics on a worker, the palletizing and walking in between stations is not included in the graph. If those activities would be added into the statistics, it would show that the worker has a higher occupation. If both these factors are considered, it seems probable that the shipping box packing is the bottleneck in this situation.

6.3 Verification

To be able to verify the model, the data must be tested for correctness. This is also done in two ways. Firstly, it is done in a similar way as the white-box validation, but more on a technical level, by checking the programming code per station and verifying if the output is correct. Secondly, the correctness of the model can be verified by calculating the correct number of necessary replications.

The verification by assessing each station separately was done reviewing the programming code and using the debug mode to run through it in case of incorrect behavior. This method worked very well for the stations that were not to complex such as the error generating methods. For methods that are more complex, testing variables were used. These are extra variables that would give intermediate output values that can be used to check if they are correct. This way, small parts of complex methods could be tested separately. Once every part is verified to work correctly, the complete station could be tested for correctness. The last method that was used for programming code verification is input verification. The inputs that are given by the user are always restricted by certain boundaries. For example, it can be that negative numbers are not allowed, or a value should always start at zero. At the very start of the simulation, a method checks if all the input data is filled in correctly and it gives an error message if something is wrong. By doing this, it reduces the chance that an experiment will be run with the wrong input settings.

To determine how many replications are needed for the data to be correct, the method that was discussed in section 3.1 was used. The model that has been developed is a terminating discrete event simulation. It starts and returns to an empty state, this means that it is not necessary to use an initialization bias.

To be able to have reliable data, enough replications are necessary. To calculate the number of replications that is necessary to achieve this, the confidence interval method from section 3.1 is used. For the value of *d* 5% was chosen. This means that when the value of the formula becomes smaller than 0,05 enough replications have been done. This value was reached after 7 replications. How this calculation was done can be found in appendix A. However, in order to be able to use this number of replications for all the experiments, a safety margin should be applied to it. To be sure that enough replications will be done, 50% of 7 will be added to the number of replications. 7 + 3,5 = 10,5. When rounded up, this means that 11 replications will be done to obtain sufficient data.

6.4 Conclusion

The simulation model has been implemented. It is clear how the model functions and how the data is generated. Furthermore, data validation has been done by comparing the simulation to the real-world data and by comparing earlier found bottleneck to the bottleneck that was found by the resource statistics of Plant Simulation. In the next chapter we will look at what experiments will be conducted, how this is done and their results.

7. Experimentation

In this chapter the experiments will be described. First, we will take a look at what experiments will be done and what variables will be varied. After that, one by one, the experiments will be done, and the results will be shown.

7.1 What experiments?

What experiments will be performed is decided on by literature, observation and brainstorming. From literature it has been found that adding buffers can improve the performance. Since buffering is already done in the current system, the size of these buffers will be evaluated. Through observation it has been found that a lot of time is wasted by having to stop the system to refill buffers. This is not always the case, since sometimes someone is available to refill the buffers while the system is running. Simulating this can show the difference between the two situations. It also has been observed that the packaging unit influences the time that it takes to pack the shipping boxes. This could be an interesting factor as well. In a brainstorm with experts on the packaging line, two more questions came forward. Firstly, is it possible to run the system with less workers in shipping box packaging? Secondly, what would happen if the shipping box packing is automated?

Even though most of the time the bottleneck can be found in product packaging, most of these situations are focused on the shipping box packing. The reason for this is that the product packing is very product-dependent and because there is such a big variability in the different products, it is almost impossible to run a simulation on that covers all the aspects of all the products. How the product packaging can be improved will be discussed in the conclusions and recommendations chapter.

Finally, it has been decided to experiment on six scenarios. These scenarios are:

1. Varying the buffer size after the gluing machine.
2. Varying the buffer size after the shipping box packing.
3. Refilling supplies during runtime.
4. Varying the packaging unit of the shipping boxes.
5. Automation of the shipping box packing.
6. Varying the number of workers in shipping box packing.

7.2 Experiments

Experiment 1: Buffer after gluing machine

This experiment is only done on the situation where the shipping box packing is the bottleneck, since it will not influence the other situation much. In the situation where the packaging line is running at 40%, the buffer does not get full often, so increasing the size will not make a big difference. The maximum capacity of the buffer will be varied from 10 to 22. It will be set down to 10 to see if space can be saved by using a smaller buffer. It will be set to a maximum of 22, since space will be a limiting factor.

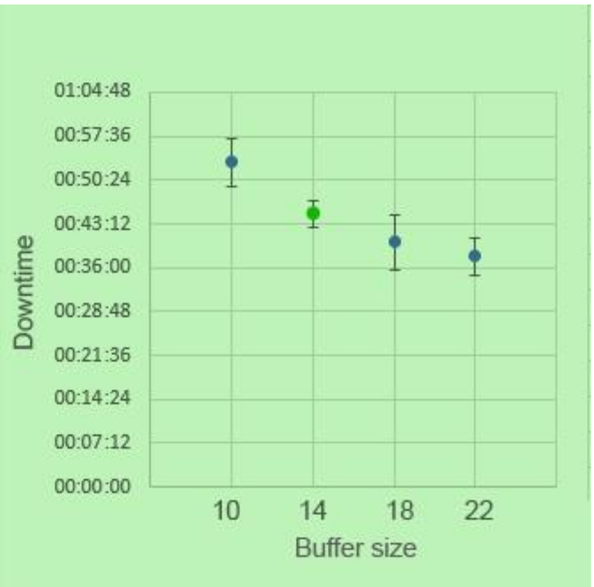

Figure 7.1) Experiment 1 - downtime

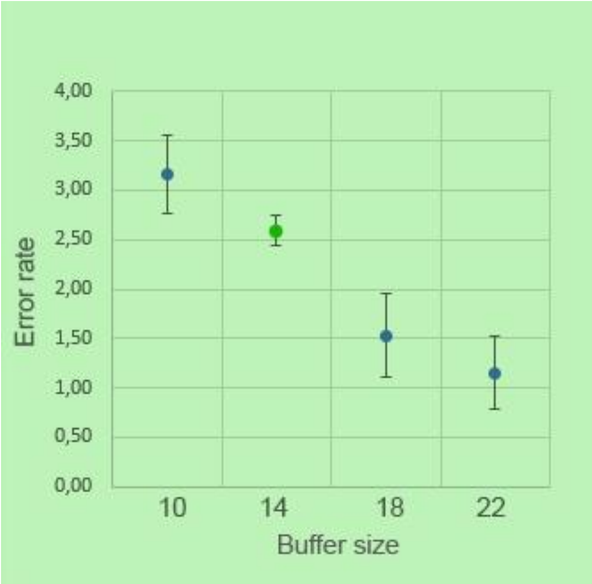

Figure 7.2) Experiment 1 – error rate

In figure 7.1, 7.2 and 7.3, the results of varying the buffer after the gluing machine can be seen in a 95% confidence interval. The standard buffer size that is used is 14. The dot that indicates where the median has been colored green for the standard values. The graphs show how the downtime, error rate and total products made vary over a three-hour run of the simulation.

In all the graphs when the buffer size increases, the performance of the packaging line improves. Both the downtime and the error rate can be seen going down when the buffer size increases. As they go down, the total products made goes up.

