Increasing the throughput by designing the logistical process

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Bachelor Industrial Engineering & Management

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Preface

Dear reader,

In front of you lies the Bachelor thesis “Increasing the throughput by designing the logistical process”. This research is conducted at Machinefabriek Boessenkool B.V./Aerosol Recycling Twente B.V. in Almelo between April 2022 and August 2022.

First, I want to thank Machinefabriek Boessenkool B.V. and Aerosol Recycling Twente B.V. for offering me this challenging assignment. I am grateful for everyone’s help during the research, and I learned a lot from my first experience in a company. Especially, I want to thank my supervisor Jos van der Horst for always supporting and guiding me.

Next, I would like to thank my first UT supervisor Peter Schuur for his guidance throughout the research. Our meetings were always helpful to me, and getting feedback from him helped a lot in improving the quality of the thesis. I would also like to thank my second UT supervisor Martijn Koot for supporting me in the last few weeks of the research. It was nice to have him as an additional person to help me finish the thesis.

Moreover, I would like to thank my buddies Koen and Max for providing feedback, supporting me, and having pleasant meetings.

Lastly, I want to thank my friends and family for keeping me motivated and supporting me.

I hope you enjoy reading my thesis!

Stef Kosters

Enter, August 2022

Management Summary

This research is conducted at a recently founded company called Aerosol Recycling Twente B.V. (A.R.T.), located in Almelo. A.R.T. is a start-up set up partially by the CEO of Machinefabriek Boessenkool. Both companies operate at the same company site. The company uses a machine that recycles aerosol cans and separates liquids, gasses, and metals so that these can be reused as raw materials again. This machine was developed by a start-up of Machinefabriek Boessenkoel called Despray Environmental.

Motivation

Currently, the process is not running effectively, causing the throughput is not maximized. This has multiple reasons. The first reason is that since the company was recently founded, many occasions are new to everyone, and structure is missing. The second reason is that the machine has multiple problems, and many errors occur, causing the effective working hours to be too low. The third reason is that the logistical process is not fully designed yet, meaning there is no complete storage location design and no order policy. Because of this, stockouts can occur, causing low throughput.

So, having no fully designed logistical design causes a relatively low throughput. For storing and ordering, a policy is necessary to work structured and disciplined, which should make the process more effective. This research focuses both on storage and ordering. Storage and ordering are complex since the storage location has a maximum capacity. Moreover, the most significant constraint making storing and ordering complex is that, at most, 10,000 kg of hazardous substances may be stored in the storage location.

A design for the storage location should fulfill the requirements of an effective storage location. For example, it should be easily workable for the operators, and all SKUs should be reachable. Moreover, there should be little unused space. Furthermore, each product type should be accessible, and there should be enough moving space.

The order policy developed in this research should give a low chance of running out of stock and should guarantee that the amount of hazardous substances present in the storage location should never exceed its maximum.

In the future, A.R.T. plans to acquire an extra machine and to let the operators work in shifts. About these ways of expansion, nothing is known yet. A.R.T. wants to know what expanding does with the throughput and the logistical processes.

Central Research Question

The core problem is that a fully designed layout of the storage location and an order policy are missing now and should be designed. The central research question connected to the core problem is "How to make the logistical process of Aerosol Recycling Twente B.V., which includes the process of storage and the order policy, more effective to increase throughput". In this case, "more effective" means the machine can run without stopping because no aerosol cans are available to process.

First, an effective layout for the storage location is designed. After that, an reorder point (ROP) model is developed to determine a suitable reorder point. Then, for applying this reorder point, the way to implement it is explained. After that, different ways of expansion are considered.

Methods used

The research started with familiarizing the problem and exploring the company's process. This has been done through conversations and observations. After that, the current situation has been outlined and described using visualizations and descriptions of the way of working and the company's current state.

An extensive literature study has been performed to have a basis for the research. This literature study consists of two parts corresponding to the different components of the research. The first part of the literature study dives into optimizing storage locations and warehouses. For this, optimization theories and techniques have been researched to use as a basis for creating design alternatives. The second part of the literature study focuses on developing a model to find an optimal reorder point.

After collecting all required data and finding relevant literature, five design alternatives for the storage location could be created focusing on storing the inbound products; pallets and blue bins. The design alternatives are designed based on three different things. The first one is observations focused on how the operators work and the bottlenecks the system includes. Secondly, it is based on the literature review earlier in the research. The last one is that every design alternative includes at least one remarkable advantage, which is taken as a viewpoint in designing the design alternative. This is done to have varied design alternatives, all having different strengths and weaknesses. Next, the design alternatives are compared based on important criteria. After that, the two best design alternatives are compared based on a discussion. Lastly, the best design alternative is chosen.

Design alternative 1 first stores blue bins and then stores the pallets in front of the last stored blue bin. Design alternative 2 uses dedicated storage in which only one product may be stored in a lane. Design alternative 3 first stores pallets. After that, it stores the blue bins in front of the last stored pallets. Design alternative 4 stores the products alternately first. So, in lane 1, first blue bins, in lane 2, first pallets, then in lane 3, first blue bins again, and so on. Design alternative 5 uses randomized storage in which each product is stored in the lane, including the least amount of products.

For determining the reorder point, a combination of observations and literature is used to create a model that could be used for this specific case. First, the model considers the number of products in the storage location and the amount of hazardous substances in the storage location. Next, this model is applied to different situations ranging from the current situation of a faltering process to the optimal situation in which the machine has almost no errors or breakdowns. Finally, these different outcomes are compared, and an appropriate reorder point is determined for all situations.

In the future, A.R.T. is planning to let the operators work in shifts. Moreover, A.R.T. is thinking about purchasing a second machine. This gives some new possible situations from which they want to know what it does with the order policy. Therefore, the models are adapted and extended to check what expansion does with the throughput and the order policy. For these situations, we analyzed how many operators should work at which moments to maximize throughput.

Results

In designing the storage location, the best design alternative is design alternative 1, which stores first the blue bins followed by the pallets stored immediately in front of the last stored blue bin. This design alternative is shown in figure M1. This design alternative is easy to work with for the operators and is easy to implement. Moreover, it utilizes space effectively and scores well on all criteria.

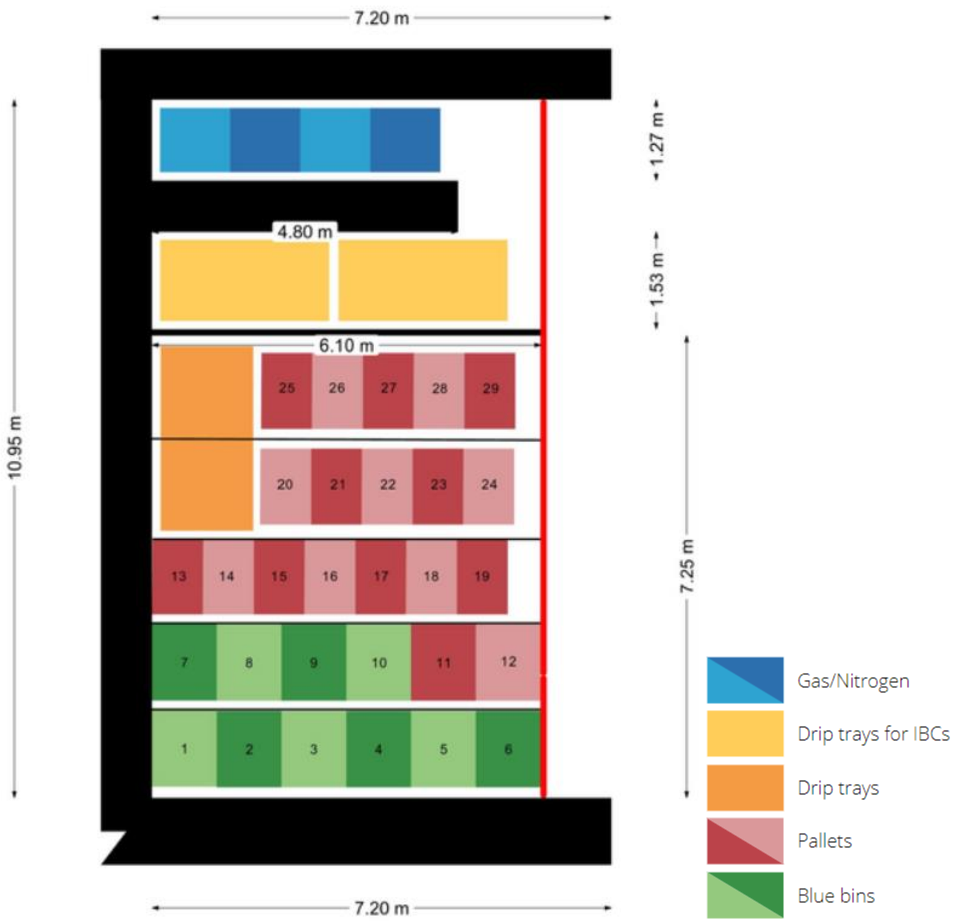

Figure M1 – Best scoring design alternative

The developed ROP model consists of two parts. The first part develops the formula for determining a mixed reorder point. The formula for determining the mixed reorder point is $\frac{1}{2}X_{BB} + X_{Pa} \leq ROP_{BB}$. In this equation X_{BB} is the number of blue bins in the storage location and X_{Pa} is the number of pallets in the storage location. ROP_{BB} is the reorder point for the blue bins if it would not be a mixed reorder point. ROP_{BB} equals two times the reorder point for the separate reorder point for the pallets.

The second part of the model checks whether an order would increase the maximum amount of hazardous substances. The equation for checking whether an order would lead to exceeding the maximum amount of hazardous substances at the moment of delivery is

$$\text{Amount of haz. sub. in storage location} = 65X_{BB} + 281X_{Pa} + 300X_G + 800X_I + 105X_{DBB} + 180X_N \leq 10{,}000$$

The variables in this equation correspond to the number of units from that product in the storage location. The numbers in front of the variables indicate the amount of hazardous substances one product includes.

With the developed ROP model, different situations can be analyzed for which a mixed reorder point can be determined based on the number of blue bins and pallets and a reorder based on the amount of hazardous substances. For the three situations to which the model is applied, suitable reorder points are determined. It seems the case that the mixed reorder point increases as the throughput increases. If the standard deviation decreases, the mixed reorder point decreases as well. An increase in the mixed reorder causes an increase in the reorder point based on the hazardous substances.

For the current situation, A.R.T. should use $\frac{1}{2}X_{BB} + X_{Pa} \leq 20$ as mixed reorder point with a corresponding reorder point based on the amount of hazardous substances of 3,263.05. For the scenario in which the machine runs smoothly, A.R.T. should use $\frac{1}{2}X_{BB} + X_{Pa} \leq 29$ as mixed reorder point with 4,213.83 kg as the corresponding reorder point based on hazardous substances.

In the case of working with two machines, the application of the models gives strange values and seems to be not applicable anymore since the throughput during the lead time and review period exceeds the order quantity, and the model is unable to deal with this. This model is applicable again if an extra storage location is built and if the order quantity increases so that the size of the delivered load is larger than the demand during the lead time and review period. When working with two machines, it is effective to work with four operators. When working in shifts, it is best to let the operators work four days a week and nine hours a day.

Recommendations

We recommend A.R.T. to implement the best-assessed design alternative for the layout of the storage location. Another recommendation is to determine the reorder point based on the outlined situations. If A.R.T. is, as regards the throughput, in between two different situations, the reorder point can be based on averaging those two situations. Moreover, we recommend A.R.T. to acquire an extra machine and, when doing that, also build an extra storage location. Furthermore, we recommend A.R.T. finding an extra supplier when working with two machines since the current supplier cannot satisfy all demand in that case. Additionally, we recommend A.R.T. to work with four operators in case two machines are used. Finally, if the operators work in shifts, we recommend letting all operators work four days a week.

Contents

Reader's guide

Chapter 1: Introduction

In this chapter, the company is introduced, and the action problem this research is focused on is described. Then, the core problem and the related central research question are discussed and separated into different parts of the research. Moreover, this chapter discusses the problem solving approach and the research design. In general, this chapter is an introduction chapter that introduces you to this research.

Chapter 2: Current Situation

This chapter describes the current situation. First, a general description of the current situation is given, followed by a process flow. After that, the storage location is analyzed and described, followed by an analysis of the current order policy. Lastly, this chapter discusses the plan of A.R.T. to expand in the future.

Chapter 3: Literature Review

In this chapter, relevant literature is reviewed, which contributes as a basis for developing the design developed in later chapters. First, a literature review is done on theories and optimization techniques for storage locations and warehouses. After that, a literature review is done on developing models to determine an optimal reorder point.

Chapter 4: Data Gathering

This chapter analyzes the observations and acknowledges the information necessary to create the designs. This chapter aims to find all information and data necessary to create the designs.

Chapter 5: Current Process Optimization

In this chapter, the designs are created. First, design alternatives for the storage locations are designed and compared to each other, after which the best design alternative is selected based on discussion. Finally, this chapter develops and applies the ROP model to different situations.

Chapter 6: Expansion

This chapter discusses three cases of expansion. First, a model is designed for the case of working with one machine and the operators working in shifts. After that, a model is designed for working with two machines without working in shifts. Finally, this chapter ends with a model for working with two machines and working in shifts. Every model is applied to different situations. Moreover, a connection with reality is made for every model.

Chapter 7: Conclusions and recommendations

This last chapter starts with a summary with corresponding conclusions for every part of the research. Next, some recommendations for A.R.T. based on this research are discussed. This is done for every part of the research as well. Finally, this chapter ends with giving possible directions for future research.

Glossary

Abbreviation/Concept	**Description**	**Introduced on Page**
A.R.T.	Aerosol Recycling Twente B.V.	1
IBC	Intermediate Bulk Container	2
Storage	This covers the processes of storage, processing, and dispatching	2
ROP	Reorder point	5
Effective working minutes	The number of minutes during the working day that the process runs, i.e., the time the machine did not stop because of an error or breakdown.	6
Drip tray	A tray on which an object with a chance of leakage can be placed to catch the liquids and prevent them from having contact with the floor	11
SKU	Stock Keeping Unit	19
CSL	Cycle Service Level	22

1 – Introduction

In this chapter, an introduction to this research is given. Section 1.1 describes the company at which the research is executed. In section 1.2, the problem is identified with a focus on the action problem, core problem, and the related central research question. Section 1.3 describes the problem solving approach used in this research. To end this chapter, section 1.4 dives into the scope and design of the research. This section treats the structure, deliverables, data/information gathering & analysis methods, and limitations.

1.1 – Company Description

Officially the bachelor assignment is executed at Machinefabriek Boessenkool B.V. in Almelo. Boessenkool is a company that designs and develops different machines for different markets and was founded in 1902. For selling those machines, some start-ups are set up. These start-ups focus on different products and different markets. One of their start-ups is DeSpray Environment B.V. This start-up develops and sells machines that have wasted aerosol cans as input and recover 100% of the inputs in a safe and profitable way. They sell these machines to places all over the world. The machine processes aerosol cans so that 100% of the outputs can be reused as raw materials again. The inputs of this machine are discarded aerosol cans, and the outputs are metal bricks, liquids, and gasses.

Three investors, from which one is the CEO of Boessenkool, decided to invest in a machine and obtained a plot at the company site of Boessenkool to set up the business. As a result, the investors founded a new company called Aerosol Recycling Twente B.V. (A.R.T.), whose business is to operate the machine commercially, be profitable, and to demonstrate. A.R.T. was founded in 2021. The machine is shown in figure 1.1.

At this moment, this process is still in the start-up phase. The process of A.R.T. is not focused on large-scale waste processing but on efficiency and rentability, demonstration, training, process optimization, and product improvement. This is to facilitate Boessenkool and DeSpray to observe, design, and test product improvements. Moreover, A.R.T. wants to increase the throughput with the current means. To contribute to this, this research is created to design the overall logistical process.

Figure 1.1 - Aerosol Recycling DS-1500 machine

1.2 – Problem Identification

In this section, the problem is identified. First, section 1.2.1 discusses the action problem. Then, in section 1.2.2, the core problem and central research question relating to the action problem are formulated. Finally, section 1.2.3 includes a small discussion on the norm and reality corresponding to the core problem.

1.2.1 – Action problem

Currently, the logistical processes are not fully designed, causing the throughput is not optimal. This is because, without a logistical plan, storage and ordering happen based on intuition.

At this moment, there is no fully designed storage location layout. The outbound products have assigned locations, but the inbound products, which are the unprocessed aerosol cans, have not. There is also no fully designed order policy regarding requesting a new load of unprocessed aerosol cans. When to make a request is difficult to determine since it has to consider the storage location's capacity, the maximum amount of hazardous substances, and the inbound and outbound products already present in the storage location. A.R.T. always wants to have unprocessed aerosol cans available so that no stockouts occur while never exceeding the maximum amount of hazardous substances and the storage capacity. Always having inbound products available makes the throughput higher than in case stockouts occur.

The logistics are bounded by different constraints causing the throughput to be not maximal. The biggest constraint is the licensing requirements which limit A.R.T. to have at most 10,000 kg of hazardous substances in the storage location. The storage location includes storage of aerosol cans that are not processed yet, gas tanks, IBCs (Intermediate Bulk Containers) with a mixture of (hazardous) liquids, and nitrogen racks. A fully designed logistical plan, which is not yet available, is necessary to increase the effectiveness of storage and ordering. In addition, a good level of documentation and registration is required to check the amount of hazardous substances. Currently, this is not done sufficiently. Another constraint is that the storage location has limited space in which the inputs and most outputs must be stored.

A fully designed logistical plan should increase product availability which should increase the total throughput. Increasing the total throughput increases the revenue, and it increases the contribution to a more sustainable world. Thus, a solution might have value for A.R.T. and society. In the future, A.R.T. wants to invest in an extra machine. This expansion requires an investment, and they want to know what this does with the storage efficiency, the order policy, the suppliers, and the process effectiveness.

1.2.2 – Core problem & Central research question

For storage and ordering, there is no detailed plan on how to deal with it. The problem cluster corresponding to the action problem is shown in figure 1.2.

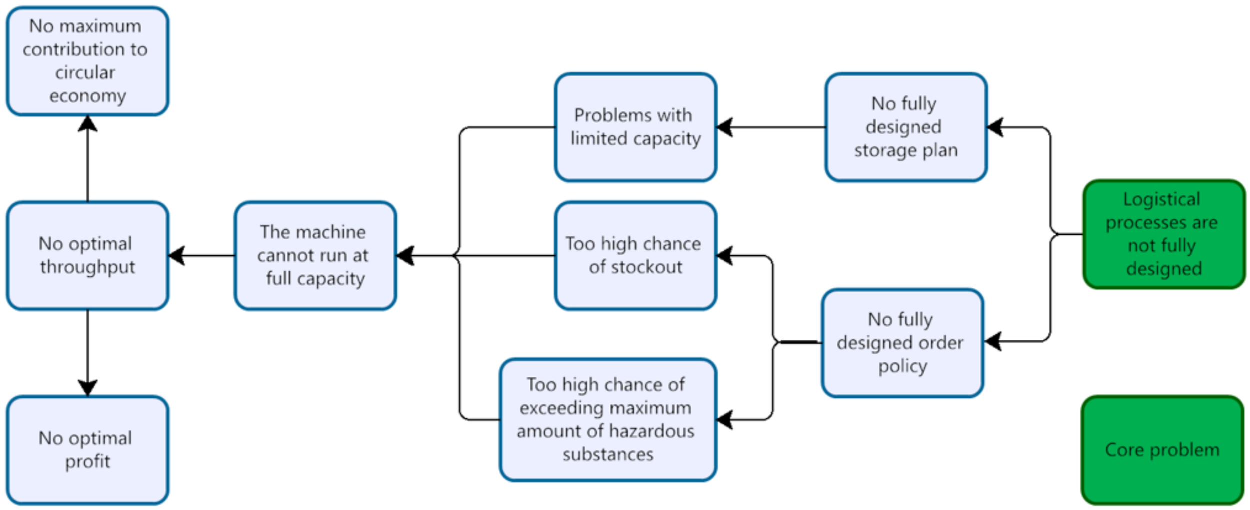

Figure 1.2: Problem cluster

Having no fully designed storage plan causes problems with limited capacity and causes that space is not used effectively. This can cause insufficient space to store inbound and outbound products. Having no fully designed order policy causes an improper way of dealing with the number of units in stock and the amount of hazardous substances. This can cause stockouts[1] and exceed the maximum amount of hazardous substances. Altogether, this causes the machine to not run at full capacity[2] since the machine is being stopped temporarily. If the machine cannot run at full capacity, the throughput is not optimal with the current means. No optimal throughput causes no maximum contribution to the circular economy, and the profit is not optimal. There is no maximum contribution to the circular economy since there are few regained substances compared to when the throughput is higher, so there is room to increase recycling rates.

Core problem: The logistical processes, including the storage location and the order policy, are not fully designed yet and should be designed to increase machine throughput and prevent stockouts.

Central research question: What designs for the logistical processes to implement to increase machine throughput and prevent stockouts?

Sub-question 1: What design for the storage location to implement to increase capacity and score high on important criteria of what the storage location has to include?

Sub-question 2: What order policy to implement to increase machine throughput and prevent stockouts?

[1] This is about a chance of stockout for the inbound products. So, it is about the unprocessed aerosol cans that are the input for the machine.

[2] Full capacity means that the machine does not have to stop because of stockouts, problems with limited storage capacity, or a too large amount of hazardous substances in the storage location.

The central research question is divided into a sub-question related to the storage location and a sub-question related to the order policy. First, an effective layout of the storage location is designed to increase capacity. After that, an order policy is designed. Next, research has been done on the effect of an extra machine and of letting the operators work in shifts. In this, it is considered how much extra supply this requires. The current largest supplier can deliver high quantities but has a limit. Therefore, research should be done for each scenario to determine when and in which scenarios additional suppliers are necessary. Moreover, the reorder point, different scenarios, and corresponding throughputs are considered.

1.2.3 – Norm & reality

The process of A.R.T. around the Despray machine is in the start-up phase. In the last year, a plan for the business operations, including the logistical processes, has been made. The optimality of the logistics is bounded by some restrictions, which makes it complex to optimize the process.

The norm is to have a fully designed logistical plan that gives higher throughput by letting the machine run at full capacity without being interrupted for logistical reasons. For this, constraints must be met, including licensing requirements and capacity constraints. We aim to create a model that ensures having practically no stockouts and ensures an order never exceed the maximum amount of hazardous substances.

The reality is that there is no detailed logistical plan yet regarding storage and ordering. Therefore, the process can, with the current conditions, not run at full capacity. This is because the constraints are not dealt with effectively. Moreover, in the first four weeks of processing, the process was interrupted multiple times because there was a stockout or because the amount of hazardous substances was more than 10,000 kg.

1.3 – Problem solving approach

There are several approaches to solving problems that all have their strengths and weaknesses. In this research, the Design Science Research Methodology (DSRM), discussed by Peffers et al. (2007) and Vom Brocke et al. (2020), is applied. The main reason for this is that the problem is not a problem about an already existing, fully running process, but the problem is that a design is missing at the moment. Therefore, a structured approach for creating and delivering a design is necessary. Such an approach is more suitable than, for example, the Managerial Problem Solving Approach (MPSM), discussed by Heerkens & van Winden (2017), which focuses more on solving a problem than on designing a process. After researching the existing approaches, the DSRM looks very suitable for this research.

The DSRM consists of six phases: identify problem & motivate, define objectives of a solution, design & development, demonstration, evaluation, and communication (Peffers et al., 2007). The initial phases of the DSRM can be found in Appendix A. Since this research consists of three sequential elements, steps 3, 4, and 5 are passed three times. Figure 1.3 shows the sequence of the steps explained below.