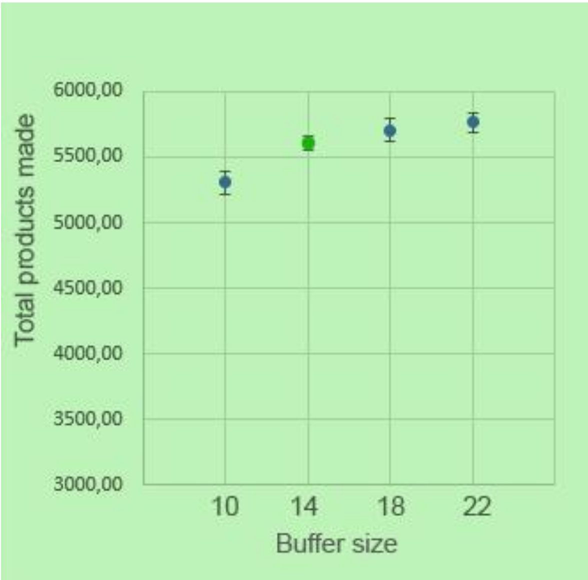

Figure 7.3) Experiment 1 – total products made

These results show that when the packaging line is running at 60%, a bigger buffer after the gluing machine will improve the packaging line. Increasing the buffer size to 18 will improve the total number of products made by 1,82% and increasing it to 22 will improve the products made by 2,89%. It also shows that decreasing the buffer size to 10 will decrease the number of products made by 5,35%.

Experiment 2: Buffer after shipping box packing

This experiment is also only done on the situation where the shipping box packing is the bottleneck, for the same reason as the previous experiment. The influence of this buffer is a bit more complicated than the other buffer, since once the buffer is full, it will not cause the whole line to be stopped. However, if this buffer is full, the worker will be forced to empty it before he can get back to work, which will cause the buffer after the gluing machine to fill up, which will cause the line to stop. The maximum capacity of the buffer will be varied from 4 to 16. Again, the dot that indicates the median on the buffer size that is used in the current system has been marked in green. In this experiment the buffer size will not be set down, since the buffer size that is used is already quite small. Again, the limiting factor of the maximum buffer size is the available space.

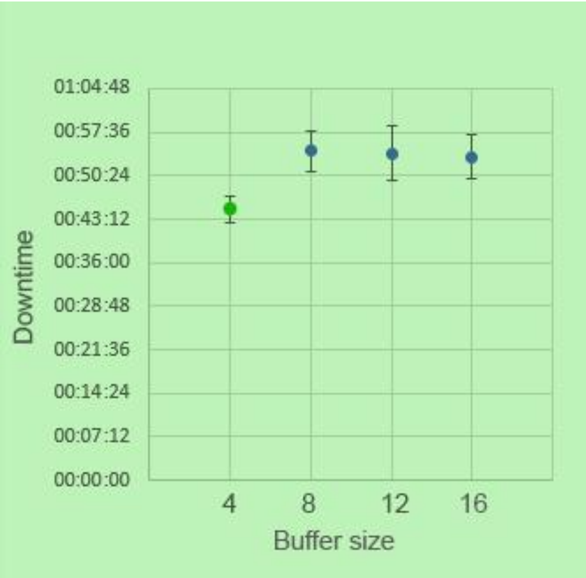

Figure 7.4) Experiment 2 – Downtime

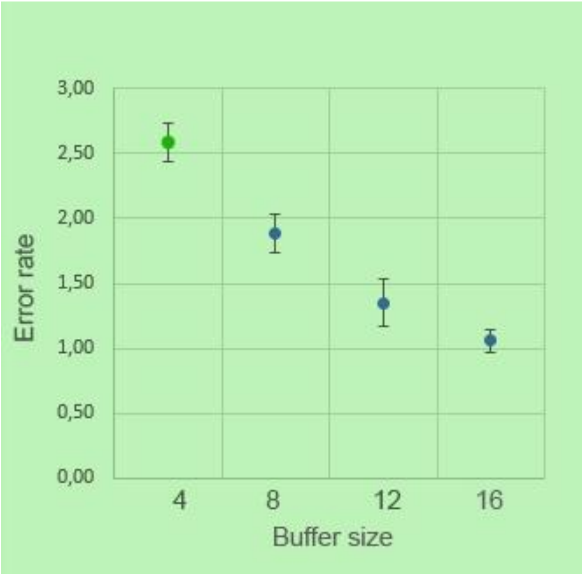

Figure 7.5) Experiment 2 – Error rate

In figure 7.4, 7.5 and 7.6, the results can be seen. Increasing the buffer size causes the downtime to go up, while the error rate declines. Since there is less uptime, the total number of products that is made also goes down. The downtime increasing is an unexpected result. These results mean that less errors are made, but they have a longer duration, causing more downtime. As the workers fill palletize the shipping boxes, they are not able to clear the buffer behind the gluing machine. When the shipping box buffer increases, they spend more time palletizing and the buffer after the gluing machine will be full for a longer time. This causes the downtime to go up and the throughput to go down.

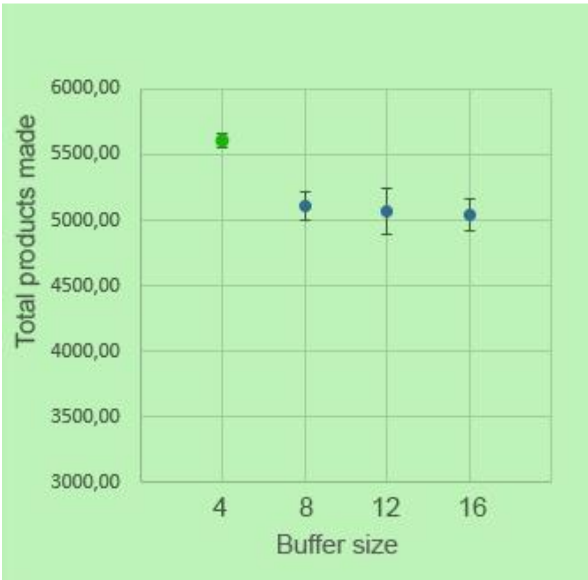

Figure 7.6) Experiment 2 – Total products made

The current packaging line allows for a buffer size of 8 to be used. If the available space would be used, the number of products made will go down by 8,74%. Increasing the buffer size any further will result in an even worse performance.

Experiment 3: Extra worker who fills supplies

This experiment will be conducted for both the slow situation where the line is running at 40% and the fast situation where the line is running at 60%. The situation where the packaging line is running slowly will be shown in the yellow graphs on the left and the fast situation will be shown in the green graphs on the right. The way that the extra worker will be modeled will be by not depleting the supply of the box folder. When the supplies do not run out, it can be assumed that there will be less errors in the product packaging as well, but because of the high variability in products, it is very difficult to get a good estimate. Therefore, we will not take this into account.

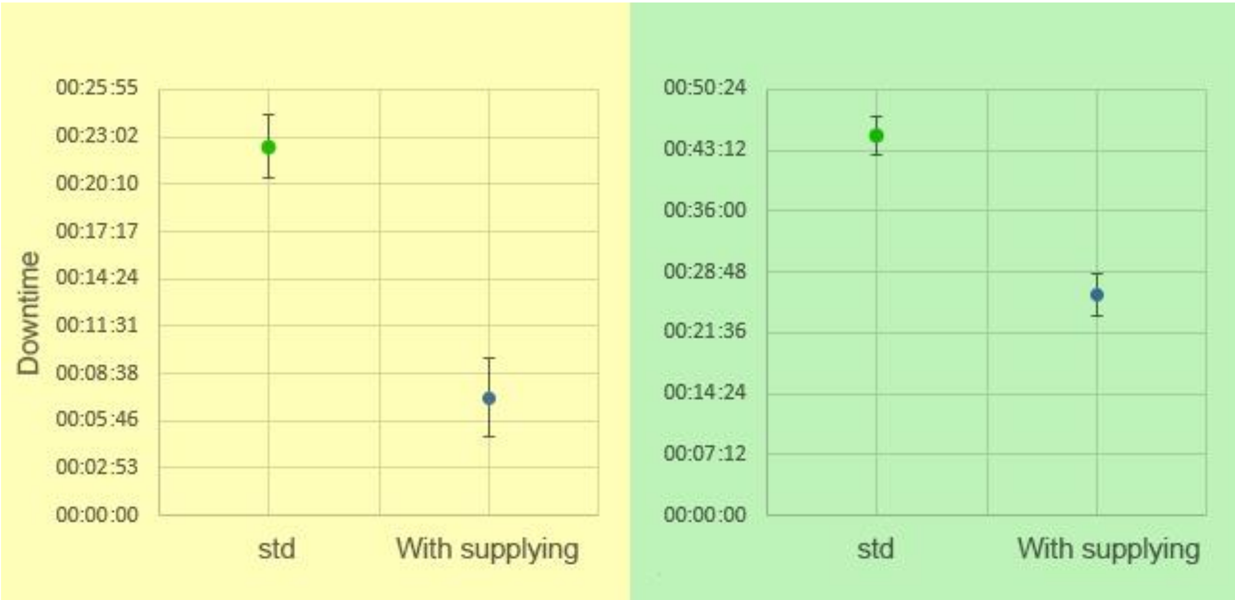

Figure 7.7) Experiment 3 - downtime

The results for the downtime and error rate are shown in figure 7.7 and figure 7.8. The medians of the standard situation are shown in green again. On the left, we see the situation where the box folder is running at 40% and on the right where it is running at 60%. For both situations a clear difference can be seen. Having a constant supply brings both the downtime and error rate down significantly. Downtime decreases by 67,62% and 42,04% for the 40% and 60% situation respectively. Error rate decreases by 39,53% for the slow situation and 7,72% for the fast situation.

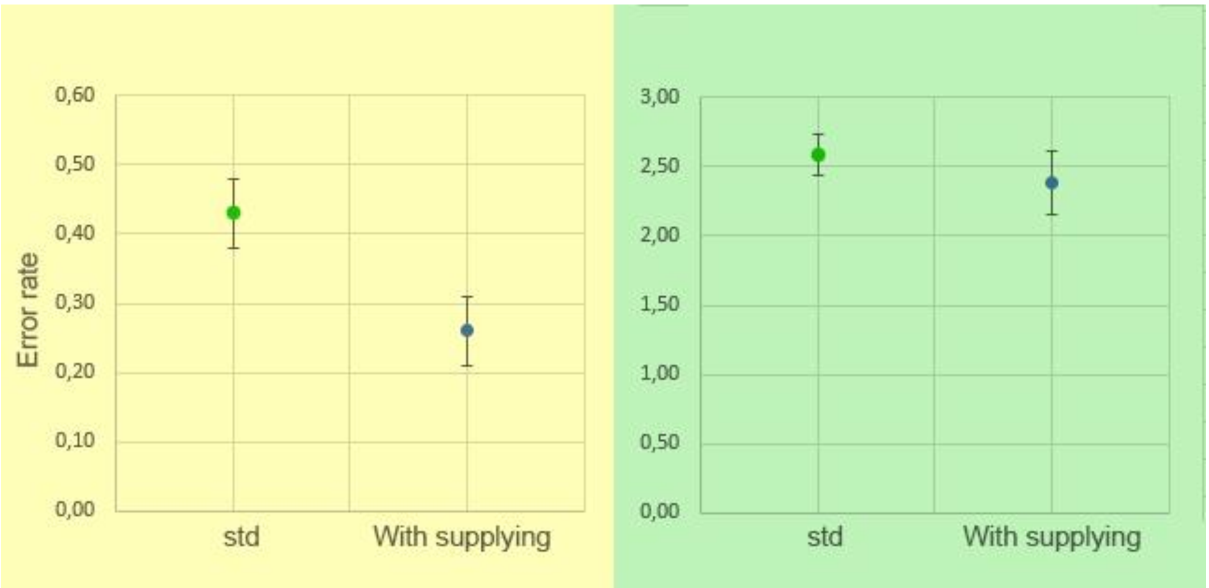

Figure 7.8) Experiment 3 – Error rate

The influence of the decrease in downtime can be seen in the increase of throughput. The results of the total number of products made can be seen in figure 7.9. In the 40% situation, the products that were made increased by 9,75%. In the 60% situation, the products that were made increased by 14,13%. This experiment shows that refilling the supplies causes less downtime and this causes an increase in throughput.

Figure 7.9) Experiment 3 – total products made

Experiment 4: Packaging units

This experiment will also be conducted for both the 40% and the 60% situation. All the packaging units that are tested are also being used in the current situation. This experiment will show which of the packaging units performs the best. Again, the 40% situation is shown on the left in yellow and the 60% situation is shown on the right in green.

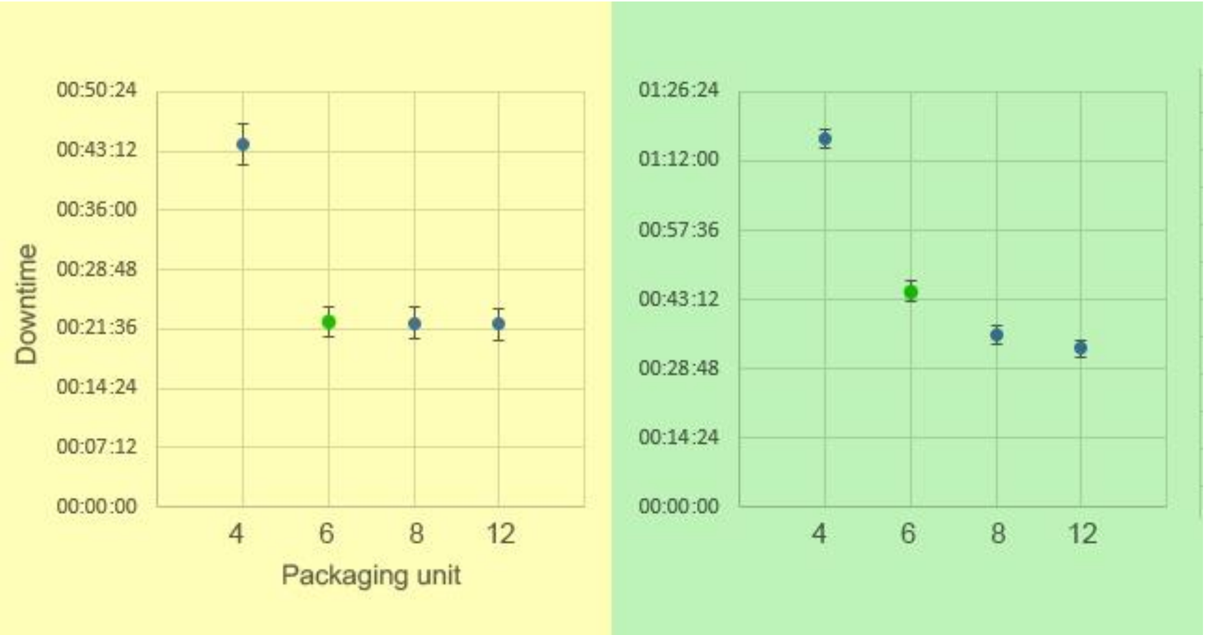

Figure 7.10) Experiment 4 – Downtime

In figure 7.10, 7.11 and 7.12, the results can be seen. In the standard situation, PU size 6 was used. A PU of 4 performs worse than the other PU's in both situations. In the 40% situation, increasing the PU does not seem to have a big influence. However, in the situation where the box folder is running faster, a clear relation can be seen. Increasing the PU results in less downtime, less errors and more products made in 3 hours. But, the more the PU increases, the smaller the difference seems to become.