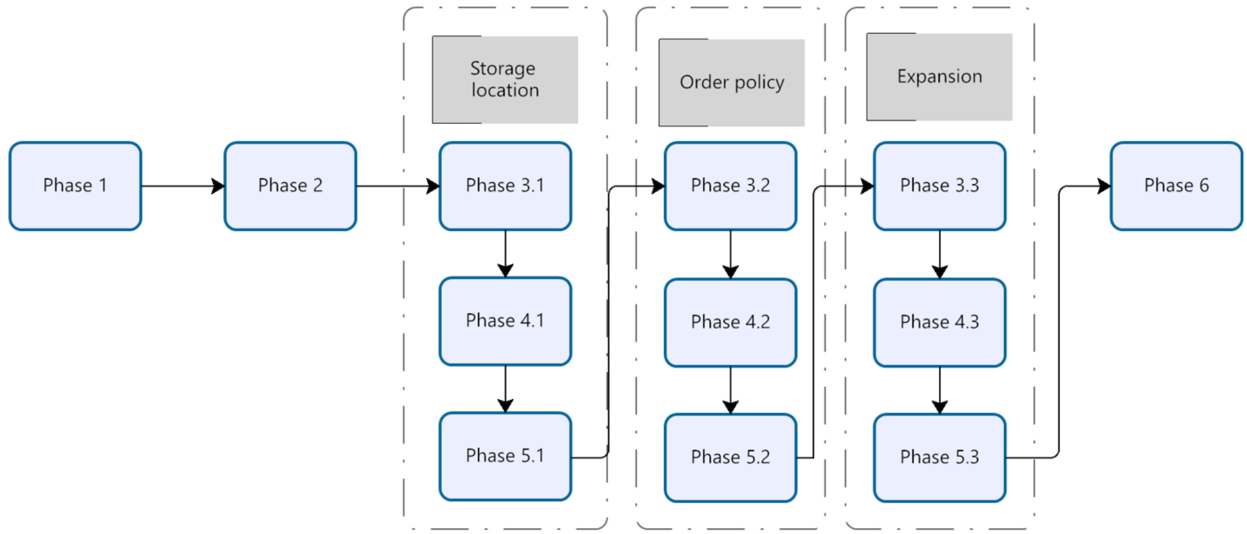

Figure 1.3 – Sequence of steps of the DSRM in this research

Phase 1 Identify problem & motivate: In the first phase of the DSRM, the action problem of this research is discussed, its importance is shown and justified, and the gap between norm and reality is analyzed. Moreover, a problem cluster is shown, and the core problem and central research question are defined. Phase 1 corresponds to section 1.2 of the thesis.

Phase 2 Define objectives of a solution: The second phase defines how the problem should be solved and what a possible solution should include. Moreover, in this phase, methods to use are discussed, and the way how to come to a solution is outlined. This section and section 1.4 correspond to phase 2 of the DSRM.

Phase 3.1 Design and development (Storage location): In the third phase, the models and designs are created. This research includes three separate parts. The first part, corresponding to phase 3.1, is about increasing the effectiveness of the storage location, which should increase the capacity of the storage location. For this, aspects like being easily workable for the operators, clarity, accessibility, and constraints are considered. This is done by combining optimization techniques, literature, and theories that connect theory and practice. The output of this phase is five design alternatives for the future storage location. Phase 3.1 corresponds to sections 5.1.1 and 5.1.2.

Phase 4.1 Demonstration (Storage location): In phase 4, the design alternatives are compared based on the most important criteria. This phase corresponds to section 5.1.3.

Phase 5.1 Evaluation (Storage location): In phase 5, the best fitting design alternative is chosen based on a discussion between the best two design alternatives. After phase 5, the design of the storage location is fixed. Phase 5 corresponds to section 5.1.4.

Phase 3.2 Design and development (Order policy): In the second part, the order policy is designed. This order policy is focused on finding optimal reorder points for particular situations. In this phase, the ROP model is developed. This phase corresponds to sections 5.2.1., 5.2.2, 5.2.3, and 5.2.4.

Phase 4.2 Demonstration (Order policy): After the ROP model has been developed, it can be applied to real situations. In this phase, three situations are considered. In these situations, we assume that the operators work from 07:30 AM until 4:30 PM. Every situation has parameters regarding the number of effective working minutes and corresponding standard deviation. This phase corresponds Appendix D.

Phase 5.2 Evaluation (Order policy): In phase 5.2, the outcomes of phase 4.2 are compared to each other, followed by a discussion on the important values. Moreover, it checks how the model fits reality and describes how the model should be implemented. Sections 5.2.5 and 5.2.6 correspond to this phase.

Phase 3.3 Design and development (Expansion): In this part of phase 3, the ROP model is adapted and expanded based on the wish of A.R.T to expand. They are planning to invest in an extra machine, and if necessary, they want to increase the number of suppliers. Sections 6.1.1, 6.1.2, and 6.1.3, 6.2.1, 6.2.2, 6.2.3, 6.3.1, and 6.3.2. correspond to this phase.

Phase 4.3 Demonstration (Expansion): In this phase, the adapted model is applied to situations deviating from the current way of working. The first situation considers the operators will still work with one machine but work in shifts from 7:00 AM until 7:00 PM. So, the effective working minutes are considered higher in this situation. In the next situation, we assume the operators work with two machines and work from 7:30 AM until 4:30 PM. In the last situation, we assume the operators operate with two machines from 7:00 AM until 4:30 PM. In the last situation, we assume the operators operate with two machines and work in shifts from 7:00 AM until 7:00 PM. Appendices E, F, and G correspond to this phase.

Phase 5.3 Evaluation (Expansion): In this phase, the important values of the phase are analyzed, and conclusions are formed. It checks how the model fits reality, and future implementation is explored. Sections 6.1.4, 6.1.5, 6.1.6, 6.2.4, 6.2.5, 6.2.6, and 6.3.3 correspond to this phase.

Phase 6 Communication: In phase 6, conclusions and recommendations are formed. After that, the thesis can be handed in, and A.R.T. receives the recommendations based on this research. Finally, the thesis ends by telling and showing A.R.T. what to do to let the machine run at a higher capacity and increase the process's throughput. Phase 6 corresponds to chapter 6.

1.4 – Research Design

In this section, the research design is discussed. First, in section 1.4.1, the research structure is discussed, and the deliverables are described. Then, section 1.4.2 describes the methods used to get information, knowledge, and data necessary for the research. Moreover, this section discusses the methods used to analyze the obtained information, knowledge, and data. Finally, section 1.4.3 treats the limitations of the research.

1.4.1 – Structure & deliverables

As explained in section 1.3, the research consists of three components. First, in section 5.1, the storage location is designed. Second, in section 5.2, an ROP model for the order policy is developed and applied to three current scenarios. The third part, corresponding to chapter 5, adapts and applies the model to three possible future scenarios. In some of theses scenarios an extra machine is considered and in some scenarios working in shifts is considered. This research includes multiple deliverables.

For the storage location, five design alternatives are designed. After that, the best design alternative is chosen based on important criteria.

An order policy is designed for the current working conditions, and an order policy is designed for the expansion scenarios. For the current working conditions, an ROP model has been developed. After that, the model is applied to three situations. Part of this deliverable is the worked-out steps for all situations, which is shown in Appendix D. For all situations, the connection with reality is made. To apply the order policy, the operators should track the content in the storage location daily and determine whether an order should be placed or not. This might be done in the daily report, which can be designed as user-friendly to make it easy to work with for the operators.

The ROP model developed for the current situation is adapted and expanded differently for every expansion scenario. Every situation these models apply to is worked out in the appendices. These models are also connected to reality.

There are two general deliverables. The first one is a process map to clarify the company's process. The second one is the conclusions and recommendations for A.R.T. based on the research.

1.4.2 – Data and information gathering and analysis methods

Data and information gathering methods

The primary method to gather data for this research was by doing many observations. In this research, the observations are both quantitative (e.g. lead time) and qualitative (e.g. behavior of operators). If necessary, the operators were asked questions to acquire information about things like the way of working and other things they face in a working day. A qualitative information gathering method used during this research is a literature search. Finally, data collection was an essential part of the research since there was no data available before starting the research because, at that moment, the machine was not even installed. In the first few weeks, observations were done every day from the start till the end of the day.

Data and information analysis methods

After collecting a lot of data and information, the data had to be analyzed. The information collected from the literature is analyzed in chapter 3. It is mainly used for designing the design alternatives for the storage location and to develop the ROP model. The data collected by observations is mainly used to derive the ROP models' input variables.

To make the data usable, the quantitative data first had to be structured. After that, SPSS and MS Excel were used to find important statistics and outcomes of the data sets. These measures and outcomes are used in the by literature developed models and should make the model as accurate and valid as possible. The data is visualized to make it understandable, clear, and to make the data easier to work with. Visualization is mainly done by using MS Excel.

1.4.3 – Limitations

Since this research is about a recently founded company, it includes multiple limitations because many things are uncertain. The first limitation is that the model inputs are based on only 18 working days of observations. This is because the process did not run during the first two weeks of the research. These two weeks might have been useful in making the research more reliable. The more days of observing there are, the more reliable the data is.

Since the process is in the start-up phase, more errors and breakdowns occur than will occur in the future. This is because the machine is not in the condition it should and will be. Currently, A.R.T. is trying to improve the machine. Because of that, the effective working minutes per day as it is now is not as it will be in the future. Predicting the future is challenging but necessary. In chapter 4, this is systematically predicted and derived based on the current situation.

Another limitation is that it is still unknown how the gasses will be dispatched and how long they will stay in the storage location. This makes it hard to accurately estimate the amount of hazardous substances in the storage location.

Since the company is recently founded, the administration has been confusing at some points. This causes high effort to collect all relevant and necessary data. Moreover, the data that came available was sometimes not reliable because of human mistakes. On day one of the research, no historical data was available, so everything had to be collected.

The next limitation is that there changed a lot in the company during the research. For example, first, the plan was to store no nitrogen racks. Later, the plan was to store one nitrogen rack. Things like this happened a lot, requiring much effort and time to revise. This will probably occur in the future as well, which could make this research outdated at some points. Since a lot was unclear about the process, multiple assumptions have been made.

2 – Current Situation

This chapter describes what the current system before implementing the designs looks like. First, section 2.1 briefly describes the current general situation of A.R.T. as a company. Section 2.2 discusses the current state of the storage process, and section 2.3 describes the current ordering process. Finally, this chapter ends with section 2.4, in which the current view about expansion is discussed.

2.1 – General

The process of A.R.T. has just started and is not running as smoothly as it should. Many errors occur, and the effective working minutes are low compared to what can be expected from a smoothly running process. Both the storage and ordering processes happen based on intuition and common sense. Structure or methods are missing in this. The machine has been running for a couple of weeks now, and the operators are becoming increasingly familiar with it, causing the process to run more smoothly every week. However, a significant fraction of each day is wasted due to errors, reparations, or other unexpected problems.

2.2 – Storage location

In this section, the storage location is described by taking two views. First, the structural, static view is discussed in which the inputs, outputs, properties, and a map of the storage location are described. After that, the behavioral view shows relationships and movements between the different products. The difference between the structural and behavior view, as Dotoli et al. (2015) use it, is discussed in section 3.1.

2.2.1 – Structural view

Empty Storage location

The storage location, illustrated in figure 2.1, was built before the machine was installed. Therefore, the surface of the storage location is fixed. The inside length of the storage location is 10.95 m, and the inside width is 6.10 m. Between the exterior walls are a fire-resistant wall and a fence to limit the danger in case products, including hazardous substances, will rocket or explode. The fire-resistant wall is the same width as the exterior walls, and the fence is relatively tiny. There is a red line on the floor in front of the storage location, indicating the boundary of the storage location. In reality, this line is painted on the floor. No products that include hazardous substances may be stored outside the storage location.

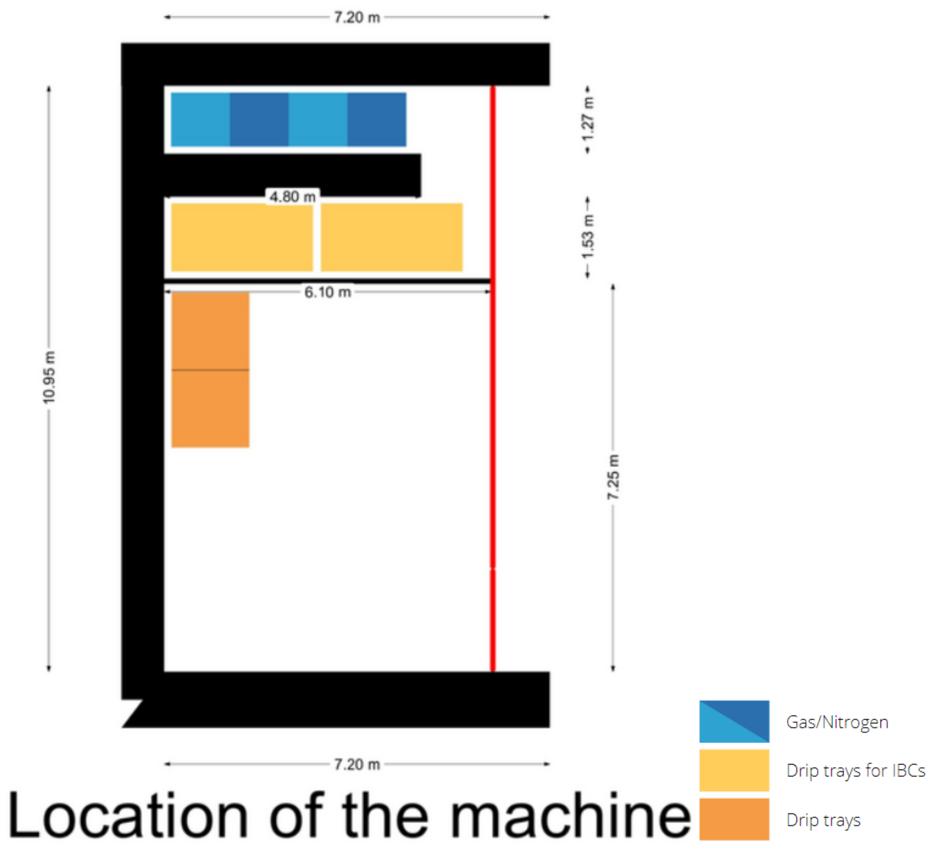

Figure 2.1 – Current fixed layout

The machine is on the left side of the storage location, viewed from the front. Figure 2.1 indicates this by "Location of the machine". In the rest of the figures, this is not indicated.

Products in storage location

The storage location both includes inbound and outbound products. The inbound products are the inputs for the machine, which are the aerosol cans delivered by the suppliers. The delivered aerosol cans can belong to two different streams. The first stream is the mono stream in which aerosol cans, filled with the initial content, are delivered in boxes piled on pallets. The second stream is the mix stream, in which aerosol cans thrown away by people are delivered in blue bins. Mix stream aerosol cans are not filled anymore since people threw these away as being empty. However, such aerosol cans are never empty because there always remains some gas and liquids that cannot come out by spraying. For the inbound products, a surface of approximately 40 m^2 is available.

The outbound products are the outputs of the machine, which are gasses in gas tanks, liquids in IBCs, and metal rolls. Only the products that include hazardous substances must be stored in the storage location. The outputs that include hazardous substances are gasses and liquids. The metal rolls can be stored in a container in the open air.

So far, we have discussed the process's primary inbound and outbound products, but the process around the storage location also includes some secondary inbound and outbound products. These products are not part of the initial inputs and outputs of the machine. The only secondary inbound product is nitrogen which is a crucial excipient. Without nitrogen, the machine cannot run.

The first secondary outbound product is cardboard waste. Cardboard waste comes from unpacking boxes to get out the aerosol cans. Cardboard does not have to be stored in the storage location since it includes no hazardous substances[3]. The initial supplier disposes of the cardboard. The second secondary outbound product is plastic that binds the boxes together on the pallet. As regards disposal, the same happens with plastic as with cardboard. The next secondary outbound product is the disapproved aerosol cans. These are cans that the machine cannot handle, and these have to be sorted out by the operators. These cans go into a blue bin and have to be stored in the storage location since the content is classified as hazardous substances. Again, the initial supplier disposes of disapproved aerosol cans.

As shown in figure 2.1, in the current state, it is determined where to store the gas tanks and where to store the IBCs. Gas tanks have to be stored behind a fire-resistant wall to limit the impact in case of fire or explosions. There is room for four gas tanks behind each other, and two gas tanks can be stacked on top of each other, so there is room for eight gas tanks. Since there are currently four gas tanks available, stacking is unnecessary and is not used in the current state. Nitrogen racks must be stored behind the same fire-resistant wall as the gas tanks.

The IBCs must be placed on top of a drip tray to prevent hazardous substances from falling on the floor in case of leakage. Moreover, IBCs must be placed between the fire-resistant wall and the fence to limit consequences in case of fire or explosions. There is room for four IBCs behind each other, and two IBCs may be stacked on top of each other, so there is room for eight IBCs. As shown in figure 2.1, there are two drip trays to store IBCs, and on both of them, there is room for four IBCs behind each other. A picture of the dedicated locations for the inbound and outbound products is shown in figure 2.2.

Figure 2.2 - Dedicated locations for inbound and outbound products

[3] The products that do not have to be stored in the storage location are stored elsewhere on the company site.

The two square drip trays placed on the other side of the fence, as shown in figure 2.3, are used for leaking or broken objects. Leaking does not occur often, but if it occurs, these drip trays are necessary to prevent hazardous substances from falling on the floor.

Figure 2.3 - Square drip trays

All the remaining space in the storage location is available for the inbound logistics and the disapproved aerosol cans. It is not yet determined where to store the inputs and what to process. The height of the stacked bins may not exceed 3.60 meters, and the products may not cross the borderline of the storage location. The most important constraint is that there may be a maximum of 10,000 kg of hazardous substances in the storage location.

2.2.2 – Behavioral view

The behavioral view is focused on relationships between the different storage processes (Dotoli et al., 2015). It is also focused on analyzing the products in the storage location. As explained before, six different products have to be stored in the storage location. The inbound products that need to be stored are the pallets with boxes and the blue bins. Both include aerosol cans that should be thrown into the machine.

The outbound products that need to be stored in the storage location are IBCs with liquids and gas tanks with gasses. Additionally, nitrogen racks and disapproved aerosol cans must be stored in the storage location. A flow chart of the product flows can be found in figure 2.4. There is one forklift, driven by one of the operators, by which all movements are being made.

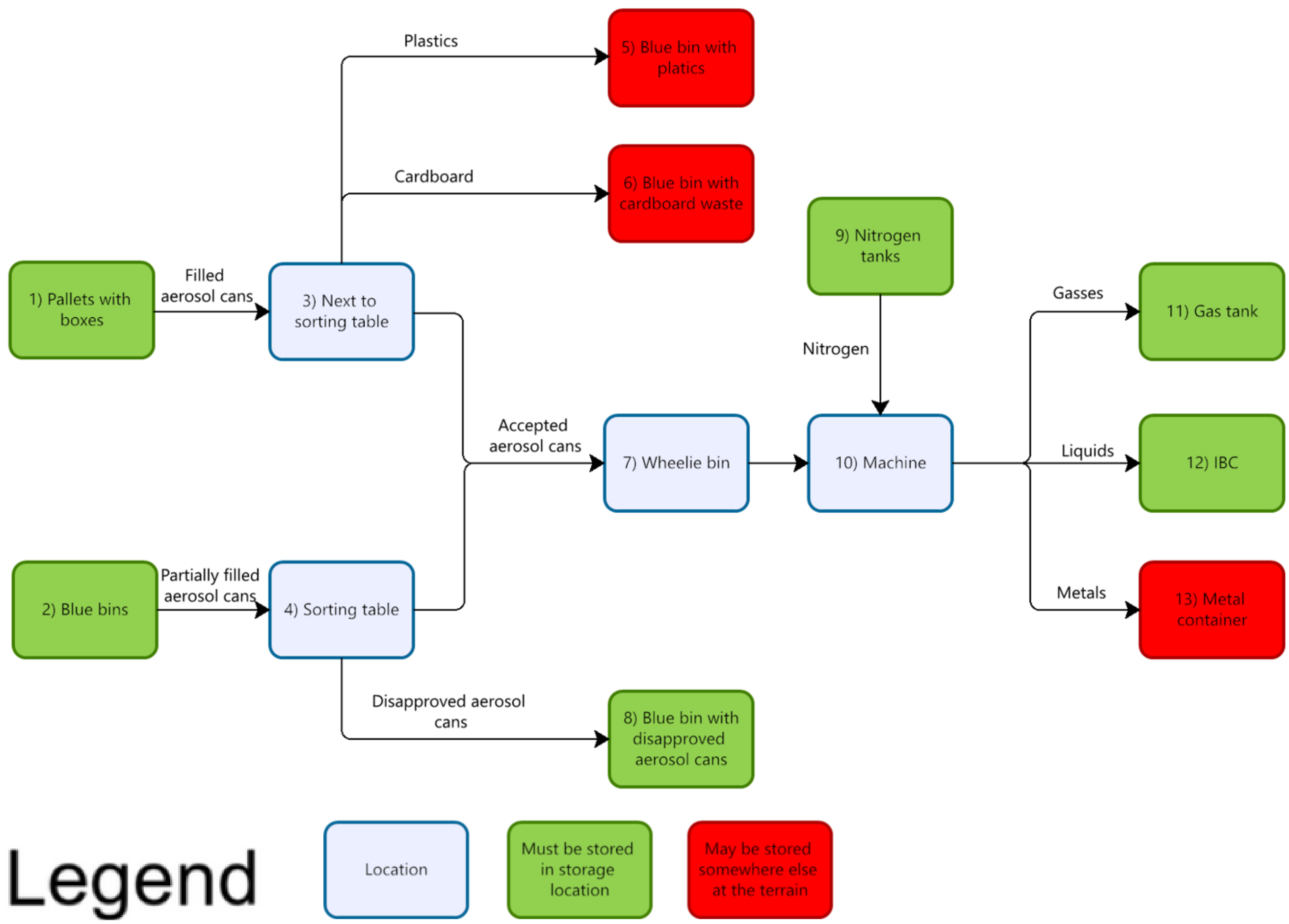

Figure 2.4 - Product flow

Inbound

The pallets with boxes (1) include aerosol cans accepted by A.R.T. Those do not have to be sorted before entering the machine. However, the unprocessed aerosol cans in blue bins (2) must be sorted before going into the machine. The operators sort the aerosol cans on a sorting table and sort out products the machine cannot handle (4).

The boxes on the pallets are unpackaged next to the sorting table (3). Next, the plastic and cardboard go into a different blue bin (5 & 6). After sorting, the accepted, partially filled aerosol cans mixed with the filled aerosol cans from the pallets are thrown into a wheelie bin (7). This wheelie bin is placed in the machine, and then the machine starts processing. Both streams are mixed because the machine cannot handle only filled aerosol cans easily since the machine is built to process relatively empty aerosol cans.

Currently, storing the inbound products is the bottleneck in the storing process. For the outbound products, locations are already assigned. However, no exact locations are assigned for the blue bins and pallets. This research should create a layout that clarifies where to store what.

Outbound

After the machine has processed the aerosol cans and separated the different substances, the substances come out of the machine. The metal rolls are thrown out and fall into a small container (13). If this small container is filled, one of the operators empties the small container into a large container.

The liquids flow into an IBC connected to the machine (12). If this IBC is filled, the IBC is transported to the storage location, and an empty IBC is connected to the machine.

The gasses flow out of the machine in a gas tank that is part of the machine (11). If this one is filled, the gas is pumped into a transportable gas tank, and if that one is filled, it is placed in the storage location, and an empty gas tank is connected to the machine.