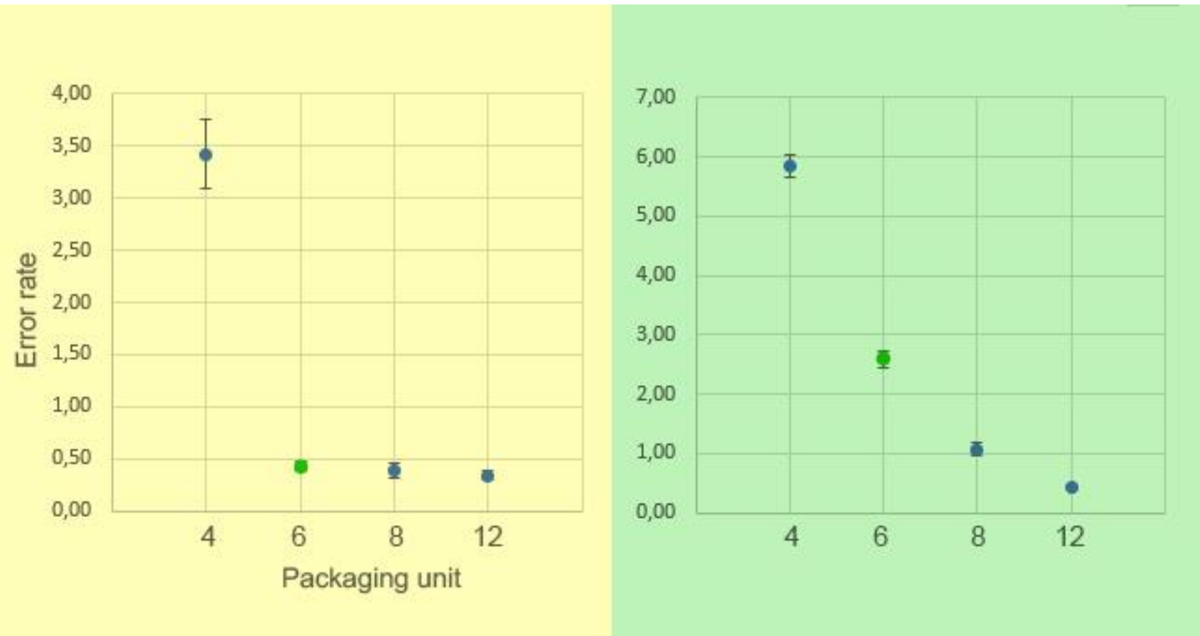

Figure 7.11) Experiment 4 – error rate

When looking at the throughput in figure 7.12, it shows that the standard situation with a PU of 6 is optimal for running the line at 40%. However, increasing the PU does not have significant consequences. Increasing the PU to 8 and 12 will decrease the total products made by 0,22% and 0,69% respectively. For the fast orders, it can clearly be observed that a higher PU will increase the throughput. Increasing the PU to 8 and 12 increases throughput by 3,89% and 4,53% respectively.

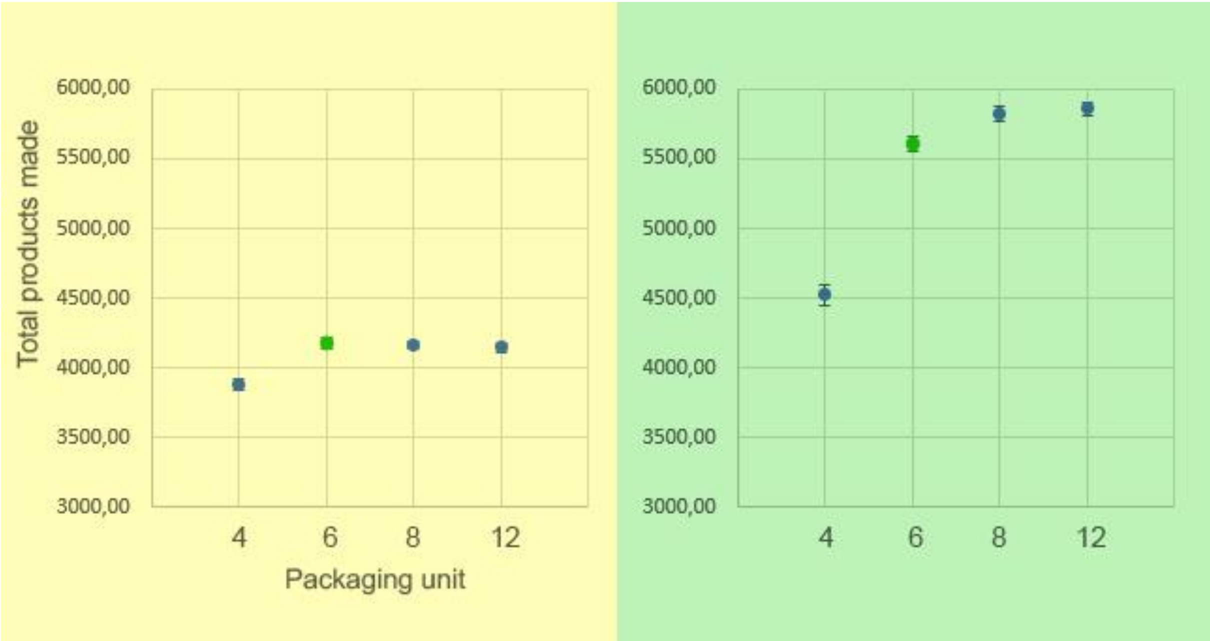

Figure 7.12) Experiment 4 – total products made

Experiment 5: Automation of the shipping box packing

This experiment will be conducted for both situations. Again, on the left the 40% situation can be found and, on the right, the 60% situation. For this experiment, the complete shipping box packing part of model was removed. It was replaced by a station that handles the packing at a speed of 60 boxes per minute. It is assumed that the machine does not fail. The buffer after the gluing machine and the worker palletizing the shipping boxes both stay. There are automation possibilities that will make it possible to also remove the palletizing worker, but it was decided that there should be a worker at the end of the line to be able to perform a form of quality control on the finished products.

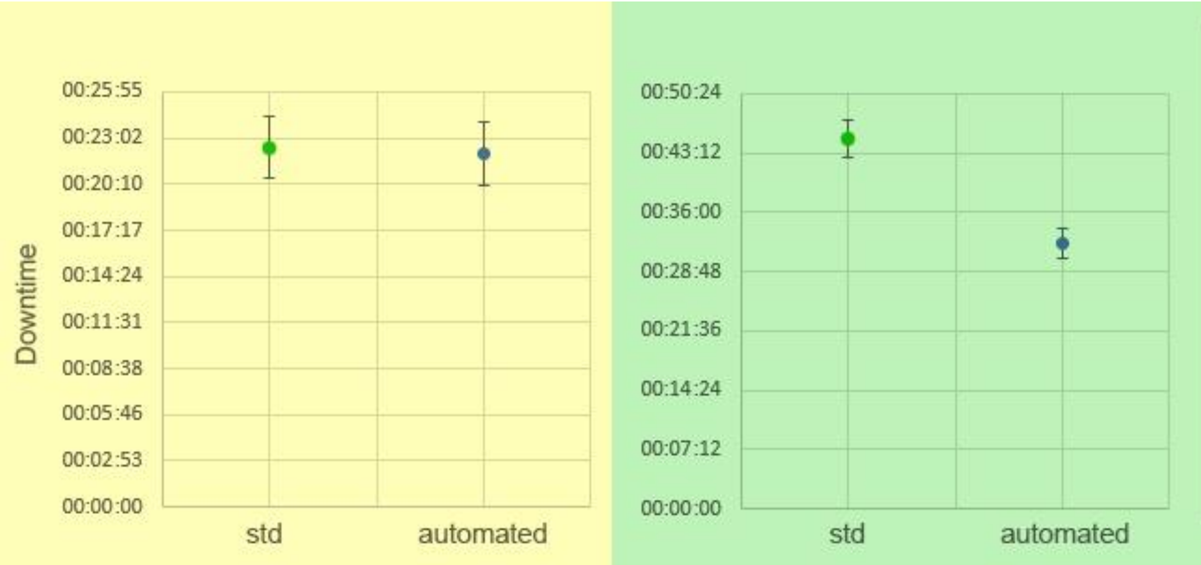

Figure 7.13) Experiment 5 – downtime

The results can be found in figure 7.13, 7.14 and 7.15. In the situation where the box folder is running at a low speed, no big differences can be seen, although there is a slight improvement overall. At the higher speeds, a clear difference is found. The downtime, error rate and products made are all improved.

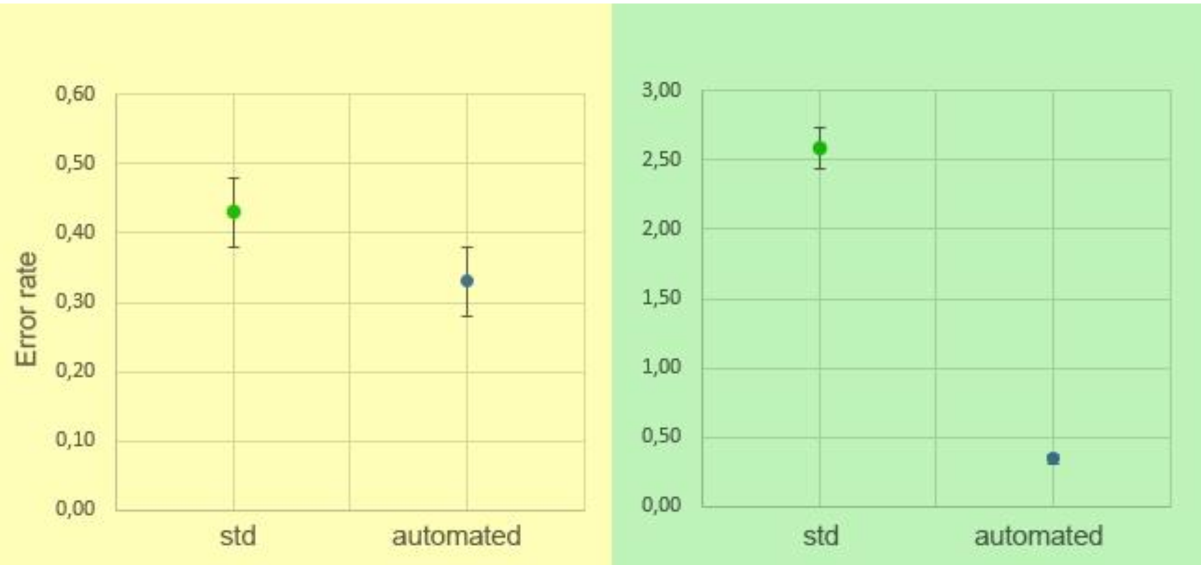

Figure 7.14) Experiment 5 – error rate

The total products that are made in three hours show that for the slow orders, not a lot changes. There is an increase in throughput of 0,60%. This is logical, because in these situations, the bottleneck is the product packing. Increasing the capacity of the shipment box packing will not improve the system a lot. For faster orders however, throughput is increased by 5,89%. The main reason for this seems to be the drastic decline in errors. Automating the shipping box packing decreased the error rate by 87,78%.

Figure 7.15) Experiment 5 – total products made

Experiment 6: Number of workers

This experiment will test if the system can be run with less workers in shipping box packing and palletizing. Both the situations will be tested in different configurations. For the 40% situation the configurations will be the standard situation where there are two workers, both palletizing their own boxes, on worker packing the boxes and one worker palletizing them and one worker both packing and palletizing. For the 60% situation, next to the standard situation where there are two workers packing the shipping boxes and one palletizing, there is a configuration where there are two workers both packing and palletizing. This is a situation that already occurs in the current system.

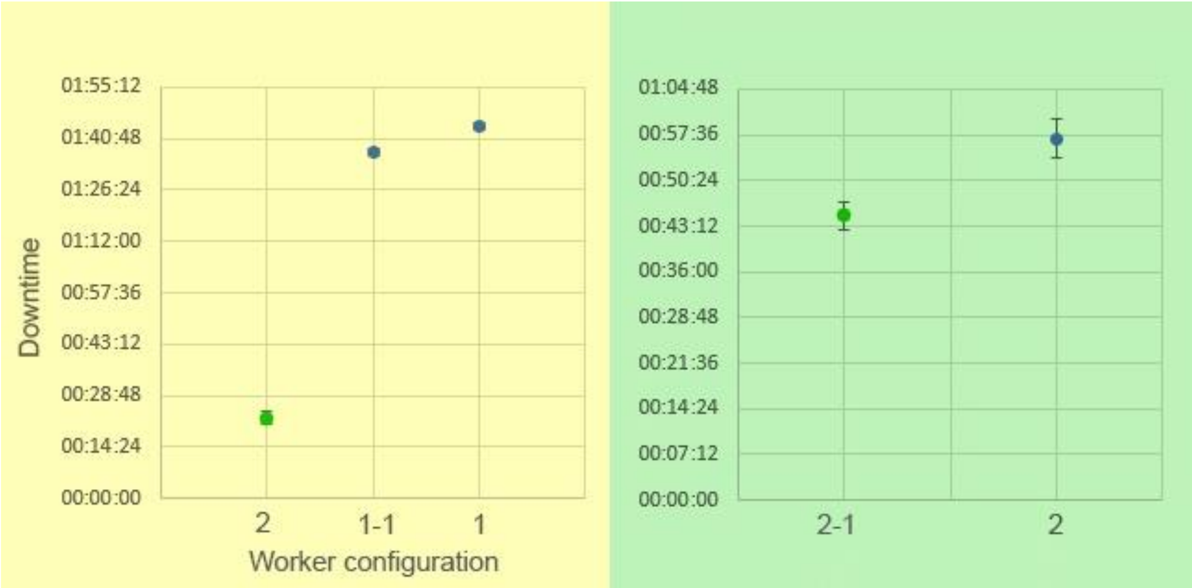

Figure 7.16) Experiment 6 – downtime

The results can be found in figure 7.16, 7.17 and 7.18. For the 40% situation, the performance of the line goes way down in both the other configurations. The situation where there is a separate palletizer performs slightly better than the situation where there is one worker, but both the performances are bad. For the situation where the machine is running at a high speed, the performance of the other situation also goes down, but not as much.