Secondary

A rack with nitrogen cylinders is always connected to the machine. If it is (almost) empty, a new rack with nitrogen cylinders replaces the empty one (9). The blue bin filled with disapproved aerosol cans is close to the sorting table during working hours. At the end of the day or when the blue bin is filled, it has to be stored in the storage location (8). The blue bins filled with cardboard and plastic may stay close to the sorting table even if they are filled since they include no hazardous substances. Therefore, these blue bins are conveniently stored where they do not have to be moved intensively.

2.2.3 – Layout to design

Chapter 5 focuses on designing the layout of the storage location. The current layout is not substantiated by theories or a used method. Currently, the operators do things based on common sense. Creating a design based on theories and optimization techniques might cause the operators to use the storage location more effectively and efficiently.

The current layout is used as a basis to start with in developing five design alternatives. These design alternatives consider only the products that have no assigned locations yet. These mainly include the inbound products which are the blue bins and pallets. Moreover, it includes blue bins with disapproval, but since most of the time, this is about one or two blue bins, there is no focus on this. In these design alternatives, strategies for storing and processing are considered and discussed. After designing the five design alternatives, they are compared based on important criteria, and the best fitting layout is chosen to recommend A.R.T. to implement.

2.3 – Order Policy

In this section, the current order policy is described. First, section 2.3.1 mentions the current suppliers of aerosol cans. After that, in section 2.3.2, the process of supply is described. This is followed by a description of the content of the deliveries.

2.3.1 – Suppliers

Currently, two suppliers deliver aerosol cans to be processed. The first supplier is Supplier A which is the biggest supplier. Supplier A is responsible for almost all delivered aerosol cans. The second supplier is Supplier B. Supplier B is responsible for a small part of the deliveries. However, this part is so small that it is negligible.

Supplier A can deliver high quantities, but there is a limit. The agreement is that Supplier A delivers enough aerosol cans to feed one machine. Since A.R.T. wants to expand with an extra machine, possibly extra supplier(s) are necessary, but who these suppliers might be, is not known yet.

2.3.2 – Process

A.R.T. requests a new load when they think it is possible to receive it. Currently, this is done based on estimations and common sense, and no detailed plan for this is available. This decision is based on the amount of hazardous substances in the storage location and the available working stock. Supplier A is responsible for delivery. Supplier A ensures a truck will deliver the load three days after a new load is requested. If receiving is not possible, A.R.T. does not apply for delivery, and at a later moment, receiving a new delivery will be considered again. This research develops a model that can be used to determine whether a new load should be ordered or should be postponed.

The content of a truck delivering the aerosol cans from Supplier A is (almost) always the same. The supplier determines the exact content since it depends on the stock of Supplier A. The content is based on what supplier A has in stock and what fits in the truck. It includes 16 pallets filled with boxes and between 23 and 28 blue bins, which equals an entire truck. Most of the time, it includes 28 blue bins, so in the remaining of the thesis, we assume that Supplier A delivers 28 blue bins per delivery. Supplier B can occasionally deliver a couple of blue bins, but this is not at a fixed moment and includes no fixed number of blue bins. An estimation is that this is, on average, four blue bins per week. Assuming Supplier A delivers approximately once a week, the ratio of blue bins-to pallets in the storage location is approximately 2:1. This is further discussed and explained in section 4.3.3.

One of the operators unloads the truck with a forklift and places it immediately in the storage location. After that, the operator loads the filled IBCs in the truck since those are transported back to Supplier A. Moreover, the operator loads the empty blue bins from the previous deliveries and the blue bins with cardboard and plastic since those go back to Supplier A as well.

2.3.3 – Model to design

Section 5.2 aims to create an ROP model for determining when to place an order. This model consists of two parts. The first part checks whether a new order should be placed based on the number of inbound products in the storage location to prevent stockouts. If, based on the first part, an order can be placed, the second part of the model should be considered. The second part checks whether placing an order will exceed the maximum amount of hazardous substances at the moment of delivery or not. If this is not the case, an order can be placed. If the chance is too large that the amount of hazardous substances might be exceeded when placing an order, no order should be placed, and placing an order should be considered the next day again.

2.4 – Expansion

2.4.1 – Idea of expansion

A.R.T. is currently working with only one machine, and they want this process to run more effectively compared to what it is now. At this moment, this is challenging since a lot of unexpected and unforeseen things happen each day. Because of that, the effective working hours are low. Currently, the effective working hours are, on average, a bit more than three hours a day.

Shortly, the effective working hours should become six hours a day. This is because the operators will become better at solving errors and fixing mechanical problems. If the process runs more smoothly and the throughput significantly increases, A.R.T. considers purchasing an extra machine. This idea is not yet developed, and at this moment, A.R.T. is not sure when they want to purchase that machine.

As mentioned, two operators currently work 36 hours weekly with one machine. However, in the case of expansion, it is not determined how many operators should be available and how long the machine might run each day. So, the idea of expansion is there, but when and whether they will invest in it is not thought about yet.

2.4.2 – Models to design for expansion

As regards expansion, three different scenarios are considered, and a model for determining the reorder point has been developed for all scenarios. All models are expanded and adapted versions of the earlier developed model for the order policy. The first expansion scenario considers operators working in shifts with one machine. Next, the second expansion scenario considers the operators working with two machines during general working hours. At last, the third expansion scenario considers the operators to work with machines in shifts. All these models are applied to possible situations, and outcomes are analyzed. Based on these outcomes and a discussion, recommendations for A.R.T. on what to do with the storage location, suppliers, operators, and more are given.

2.5 – Conclusion

In this chapter, the current situation in which A.R.T. is right now is described, and expansion plans are discussed. A.R.T. is a recently founded company causing that not everything is as organized as in longer existing companies. Currently, the process is run by two operators working with only one machine. A.R.T. is considering expanding in the future by acquiring an extra machine, increasing the number of operators, and possibly letting the operators work in shifts.

Currently, storing happens without a plan, and the operators act based on common sense. This causes the storing process to be as effective as it could be. For the ordering process, there is neither a structured policy. Ordering happens based on common sense and estimation without thorough substantiation.

3 – Literature Review

The goal of the literature review in this chapter is to support the research and substantiate the later developed models. In section 3.1, a literature review has been done, which should help optimize the storage location. First, a general literature review on warehouses and storage locations is performed, followed by a literature review on the effective use of space and convenient layouts. Next, different storage policies are described and compared, followed by a literature review on how to deal with the future.

In section 3.2, a literature review to reorder point models is performed. First, different types of inventory are discussed and analyzed how to deal with those. Next, a short introduction to reorder points is outlined. After that, we discussed literature on fill rates and cycle service levels. Finally, we evaluated literature on specific review policies.

3.1 – Storage location

There is an enormous amount of literature available regarding warehousing and storage. Warehousing and storage are broad terms, and the implementation depends on the situation. Therefore, finding relevant literature that fits this specific case is not easy. To find literature for optimizing the storage location, the following research question has been constructed:

Literature Research Question: What are useful theories/techniques to help in optimizing the layout of the storage location and what should be taken into account?

Scopus and Web of Science databases are used to find articles that might contribute to this literature review. Moreover, we found some literature using snowballing in which the reference lists from earlier found articles are used to find more sources. Furthermore, some literature is collected by coincidence or because someone else recommended it. Together, all these different literature collection methods form the basis of this part of the literature review.

General

A warehouse or storage location is a place where received goods are stored and dispatched as quickly, effectively, and efficiently as possible (Richards, 2014). No storage locations are the same, and for every storage location, the connected operations differ. Therefore, it is difficult to have a standardized layout of a storage location since it is not fully duplicable. In designing the layout of a storage location, trade-offs between speed, travel distances, space utilization, handling, access, safety, risk, and cost must be considered (Richards, 2014). There are many articles available that discuss empirical and specific examples of designing a warehouse.

There are many different theories and techniques to optimize storage locations. Common sense could be a straightforward, time-saving approach, but most warehouses are too complex for only using common sense. There are endless methods to come close to an optimal design. For example, Expósito-Izquierdo et al. (2014) use Mixed Integer Linear Programming in combination with heuristics to optimize the retrieval process. Methods like these can be very beneficial. Currently, A.R.T. uses common sense, but warehouse optimization techniques may be helpful to increase effectiveness.

Another way to get insight into complex storage locations and optimize them is by using simulation. For example, Derhami et al. (2020) use a simulation to design a layout for block stacking[4]. Multiple variables, depending on each other, are part of this optimization process. These variables include common variables in warehouses such as the number of aisles and cross-aisles, bay depths, cross-aisle types, space utilization, and material handling costs. This makes it very complex, and simulations are handy in such situations. A significant disadvantage of simulation is that it requires much time, and for simple warehouses, it could be that this time is not worth it. The storage location in this research is not complex enough to put much effort into creating a simulation.

Dotoli et al. (2015) mention two views to describe and detail a storage location: a structural and a behavioral view. In this research, the structural view is about the static structure of the storage location and describes its objects and attributes (Dotoli et al., 2015). The behavioral view is about the dynamical behavior of the storage location. It describes relationships and shows what happens over time (Dotoli et al., 2015). An analysis of the structural and behavioral views for the storage location of A.R.T. has been performed in section 2.2.

According to Ackerman (2003), to find an optimal layout for large storage locations, it is important to measure the storage location's reliability, flexibility, cost, and asset utilization (Richards, 2014). It is essential to gather as much data as possible, analyze it, think about the future, standardize the process of movement and storage, and understand the local building regulations and floor loading requirements (Richards, 2014). The main trade-offs in warehouses are between high customer service level, low cost, and lower inventory (Richards, 2014). Changing the inventory level has an impact on all of them.

Most of today's warehouses are large, and in most warehouses, products are fast-moving. This makes it impossible for employees to track and manage all aspects of the warehouse. To make tracking and managing easier in large warehouses, Warehouse Management Systems (WMS) are essential to improve the speed, productivity, and accuracy of large and complex warehouses (Richards, 2014). A WMS is a database-driven computer application aiming to improve warehouse efficiency by documenting transactions and controlling movements (Ramaa et al., 2012). Currently, A.R.T. has no WMS since it is in the start-up phase. Moreover, since the storage location of A.R.T. is not large and complex, a WMS is not essential in this case.

Effective use of space and convenient layout

In this section, we try to find how to use the available space effectively and what to consider to get a convenient layout. In many storage locations, also in this research, block stacking is used. In block stacking, the aim is to effectively utilize the available floor space (Goetschalckx & Ratliff, 1991). While doing this, handling costs of storage and retrieval should be minimized (Goetschalckx & Ratliff, 1991). To improve the productivity of storage and retrieval, it is important to book arrival slots for the suppliers to ensure enough space is available and to minimize the chance of a stock out (Richards, 2014).

If block stacking can be used, which is not always the case, there is more space available than only the floor space. Therefore, in that case, the floor space is not the capacity to focus on, but the focus must be

[4] According to Derhami et al. (2019), block stacking is: "Storing pallets of Stock Keeping Units (SKUs) on top of one another on a warehouse floor."

on the storage location's cubic capacity (Richards, 2014). For example, If four units can be stacked on top of each other, 25% of the floor space is required compared to the case the products would not be stacked.

To calculate the occupation of this capacity, little's law can be used. Little's law is the following formula: $L = \lambda * W$ (Bartholdi & Hackman, 2019; Chopra & Meindl, 2019; Little & Graves, 2008). In this equation, L is the average space occupied, λ is the arrival rate, and W is the average time a unit stays in the storage location (Little & Graves, 2008). For example, if three units arrive daily and remain in the storage location for three days, nine spots are utilized for that product.

According to Kooy (1981), an optimal storage location should always have an empty lane since there needs to be space available to store arriving products optimally (Goetschalckx & Ratliff, 1991). According to Bartholdi & Hackman (2019), space can be tried to save by congesting more products into the available space. In doing this, always ensure that all space and every SKU can be reached. Economic efficiency can be achieved by placing heavy, popular, and fast-moving items in the golden zone[5] (Bartholdi & Hackman, 2019).

Sometimes there is too little capacity to store everything, so in that case, additional space is required. Additional space can be found by expanding the storage location, renting additional space, and creating more space with the current premises (Richards, 2014). In chapter 6, possible expansion scenarios for A.R.T. are highlighted. In this chapter, increasing the storage capacity is considered for the case A.R.T. acquires an extra machine.

The design of the storage location always has to fit the existing storage equipment and material handling equipment (Richards, 2014). Furthermore, to work efficiently, the objective of the product touches has to be minimized since it wastes time and decreases the clarity of the overall picture (Richards, 2014).

During the whole process, especially in working with the equipment, the health and safety of the employees should come first. Moreover, appropriate and good working conditions increase the motivation and productivity of the employees (Richards, 2014). In this research, in creating the design, the human well-being of the operators should be considered.

Storage policies

Naik (2004) identified three different storage policies. The first policy is called "dedicated storage" and is the most common one. In this policy, every SKU is appointed to a particular part of the storage location where only that SKU may be stored (Naik, 2004). This policy requires the most space since no inventories can be combined, and for every product, there has to be enough space available. So this policy wastes much space (Battista et al., 2011).

The second policy is called "randomized storage". This policy places the arriving products in the nearest available location (Naik, 2004). This policy requires the least space since inventories can be aggregated, which minimizes the number of required slots (Battista et al., 2011).

The third policy is "class-based storage". This policy includes aspects from both of the earlier discussed policies. First, all products are divided into three classes (A, B, and C) based on how frequently they have to be picked. Then, the most frequently picked products (class A) are placed closest to the input/output

[5] The golden zone is the most accessible place to pick from (Bartholdi & Hackman, 2019).

point, and the least frequently picked products (class C) are placed in the least convenient places (Naik, 2004).

Future

In designing storage locations, it is essential to think about the future. Richards (2014) states: "build for today, design for the future". To do this, a storage location should be designed for flexibility and scalability since things can always change, and a design should be able to deal with this (Richards, 2014).

It is essential always to measure things like productivity, accuracy, and product dimensions to see what happens and to guarantee that the design of the storage location fits the current and will fit future operations. Always learn from obtaining and exploring things to find new aspects that can be optimized (Richards, 2014).

3.2 – Order Policy

In this section, literature is used to get a basic understanding of ROP models and to find out what type of model is suitable for this research. This section is used as a basis to develop the models in chapters 5 and 6. First, different types of inventory are outlined and discussed. Next, the term reorder point and the basic equation for determining this are explained. After that, we show to work with the fill rate and the Cycle Service Level and how those are related to the reorder point. Next, the difference between continuous and periodic review policies is analyzed. Finally, more specific order policies are highlighted.

Scopus, Web of Science, and MathSciNet databases have been used to find literature that might contribute to the literature review on order policies. As for the storage location, snowballing has been used as well.

Types of inventory

The reason why a system needs inventory is that demand and supply do not match each other. Chopra & Meindl (2019) identified three types of inventory preventing a system from running out of stock. The first type of inventory is cycle inventory. This is the average amount of inventory used to meet demand between deliveries of sequential orders (Chopra & Meindl, 2019).

The second type of inventory is the safety inventory. If demand is always the same, safety inventory is not needed. However, demand constantly fluctuates, and therefore a little buffer is needed to not run out of stock (Chopra & Meindl, 2019; Gupta et al., 2022). This buffer is called the safety inventory. The higher the uncertainty, the more safety inventory is required.

The third type of inventory is seasonal inventory. Seasonal inventory includes extra inventory collected during periods of low demand and is stored to satisfy demand in periods when demand is higher (Chopra & Meindl, 2019). This increase in demand in several periods is predictable, and companies expect it to be higher.

Figure 3.1 illustrates a standard inventory profile over time. The demand in this picture does not fluctuate, so the safety inventory is not touched. However, if demand fluctuates and is higher at some moments, the safety inventory must satisfy demand. If there is no safety inventory and demand is higher than average, demand cannot be satisfied, resulting in lost sales or backlogs[6].

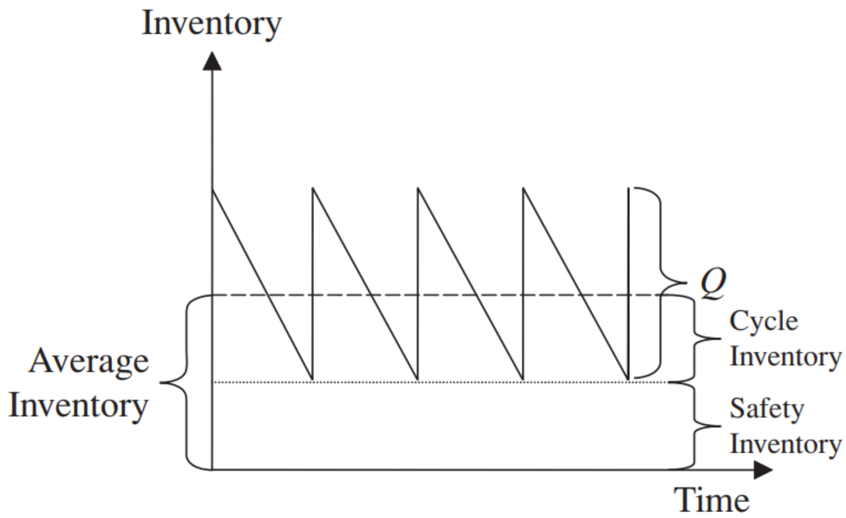

Figure 3.1 - Inventory profile (Chopra & Meindl, 2019)

Reorder point

According to Gupta et al. (2022), determining the reorder point is an approach to analyzing when to place an order. When the inventory drops to or below the reorder point, a new order should be placed. A reorder point does not say anything about the order quantity. The order quantity depends on the policy and strategy being used. If lead time would be zero time units and products can be delivered immediately, the reorder point would be zero since then the inventory costs are minimized, and no stockout occurs (Axsäter, 2015). However, in principle, no products can be delivered in the same second as the order is placed. The shorter and the less fluctuating the lead time, the more accurate the model is.

The general formula for determining the reorder point is (Axsäter, 2015; Chopra & Meindl, 2019; Gupta et al., 2022):

$$ROP = ss + D * L$$

With:

- ROP: reorder point
- ss: safety inventory
- D: demand
- L: lead time

This formula consists of two components. The first component is the demand during the lead time, which is D * L. Imagine the lead time is two weeks, and per week the demand is 100 units, then 200 units should be in inventory when placing an order to satisfy the lead time demand. Otherwise, a stockout occurs, and lead time demand cannot be satisfied.

[6] In inventory management, backlogs are sales that can be delivered later when products are available again (Chopra & Meindl, 2019).

The second component is the safety inventory. Imagine the demand would be higher than expected, then there should be enough units in inventory to satisfy this demand. Therefore, the inventory position at which a new order should be placed is the safety inventory plus the demand during lead time.

In determining the reorder point, assuming the order quantity is constant, the trade-off between inventory costs and costs for having no stock should be considered. The higher the reorder point, the higher the number of reorders and the higher the average stock level (Ghezzi, 2017). A high reorder point results in high inventory costs. A low reorder point increases the chance of having no stock and can result in lost sales or backlogs (Axsäter, 2015). Backlogs occur when a customer is willing to wait until the product is available, which could lead to extra costs for administration, material handling, transportation, and price discounts to compensate for late delivery (Axsäter, 2015; Singha et al., 2017). It could also be the case that customers are unwilling to wait until the product is available. In that case, the sales are lost, which results in a lower revenue (Axsäter, 2015; Chopra & Meindl, 2019).

Continuous demand would be an ideal situation, but continuous demand is, in most cases, not realistic (Khanra & Chaudhuri, 2003). Another ideal situation, which is seldom true, is zero or continuous lead time. There are many variations of models using continuous demand and lead time. However, these are primarily theoretical models that assume this for simplicity to give a reasonable estimation of reality.

Fill rate & Cycle Service Level

The reorder point can depend on the fill rate (fr) or the Cycle Service Level (CSL). The fill rate is the fraction of demand that should be met on time from stock on hand (Axsäter, 2015; Chopra & Meindl, 2019). For example, if 99% of the demand should be met, the fill rate should be 0.99. The more demand and lead time vary, the more complicated it is to determine the fill rate, and the more safety inventory is needed to fulfill the fill rate constraint (Axsäter, 2015). According to Chopra & Meindl (2019), the fill rate should be measured over a specific number of units and not over a time period.

The formula for the fill rate is (Chopra & Meindl, 2019):

$$\text{fr} = 1 - \frac{ESC}{Q} = (Q - ESC) * Q$$

With:

- Q: Order quantity (and average demand in a replenishment cycle)
- ESC: Expected shortage per replenishment cycle

Next to the fill rate, the Cycle Service Level (CSL) is another way to measure product availability. The CSL is the fraction of replenishment cycles in which no stockouts occur (Axsäter, 2015; Gutierrez & Rivera, 2021). Chopra & Meindl (2019) formulated CSL as "the fraction of replenishment cycles that end with all the customer demand being met". According to Chopra & Meindl (2019), the fill rate and the CSL are closely related. By increasing the CSL, also the fill rate will increase. As mentioned before, the safety inventory will increase by increasing the fill rate, and the same happens by increasing CSL. In most cases, the CSL is considered very high because shortage costs are, in most cases, higher than inventory costs (Geunes et al., 2001). So, holding a unit in stock does, in most cases, cost less than losing a sale or backlogging.

According to Chopra & Meindl (2019):

$$CSL = Prob(demand\ during\ lead\ time\ of\ L\ weeks \leq ROP)$$

In many cases, the ROP is determined based on a given CSL, so this has to be determined first. In that case, according to Chopra & Meindl (2019), the safety inventory can be determined based on the following equation:

$$Probability(demand\ during\ lead\ time \leq D_L + ss) = CSL$$

In this equation, D_L is the lead time demand, and ss is the safety inventory. The next steps to determine the safety stock depend on the distribution of the demand.

Continuous review policies & Periodic review policies

Two groups of policies can be distinguished in inventory management: continuous and periodic review policies. In continuous review policies, the inventory is continuously reviewed, and if the inventory level drops to the ROP, a new order will be placed. In periodic review policies, the inventory will be reviewed at the end of every time interval T. If the inventory drops to or below the ROP, an order will be placed. If not, no order will be placed, and the inventory will be reviewed again at the end of the next time interval (Axsäter, 2015; Lagodimos et al., 2012; Sarkar & Mahapatra, 2017).

There are advantages and disadvantages to both continuous and periodic review policies. Continuous review policies have higher reviewing and carrying costs and require more effort than periodic review policies. This is because continuous review inventories have to be reviewed continuously, while periodic review inventories have to be checked once after a certain interval period (Glud Johansen & Thorstenson, 1993). In continuous review policies, the safety inventory is used for covering demand uncertainly for lead time L, whereas in periodic review policies, the safety inventory is used for demand uncertainty for lead time and the review period, so the period L + T (Axsäter, 2015; Chopra & Meindl, 2019).

Warehouse Management Systems (WMS) decreased the effort of checking the inventory continuously. So, this disadvantage is now smaller and is less common than it was in the past. However, periodic review policies can save costs since an investment in WMS is less necessary (Axsäter, 2015; Singha et al., 2017).

An advantage of a continuous review policy is that it requires less safety inventory since the order can be placed immediately after dropping on or below the reorder point. Whereas in a periodic review policy, this will be recognized at the end of a time interval (Axsäter, 2015). Therefore, a continuous review policy can save inventory costs compared to periodic review policies.

Policies

After making a distinction between continuous and periodic review policies, different, more specific policies can be distinguished. Some of these policies are applicable both as continuous and periodic review policies. The two most common policies are the (r, Q) policy and the (s, S) policy (Axsäter, 2015). The names of the policies vary in different sources, but (r, Q) and (s, S) are the most recognized names.