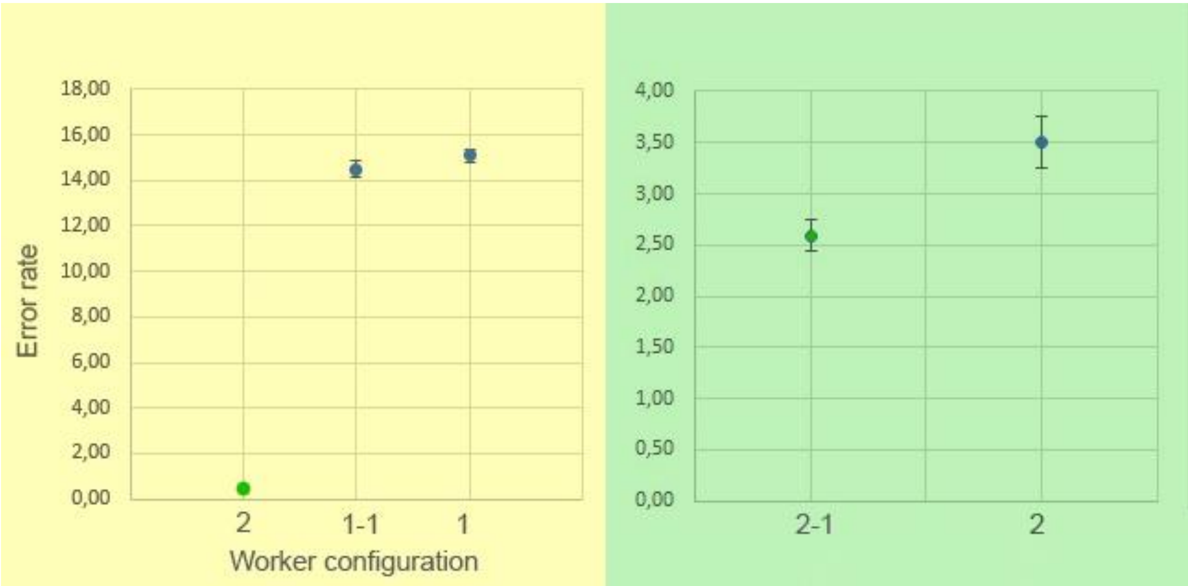

Figure 7.17) Experiment 6 – error rate

These results show the importance of planning to assign enough people for the shipping box packing. Removing one worker decreases the throughput by 26,28% and 7,67% for the 40% and the 60% situation respectively.

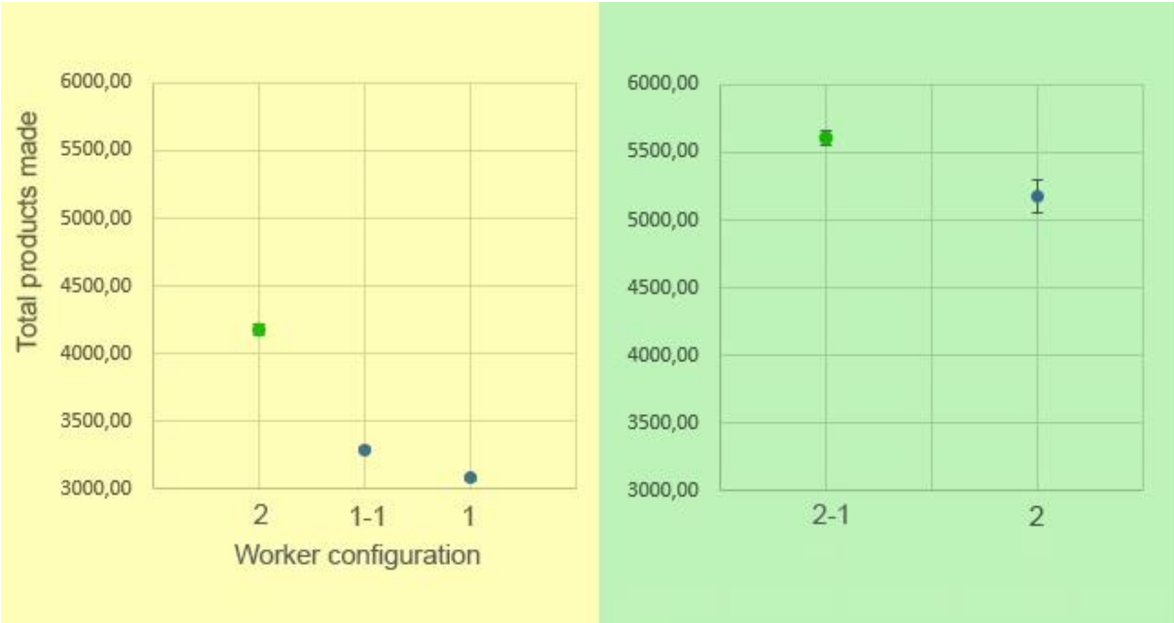

Figure 7.18) Experiment 6 – total products made

7.3 Conclusion

In table 7.1, the improvements of all of the experiments can be seen in percentages. Again, on the left side in yellow, the slow orders are shown and in green on the right side, the fast orders. The first experiment showed that filling up all the available space after the gluing machine by increasing the buffer size to 22 products will yield the best results. This will increase the throughput by 2,89%. The second experiment showed that increasing the buffer of the shipping boxes will not improve the performance of the packaging line. In the third experiment it was shown that throughput can be increased by 9,75% for slow orders and 14,13% for fast orders if supplies never run out. The fourth experiment shows that for the slow orders, a packaging unit of 6 is optimal, but increasing it further does not have a lot of negative effects. For the fast orders, a higher packaging unit is better, but this seems to decline the higher the packaging unit gets. The best PU for fast situations was found to be 12. This improves the throughput by 4,53%. In the fifth experiment it was shown that automating the shipping box packing only has a throughput improvement of 0,60% for slow orders. However, it does bring down the error rate by 23,26%. For fast orders, it improves throughput by 5,89%. In the sixth experiment it was shown that decreasing the number of workers at the shipping box packing will cause significant drops in performance. For slow orders, one person less will result in a decrease in throughput of 26,28%. For fast orders, this will lead to a decrease in throughput of 7,67%.

Table 7.1) The results in percentages of all the experiments for the 40% (yellow) and 60% (green) situations.

	Error rate	Downtime	Products made	Error rate	Downtime	Products made
Product buffer 10	-	-	-	22,01%	18,63%	-5,35%
Product buffer 14	-	-	-	0,00%	0,00%	0,00%
Product buffer 18	-	-	-	-40,93%	-10,54%	1,82%
Product buffer 22	-	-	-	-55,60%	-15,70%	2,89%
Shipping box buffer 4	-	-	-	0,00%	0,00%	0,00%
Shipping box buffer 8	-	-	-	-27,41%	21,19%	-8,74%
Shipping box buffer 12	-	-	-	-47,88%	20,45%	-9,64%
Shipping box buffer 16	-	-	-	-59,07%	19,22%	-10,06%
Supplies are filled	-39,53%	-67,62%	9,75%	-7,72%	-42,04%	14,13%
Packaging Unit 4	695,35%	98,87%	-7,09%	125,87%	70,72%	19,29%
Packaging Unit 6	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Packaging Unit 8	-11,63%	-0,75%	-0,22%	-58,69%	-20,26%	3,89%
Packaging Unit 12	-20,93%	0,08%	-0,69%	-83,78%	-26,53%	4,53%
Automated	-23,26%	-0,23%	0,60%	-87,26%	-28,35%	5,89%
Worker conf. 1-1	3272,09%	338,10%	-21,18%	-	-	-
Worker conf. 1	3427,91%	371,91%	-26,28%	-	-	-
Worker conf. 2	-	-	-	35,91%	26,83%	-7,67%

8. Conclusions and discussion

In this chapter, the results from the previous chapter will be discussed and explained. This will be divided in two parts. First the results on buffer sizes and the packaging unit will be discussed, then the experiments that are influenced by the number of workers will be discussed. Afterwards, recommendations based on the simulation study will be given. Then, additional recommendations will be given, based on the data collection part of the project. In the discussion, we will talk about what could have been better and more reliable to improve this project. Finally, possibilities for future research are given.