The (r, Q) policy is mainly used as a continuous review policy (Singha et al., 2017). In this policy, when the inventory level drops to or below the quantity of r, a batch of Q units is ordered (Axsäter, 2015; Chen, 2005; Chopra & Meindl, 2019; Zhao et al., 2007). So in this policy, r is the reorder point, and Q stands for the order quantity. Therefore, in this case, the maximum storage capacity a system needs is r + Q since the inventory would never exceed this quantity if ordered one batch at a time (Zhao et al., 2007).

The (r, Q) policy can also be used for a periodic review policy. However, a periodic review (r, Q) policy is used less frequently than the continuous version. The reason for this is that in continuous review policies, the inventory is raised to the same level each time, and for periodic review policies, this is not the case (Axsäter, 2015). This is because, in the periodic version, the order is not placed immediately after the inventory drops below the reorder point (Lagodimos et al., 2012). One would use this policy in a periodic review case, because there could be no option or convenience to order different quantities (Singha et al., 2017).

Axsäter (2015), He & Chai (2017), Chen (2005), and probably a lot of other literature discusses the periodic version of this policy as an (r, nQ) policy or the same sort of policy with a slightly different name. In the name of this policy, n is a multiplier that should ensure the inventory ends up higher than the reorder point after ordering. Namely, in periodic review policies, it could be the case that the inventory drops so far before a new order is placed that one order is not enough to end up higher than the reorder point. In that case, more than one batch of size Q might be ordered (Axsäter, 2015; Chen, 2005).

3.3 – Conclusion

The literature review in this chapter contributes to designing the storage location and the order policy in chapter 5. The literature review that contributes to the increase effectiveness of the layout of a storage location is done in section 3.1. The literature review to help in designing an order policy is performed in section 3.2.

Storage location

The goal of section 3.1 was to find theories and techniques that could contribute to creating an effective layout for the storage location and to find things that should be taken into account.

In designing a storage location trade-offs between speed, travel distance, space utilization, handling, access, safety, risk, service level, and costs have to be considered. For large storage locations, it is important to measure reliability, flexibility, cost and asset utilization. Moreover, an essential task in designing a storage location is to gather a lot of data and to analyze it. In this, the future always has to be taken into account. Moreover, things like regulations, licensing requirements, and general requirements are essential to fulfill.

Important variables to consider in designing storage locations are bay depts, cross-aisles, cross-aisle types, space utilization and material handling costs. To be able to receive new products, one should try to always have an empty lane available for this. In designing the storage location, the health and safety of employees should always have priority. Moreover, the design always has to fit existing storage and material handling equipment.

For simple storage location, common sense could be a time-saving approach to use in working with storage locations. However, most storage locations are too complex to only use common sense. Therefore methods like heuristics, linear programming, and simulation can be beneficial in increasing effectiveness.

To save space, block stacking can be used. Block stacking aims to effectively utilize space by stacking products on top of each other. If more space is necessary, one can consider to increase capacity and acquire more space.

Order policy

The goal of section 3.2 was to get a basic understanding of ROP models and to find a model type that can be used in this research. What an ROP model exactly looks like depends on the policy being used. In inventory management, two groups of policies can be distinguished: continuous and periodic review policies. The exact derivation of the reorder point depends on the policy being used. However, there is a general formula for this. Supported by a lot of literature, the general formula for determining the reorder point is:

- $ROP = ss + D * L$

This formula consists of two components: the safety inventory and the demand during lead time. The safety inventory is necessary to satisfy demand in case demand is higher than expected. The demand during lead time is the expected demand between the moment of ordering and arrival. In determining the reordering point, a trade-off between inventory costs and costs for having no stock has to be considered. The ROP also depends on the CSL or the fill rate being used. The higher the CSL or fill rate, the higher the reorder point.

4 – Data Gathering

This chapter aims to obtain all information and data necessary to start creating the designs. Data gathering is an important part of the research since no data was available because the process did not even start at the beginning of the research.

To design the storage location and to develop the models, much information regarding working speed, products, weight, content, capacity, hazardous substances, and more is necessary. In this section, all information is treated so that it can be used as a basis to work with. In section 4.1, the observations for this research are described and summarized. After that, section 4.2 describes the products in the storage location and the lane system[7] used for designing the layout of the storage location.

Next, section 4.3 discusses the weights and contents of the products and the content of a truck delivering the aerosol cans. Then, in section 4.4, the capacity of the storage location and the amount of hazardous substances in the storage location is analyzed. Finally, in section 4.5, data and information regarding processing time & throughput are discussed. Moreover, section 4.5 outlines the situations for which an ROP model is developed in chapter 5.

Observations are an essential part of the research since no data was available at the start of the research. Multiple things have been observed to get accurate models and designs. The daily observed objects, to make the research as accurate and valid as possible, can be found in Appendix B. The results of the observations are discussed and used in the upcoming sections.

4.1 – Products & lane system

In this section, the products in the storage location are appointed again. Next, the lane system that is being used for the layout of the storage location is designed and described.

As discussed in section 2.2.2, the products that must be stored in the storage location are pallets with boxes, blue bins with unprocessed aerosol cans, disapproved aerosol cans, nitrogen tanks, gas tanks, and IBCs. The locations for the gas tanks, nitrogen tanks, and IBCs are fixed because of the licensing requirements to prevent danger. The locations for the blue bins with unprocessed aerosol cans, pallets with boxes, and disapproved aerosol cans are not fixed yet. So, the remaining space can be used for unprocessed and disapproved aerosol cans.

One pallet and one blue bin have approximately the same width, which is 120 cm. This makes it easy to create lanes since all those lanes can have approximately the same width. In the available space, there is room to create five lanes. Most design alternatives in the following sections include this system of storing the products in lanes. This is, in this case, a useful way to store products since both blue bins and pallets have the same width. Five lanes can be used to store products. The lane system in figure 4.1 includes imaginary lines between the different lanes, which are not visible in reality but are drawn on the map to make it clear. As discussed in chapter 2, the machine is located next to the storage location on the side of lane 1.

[7] In this research, the lane system is a type of layout for the storage location. In this storage location, five lanes of approximately the same width can be created in which the products can be stored.

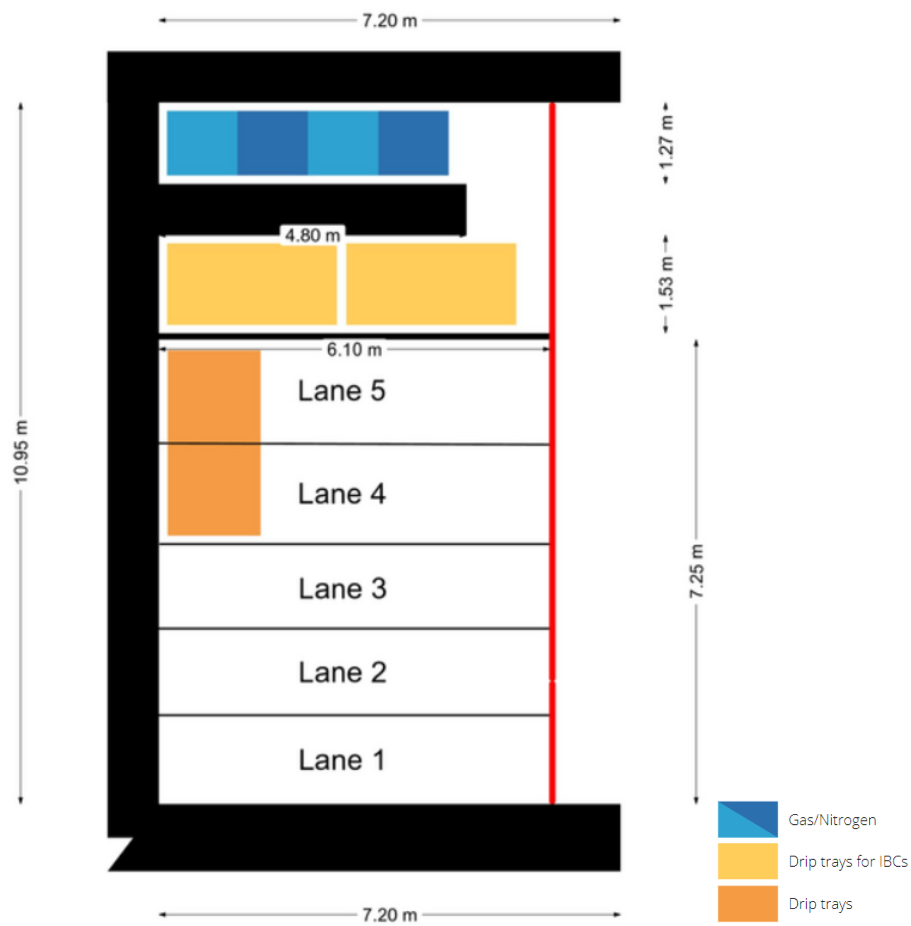

Figure 4.1 - Lane system

The order of processing does not matter in this process. This is because all pallets are considered to be the same, all blue bins are considered to be the same, and shelf life is not relevant in recycling aerosol cans. This makes storing easier since it does not matter if older products are hard to reach compared to newer products. So, if a product is in the back of the warehouse for multiple replenishment cycles before being processed, there is no problem. For that reason, we do not focus on the order of processing.

4.2 – Weight & content

This section discusses the weights and contents of the inbound products depicted in figure 2.4. First, the weights of pallets and blue bins are analyzed. After that, the content of the pallets and blue bins as regards hazardous substances are derived. The weights are necessary to find the amount of hazardous substances per product. The hazardous substances per product are essential to know to be sure to always stay below 10,000 kg of hazardous substances in the storage location. Finally, the content of a truck is analyzed.

Weighing pallets & blue bins

Since the process is in the start-up phase, little historical data is available. Therefore, the accuracy of the inputs of the model is not as high and reliable as desired. With the available means, we try to make the inputs as reliable as possible. This has been done by observing a lot and by logical reasoning.

From the delivery of Supplier A, A.R.T. does not weigh every blue bin or pallet separately. Instead, a truck is weighted before and after delivery. Based on that, the total weight can be calculated. This makes it difficult to determine the exact weight of every single delivered component.

To get an accurate overview of the weight of the blue bins and pallets, single objects have been weighted. Together with one of the operators, we weighted all blue bins and pallets in the storage location separately to use for the research. This is done because there was zero insight into the content of the blue bins and pallets. We weighted 26 blue bins and 16 pallets. With those outcomes, descriptive statistics are derived using SPSS.

The pallets are weighed one by one. Pallets consist of filled aerosol cans. To calculate the total weight of the aerosol cans, the weight of the pallet itself, the cardboard, and the plastic to bind the boxes have to be subtracted from the total weight. For this, A.R.T. assigns 15 kilos in total per pallet. The inputs and the descriptive statistics for finding the weights are in Appendix C. The most important values are shown in Table 4.1.

Poplulation size	N = 16
Mean	361.81
Standard deviation	62.33

Table 4.1

The blue bins are weighed one by one as well. To find out the weight of the content, the weight of the blue bin itself has to be subtracted from the total weight. One blue bin weighs 40 kilos. With SPSS, descriptive statistics are derived for the net weight of the blue bins. The inputs and the descriptive statistics are in Appendix C. The most important values regarding the blue bins are shown in Table 4.2.

Poplulation size	N = 25
Mean	111.22
Standard deviation	18.86

Table 4.2

Since these weights also include the weights of the metals, not all of it is considered to be hazardous substances. The upcoming section will derive the amount of hazardous using the information from this section.

Content pallets

Based on the company's earlier research, the content of the pallets can be determined. They found out that an average filled aerosol can weighs 450 grams. Of this, 70 grams consist of gasses, 280 grams consist of liquids, and 100 grams consist of metals. This means that from the net weight of a pallet, 77.77% consists of hazardous substances[8]. So, on average, one pallet includes approximately 281 kg of hazardous substances.

Content blue bins

The blue bins include aerosol cans with different filling levels. It is impossible to measure the filling level for every aerosol can separately. Therefore, for this research, one of the operators took a blue bin and

[8] Average amount of hazardous substances per aerosol can on a pallet = $\frac{70+280}{450} = 0.7777$ → 77.77%

counted the number of relatively full cans, the number of relatively empty cans, and the number of disapproved cans. After that, a conversation with one of the operators about the average filling level was necessary to form conclusions. We concluded that in a relatively empty aerosol can, approximately 20% is still filled with hazardous substances. A relatively full aerosol can is filled with approximately 60% hazardous substances. The operator said that disapproved aerosol cans have approximately the same fill rate as full cans, so these are also considered to be filled with 60%.

The operators counted the aerosol cans of two blue bins[9]. The results are shown in Table 4.3.

	Box 1	Box 2	Average
Net weight	126.5	127	126.75
Relatively full cans	217	209	213
Relatively empty cans	292	355	324
Disapproved cans	25	25	25
Total cans	534	589	561.5

Table 4.3 – Counted aerosol cans

Calculating the average amount of hazardous substances gives the following results:

- Total filling relatively full cans = 213 * 0.60 = 127.8
- Total filling relatively empty cans = 324 * 0.20 = 64.8
- Total filling disapproved cans = 25 * 0.60 = 15
- Average filling rate per aerosol can = $\frac{(127.8+64.8+15)}{561.5} \approx 0.37$

So, an aerosol can in a blue bin is, on average, for 37% filled with hazardous substances.

Earlier research assumed that an aerosol can, filled with 25% of its content, includes 87.5 grams of hazardous substances. Based on that, we can conclude that an aerosol can, filled with 37% of its content, includes 129.5 grams of hazardous substances. The average net weight of a blue bin is 111.22 kg, corresponding to approximately 500 aerosol cans. Multiplying the number of aerosol cans with 129.5 grams of hazardous substances resulted in approximately 65 kg of hazardous substances on average per blue bin.

Content of a truck

A full truck delivering aerosol cans includes 28 blue bins and 16 pallets. Therefore, the amount of hazardous substances per order is built up as follows:

- Hazardous substances in blue bins = 28 * 65 kg = 1,820 kg
- Hazardous substances on pallets = 16 * 281 kg = 4,496 kg
- Total hazardous substances in a truck = 1,820 kg + 4,496 kg = 6,316 kg

So the amount of hazardous substances per load ordered is approximately 6,316 kg. Since A.R.T. may store at most 10,000 kg of hazardous substances in the storage location, receiving two batches per delivery is impossible. With this information, we can conclude that ordering batch sizes larger than one is not

[9] One box is counted by one operator and one box by two different operators. Therefore, the outcomes are less accurate since the interpretation of being relatively full or relatively empty can differ.

possible with the current conditions. A batch size of two would already exceed 10,000 kg, so this is not allowed.

4.3 – Capacity & hazardous substances

The storage location is designed using block stacking, in which products can be stacked on top of each other (Goetschalckx & Ratliff, 1991). From the inbound products, stacking products is only possible with blue bins, and four of them can be stacked on top of each other.

We designed a lane system with five lanes in which inbound products can be stored. The possible configurations for blue bins and pallets are represented in figure 4.2. In this figure, the maximum number of spots available to store blue bins given the spots assigned to pallets and the other way around are compared against each other. Since the disapproved aerosol cans are also stored in blue bins, this can be taken together with the other blue bins regarding capacity. In one spot, four blue bins can be stored, so, in total, a maximum of 104 blue bins[10] can be stored if there are no pallets in the storage location. Figure 4.2 is derived from calculations on how many blue bins and pallets can be stored in each lane. This is complex since the sizes of pallets and blue bins differ[11].

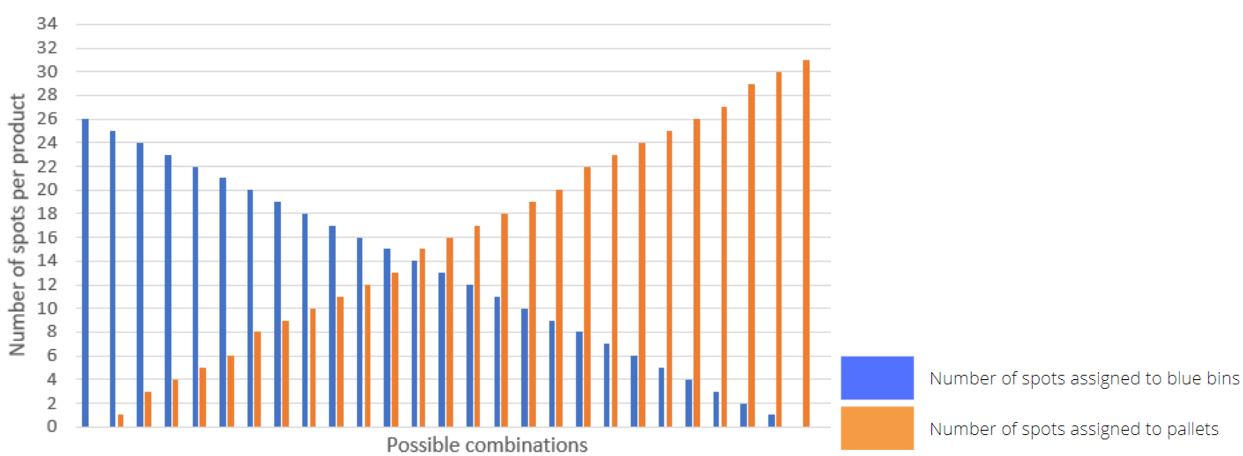

Figure 4.2 – Capacity – possible configurations for blue bins and pallets. E.g. the second column indicates that there is room for one pallet if there are 25 blue bins stored.

In section 4.2, the amount of hazardous substances per pallet and blue bin have been calculated. Figure 4.3 represents the amount of hazardous substances corresponding to figure 4.2. On the horizontal axis, the spots assigned to pallets are shown. The corresponding number of spots for blue bins can be found in figure 4.2. The corresponding amount of hazardous substances in kg is shown on the vertical axis.

[10] There are 26 spots for blue bins, so 26 x 4 = 104 blue bins can be stored.
[11] In lanes 1, 2, and 3, a maximum of seven pallets and six blue bins can be stored. In lanes 4 and 5, a maximum of five pallets and four blue bins can be stored.

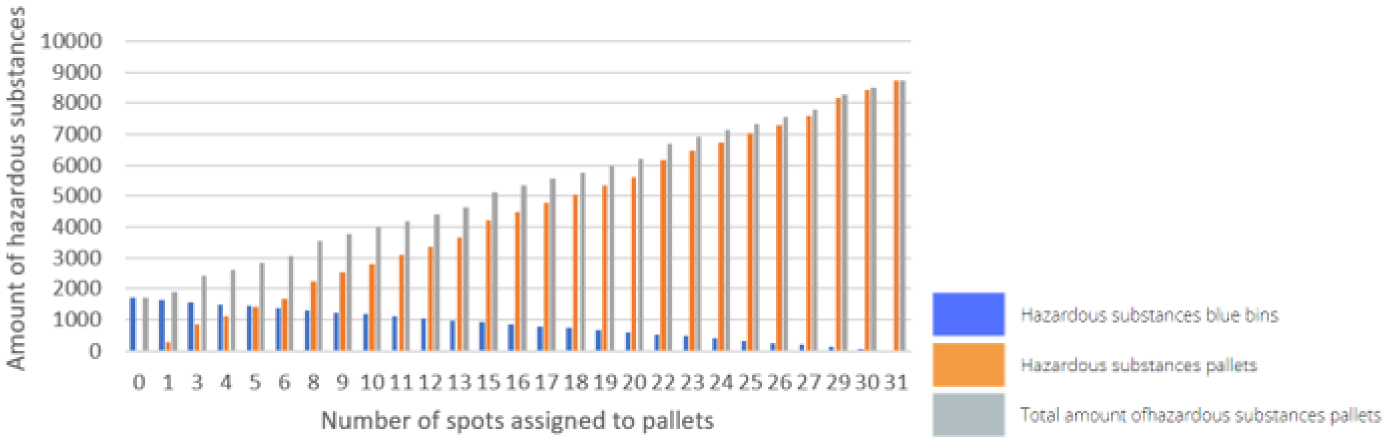

Figure 4.3 – Amount of hazardous substances corresponding to capacity. E.g. the second column indicates that if there are 25 blue bins and one pallet in the storage location, there is 1,625 kg of hazardous substances from the inbound products in the storage location

No more than 10,000 kg of hazardous substances may be in the storage location. This includes not only the inbound products shown in figure 4.3 but also outbound products. Currently, A.R.T. is not sure what they are going to do with the regained gasses. There are several options, but nothing is determined about this. An estimation is that there are, on average, two gas tanks in the storage location, accounting for 300 kg of hazardous each, so in total, 600 kg of hazardous substances.

The number of IBCs in the storage location fluctuates as the process runs. In principle, there is room for eight IBCs in the storage location. Currently, the number of IBCs in the storage location fluctuates between 1 and 6. Since one IBC contains 800 kg of hazardous substances on average, IBCs account for between 800 and 4,800 kg of hazardous substances in the storage location.

Fortunately, there is a high negative correlation[12] between the inbound and outbound products. The more the machine processes, the fewer inbound products there are in the storage location and the quicker the outbound products accumulate. This makes it easier to stay below 10,000 kg of hazardous substances.

At the moment of supply, Supplier A is delivering approximately 6,316 kg of hazardous substances. At the same moment, it takes back the filled IBCs. It would be helpful if Supplier A would take back all filled IBCs, but, unfortunately, this is not the case. A.R.T. has to register the IBCs that must be taken back when it requests a new truck, which is three days before delivery. If in between registering and taking back extra IBCs are filled, these IBCs cannot be taken back and have to wait for the next delivery.

Based on the observations, the operators can, on average, fill one IBC in 5-6 effective working hours[13]. This means that if the machines runs for 27 hours a week, which should be the target with the current

[12] Picardo (2021) states negative correlation as: “Negative correlation is a relationship between two variables in which one variable increases as the other decreases, and vice versa.”
[13] This amount is obtained based on daily observations. Approximately every 5-6 hours of working effectively, an extra IBC has been filled.

working conditions, they can fill approximately five IBCs per week. So in that scenario, the IBCs have to be dispatched once a week. Otherwise, there is a risk of exceeding the capacity.

The content of disapproved aerosol cans is considered hazardous substances as well. On average, there is one blue bin with disapproved aerosol cans in the storage location.

4.4 – Processing time and throughput per day

This section derives the processing time and throughput per day based on observations, statistics, and assumptions. This is done for three situations. The first situation is the current situation in which the processing time and throughput correspond to the performed observations. Situation 1 is a bit more optimistic than the current situation. Regarding the effective working minutes, it is between the current and optimal situation. Situation 2 is the situation A.R.T. aims to achieve with the current means. This situation is developed based on a discussion with one of the company's owners.

Current situation

Almost all data needed for the research did not exist since the process is in the start-up phase, and the machine was not installed during the first weeks of exploratory research. Therefore, all data had to be collected by observations and searching, which required effort and time but was needed to create an accurate model. So, the data used is category B data, which is data that is not available but has to be collected before use (Robinson, 2014).

The current daily effective working minutes vary a lot because of the high number of errors and the high repairing time. In the first four weeks of observing, the machine ran on average for approximately 200 minutes[14] (3 hours and 20 minutes) per day. Eighteen days of observing led to the results shown in figure 4.4. Using more days of observations was not possible because of the limited time and because the machine was broken during the first few weeks of the research. Because of the few days of observation, the data is less reliable than expected on forehand. However, since the observations were done from the start until the end of the day without skipping days in between, the data is valid.

Every day, a log is kept in which the time the machine was processing is explicitly written down. Moreover, every minute there was an error is tracked, and the amount of effective working minutes is calculated at the end of the day. Errors and breakdowns of the machine cause the variation in the effective working minutes.

[14] Observations are only done on full working days. So, Fridays, on which the operators work half a day, are excluded.

Minutes
380
210
285
180
135
105
220
200
265
80
215
290
0
180
135
215
300
195

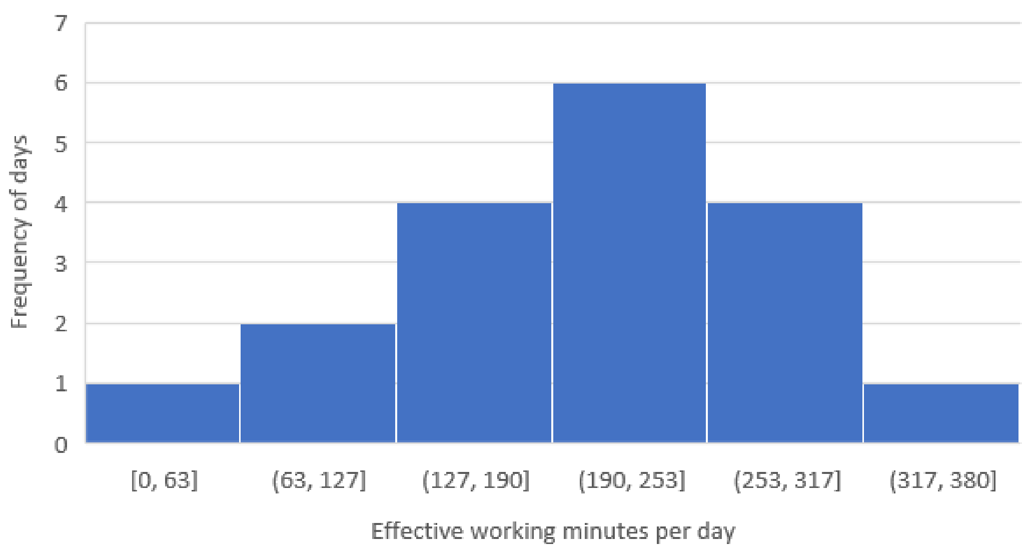

Figure 4.4 - Effective working minutes per day

Robinson (2014) uses a stepwise approach to connect empirical data with a statical distribution that fits the data. First, a statistical distribution has to be selected. This can be done by inspecting the data and by looking at the properties of the empirical data. Then, b analyzing those properties, it can be compared to the properties of statistical distributions (Robinson, 2014).

The histogram in figure 4.4 looks like a normal distribution. However, more distributions can have a shape closely related to this shape. So, based on looking at the histogram, no final conclusion can be formed. However, some statistical distributions can be crossed out since those have a shape that is not close to this one.

Next to looking at the histogram, the descriptive statistics, shown in Table 4.4, can be analyzed and tried to be linked to a statistical distribution. Since the skewness is close to 0, we can conclude that the distribution is quite symmetrical, which is another argument for having a close to normal distribution (Robinson, 2014). Therefore, based on the analysis, we assume to have a normal distribution.

The next step is determining the most important parameters, which can be derived from the descriptive statistics in Table 4.4 (Robinson, 2014). The most important variables are the mean which is 199.44, and the standard deviation which is 89.31. For simplicity, the mean used for this is assumed to be 200. On Fridays, the operators work half a day. So the mean effective working minutes for Fridays is 100, and the standard deviation is 44.65.

Mean	199.4444444
Standard Error	21.05039428
Median	205
Mode	180
Standard Deviation	89.30925927
Sample Variance	7976.143791
Kurtosis	0.610121255
Skewness	-0.22846407
Range	380
Minimum	0
Maximum	380
Sum	3590
Count	18

Table 4.4 – Descriptive statistics; Effective working minutes

The next step is to test the goodness-of-fit in which the empirical distribution is compared to the statistical distribution. There are several ways to do this, for example, by using a graphical approach (e.g. Q-Q plot or P-P plot) or by doing a statistical test (e.g. Shapiro-Wilk's test on normality) (Robinson, 2014). Both can be used to determine how closely the empirical distribution and statistical distribution are connected (Robinson, 2014). In this research, a Q-Q plot is used to test the goodness-of-fit.

The Q-Q plot in figure 4.5 compares the empirical distribution of the effective working minutes and the normal distribution. If the dots are on or close to the line in the middle, the normal distribution is fitting in this case. As shown in figure 4.5, all dots are close to the line, so the empirical distribution fits the normal distribution.

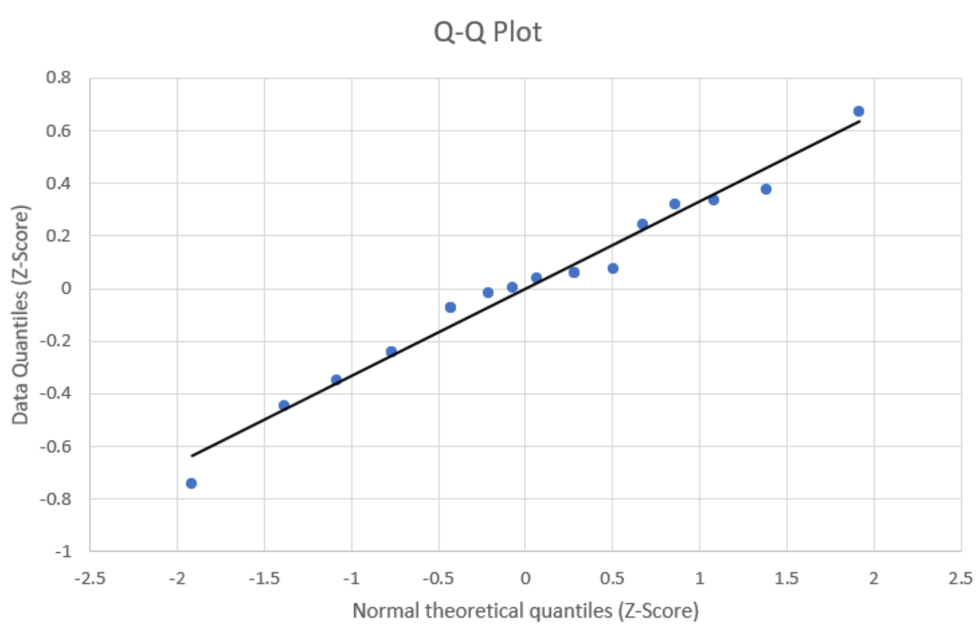

Figure 4.5 - Goodness-of-Fit - Q-Q Plot

Currently, on average, it takes the operators 50 minutes to process one pallet and 25 minutes to process one blue bin. So, with the current circumstances, the operators can process, on average, four blue bins and two pallets (4 x 25 + 2 x 50 = 200) each day. This has been derived from the performed observations.

To process the maximum content of a truck delivering products from supplier A, it takes the following number of hours:

- Time to process all blue bins = 28 * 25 minutes = 700 minutes
- Time to process all pallets = 16 * 50 minutes = 800 minutes
- Total time to process one truck = 700 + 800 = 1500 minutes = 25 hours

So, with the current working speed it does cost the operators $\frac{1500}{200} = 7.5$ full days to process a full load.

Situation 1

In the future, the effective working minutes will probably increase to approximately 360 minutes daily. This is an assumption that should be made since, if the current processing time is used, in reality, there will be more effective working minutes in the future, and this research becomes outdated. For the distribution of the effective working minutes, this would give some problems with the accuracy since it is all about estimations and assumptions.

The assumption that the effective working minutes will increase towards 360 minutes with the current working minutes from the operators is optimistic. Therefore an extra situation is considered, which is between the current and the optimistic situation.

The first situation is the least optimistic situation. In this situation, the mean effective working minutes are assumed to be multiplied by a factor of 1.4. So, this model assumes the effective working minutes to be 1.4 * 200 = 280 minutes (4 hours and 40 minutes). A.R.T. can use this situation to bridge the time between the present and the optimal situation.

The empirically derived standard deviation is based on a relatively small sample size and is derived from an unstable processing period. The standard deviation for the current situation is 89.31. Based on the expectation that the process will run more smoothly in the future, a smaller standard deviation is used in this situation. For this situation, the standard deviation is assumed to be 65.

For all situations, we assume the working speed remains the same. So, in this situation, the operators can process approximately 5.6 blue bins and 2.8 pallets[15] per day. In this situation, it takes $\frac{1500}{280} = 5.36$ full days of working to process a full truck.

Situation 2

The second situation is more optimistic than the previous one. In this situation, we assume the effective working minutes will become 360 minutes (6 hours), so the mean of the current situation will be multiplied by a factor of 1.8. Together with one of the owners of A.R.T., based on observations, we concluded that 360 effective working minutes is feasible with the current means. Since this design mainly focuses on a fully running process and not on the faltering process, we consider this situation.

[15] 5.6 x 25 minutes + 2.8 x 50 minutes = 280 minutes

The standard deviation of this process is considered to be smaller than the previous ones because this is the state where the process should run smoothly and in which there is more certainty. Therefore, the standard deviation for this situation is considered to be 45.

In this situation, the operators can process, on average, approximately 7.2 blue bins and 3.6 pallets[16] per day. In this optimistic situation, it takes 1500/360 = 4.17 full days of working to process a full truck. Since, in this situation, the operators do work 4.5 days, it seems feasible to process a full truck in one week.

4.5 - Conclusion

Data gathering is essential to this research to make valid and reliable designs. Unfortunately, no data was available at the start of the research since the machine was not yet installed. So, this data had to be collected. Therefore, this chapter obtained a lot of data and information for this research.

In section 4.1, we developed a lane system that can be used to store the products. This lane system is developed to be used in chapter 5 to create the design alternatives for the storage location. The lane system consists of five lanes in which the inbound products must be stored.

Section 4.2 obtained the weights and contents of the inbound products. Based on performed measurements, we found out that the average weight of the content of one pallet is 361.82 kg and the corresponding standard deviation is 62.33 kg. Based on earlier research and this research, we found out that from this weight, 281 kg is considered to be hazardous substances. Furthermore, according to the same way of working, we found out that the content of one blue bin weighs on average 111.22 kg with a corresponding standard deviation of 18.86 kg. From this, 65 kg is considered to be hazardous substances. Based on this, we derived that one delivery of Supplier A includes 6,316 kg of hazardous substances meaning no batch sizes larger than one can be ordered.

Section 4.3 focused on the capacity with corresponding hazardous substances. This section analyzed the amount of hazardous substances of each product in combination with the capacity. On average, we assume two gas tanks are in the storage location, accounting for 300 kg each. This is an assumption because, currently, A.R.T. does not know how to dispatch the gasses. Currently, the number of IBCs in the storage location fluctuates between 1 and 6, accounting for approximately 800 kg each.

Section 4.4 analyzed the processing times and throughput for the current situation and two possible future situations. Currently, the effective working minutes are 200 minutes per day, but in the future, the goal is that this would become 360 minutes per day. The current daily throughput is four blue bins and two pallets per day. If the effective working minutes increase to 360 minutes per day, the throughput will become approximately 7.2 blue bins and 3.6 pallets per day.

[16] 7.2 x 25 minutes + 3.6 x 50 minutes = 360 minutes

5 – Current Process Optimization

This chapter aims to create an effective logistical plan for the current situation. First, in section 5.1, we try to find a suitable layout for the storage location. After that, in section 5.2, an effective order policy for the current process is designed. This is done by determining the reorder point and using a model to find an effective solution. The literature review of chapter 3 and the data and information gathered in chapter 4 are used for creating these designs.

5.1 – Storage location optimization

In this section, an effective layout for the storage location is designed. In section 5.1.1, the requirements and constraints for the optimization problem are summed up. Moreover, section 5.1.1 section shows the measurements from all different objects in the storage location. Section 5.1.2 creates several design alternatives that might become close to optimal. In section 5.1.3, the different design alternatives are compared to each other based on the important criteria. Finally, in section 5.1.4, the most effective design alternative to implement is chosen based on a discussion of the two most effective design alternatives.

5.1.1 – Requirements & constraints

The storage location has some requirements and constraints it has to comply with. These requirements and constraints are based on capacity and regulations. The requirements and constraints for the storage location are:

- All gas tanks, regardless of the content, must be placed behind a fire-resistant wall, separated from the other products in the storage location.
- IBCs have to be placed between a fence and the fire-resistant wall.
- Gas tanks may be stored on top of each other if those do not rise above the wall. So, two gas tanks may be stored on top of each other. There is room for eight gas tanks.
- IBCs have to be placed on top of a drip tray and may be stored on top of each other if those do not rise above the wall. Therefore, two IBCs may be placed on top of each other, so there is room for eight IBCs.
- The height of the stacked blue bins with aerosol cans may not exceed 3.60 meters.
- Nitrogen racks must to be stored in the same place as the gas tanks. Placing nitrogen racks on top of each other is not possible.
- The amount of hazardous substances in the storage location may not exceed 10,000 kg. The following products in the storage location include hazardous substances:
  - Unprocessed aerosol cans
  - Disapproved aerosol cans
  - IBCs with liquids
  - Gas tanks
  - Nitrogen cylinders
- The maximum available space for inbound products is $7.25 \times 6.10 - 1.45 * 1.45 * 2 \approx 40\ m^2$

The objects in the storage location do have different sizes and contents. The sizes of the different objects in the storage location can be found in Table 5.1.

	Length	Width	Height	Max. content
Blue bin	100	120	90	
Average pallet	80	120	140	
IBC	120	100	115	1000 L
Drip tray (Liquid, rectangle)	265	130	75	
Drip tray (Square)	145	145	65	
Gas tank incl. frame	110	110	150	750 L
Nitrogen gas rack	150	90	190	800 L

Table 5.1 - Sizes of storage location objects

In section 4.1, a lane system with five lanes has been developed. This lane system is illustrated in figure 4.1. Lanes 1, 2, and 3 are long lanes, and lanes four and five are shorter. If in one long lane only pallets are stored, seven pallets can be stored behind each other. If only blue bins are stored in one long lane, four can be stored on top of each other, and six can be stored behind each other. So in a lane, 24 blue bins can be stored.

Five pallets can be stored behind each other in a short lane if only pallets are stored. If only blue bins are stored, four can be stored behind each other. Given that four can be piled on top of each other gives that in one short lane, 16 blue bins can be stored.

There are two lanes in which fewer products can be stored because these lanes both have a drip tray in the back. It is possible to store products in front of the drip trays. However, to make the drip trays accessible, it is preferable only to store products in front of them if necessary. If a drip tray has to be used and multiple products are in front of it, it causes additional material handling costs to make the drip tray accessible.

In all design alternatives, we have chosen not to change the location of the drip trays compared to the current situation. The drip trays are located next to each other because placing them behind each other causes the drip tray in the back to be accessed from the side. This requires much moving space for the forklift and is, for that reason, too inefficient to consider. Placing the drip trays next to each without lanes in between causes more structure in storing products and gives high clarity. We locate the drip trays in lanes 4 and 5 because this is the farthest away from the machine causing the lanes closer to the machines can be filled with just inbound products. This causes the forklift to drive shorter distances to feed the machine. Moreover, the lanes in which the drip trays are located should be filled as little as possible to have enough moving space available in front of the drip trays.

5.1.2 – Several Design Alternatives

In this section, five design alternatives for the storage location are designed using common sense, the current state, observations, and the literature review earlier in the thesis. In creating these design alternatives, we tried to emphasize different aspects in different design alternatives. So, all design alternatives are designed based on at least one remarkable advantage that makes that particular design alternative powerful.

Moreover, we tried to use different storage policies from the discussed policies in section 3.1. These storage policies include dedicated storage, randomized storage, and class-based storage. The first four design alternatives are designed based on dedicated or partially dedicated storage. The fifth design alternative is based on randomized storage.

Design alternative 1

System description

The first design alternative includes the system of storing products in five lanes. The advantage this design alternative is based on is to use space as effectively as possible and to have enough space available to use the drip trays.

As mentioned in section 2.3.2, a truck delivering aerosol cans includes a maximum of 28 blue bins and 16 pallets. Moreover, the safety stock must be considered when assigning locations for the products.

Lane 1 is the closest to the machine, and lane 5 is the closest to the assigned space for storing IBCs. In the first lane, 24 blue bins can be stored, so assigning one lane to blue bins is not enough. Since there is safety stock, a large part of the second lane is probably necessary to store the remaining blue bins. How big the safety stock is, is determined later in this thesis. The remaining space in the second lane can be filled with pallets.

To store the pallets, 16 spots are necessary to store the products of one delivery. Furthermore, there needs to be some space available for storing the safety stock. For pallets, there are seven spots available in one lane. So, assuming that approximately 2-4 pallets can be stored in lane 2 and that there is a safety stock for pallets as well, lanes 3 and 4 can be filled with pallets. If there are still pallets left to store, those can be stored in the fifth lane.

The blue bins with disapproved aerosol cans[17] should be stored at the front of the last stored pallet or in an empty lane. Based on the available data, there are at most two blue bins with disapproved aerosol cans. Those blue bins with disapproval can be stacked, so those require at most one spot. The IBCs, gas tanks, and nitrogen racks are stored in their assigned spots.

[17] Disapproved aerosol cans are not shown in the figures of the design alternatives since, most of the time, this is only zero or one blue bin and at most two blue bins.

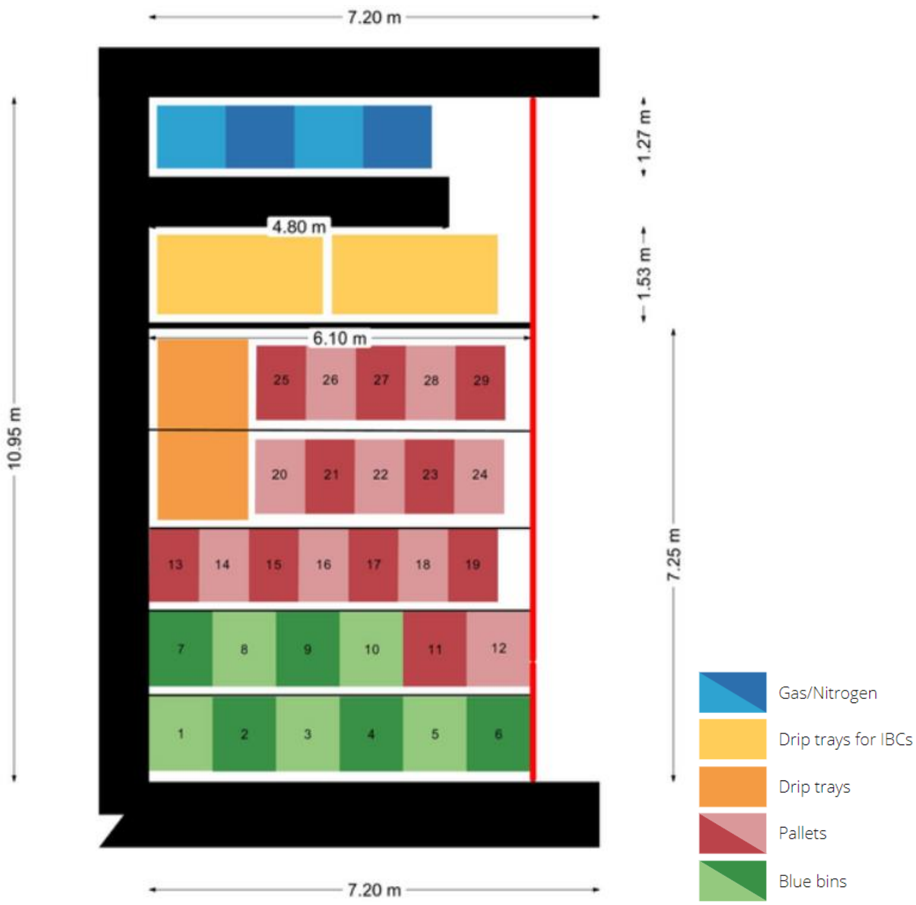

Figure 5.1 - Design alternative 1 - The first two lanes are assigned to blue bins, the next available space is for storing pallets. The remaining space can be used to store blue bins with disapproved aerosol cans. Note: in all design alternatives lanes 4 and 5 are entirely filled. In reality, lanes 4 and 5 are less/not filled.

In figure 5.1, the spots are numbered. In this design alternative, spot 1 until approximately 9 to 11 will probably be used for blue bins. If all blue bins have been stored, the next spots are for the pallets. If pallets need no spots anymore, the next spots are for disapproved aerosol cans.

Processing should happen from the right (lane 5) to the left (lane 1). The pallet at a front spot from the most right lane should be processed first, and the same holds for the blue bins. For the blue bins, this should probably be a blue bin in the first lane since in the second lane there are probably pallets at the front.

Advantages and disadvantages

The advantage of working from right to left is that there is a high chance of having movement space to use the drip trays easily since the left part of the storage location is loaded effectively. According to Kooy (1981), there should always be an empty lane to store arriving products. If there is no empty lane, arriving products cannot be stored. This design alternative gives a high chance of having an empty lane since it starts processing a full lane of one product before going to the next lane. Since, in principle, all products are stored from left to right and processed from right to left, this system is clear and easily workable for the operators. Furthermore, this design alternative does not have lost space since different products can be stored in the same row, meaning inventories can be partially combined (Battista et al., 2011).

The disadvantage of processing from right to left is that the forklift has to drive a long distance to pick up new products to process. Another disadvantage is that, unless there should be processed from right to left, only blue bins in the first, most left lane can be reached. So not in all lanes, the different products are reachable.

Design alternative 2

System description

The second design alternative also uses the system of storing products in five lanes. This one is designed around the advantage of being clear to the operators and being easy to work with.

In this design alternative, the first lane may be used for storing blue bins, lanes 2 and 3 for storing pallets, the fourth lane for storing blue bins, and the fifth lane for storing the remaining blue bins, pallets, and or disapproved aerosol cans. The advantage of having blue bins and pallets in the left and right lanes is that, on average, approximately the same distance has to be driven for both products.

For the blue bins, in figure 5.2, spots 1 until 10 are available, so 40 blue bins can be stored. This should be enough unless the safety stock is incredibly large.

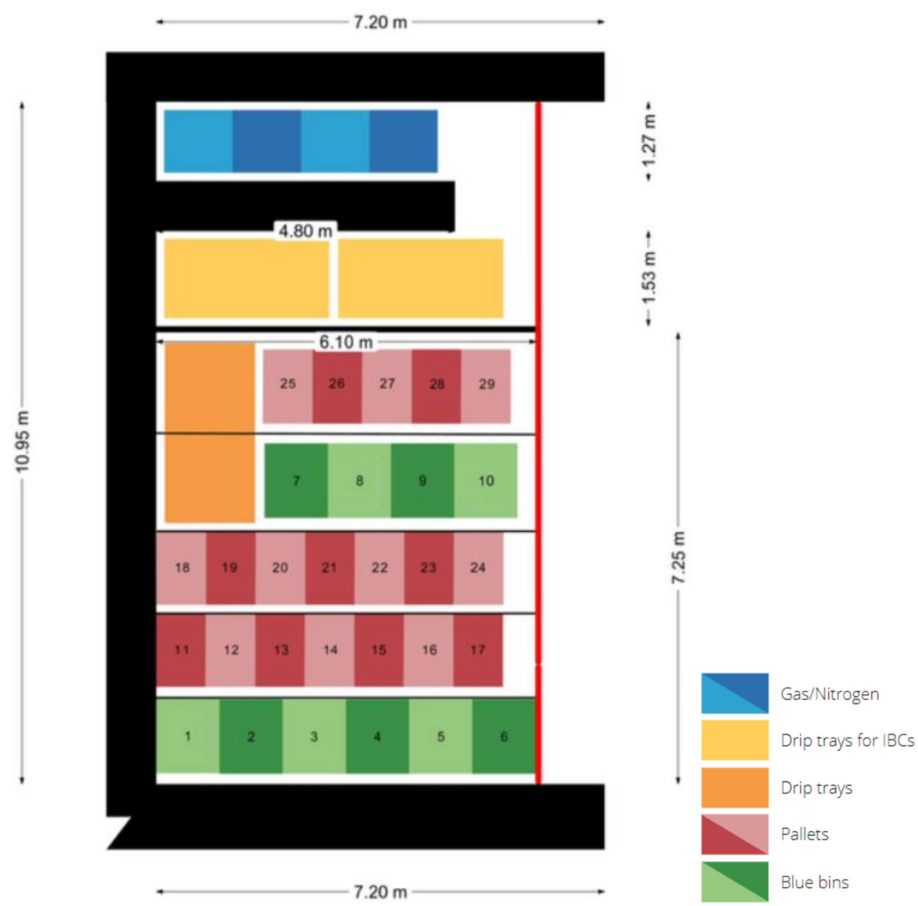

Figure 5.2 - Design alternative 2 - Lanes 1 and 4 should be used for storing blue bins, lanes 2 and 3 should be used for storing pallets, and lane 5 should be used for storing the remaining products.