8.1 Conclusions

In the conclusion we will look at the research question and see if it was answered. The research question was: **“***How to improve the packaging line of SES in order to keep up with the flexible demand?”* To answer the question, a simulation was made and several experiments were conducted to see how the packaging line could be improved.

The experiments that have been conducted tested the difference in the sizes of the buffers after the gluing machine and after the shipping box packing, the differences in certain worker configurations, the influence of different packaging units and the effects of automation of the shipping box packing. It has been found that four of the experiments show improvements over the current situation and that two of the configurations are not improved.

Configurations that will not result in an improvement of the system are: reducing the buffer size of the buffer after the gluing machine, increasing the buffer size of the buffer after shipping box packing, decreasing the packaging unit and using configurations with less workers in shipping box packing. All of these configurations resulted in a decrease in throughput.

To answer the research question, the configurations that did result in improvements over the current system are, increasing the buffer size of the buffer after the gluing machine, increasing the packaging unit, automating the shipping box packing and using an extra worker to refill supplies. Several methods to improve the packaging line has been found. A more efficient packaging line will allow orders to be finished quicker and leaves more time to plan other orders. This way, it will be possible to use the packaging line in a more flexible way. Recommendations on how to improve the packaging line more concretely can be found in the next section.

8.2 Recommendations

Two types of recommendations will be done. Firstly, recommendations that are based on the simulation. These recommendations use the data that was generated from experiments. Secondly, the recommendations that are based on observations that have been done during the research. These observations are interviews and meetings and simply the observations of the processes. At the end of this section an overview of the specific recommendations is given.

Recommendations based on simulation

Based on the simulation several recommendations can be done. Firstly, there should always be a worker available to refill supplies. This increases the throughput significantly and there is usually already an operator or a supervisor present who can do it. If it can be done this way, there does not have to be an extra worker that is scheduled just to refill supplies. The rest of the recommendation is based on the decision if automation should be done or not. First, both situations will be discussed, afterwards an advice is given.

Without automation, the throughput can be increased by increasing the capacity of the buffer after the gluing machine to 22 products. An even higher capacity might further increase the throughput if there is space for it. The packaging unit should be at least 8 products per shipping box. A PU of 6 is also acceptable, especially for the slower orders, but 8 should be the new standard. Any PU's that are lower than 6 should be reconsidered, because this causes a bad performance of the packaging line. The number of workers that are doing the shipping box packing should stay at two. On fast orders, they will need support from a worker that does the palletizing.

With automation, the packaging unit will not have to be adjusted. The buffer size can remain the same, or when the machine has a low error rate, the buffer can even be removed. The biggest problem with automation is the purchase of a new machine. If a machine would be purchased, this would save costs on one worker for slow orders and one worker for fast orders. If we assume that half of the orders are fast orders and the other half slow orders, then costs for at least one worker can be saved. If the machine can be depreciated in five years and the annual salary of a worker is €25.000, then the maximum cost of the machine is 1 x 5 x 25.000 = €125.000.

Given that a machine can be bought with the available budget, automation is a good idea. It makes it possible to use whatever PU is convenient, it saves space that should otherwise be used for buffering and it simplifies planning, because the number of workers at the shipping box packing is not dependent on the speed of the packaging line anymore. Because of these reasons, I would recommend automating the shipping box packing part of the packaging line.

Recommendations based on observations

Next to the conclusions that can be drawn from the simulation, more recommendations can be done. Since it was not possible to include the product packaging in the simulation, recommendations on how to improve it will be done here. The objective with the product packaging is to achieve a speed as high as possible, without using a lot of workers. Since multiple workers packing one part can easily improve the packing speed, this is a planning problem.

To be able to plan workers effectively, it is important to have information on the product. It is important to at least know how many parts a product has and how difficult these are to pack. To assign a packing difficulty levels, the categories that are described in section 4.3 can be used. With this information, the number of workers can be planned.

When making the planning, it is important to look at the different parts that must be packed and their difficulty level. If a product only consists out of difficult parts, it does not make sense to plan a lot of extra workers, since this will get very expensive very fast. In this case it would be better to accept that a product is slow. When a product consists out of a lot of simple parts and one difficult one, throughput can easily be improved by using an extra worker on the difficult part.

To be able to plan like this, there needs to be a way to store the data on the product parts. In the current situation, the packaging instructions, as discussed in section 2.3, already include how many parts are in a product and how they should be placed in the box. If the parts can get a difficulty level assigned to them during product development, this can help to determine the number of workers that is needed to pack the parts efficiently. Finally, the packaging instructions should include an estimation of the speed at which the box folder should be set. The categorization from section 4.2 can be used for this, but any format that will give an estimation of the startup speed should work.

Since things do not always work out as they in theory should, it is important that the workers give feedback on the packing instructions and that they are changed when necessary. This way, the packaging instructions will contain all the data that is necessary for planning and executing the order. Then, the data that is gathered through the integrated system can be used for verification of the data on the packaging instruction instead of as a planning tool.

Recommendations

My first recommendation is that automation of the shipping box packing will improve the packaging line significantly. The problem of automation is that it is expensive at first. Therefore, two separate recommendations are given. The first one with automation, the second one without. In the case that there is enough budget available for automation, the recommendations are:

1. There should always be a worker that has enough time to refill supplies
2. An investment of maximum €125.000 should be done to automate the shipping box packing.
3. The packaging instructions should include the difficulty of the part and the box folder speed.
4. The packaging instructions should be used as a feedback tool to evaluate orders.

In the case that there is not enough budget available for automation, the recommendations are:

1. There should always be a worker that has enough time to refill supplies
2. The buffer after the gluing machine should be increased to 22.
3. The packaging unit should be increased to at least 8.
4. The packaging instructions should include the difficulty of the part and the box folder speed.
5. The packaging instructions should be used as a feedback tool to evaluate orders.

8.3 Discussion

To find the limitations of this project, a critical evaluation of the collection of data and how this is used for validation is necessary. Furthermore, the correctness and the limitations of the assumptions should be discussed. Finally, the influence of limited time on the project must be assessed.

Data collection

Most of the data that was collected came from the integrated data collection system from the packaging line. As discussed in section 2.7, there are quite some problems with the reliability of this data. The data was often incomplete and sometimes incorrect, because of measurement errors. The main problem with the data collection system is that it is relatively new. Especially with the earlier data, the people using the system were not used to it yet, resulting in a lot of measurement errors. Furthermore, the system did not have enough time to gather data on all the products yet. From the products that there was data about, often there were only a couple of measurements available. Lastly, the system was still under development during the project, so the way that some measurements were done might have changed during the project. Ideally, the system would have been running for a way longer time, so that all the products would have at least a minimum number of measurements. This way, the measurement errors would be easily filtered out.

During the collection of data on the distributions that were used, observations were done. However, there were only a limited amount of observations done. The amount of observations that were done was 30. This is enough to use it for an estimation, but the data would be more reliable when more observations would have been done.

If more reliable data would have been available, this data could have been used to validate the data that was generated. Since the collected data itself was not reliable, testing the generated data to fit the collected data would have been meaningless. However, if the data would have been reliable, this would be a very good way for proving the correctness of the generated data.

Assumptions

During the construction of the conceptual model, a lot of assumptions were done. These assumptions were done to make the model manageable. They take away some of the complexity of the model, but they also take some of the realism away. If there would have been more time for the project, a more complex, more realistic model could have been made. Extra features that would make the model more accurate would be features such as: Allowing re-entrance, taking changeover times into account, taking the moving of pallets into account and allowing for longer failure durations.