For pallets, this means that 14 of them can be stored in lanes 3 and 4. Spots 11 to 24 are available for those. Since a truck includes 16 pallets, 14 spots are certainly not enough, and the remaining pallets must be stored in the fifth lane. The disapproved aerosol has to be stored in the fifth lane, but if that one is already full, those can be stored in front of the blue bins.

For storing both the blue bins and pallets, storing should start at the smallest spot number, so for blue bins at spot 1 and pallets at spot 11. Processing should be done from lane 5 to lane 1 to have the highest chance of having moving space to use the drip trays. First, one lane has to be empty until the operators should move on to the next lane. This gives the highest chance of having an empty lane to store arriving products.

Advantages and disadvantages

An advantage of this design alternative is that all products have assigned slots which gives clarity and makes the system easy to work with for the operators. Another advantage is that the products can be reached easily without having another product in front. There is no problem in having no empty lane for a large fraction of time since processing happens from right to left, meaning that an empty lane arises quite quickly.

A disadvantage of this design alternative is that there is a high amount of unused space since no inventories can be combined (Battista et al., 2011). In case there is no place to store a product, it has to be stored in the location of another product, but that is not desirable in this design alternative, so that has to be avoided. Furthermore, since processing happens from right to left, the forklift has to drive a relatively large distance.

Design alternative 3

System description

Like the previous design alternatives, this design alternative also uses the system of storing products in lanes. The advantage this design alternative is designed around is the same as the first design alternative. The advantage is that space is used effectively. The difference compared with the design alternative one is that in this design alternative, first the pallets are stored. So, the pallets and blue bins are swapped.

As shown in figure 5.3, in principle, the slots for pallets are slots 1 until approximately 19, depending on how much is in stock at the moment of delivery. The first blue bins are stored in front of the last pallet stored in the third lane, and the remaining blue bins are stored in lane 4. If lane 4 is full and still some blue bins have to be stored, those may be stored in lane 5.

As regards the blue bins, first, the blue bins in the most right lanes have to be processed to make the drip trays accessible. The pallets have to be processed from right to left as well, starting with the first lane having a pallet at the front. So, generally, processing happens from right to left and storing from left to right.

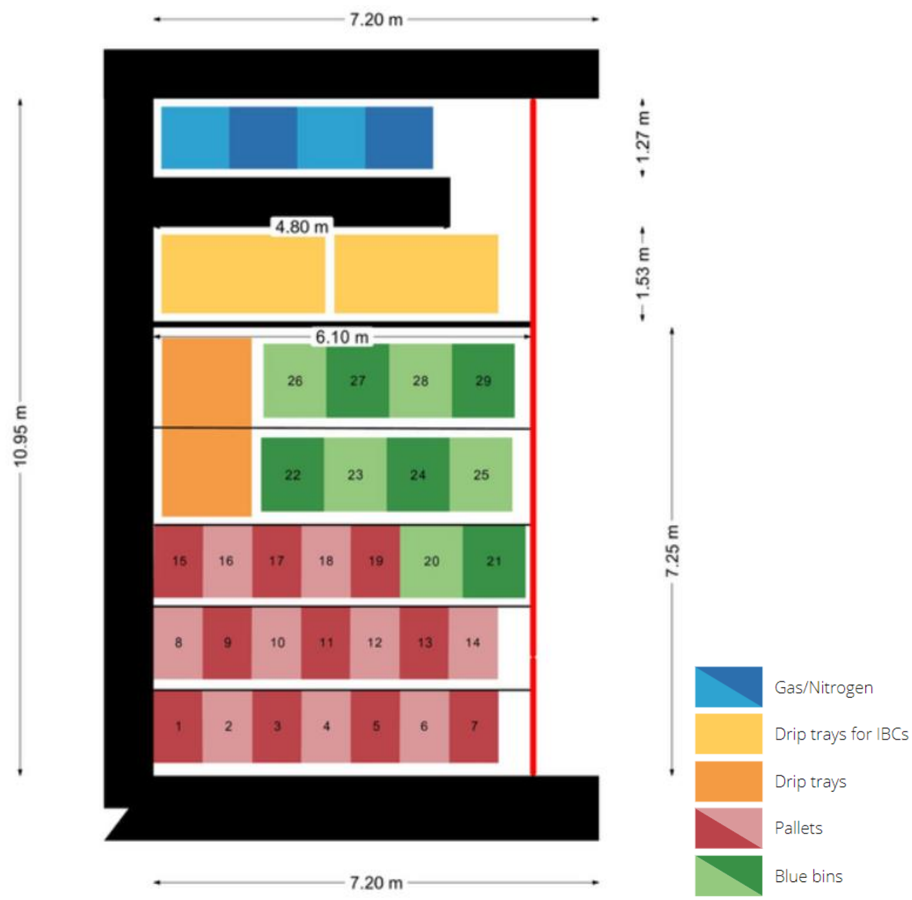

Figure 5.3 - Design alternative 3 - First storing pallets, starting in Lane 1. If all pallets are stored, start storing blue bins in front of the last stored pallet.

Advantages and disadvantages

An advantage of this design alternative is that each product can be reached easily. Another advantage is that there is a low amount of unused space since inventories can be combined.

A disadvantage is that since the blue bins are stored on the right side of the storage location, the blue bins filled with disapproved aerosol cans can be easily confused with blue bins filled with unprocessed aerosol cans. Another disadvantage is that the right side of the storage location is quite busy, and it becomes even busier by storing blue bins there. This is because blue bins can be stacked up to 3.60 meters, and pallets cannot. So, this design alternative is not the clearest one.

Since the blue bins are stacked on top of each other, it takes longer to process the blue bins in front of the drip trays than processing pallets if those were there. Therefore, this design is not useful for creating space in front of the drip trays. For the same reason, it takes relatively long to have an empty lane, and the distance the forklift has to drive is relatively large.

Design alternative 4

System description

The fourth design alternative is a complex one. Like the previous ones, this design alternative also uses the lane system. This design alternative is designed around the advantage of having different products at the front of different lanes. This makes products easily accessible.

Every lane consists of both pallets and blue bins in this design alternative. The first lane first has room for two times four blue bins and five pallets in front of it. The second lane first has room for five pallets and then two times four blue bins in front of it. The third lane is the same as the first. The fourth and fifth lanes are mirrored with each other as well, and both include two times four spots for blue bins and three spots for pallets. This causes every lane to include more or less the same content.

In figure 5.4, the spots numbered from 1 to 10 are, in the first instance, meant for storing blue bins, and the spots numbered from 11 to 31 are meant for pallets. The ratio of pallets to blue bins can differ during each replenishment cycle, so this is an estimation. If the ratio differs, the last two lanes will look different since storing starts at the left. Finally, the disapproved aerosol cans should be placed in lane 5.

Processing starts at the right. This is because, in that case, there is the highest chance of having movement space available to use the drip trays. So the most right lane with the necessary product at the front is the lane from which the product should be picked.

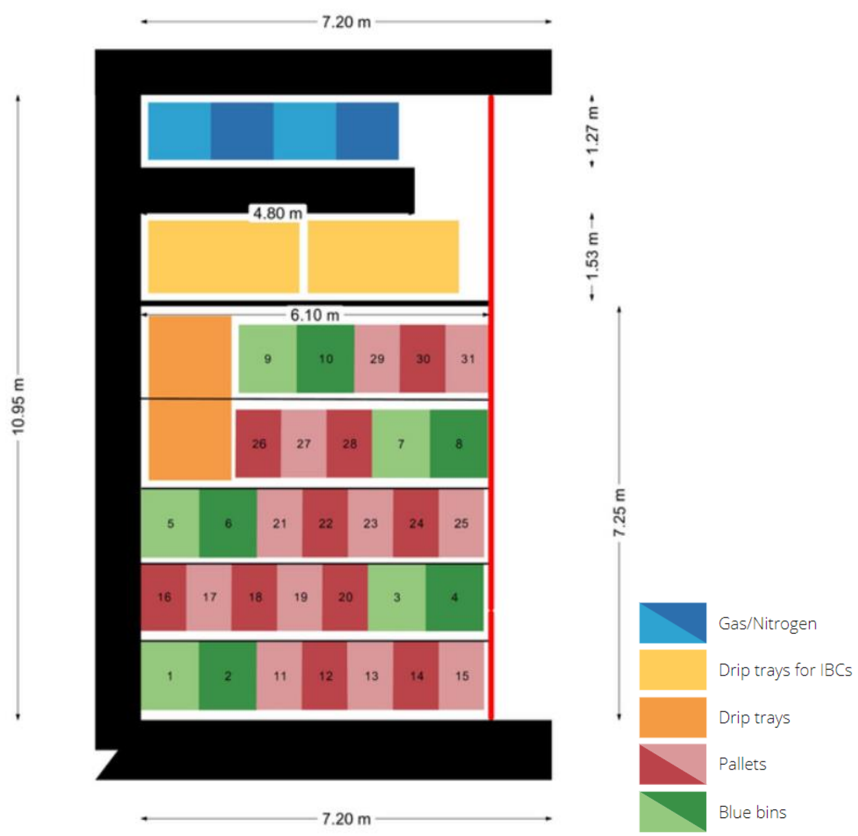

Figure 5.4 - Design alternative 4 – Every lane might be used to store blue bins and pallets. The first lane has pallets at the front and blue bins in the back. The second lane is the opposite. The third lane has the same layout as the first one. The fourth and fifth lanes are mirrored as well.

Advantages and disadvantages

Since the lanes have different products at the front, both pallets and blue bins can be reached. Another advantage is that there is, in theory, no unused space after storing since inventories can be combined, and from left to right, every lane will be filled before storing products in the next lane (Battista et al., 2011). In practice, this could be different, as discussed in the next paragraph. Since processing happens from right to left, the drip trays will be accessible quite quickly.

This design alternative is not so useful for unloading a truck since it makes storing more complex than the other design alternatives. Since this is a process that should not take too long, this is a significant disadvantage. This design alternative is also complex and chaotic for operators in storing and picking since it requires more thinking than the other design alternatives. Another disadvantage is that, as can be seen in figure 5.4, the products are in all lanes (almost) touching the line. This design alternative assumes the pallets and blue bins are tight against each other, but in reality, there will probably be a bit of space between the products somewhere. So, in reality, the products will probably cross the line a bit, and then the products crossing the line have to be placed into another lane resulting in unused space.

Design alternative 5

System description

The fifth design alternative is different from the previous design alternatives. Some of the previous design alternatives were designed according to a dedicated storage policy, and some were designed according to a partially dedicated storage policy (Naik, 2004). This design alternative is designed using a storage policy in which the products are stored in the lane with the most space available (Naik, 2004), called a randomized storage policy. This design alternative is the least structured one of all alternatives discussed. Since there are no fixed locations for the products, it is not possible to draw a picture of the previous alternatives.

The products do not come randomly out of the truck, but first, the blue bins are unloaded, followed by the pallets. This makes it a bit more structured than if it were random. In this system, processing should happen from right to left to make the drip trays accessible as quickly as possible.

Advantages and disadvantages

An advantage of this design alternative is that space is used effectively since the lane with the least products is chosen to store a product. Therefore, there is no unused space.

The most significant disadvantage is that if the official rules of this randomized policy should be followed strictly, probably only pallets are in the front row since those are unloaded after the blue bins. This makes mixing the pallets' and the blue bins' content complex and challenging. For the operators, this policy is not the easiest one to work with since it misses structure. Since all lanes are equally filled in this policy, there is no relatively empty lane, so it takes some time to have an empty lane, and according to Kooy (1981), there should always be one.

5.1.3 – Comparing Design Alternatives

Several advantages and disadvantages based on different criteria are discussed in this previous section. These criteria are assessed in the following sections. Based on the assessment, the most effective design alternative is chosen to implement. According to Heerkens & van Winden (2017), first criteria have to be established, then criteria have to be scaled, and then the average scores can be calculated.

Establishing criteria

The criteria are established based on the important advantages and disadvantages mentioned in the previous sections. In addition, the trade-offs Richards (2014) mentioned, treated in section 3.1, are incorporated into this. The established criteria are:

1. **Empty lane** → Is there an empty lane quickly?
2. **Moving space** → Is there moving space in front of the drip trays?
3. **Layout clarity/easily workable** → Is the layout clear, and is it workable for the operators?
4. **Product accessibility** → Can each product be accessed?
5. **Unused space** → Is there unused space?

Scaling criteria

Now, the criteria have to be scaled. For every criterion, points can be awarded on a scale from 1 to 5. This Likert scale is used since the design alternatives can meet the criteria to different extents. The scales are presented in Table 5.2.

Score	Description
1	Very bad
2	Bad
3	Neutral
4	Good
5	Very good

Table 5.2 - Scaling criteria

Weighting criteria

The next step is to weigh the criteria. This distinguishes the different criteria based on their importance (Heerkens & van Winden, 2017). The total weight of all criteria should satisfy the following formula in which w_i is the weight of criteria i.

$$\sum_{i=1}^{5} w_i = 1$$

Based on logical thinking, observations, and conversations, this gives the results shown in Table 5.3.

Criteria	Weight
1) Empty lane	0.15
2) Moving space	0.25
3) Layout clarity/easily workable	0.25
4) Product accessibility	0.20
5) Unused space	0.15

Table 5.3 - Weighing criteria

The weights are quite close to each other since the criteria are almost equally important. However, there are some slight differences in importance, so the weights vary a bit.

Scoring

	1	2	3	4	5
1) Empty lane	5	4	2	4	2
2) Moving space	5	4	2	4	2
3) Layout clarity/easily workable	4	5	2	1	2
4) Product accessibility	3	5	5	5	1
5) Unused space	4	2	4	3	5

Table 5.4 - Scoring

The scores are shown in Table 5.4. In practice, criteria 1 and 2 seem to be a bit overlapping. However, these do not have to be combined since the criteria are not equal, and since the impact these have different impacts, the weights can be added. The weighted scores are given in Table 5.5.

	1	2	3	4	5
1) Empty lane	0.75	0.6	0.3	0.6	0.3
2) Moving space	1.25	1	0.5	1	0.5
3) Layout clarity/easily workable	1	1.25	0.5	0.25	0.5
4) Product accessibility	0.6	1	1	1	0.2
5) Unused space	0.6	0.3	0.6	0.45	0.75
Total score	4.2	4.15	2.9	3.3	2.25

Table 5.5 - Weighted scoring

According to the scores, the best design alternative would be the first one but is closely followed by the second one. Design alternatives 3 and 4 are scoring much lower. Design alternative 5 is, according to these scores, the worst choice.

5.1.4 – Choosing the best design alternative

The score of design alternative 1 is 4.2, and the score of design alternative 2 is 4.15. Based on that, design alternative 1 should be chosen to implement. However, these differences are so small that an extra discussion can be useful to come to the best solution to recommend A.R.T. to implement.

After doing research and creating the design alternatives, it seems to be useful to first store as many products as possible on the left side of the storage location. This is because it makes the right side, where the most movements occur and where the overview is important, less busy, and easy to work with. The first two criteria are related to this. On both criteria, design alternative 1 scores the maximum of five points, and design alternative 2, scores four points. Design alternative 1 is the best one based on these two criteria since it starts bulking all massive piles of blue bins as far to the left as possible. When no blue bins are left, it starts placing pallets at the front of it. Design alternative 2 scores a bit lower since it puts some blue bins in front of a drip tray.

The following criterion is about whether the design alternative is easily workable for the operators or not. Design alternative 1 scores four points, and design alternative 2 scores the maximum of five points. Design alternative 1 is easily workable for the operators since the layout is not complex. However, working from right to left is a bit confusing in this. This is because the first processed blue bin comes from lane 1 since, in all other lanes, no blue bin is at the front. In design alternative 2, every lane may, in principle, only store one product which makes it clear for the operators. For that reason, design alternative 2 receives the full five points.

The fourth criterion is about whether every product can be reached or not. For this criterion, design alternative 1 scores three points, and design alternative 2 scores five points. In design alternative 1, after delivery, every product can be reached. However, if the first lane with blue bins is processed completely, the blue bins in the backside of the next lane cannot be reached.

To prevent this, the order of processing of design alternative 1 has to be changed a little bit. The first pallets to process have to be the pallets in front of the blue bins so that those can be reached. After that, the earlier designed order of processing can be followed. With this small change, design alternative one scores five points on this criterion. Design alternative 2 has no problems reaching products since every lane may only store one product.

The last criterion is about whether there is unused space or not. It is not about unused space at a place where it is convenient to have unused space but is about unused space which you prefer should be used. Design alternative 1 scores better in this than design alternative 2 since it combines inventories, and design alternative two uses dedicated storage, causing a large amount of unused space (Naik, 2004).

The new weighted scores of design alternatives 1 and 2 are illustrated in Table 5.6.

	1	**2**
1) Empty lane	0.75	0.6
2) Moving space	1.25	1
3) Layout clarity/easily workable	1	1.25
4) Product accessibility	1	1
5) Unused space	0.6	0.3
Total score	4.6	4.15

Table 5.6 - Scoring table - revised

Since the score of the third criterion changed for design alternative 1, the total score of design alternative 1 increased and is not significantly a better option than design alternative 2. Therefore, design alternative 1 is the best one to implement.

5.2 – Order policy optimization

In this section, for the situations outlined in section 4.4, an ROP model is developed to determine an appropriate mixed reorder point. The mixed reorder point is a reorder point that considers both the number of blue bins and the number of pallets in the storage location. In section 5.2.1, the structure of the model is described, and the way the operators should deal with it is outlined. After that, in section 5.2.2, the notation for all models is given.

Then, in section 5.2.3, the first part of the model is developed in which the mixed reorder point is derived based on only the inventory position as regards the number of blue bins and the number of pallets in the storage location. Next, in section 5.2.4, the second part of the model is developed in which the amount of hazardous substances in the storage location is considered. This part of the model checks whether the maximum amount of hazardous substances will be exceeded if an order is placed.

Section 5.2.5 discusses the different situations to which the model is applied. Finally, section 5.2.6 connects the model to reality, describes how to implement it, and summarizes this chapter.

5.2.1 – Model structure

The model we use in this research is a periodic review model. Moreover, it is a decision model that should contribute to deciding whether a new order should be placed or not. At the start of every day, the inventory is checked by an operator. The operator writes down the number of blue bins and pallets in the storage location. During the remaining of the day, the inventory is not checked. The model in this chapter should be designed to be applicable to this way of working.

For determining whether an order should be placed or not, we developed a daily repeating process. Figure 5.5 represents this daily repeating process of applying the designed model. First, an operator counts the number of blue bins and the number of pallets. Then, the operator writes it down in the daily report. Based on that, the operator should determine whether the inventory is below the mixed reorder point or not. No order should be placed if the inventory is not below the reorder point.

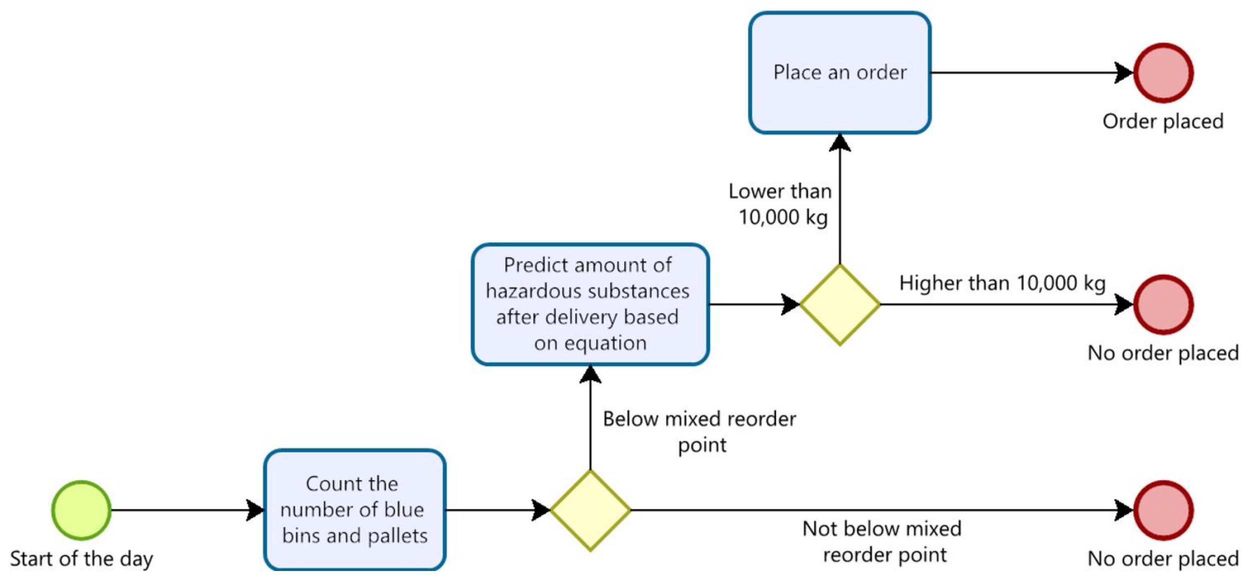

Figure 5.5 - Daily repeating process of checking inventory. Based on this process, it is determined whether an order can be placed or not.

If the inventory is below the mixed reorder point, the amount of hazardous substances after delivery should be predicted by the equation in the second part of the model. This equation can be filled in quickly by one of the operators. If this equation predicts that the amount of hazardous substances will become higher than 10,000 kg after delivery, no order should be placed, and the same consideration should be done the next day.

If no order is placed because the model predicts the amount of hazardous substances becoming too high, the chance that A.R.T. runs out of stock during the lead time increases. This is unavoidable. However, the next day, there are more full IBCs in the storage location since the machine continues processing. These extra IBCs are scheduled to be dispatched by Supplier A at delivery. This decreases the amount of hazardous substances after delivery. Therefore, the next day, the chance that the model predicts that an order can be placed increases. Moreover, it could be that in the meanwhile, the gasses are dispatched. However, as mentioned before, A.R.T. has no idea yet what to do with the gasses, so it is difficult to draw conclusions.

If the prediction is that the chance that the amount of hazardous substances will end below 10,000 kg is sufficiently large, a new order can be placed. In that case, the operator has to contact the person responsible for ordering so that she can place the order. This is the only scenario an order should be placed.

5.2.2 – Notation

In this section, the notation used in the models is defined. By doing so, we intend to make it easy for the reader to understand the models since all notations can be found in one section. The model we use in this thesis is based on the ROP calculations Chopra & Meindl (2019) uses but is adapted and extended based on this particular situation.