The main problem with these assumptions is that they flatten the whole system out and do not allow for any unexpected things to happen anymore. An example of this is that workers would block some boxes so that they would be easier to pack. However, a worker further down the line would get a lot of boxes at once and an error would occur. Even though such unexpected things are not wanted in a simulation, they could have given some valuable insights in things that happen in the system that are not observed now.

Time

The limited amount of time narrowed the scope of the research down. If the project would have had a longer duration, it could have been extended with some of the projects stated in the future research, such as planning of orders over a longer period. This would have given the possibility to find planning heuristics that could reduce changeover times and reduce inventories. Furthermore, a longer duration of the project would have allowed for more scenarios to experiment on. There are some more complex scenarios that would have taken more programming time, but these might have given valuable insights.

8.4 Future research

How to schedule separate orders?

The simulation from this project stops the moment an order ends, but during a normal production time, this would be the moment for changeovers to get ready for the next order. The simulation gives no insight in how these orders flow from one to another. Because of this limitation it is not possible to test scheduling heuristics. If the simulation would be extended to run multiple orders in a row, it can be used to improve the scheduling of the packaging line.

Product packing heuristics

Getting a good estimate of the product packing speed proved to be one of the biggest problems of this project. Next to the fact that there are way too many different products to analyze in this project alone is the problem of ergonomics. To be able to get a good idea of how the product packing can be improved, the movements of the workers have to be analyzed. Over the course of the project, a lot of improvement has been observed because workers found a more convenient way to hold something, or because they changed their posture. If these movements can be observed and made more efficient in a safe way, this could improve the efficiency of the packaging line a lot.

Where does the packaging line fit in the whole of SES?

This project only focused on the packaging line. However, SES is not a packaging company. It does its own manufacturing, sourcing, warehousing, logistics and sales. How these elements fit together determine how efficient the company is running. It would be interesting to see how the packaging line fits in the rest of the company. How do the sales forecasts determine which products should be in stock? Is it possible to get shorter delivery times by using the packaging line in a more flexible way?

8.5 Contribution to practice

Before this project started it was unknown how certain processes influenced the performance of the packaging line. The packaging line was relatively new and there was not a lot of information available about it. In this project, a clear description of the packaging line and its processes were given. The simulation that was made gives insight in what happens when the processes in the packaging line are adjusted. This project showed what configurations are that can improve the performance of the packaging line, but it also shows which configurations do not work. Some of the configurations that are not efficient were occasionally being used. Because of this research, now we know which situations to avoid and what configurations to use. Furthermore, in researching how the data in the packaging line is gathered and used, better methods for evaluating the performance of the packaging line per product were found. This can be used to get a better estimate of the duration of orders and to improve planning.

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Appendix A: Observations

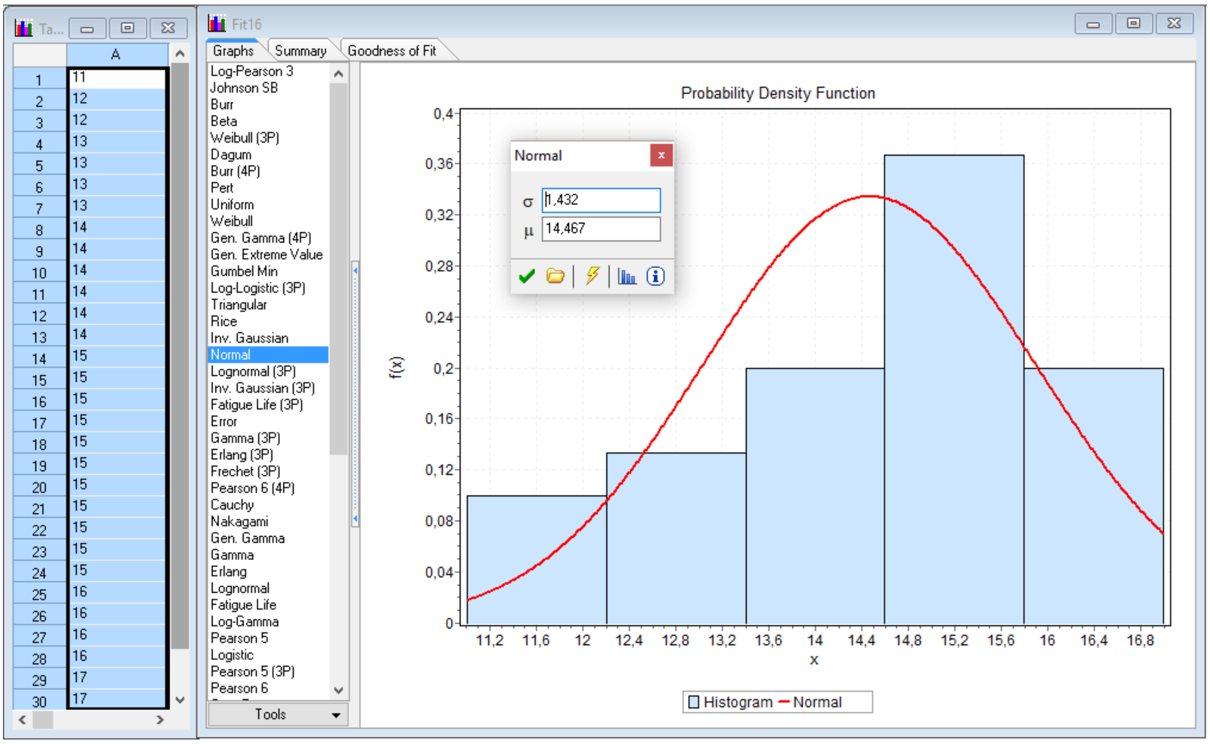

Figure A.1) Shipping box packing time distribution

Table A.1) Box folder error observations

O1	O2	O3	O4	O5	O6	O7	O8	O9	O10
134s	92s	191s	168s	108s	86s	126s	135s	188s	66s

Table A.2) Product packing error observations

O1	O2	O3	O4	O5	O6	O7	O8	O9	O10
101s	133s	41s	86s	31s	46s	66s	108s	93s	55s

Appendix B: Number of replications

To calculate the necessary number of replications for the simulation to generate reliable results, the following formula is used:

$$\frac{\frac{S}{\sqrt{n}} \times t_{n-1,1-\frac{\alpha}{2}}}{|\bar{x}|} < d$$

With:

n = the number of replications

$\bar{x}$ = The mean of the output data

S = The standard deviation from the output data

$T_{n-1,\ 1-\alpha/2}$ = The value from the student's T distribution with n-1 degrees of freedom and with a confidence of 1-α/2

d = Deviation, the chosen value is 0,05

The way that this calculation is done is by calculating the value of the formula for incrementing numbers of replications, until the value is lower than the chosen threshold of d < 0,05. The calculation was done in excel and can be seen in table A. The values that are being used as input for the formula are the found averages of the error rate in the base model. In the third, fourth and fifth column, the other necessary inputs for the formula were calculated. In the sixth column, the final value of the formula was calculated. Per row, the values of the corresponding number of replications are shown. As can be seen in the seventh row, the value of the deviation is smaller than 0,05. This means that at least 7 replications are necessary in order for the data to be reliable.

Table B1) Replications calculation

	Averages	Mean	Variance	T-Value	% deviation
1	0,96	0,96	0		0
2	0,96	0,963544254	0	12,7062047	0
3	1,08	1,003315493	0,003558941	4,30265273	0,147706135
4	0,88	0,973446216	0,001588256	3,18244631	0,065144752
5	0,84	0,946480034	0,00390181	2,77644511	0,081945612
6	1,31	1,007182374	0,030128249	2,57058184	0,180856715
7	0,97	1,002427677	2,68077E-05	2,44691185	0,004776903