Recall that the model consists of two components. The goal of the first component is to check whether a new order should be placed based on the number of products in the storage location, taking into account the possibility of a stockout. The goal of the second component is to check whether a new order might exceed the maximum amount of hazardous substances. If both components agree that a new order can be placed, a new order should be placed. If one of the components does not agree, no order should be placed. So the goal of the model is to check whether an order might be placed or not. This is a daily repeating process. The outcome of the development of the model are two equations[18] that can be filled in by the operators each day.

The model includes indices, parameters, and variables. Indices are used to make clear where the parameters refer to. Almost all parameters have indices to distinguish between pallets and blue bins. On top of that, indices help in making the distinction of which period the parameters cover. The indices used in the model discussed in this chapter are:

- BB: blue bins
- Pa: pallets
- D|BB: throughput blue bins
- D|Pa: throughput pallets
- D: total throughput = D|BB + D|Pa
- T+L|BB: blue bins during the review period and lead time
- T+L|Pa: pallets during the review period and lead time
- M: Monday
- Tu: Tuesday
- We: Wednesday
- Th: Thursday

[18] One equation for each component

- F: Friday

The parameters differ for all situations. However, these values are fixed after a variable is derived for a particular situation. By adjusting the parameters, the values for the model change, which considers a different situation and gives different outputs. The parameters for the first part of every model are:

- D: mean total daily throughput
- D_{BB}: mean daily throughput blue bins
- D_{Pa}: mean daily throughput pallets
- W: mean total daily effective working minutes
- W_{BB}: mean daily effective working minutes spent on processing blue bins
- W_{Pa}: mean daily effective working minutes spent on processing pallets
- σ_D: standard deviation total daily throughput
- $\sigma_{D|BB}$: standard deviation daily throughput blue bins
- $\sigma_{D|Pa}$: standard deviation daily throughput pallets
- σ_W: standard deviation daily effective working minutes
- $\sigma_{W|BB}$: standard deviation daily effective working minutes spent on processing blue bins
- $\sigma_{W|Pa}$: standard deviation daily effective working minutes spent on processing pallets
- $Var(W)$: variance daily effective working minutes
- $Var(W_{BB})$: variance daily effective working minutes spent on processing blue bins
- $Var(W_{Pa})$: variance daily effective working minutes spent on processing pallets
- L: lead time (in days)
- T: review period (in days)
- $D_{T+L|BB}$: mean throughput blue bins during the review period and lead time
- $D_{T+L|Pa}$: mean throughput pallets during the review period and lead time
- $\sigma_{D|T+L|BB}$: standard deviation of the throughput blue bins during the review period and lead time
- $\sigma_{D|T+L|Pa}$: standard deviation of the throughput pallets during the review period and lead time
- ss_{BB}: safety inventory blue bins
- ss_{Pa}: safety inventory pallets
- ROP_{BB}: reorder point blue bins
- ROP_{Pa}: reorder point pallets

In this model, the operators should fill in the variables based on the current state a particular moment. The variables for the first part of the model are:

- X_{BB}: number of blue bins in the storage location at a particular moment
- X_{Pa}: number of pallets in the storage location at a particular moment

In the second part of the model, several parameters and variables are added. The parameters are again fixed for each situation. Between different situations, the parameters can differ. The parameters in the second part of the model are:

- G_{T+L}: average number of gas tanks stored during the review period and lead time
- I_{T+L}: average number of IBCs stored during the review period and lead time
- DBB_{T+L}: average number of blue bins filled with disapproved aerosol cans during the review period and lead time

The variables for the second part of the model can be filled in based on the current state at a particular moment. The variables in the second part of the model are:

- X_{BB}: total number of blue bins in the storage location[19]
- $X_{BB|1}$: number of blue bins already in the storage location before delivery
- $X_{BB|2}$: number of delivered blue bins
- X_{Pa}: total number of pallets in the storage location
- $X_{Pa|1}$: number of pallets already in the storage location before delivery
- $X_{Pa|2}$: number of delivered pallets
- X_G: number of gas tanks in the storage location
- X_I: total number of filled IBCs in the storage location
- $X_{I|1}$: number of filled IBCs in the storage location before delivery
- $X_{I|2}$: number of dispatched IBCs
- X_{DBB}: total number of disapproved aerosol cans in the storage location
- $X_{DBB|1}$: number of blue bins filled with disapproved aerosol cans in the storage location before delivery
- $X_{DBB|2}$: number of dispatched blue bins with disapproved aerosol cans
- X_N: number of nitrogen racks in the storage location

The variables are constructed such that the following equations are true:

- $X_{BB} = X_{BB|1} + X_{BB|2}$
- $X_{Pa} = X_{Pa|1} + X_{Pa|2}$
- $X_I = X_{I|1} - X_{I|2}$
- $X_{DBB} = X_{DBB|1} - X_{DBB|2}$

5.2.3 – Model – part 1

In this section, the first part of the model is developed. In all situations discussed in this chapter, the operators do not work in shifts and only work with one machine. The basis for creating the first part of the model is researched in section 3.2. For developing the first part of the model, the way Chopra & Meindl (2019) approach reorder point problems is used as a basis. Chopra & Meindl (2019) give examples of different situations in which an ROP is used in the order policy. None of these situations exactly fits this particular situation. However, by adapting, extending, combining, and fitting the examples, we can take a first step in designing an order policy. The parameters of each model are calculated in Appendix D. This section describes how these variables are derived and develops the model.

As investigated in section 4.4, currently, the operators process, on average, four blue bins and two pallets per day, except for Friday when the operators work half a day. In the model, this is called the throughput. The D stands for throughput, BB stands for blue bins, and Pa stands for pallets. Since the processing time differs on Friday, the variance and the standard deviation of the processing time also differ. Therefore, in Appendix D, the parameters corresponding to the first four days of the week are derived separately from

[19] The blue bins filled with unprocessed aerosol cans are meant here. So, the blue bins with disapproved aerosol cans are not part of this.

the parameters for Friday. The indices defined in section 5.2.2 clarify the distinction between the different parameters.

As discussed in section 4.4, it takes 25 minutes to process one blue bin and 50 minutes to process one pallet. The machine can process the content of both blue bins and pallets separately. However, processing only the content of pallets is not favorable for the machine and increases the chance of breakdowns. So, for the machine, it is better to mix perfectly. Therefore, the operators mix the content of both the bins and pallets. As justified in section 2.3.2, the number of blue bins to be processed is double the number of pallets to be processed. Following this logic, half of the working time can be assigned to processing blue bins, and half of the working time can be assigned to processing pallets. Therefore, in the sequel, we assume the ratio of processed blue bins to processed pallets to be 2:1. The operators must try to work according to this ratio. In reality, it is not a significant problem when the ratio deviates at some moments.

Consequently, the working times and throughput ratio are

$$W = W_{BB} + W_{Pa}$$

$$D_{BB} = 2 * D_{Pa}$$

Since it takes 25 minutes to process one blue bin and 50 minutes to process a pallet, the throughputs are

$$D_{BB} = \frac{W_{BB}}{25}$$

$$D_{Pa} = \frac{W_{Pa}}{50}$$

The processed blue bins are perfectly correlated since an increase in the number of processed blue bins increases the processed number of pallets with the same ratio. Moreover, the processing time spent on blue bins equals the processing time spent on pallets. So, $W_{BB} = W_{Pa}$ Therefore,

$$Var(W) = Var(W_{BB} + W_{Pa}) = Var(2 * W_{BB}) = 4 * Var(W_{BB})$$

This results in

$$Var(W_{BB}) = Var(W_{Pa}) = \frac{Var(W)}{4} = \frac{\sigma_W^2}{4}$$

$$\sigma_{W|BB} = \sigma_{W|Pa} = \sqrt{Var(W_{BB})}$$

To calculate the standard deviation of the throughput, the following equations should be used:

$$\sigma_{D|BB} = \frac{\sigma_{W|BB}}{25}$$

$$\sigma_{\mathrm{D|Pa}} = \frac{\sigma_{\mathrm{W|Pa}}}{50}$$

We assume there is daily independence. Subsequently, the corresponding variances of the throughput during the lead time and review period can be calculated by

$$Var(D|T+L|BB) = (T+L) * \frac{\sigma^2_{D|BB|M} + \sigma^2_{D|BB|Tu} + \sigma^2_{D|BB|W} + \sigma^2_{D|BB|Th} + \sigma^2_{D|BB|F}}{5}$$

$$Var(D|T+L|Pa) = (T+L) * \frac{\sigma^2_{D|Pa|M} + \sigma^2_{D|Pa|Tu} + \sigma^2_{D|Pa|W} + \sigma^2_{D|Pa|Th} + \sigma^2_{D|Pa|F}}{5}$$

So, the corresponding standard deviations are

$$\sigma_{D|T+L|BB} = \sqrt{Var(D|T+L|BB)} = 2 * \sigma_{D|T+L|Pa}$$

The lead time in all situations is three days and the review period is one day since the inventory is checked at the beginning of each working day. So,

$$L = 3\ days$$

$$T = 1\ day$$

If throughput is constant over the days, the mean throughput during the time interval T + L can be calculated using

$$D_{T+L|BB} = (T+L) * D_{BB} = 2 * D_{T+L|Pa}$$

If throughput differs per day, we assume the throughput is averaged for calculating the demand during the lead time and review period. So, in that case, the equation for calculating the throughput during time interval T + L is

$$D_{T+L|BB} = (T+L) * \left(\frac{D_{BB|M} + D_{BB|Tu} + D_{BB|W} + D_{BB|Th} + D_{BB|F}}{5}\right) = 2 * D_{T+L|Pa}$$

The cycle service level (CSL) should be high since it costs a lot of time and money if the machine is not running because there is no inventory. Therefore, we use a CSL of 0.95 in all situations. As discussed in section 3.2.3, the CSL is the fraction of cycles in which no stockout occurs (Axsäter, 2015; Gutierrez & Rivera, 2021). So, in this case, it means that in 95% of the time intervals between two follow-up deliveries, the machine has enough aerosol cans to process. Increasing the CSL to, for example, 0.99 would increase the safety stock a lot, and this would increase problems with the amount of hazardous substances. Therefore, the CSL is 0.95, which is still high.

With the CSL, the safety stock for both products can be calculated. Based on Chopra & Meindl (2019), the equation for calculating the safety inventory can be derived. This equation is

$$ss_{BB} = F_s^{-1}(CSL) * \sigma_{D|T+L|BB} = NORMSINV(CSL) * \sigma_{D|T+L|BB} = 2 * ss_{Pa}$$ [20]

Using all calculations done so far, the standard formula for calculating the reorder point, as discussed in section 3.2, can be used. The reorder point will be derived by adding the mean throughput during the review period and the lead time, and the safety stock. If the products were processed separately, the equation for the reorder points is

$$ROP_{BB} = D_{T+L|BB} + ss_{BB} = 2 * ROP_{Pa}$$

[20] NORMSINV is a function in Excel for deriving the well-known Z-Value of the normal distribution

Using separate reorder points makes the order process less efficient in this case. For example, if the ROP for pallets is triggered but many blue bins are left, it could be too early to order a new load. For that reason, it is useful to use a mixed reorder point. An order should be placed if the following equation is true:

$$\frac{1}{2}X_{BB} + X_{Pa} \leq ROP_{BB}$$ [21]

On average,

$$ROP_{BB} = 2 * ROP_{Pa}$$ [22]

The mixed reorder point equation combines both reorder points and weighs them based on the time needed to process the products. Since we assume a standard ratio between the processing times, blue bins and pallets can substitute each other based on the different ratios. Furthermore, since we assume the number of processed blue bins and pallets to be independent, these weighted values can be added.

The processing time of a blue bin is, on average, precisely two times the processing time of a pallet. If there are only blue bins left to process, ROP_{BB} have to be available to process at the moment of reordering. If there are only pallets left to process, ROP_{Pa} of those have to be left to process. These are two extreme scenarios. In reality, the moment of ordering is somewhere in between these scenarios.

Imagine ROP_{BB} is 22, and ROP_{Pa} is 11. If there are 14 blue bins left to process and seven pallets, then filling in the mixed reorder point would give

$$\frac{1}{2} * 14 + 7 \leq 22$$

Since this equation holds, based on the number of inbound products in the storage location, a new load should be ordered.

This concludes the design of the first part of the model in which the reorder point is determined based on the inventory position. However, until now, the amount of hazardous substances is not yet considered. This is done in part 2 of the model, which is discussed in the next section.

5.2.4 – Model – part 2

In this section, the second part of the model is developed. In the second part of the model, we estimate whether the amount of hazardous substances will stay below 10,000 kg after delivery. If this is the case, an order can be placed. For this, an equation is designed that can be filled in by the operators every day.

According to the model so far, a new order should be placed when the inventory drops below the reorder point. However, if by that order, the amount of hazardous substances in the storage location would exceed 10,000 kg, the order may not be placed. The amount of hazardous substances is not always the same at the reorder point since it is also based on the outbound logistical products. The quantities of these outbound products are not always the same at the reorder point. For that reason, after using the

[21] Since this is an equation that might be used in reality and has to be easy to work with, the reorder point is round to integers.

[22] In this model, we assume that this equation holds. However, in reality it may deviate.

first part of the model, a prediction is necessary in which the future amount of hazardous substances is estimated based on the current products in the storage location. Calculating the amount of hazardous substances at a particular moment can be done using the following formula:

$$\text{Amount of haz. sub. in storage location} = 65X_{BB} + 281X_{Pa} + 300X_G + 800X_I + 105X_{DBB} + 180X_N \leq 10{,}000$$

This equation should always meet the restriction that is below 10,000 kg. Therefore, this is added to the equation. Recall that the numbers are coming from the kg of hazardous substances each product does include. So, a blue bin includes 65 kg of hazardous substances, a pallet 281 kg, a gas tank 300 kg, an IBC 800 kg, a blue bin with disapproved aerosol cans 105 kg, and a rack with nitrogen cylinders 180 kg. This equation can be used to calculate the amount of hazardous substances at the moment of ordering as well. However, it is difficult to use this formula to predict the amount of hazardous at the moment of ordering. This is because estimating what will happen during the lead time is difficult, but we come to that later.

For the change in the amount of hazardous substances in inventory at the moment of delivery, the following equation can be used:

$$\begin{aligned} Change\ in\ hazardous\ substances &= 65X_{BB|2}('\#\ of\ deliverd\ blue\ bins') + 281X_{Pa|2}('\#\ of\ delivered\ pallets') \\ &- 800X_{I|2}('\#\ of\ dispatched\ IBCs') \\ &- 105X_{DBB|2}('\#\ of\ dispatched\ blue\ bins\ with\ disapproved\ aerosol\ cans') \end{aligned}$$

In this equation, the dispatched amount of hazardous substances is subtracted from the delivered amount of hazardous substances in blue bins and pallets. This is approximately 800 kg per IBC and 105 kg per blue bin with disapproved aerosol cans. We use these numbers because it is an investigated average. However, in reality, A.R.T. weighs all IBCs and blue bins with disapproved aerosol cans, so reality can deviate from this.

To estimate the amount of hazardous substances in the storage location after delivery, an estimation of the processed blue bins and pallets during the lead time and review period is necessary. If the mean is used in the equation, the chance is too big that, in reality, less will be processed, and the maximum amount of hazardous substances will be exceeded. Therefore, the equations assume that the machine processes the mean minus the standard deviation. So,

$$D_{T+L|BB} - \sigma_{T+L|BB}$$

$$D_{T+L|Pa} - \sigma_{T+L|Pa}$$

The equation for predicting the amount of hazardous substances in the inventory immediately after delivery gives:

$$
\begin{aligned}
&\text{Predicted amount of haz. sub. at moment of delivery} \\
&\quad = 65\left(X_{BB|1} + X_{BB|2} - \left(D_{T+L|BB} - \sigma_{T+L|BB}\right)\right) \\
&\quad + 281\left(X_{Pa|1} + X_{Pa|2} - \left(D_{T+L|Pa} - \sigma_{T+L|Pa}\right)\right) + 300(X_G + G_{T+L}) + 800I_{T+L} \\
&\quad + 105DBB_{T+L} + 180X_N \leq 10{,}000 - S
\end{aligned}
$$
[23]

The left part of the equation should be less than 10,000 kg. However, this equation should always hold. Therefore, some extra margin is probably necessary to be sure this equation always holds. This extra margin is S in this equation. Since some components of the equation already consider a margin, we assume a margin of 300 kg which should probably be sufficient. Examples of reasons why an extra margin is necessary are that the pallets are larger than average or more IBCs are filled than expected.

Filling in all parameters for the different versions of the models and rewriting these would give an equation of the form:

$$65X_{BB|1} + 281X_{Pa|1} + 300X_G \leq Z$$

In this equation, Z differs between the models based on the values of parameters. If this equation holds, A.R.T. can receive a new truck with pallets and blue bins without exceeding the maximum amount of hazardous substances. If this equation does not hold, A.R.T. should, based on this model, not place an order, and the next day ordering should be considered again.

The variables can be filled based on the counting from the operators in the morning. This does not require a huge effort, and it is easy to do.

5.2.5 – Different situations

In the previous sections, the ROP model is developed. The calculations and results for the in section 4.4 outlined situations can be found in appendix D. This section analyses the different outcomes and tries to find patterns useful for A.R.T. Table 5.7 shows the mean, standard deviation, mixed reorder point, and the reorder point based on hazardous substances for the different situations. Moreover, it includes the mixed reorder point-to-mean ratio, which is explained and discussed later in this section.

	Mean effective working minutes	**Standard deviation**	**Mixed reorder point**	**Reorder point based on hazardous substances**	**Mixed reorder point-to-mean ratio**
Current situation	200	89.31	$\frac{1}{2}X_{BB} + X_{Pa} \leq 20$	3,263.05	0.1
Situation 1	280	65	$\frac{1}{2}X_{BB} + X_{Pa} \leq 24$	3,765.88	0.086
Situation 2	360	45	$\frac{1}{2}X_{BB} + X_{Pa} \leq 29$	4,213.83	0.081

Table 5.7 – Important values – Current process

[23] "$300(X_G + G_{T+L})$" is uncertain. This is because A.R.T. does not know yet what to do with the regained gasses. In the model, it is assumed that during the lead time and review period no gas is dispatched. Without doing this, it could be that in reality the amount of hazardous substances is higher than predicted causing a too high chance of exceeding the maximum amount of hazardous substances

It turns out that there is a large correlation between an increasing mixed reorder point and the reorder point based on the amount of hazardous substances. A better flowing process causes more effective working minutes, fewer interruptions, and more reliability. Increasing reliability and lowering the amount of interruptions decreases the standard deviation. A lower standard deviation makes the model more predictable, which causes a lower safety inventory to be required.

A lower safety inventory causes a lower reorder point. So, as the time progresses, the required mixed reorder point increases because more will be processed during the lead time and review period, but compared to the mean, it decreases because of the increase in predictability. This is shown in the last column of table 5.7 by the decrease in the mixed reorder point-to-mean ratio.

The three outlined scenarios are not the only possible scenario. There are countless scenarios in between the outlined ones. If the scenario at a particular moment is not close to one of the outlined ones, a middle ground can be used to estimate the mixed reorder point and the reorder point based on the amount of hazardous substances.

For example, imagine the mean effective working minutes are approximately 320. Then the mixed reorder point is in between situation 1 and situation 2. So, the corresponding mixed reorder point will be $\frac{20+24}{2} = 22$. The formula corresponding to this is

$$\frac{1}{2}X_{BB} + X_{Pa} \leq 22$$

The same should be done for the second part of the model, in which the amount of hazardous substances in the storage location is used to determine whether A.R.T. can receive a new truck or not. So, $\frac{3{,}263.05+3{,}765.88}{2} = 3{,}514.47$. The corresponding formula is

$$65X_{BB|1} + 281X_{Pa|1} + 300X_G \leq 3{,}514.47$$

5.2.6 – Reality and implementation

In this section, first, the reality is discussed, including the drawbacks and shortcomings of the model. Next, the way it should be implemented is discussed.

A drawback of this model is that the standard deviations are assumptions and are not well substantiated. To deal with this, reality might help make it more reliable and decrease the chance of having a too high amount of hazardous substances in the storage location. For example, if it turns out to be the case that always the same misfitting tends to occur, A.R.T. can deal with this by adapting the standard deviation or other variables. So, these models can be used as a basis, but the reality might increase accuracy.

Another drawback is that it is difficult to estimate what happens with the amount of hazardous substances during the review period, lead time, and just after delivery. This is because it depends on the filling level of the gas tank and IBCs connected to the machine, the filling level of the blue bin with disapproved aerosol cans, and the throughput. For example, this model does predict the amount of hazardous substances in the storage location three days ahead. However, the gas tank filled for 10% gives the same prediction as if the gas tank is filled for 85%.

The implementation of this model does not require a huge effort or investment but probably needs some training for the operators. Currently, the operators are filling in a daily report in which information is written down as regards errors, deliveries, weighing, and more. In addition, they also write down what is in the storage location and, only recently, the corresponding amount of hazardous substances.

Implementing this design would not make it much more difficult since the operators only need to do an extra check. However, they need to understand the mixed reorder point formula and be aware of the value of the hazardous substances at which reordering should be done. Moreover, they should be aware of the two steps the model include. They need to check whether the number of units in the storage location is below the mixed reorder point and whether the amount of hazardous substances is below the value coming from the second part of the model.

Which values A.R.T. should pick as reorder points for both parts of the model depends on how well the process runs. A.R.T. needs to assess which value to pick based on the scenarios discussed in this chapter. If reality turns out that there is some deviation from the model, slight adaptions can be done quite easily.

5.3 – Conclusion

In section 5.1, the most effective layout of the storage location is selected, and in section 5.2, an order policy is designed. This section forms conclusions about designing the storage location and order policy.

5.3.1 – Storage location

For the layout of the storage location, we designed five design alternatives. These design alternatives had to fulfill requirements and constraints regarding capacity and regulations. Every design alternative is designed based on different advantages.

Design alternative 1 first stores the blue bins. Next, it stores the first pallet immediately in front of the last stored blue bin. Then, the remaining space can be used to store the blue bins with disapproved aerosol cans.

Design alternatives 2 uses dedicated storage in which one lane may only be used for pallets or blue bins but not for both. However, the last lane can be used to store remaining inbound products and disapproved aerosol cans.

Design alternative 3 uses the same strategy as design alternative one. However, in this design alternative, first, the pallets are stored, and in front of the last stored pallet, the first blue bin should be stored. Then, the remaining space can be used to store the blue bins with disapproved aerosol cans.

Design alternative 4 is more complicated than the previous design alternatives. In this design alternative, every lane might be used to store both blue bins and pallets. The first lane has blue bins in the back and pallets at the front. The second lane is the opposite, and the third lane is the same as the first lane. Then, the fourth lane is the same as the second lane, and lane 5 can be used to store the remaining inbound products and the disapproved aerosol cans.

Design alternative 5 uses randomized storage in which the products are stored at the lane that includes the least amount of products.

All design alternatives are compared based on five important criteria and received a score from 1 to 5 for each criterion. The important criteria are:

1. **Empty lane** → Is there an empty lane quickly?
2. **Moving space** → Is there moving space in front of the drip trays?
3. **Layout clarity/easily workable** → Is the layout clear, and is it workable for the operators?
4. **Product accessibility** → Can each product be accessed?
5. **Unused space** → Is there unused space?

Based on the assessments, we concluded that the best design alternative to implement is design alternative 1. The average score of design alternative 1 is 4.6, meaning it scores well on all criteria.

So, based on this research, the operators should first store all blue bins starting in lane 1. If all blue bins are stored, the operators should store the pallets and start in front of the last stored blue bin. If all pallets are stored, the disapproved aerosol cans may be stored in front of the last stored pallet or in an empty lane. Processing should be done in reverse order. So start with the highest lane number having the required product in the front.

An advantage of this design alternative is that there is a high chance of having movement space in front of the drip trays. Moreover, this design alternative gives a high chance of having an empty lane giving the advantage of having space available for arriving products and contributes to having moving space in front of the drip trays. Furthermore, this design alternative is clear and easily workable for the operators. Finally, this design alternative has the advantage of having no lost space since all lanes are fully loaded before storing products in the next lane.

Design alternative 1 has two little disadvantages. The first one is that the fork lift has to drive relatively long distances since it starts processing the products in the lanes the farthest away from the machine. The second disadvantage is that in some lanes, the products behind other products are difficult to access. For example, if pallets are stored in front of blue bins in lane 2, then the blue bins in that lane are not accessible.

5.3.2 – Order policy

This chapter designed a model for the order policy, including two steps. First, a reorder point is determined based on the number of products in the storage location. Second, it is checked whether placing an order would exceed the maximum amount of hazardous substances in the storage location at the moment of delivery. The products in the storage location are reviewed daily. Based on the daily review and the model, the operators should determine whether an order can be placed or not.

This model is applied to three situations with different mean effective working hours and different corresponding standard deviations. The model is used to determine the reorder point for all these situations. Based on a discussion, we can conclude that an increase in reliability, corresponding to a decrease in standard deviation, decreases the required safety stock causing the reorder point is lower compared to the throughput. However, an increasing throughput increases the reorder point since more products need to be available to process.

For the current situation, with mean effective working minutes being 200 with a corresponding standard deviation of 89.31, the mixed reorder point equation is $\frac{1}{2}X_{BB} + X_{Pa} \leq 20$. Based on the second part of the model, A.R.T. can only order if the amount of hazardous substances in the blue bins, pallets, and gas tanks in the storage location does not exceed 3,263.05 kg. For the situation with mean effective working minutes being 280 and the standard deviation being 65, the mixed reorder point equation

$\frac{1}{2}X_{BB} + X_{Pa} \leq 24$ might be used. The corresponding reorder point for the second part of the model is 3,765.88 kg. The situation as it might become when the machine has no errors anymore considers the mean effective working minutes to be 360 minutes with a corresponding standard deviation of 45. The mixed reorder point that might be used in this situation is $\frac{1}{2}X_{BB} + X_{Pa} \leq 29$. The amount of hazardous substances the blue bins, pallets, and gas tanks in the storage location include should be below 4,213.83 kg at the moment A.R.T. wants to order a new load.

The models for the outlined situations can be used daily by the operators. Which situation applies to the situation A.R.T. is in at a particular moment has to be determined by looking at the throughput. The operator should be trained to use the model, but it is quite easy. Currently, the operators already administrate the values necessary to fill in the model daily, so they only need to know when the reorder point is triggered. If this is triggered, the operators need to contact the person responsible for ordering so she can order a new load.

6 – Expansion

As for working with one machine without shifts, we also develop different models for the case of expansion. The first model, discussed in section 6.1, is implementable immediately without making investments. This model presumes again that one machine is used but that the operators will work in shifts instead of working together during the same hours every day. In applying this model, two divisions of shifts are considered, both having advantages and disadvantages.

The second model considers the case of working with two machines without shifts. This case requires a massive investment since an extra machine should be purchased. This model is discussed in section 6.2. The third model, discussed in section 6.3, presumes that two machines are used and that the operators work in shifts. The cases to which model two and three apply require the same investment since an extra machine needs to be purchased.

In all models, it is discussed whether an extra supplier is necessary or not. Moreover, all models are applied to different situations varying in working hours or number of operators. These situations are analyzed based on the reorder point and throughput. Moreover, for all models, the connection with reality is made.

6.1 – One machine – shifts

This section develops a model for determining the reorder point in case one machine is used and in which the operators work in shifts. First, in section 6.1.1, the shifts and working hours assumed in both models are developed, and their application is described. Then, in section 6.1.2, the first part of the model is developed by linking the model from section 5.2 to the shifts described in section 6.1.1. After that, in section 6.1.3, the second part of the model is developed in which the hazardous substances are considered. Next, in section 6.1.4, both situations are analyzed and compared. After that, section 6.1.5 makes the connection between the model and reality. Finally, section 6.1.6 formulates the conclusion of section 6.1.

6.1.1 – Assumptions

Situation 1

In this model, the same machine is used as in the previous models. Moreover, we assume that the effective working minutes have the same ratio as in the most effective scenario of the previous chapter, in which there were 360 working minutes per day. However, since the operators do now work in shifts, the total effective working minutes are higher now.

Because of the licensing requirements, the machine may only be used between 7:00 AM and 7:00 PM. The operators do work 36 hours a week. On every full day of working, the operators have a lunch break of 30 minutes. During the other breaks, the machine keeps processing, so these are not counted as a break. In these other breaks, the operators regularly refill the machine.

If an operator works for 36 hours in four days, he or she is scheduled for 38 hours (36 + 4 * 0.5). One operator needs a startup time of 30 minutes every day before he can start processing. To not lose time, the first operator starts working 30 minutes before the machine may start processing. The same holds for shutting down, but for this, one operator needs 15 minutes. The working hours assumed in this model are in Table 6.1.

	Operator 1	Operator 2
Monday	9 hours + 0.5 hour break → self determine which hours	Off
Tuesday	06:30 AM – 4:00 PM	9:45 AM – 7:15 PM
Wednesday	06:30 AM – 4:00 PM	9:45 AM – 7:15 PM
Thursday	06:30 AM – 4:00 PM	9:45 AM – 7:15 PM
Friday	Off	9 hours + 0.5 hour break → self determine which hours

Table 6.1 - Working hours - One machine & shifts - Situation 1

In the previous models, the operators work together all the time. In this model, the operators work alone during part of the working hours. Table 6.2 calculates the number of working hours with the corresponding number of operators. The lunch breaks are deducted from this and are assumed to be taken together.

	1 operator	2 operators
Monday	9 hours	0 hours
Tuesday	6 hours and 30 minutes	5 hours and 45 minutes
Wednesday	6 hours and 30 minutes	5 hours and 45 minutes
Thursday	6 hours and 30 minutes	5 hours and 45 minutes
Friday	9 hours	0 hours
Total	37:30 hours	17:15 hours

Table 6.2 - Total working hours - One machine & shifts – Situation 1

In this model, for 37 hours and 30 minutes per week, one operator runs the process. For 17 hours and 15 minutes per week, two operators run the process. So, in total, the process runs for 54 hours and 45 minutes per week in this model. Since errors, breakdowns, and problems can still occur, these hours are not all assumed as effective working hours. Excluding breaks, in the most effective model of the previous chapter, it is assumed that 75% of the total working hours are assumed to be effective, including startup and shutdown. In this model, the same assumption is used. So, the effective working hours are 28 hours and 8 minutes for one operator and 12 hours and 56 minutes for two operators. Rounding this, to be easier workable would give 28 hours (1,680 minutes) and 13 hours (780 minutes), respectively.

Since the mean effective hours differ per day because of the different schedules, the model designed in this section is a bit more complex than the previous models. In all models in chapter 6, the same notation is used as in chapter 5. If additional notation is necessary, this is mentioned.

Situation 2

This section discusses the second situation to which the model is applied in which the shifts are arranged differently. This situation also assumes the operators are working 36 hours each but now divided over five days per operator instead of four. This means that both operators work four times seven hours per day and one time eight hours per day. Again, the lunch break is not included in this but is included in the working times. The working hours assumed in this model are in Table 6.3

	Operator 1	Operator 2
Monday	06:30 AM – 3:00 PM	11:45 AM – 7:15 PM
Tuesday	06:30 AM – 2:00 PM	11:45 AM – 7:15 PM
Wednesday	06:30 AM – 2:00 PM	11:45 AM – 7:15 PM
Thursday	06:30 AM – 2:00 PM	11:45 AM – 7:15 PM
Friday	06:30 AM – 2:00 PM	10:45 AM – 7:15 PM

Table 6.3 – Working hours - One machine & shifts - Situation 2

Table 6.4 presents the number of hours the operators work alone and the number of hours the operators work together. For simplicity, again, the lunch breaks are assumed that it is taken during the time the operators work together and is deducted from the total working hours.

	1 operator	2 operators
Monday	9 hours and 30 minutes	2 hours and 45 minutes
Tuesday	10 hours and 30 minutes	1 hour and 45 minutes
Wednesday	10 hours and 30 minutes	1 hour and 45 minutes
Thursday	10 hours and 30 minutes	1 hour and 45 minutes
Friday	9 hours and 30 minutes	2 hours and 45 minutes
Total	50:30 hours	10:45 hours

Table 6.4 – Total working hours - One machine & shifts - Situation 2

This version has more effective working hours than the previous one since it captures all possible running hours. For 50 hours and 30 minutes per week, one operator is working. For ten hours and 45 minutes per week, the operators work together. In total, the process runs for 61 hours and 25 minutes. Again 75% of the total working hours, including startup and shut down, is assumed as effective working hours. This means that the total effective working hours are approximately 46 hours. The effective working hours for one operator are 37 hours and 53 minutes. Rounding this would give 38 hours (2280 minutes). The effective working hours for two operators are 8 hours and 4 minutes. Rounding this gives 8 hours (480 minutes)

6.1.2 – The model – Part 1

In this section, the first part of the model is developed. This part is based on the first part of the model developed in chapter 5 and the information from section 6.1.1.

Since the models in the upcoming sections are a bit more complex than the model discussed in chapter 5, some additional notation is required. The additional index is

- i: i number of operators are working

The additional parameter is:

- Y_i: Scheduled working hours if i operators are working, excluding breaks (i = 1, 2, 3, 4)

In the first version, on Mondays and Fridays, one operator works alone. The previous chapter does not consider cases in which the operators can work alone. Estimating the difference between working with one and two operators is challenging. Currently, the operators always work together, so almost no observations are done on this. Based on two days of observations[24] and a conversation with the operators, we can conclude that the machine can run at approximately 65% of its capacity if one operator works.

In the previous model, the working days were 9 hours, including a lunch break of 30 minutes. In this model, a working day on Monday and Friday is 9 hours and 30 minutes, including 30 minutes of lunch break.

As in all models of this research, half of the processing time can be assigned to blue bins, and half of the processing time can be assigned to pallets. Consequently,

$$W = W_{BB} + W_{Pa}$$

$$D_{BB} = 2 * D_{Pa}$$

In the optimal scenario in chapter 5, on working days from 8.5 hours (9 hours including lunch break), the effective working minutes are 360 minutes. Based on that, assuming the same ratio, the effective working minutes can be calculated by

$$W_1 = \frac{Y_1}{(9 - 0.5)} * 360$$

$$W_2 = \frac{Y_2}{(9 - 0.5)} * 360$$

The total daily effective working minutes can be derived by

$$W = W_1 + W_2$$

This model also assumes that it takes 25 minutes to process one blue bin and 50 minutes to process a pallet if the operators work together. Recall that the throughput in the optimal situation in chapter 5 is 7.2 blue bins and 3.6 pallets. For the hours in which only one operator is working, the throughput can be calculated by

$$D_{BB|1} = 0.65 * \frac{Y_1}{(9 - 0.5)} * 7.2 = 2 * D_{Pa|1}$$

In case two operators are working, the throughput can be calculated by

$$D_{BB|2} = \frac{Y_2}{(9 - 0.5)} * 7.2 = 2 * D_{Pa|2}$$

Based on the above equation, the total daily throughput can be determined by

$$D_{BB} = D_{BB|1} + D_{BB|2}$$

Based on how the variance is calculated in the previous section and on the formulas defined in this section, the variances and standard deviations for the effective working hours in case of working with one operator can be determined using

[24] This is done on two days that one of the operators was absent.

$$Var(W_1) = (\frac{Y_1}{(9-0.5)})^2 * 0.65^2 * 45^2$$ [25]

$$Var(W_1) = Var(W_{BB|1} + W_{Pa|1}) = Var(2 * W_{BB|1}) = 4 * Var(W_{BB|1})$$

$$Var(W_{BB|1}) = Var(W_{Pa|1}) = \frac{Var(W_1)}{4} = \frac{\sigma_{W|1}^2}{4}$$

$$\sigma_{W|BB|1} = \sigma_{W|Pa|1} = \sqrt{Var(W_{BB|1})}$$

The variances and standard deviations for the effective working hours in case two operators are working can be calculated using

$$Var(W_2) = (\frac{Y_2}{(9-0.5)})^2 * 45^2$$

$$Var(W_2) = Var(W_{BB|2} + W_{Pa|2}) = Var(2 * W_{BB|2}) = 4 * Var(W_{BB|2})$$

$$Var(W_{BB|2}) = Var(W_{Pa|2}) = \frac{Var(W_2)}{4} = \frac{\sigma_{W|2}^2}{4}$$

$$\sigma_{W|BB|2} = \sigma_{W|Pa|2} = \sqrt{Var(W_{BB|2})}$$

With these standard deviations, the standard deviations for the throughput can be derived. This gives

$$\sigma_{D|BB|1} = \frac{\sigma_{W|BB|1}}{25} * \sqrt{0.65}$$

$$\sigma_{\mathrm{D|Pa|1}} = \frac{\sigma_{\mathrm{W|Pa|1}}}{50} * \sqrt{0.65}$$

$$\sigma_{D|BB|2} = \frac{\sigma_{W|BB|2}}{25}$$

$$\sigma_{\mathrm{D|Pa|2}} = \frac{\sigma_{\mathrm{W|Pa|2}}}{50}$$

Assuming independence between processing with one operator and two operators on the same day, the daily standard deviations of the daily throughput can be calculated by

$$\sigma_{D|BB} = \sqrt{\sigma_{D|BB|1}^2 + \sigma_{D|BB|2}^2}$$

$$\sigma_{D|Pa} = \sqrt{\sigma_{D|Pa|1}^2 + \sigma_{D|Pa|2}^2}$$

With this, the corresponding variances for the throughput during the lead time and review period can be determined. This gives

[25] The standard deviation is 45 in case the effective working minutes are 360

$$Var(D|T+L|BB) = (T+L) * \frac{\sigma^2_{D|BB|M} + \sigma^2_{D|BB|Tu} + \sigma^2_{D|BB|We} + \sigma^2_{D|BB|Th} + \sigma^2_{D|BB|F}}{5}$$

$$Var(D|T+L|Pa) = (T+L) * \frac{\sigma^2_{D|Pa|M} + \sigma^2_{D|Pa|Tu} + \sigma^2_{D|Pa|We} + \sigma^2_{D|Pa|Th} + \sigma^2_{D|Pa|F}}{5}$$

The corresponding standard deviations are

$$\sigma_{D|T+L|BB} = \sqrt{Var(D|T+L|BB)} = 2 * \sigma_{D|T+L|Pa}$$

Since the throughput differs per day in both versions, for determining the throughput during the lead time and review period, the throughput should be averaged. So,

$$D_{T+L|BB} = (T+L) * \left(\frac{D_{BB|M} + D_{BB|Tu} + D_{BB|We} + D_{BB|Th} + D_{BB|F}}{5}\right) = 2 * D_{T+L|Pa}$$

As in the previous chapter, in all models in this chapter, the lead time is three days and the review period is one day. Again, the CSL is in both versions 0.95. With the CSL, the required safety inventory can be calculated using the following equations:

$$ss_{BB} = F_S^{-1}(CSL) * \sigma_{D|T+L|BB} = NORMSINV(CSL) * \sigma_{D|T+L|BB} = 2 * ss_{Pa}$$

The corresponding separate reorder points can be derived using

$$ROP_{BB} = D_{T+L|BB} + ss_{BB} = 2 * ROP_{Pa}$$

The ratio regarding processing in blue bins-to-pallets remains 2:1, so nothing changes regarding this. Therefore the equation for calculating the mixed reorder point remains the same:

$$\frac{1}{2}X_{BB} + X_{Pa} \leq ROP_{BB}$$

Again, on average:

$$ROP_{BB} = 2 * ROP_{Pa}$$

With this mixed reorder point, the first part of this model is finished in which the reorder point is determined based on the inventory position.

6.1.3 – The model – Part 2

For the second part of the model, nothing changes compared to the model discussed in chapter 5. So the following equations apply to this model as well:

$$\text{Amount of haz. sub. in storage location} = 65X_{BB} + 281X_{Pa} + 300X_G + 800X_I + 105X_{DBB} + 180X_N \leq 10{,}000$$

$$\text{Change in hazardous substances} = 65X_{BB|2} + 281 * X_{Pa|2} - 800 * X_{I|2} - 105X_{DBB|2}$$

$$\text{Predicted amount of haz. sub. at moment of delivery}$$
$$= 65\left(X_{BB|1} + X_{BB|2} - \left(D_{T+L|BB} - \sigma_{T+L|BB}\right)\right) + 281\left(X_{Pa|1} + X_{Pa|2} - \left(D_{T+L|Pa} - \sigma_{T+L|Pa}\right)\right) + 300(X_G + G_{T+L}) + 800I_{T+L} + 105DBB_{T+L} + 180X_N \leq 10{,}000 - S$$

Working this out would give an equation in the form of the following form:

$$65X_{BB|1} + 281X_{Pa|1} + 300X_G \leq Z$$

6.1.4 – Different situations

As the model discussed in chapter 5, this model is also applied to different situations. It is applied to two situations that are worked out in Appendix E. The important values can be found in Table 6.5.

	Mixed reorder point	**Reorder point based on hazardous substances**	**Weekly throughput blue bins**	**Weekly throughput pallets**	**Effective working hours**
Situation 1	$\frac{1}{2}X_{BB} + X_{Pa} \leq 30$	4,418.73	35.27	17.62	38.65
Situation 2	$\frac{1}{2}X_{BB} + X_{Pa} \leq 32$	4,595.9	36.9	18.45	43.22

Table 6.5 - Important values - One Machine & Shifts

The mixed reorder point for situation 1 is $\frac{1}{2}X_{BB} + X_{Pa} \leq 30$, and the corresponding reorder point based on hazardous substances is 4,418.73. For situation 2, the mixed reorder point is $\frac{1}{2}X_{BB} + X_{Pa} \leq 32$. The corresponding reorder point based on hazardous substances is 4,595.9.

Based on Table 6.5, we can conclude that the important values for both situations are close to each other. Situation 2 generates a higher weekly throughput than Situation 1.

$$\left(\frac{36.9 - 35.27}{35.27}\right) * 100\% = 4.62\%$$

According to this research, implementing situation 2 instead of situation 1 would give 4.62% more weekly throughput. This is a relatively small difference.

Situation 2 also includes more effective working hours than Situation 1.

$$\frac{43.22 - 38.65}{38.65} * 100\% = 11.82\%$$

Situation 2 gives, according to this model, 11.82% more effective working hours than situation 1. The reason why the increase in throughput and the increase in effective working hours are not equal is that in the second situation, a larger fraction of time operators are working alone instead of working together. Working alone gives a lower throughput per time unit than working together.

6.1.5 – Reality

Based on the model and the analysis, situation two is the better choice to implement over situation one. However, reality should be taken into account. This research has to deal with operators, and their well-being is important in making decisions.

Both situations include two operators working 36 hours a week, but the hours are differently divided over the days. Situation 1 assumes the operators to work both four days a week. Situation 2 assumes the operators work five days a week. Situation 1 lets the operators work nine hours per day, and in situation 2 this is, depending on the day, seven or eight hours per day.

For the operators, it is more favorable to work 36 hours in four days than 36 hours in five days. In situation 1, the operators each have one day in which they may determine when to start working by themselves. This extra advantage makes situation 1 more favorable for the operators.

Another advantage of situation 1 is that the operators have more overlapping hours. This causes the operators to work together more often than they would do in situation 2. Working together probably increases job satisfaction.

The only advantage of situation 2 for the operators is that the working days are one or two hours shorter compared to situation one. However, getting an extra day off is probably a more significant advantage for them.

6.1.6 – Conclusion

The model developed in this section is an adapted and extended version of the model developed in chapter 5. This model includes two operators, and we assume they work in shifts with the machine running between 7:00 AM and 7:00 PM. Some fraction of the time, the operators work alone, and a fraction of the time, the operators work together.

This model again aims to find the reorder points for the outlined situations. For situation 1, in which the operators work 36 hours in four days, the mixed reorder point is $\frac{1}{2}X_{BB} + X_{Pa} \leq 30$, and the corresponding reorder point based on hazardous substances is 4,418.73. For situation 2, in which the operators work 36 hours in five days, the mixed reorder point is $\frac{1}{2}X_{BB} + X_{Pa} \leq 32$. The corresponding reorder point based on hazardous substances is 4,595.9.

Situation 2 will generate 4,62% more throughput than situation 1. However, we recommend A.R.T. to implement the shifts of situation 1. This is because situation 1 has advantages for the operators and their well-being comes first compared to a small increase in throughput. The first advantage for the operators is that they have an extra day off every week. Moreover, they work together a larger fraction of the time in situation 1, which probably increases job satisfaction.

The choice of what shifts to implement is a choice A.R.T. has to make, but we recommend letting the operators work four days a week for, in total, 36 hours.

6.2 – Two machines - No shifts

This section discusses the case in which an extra machine will be used without the operators working in shifts. This model is applied to two situations. One situation in which we assume there are three operators, and one situation in which we assume there are four operators. This model looks like the model discussed in chapter 5 since the operators work during the same hours of the day. However, since there is an extra machine and more operators, the model differs in this case.

This section starts with section 6.2.1, discussing the assumptions as regards the number of operators and the throughput. Then, sections 6.2.2 and 6.2.3 develop the model. After that, in section 6.2.4, both situations are compared. In this comparison, there is also a comparison with the current situation in which there are two operators and one machine. Next, section 6.2.5 makes the connection with reality. Finally, section 6.2 ends with a conclusion in section 6.2.6.

6.2.1 – Assumptions

In this model, all operators work from 07:30 AM until 4:30 PM on the first four days of the week. On Fridays, the operators work from 07:30 AM until 12:00 PM. Since there is currently no second machine and since this is a design for a future scenario, it is not easy to estimate the throughput.

Assumptions and estimations are necessary to estimate the throughput compared to working with one machine and two operators. We assume that if two operators work with one machine, the throughput factor[26] is 100. Then, if one operator works with one machine at 65% of the operating speed, the throughput factor is 65. If two operators work with two machines, the throughput factor would be 2*65 = 130. If three operators work with two machines, the throughput factor is $\frac{130+200}{2}$ =165. Finally, if four operators use two machines, the throughput factor would be double the current process, so 200. These derivations can be found in Table 6.6

	Number of machines	Number of operators	Throughput factor
1	1	2	100
2	2	2	65 x 2 = 130
3	2	4	100 x 2 = 200
4	2	3	1 x 100 + 1 x 65 = 165

Table 6.6 – Derivation throughput factors

For deriving these throughput factors, we assume that there is no extra advantage from working with more operators except for the cumulative increase in throughput. In reality, working with more operators could make it easier to divide tasks, giving an extra increase in throughput. However, since there is only one machine and two operators in the current process, it is impossible to estimate this.

In Appendix F, this model is worked out for two situations. Situation 1 assumes three operators run the process. Situation 2 assumes four operators run the process.

6.2.2 – The model – part 1

This model uses the same notation as the model in chapter 4. The only added variable is:

- T_i: Throughput factor in case i operators are working

[26] A throughput factor of 100 corresponds to the optimal situation discussed in chapter 5.

Since it is assumed the operators always work together, there is no difference in throughput during the day. As in the other models, half of the processing time is assigned to blue bins, and half of the processing time is assigned to pallets. Consequently,

$$W = W_{BB} + W_{Pa}$$

$$D_{BB} = 2 * D_{Pa}$$

Since we assume an extra machine to be used in this model, the throughput increased. In chapter 5, it is assumed that the operators need 25 minutes to process a blue bin and 50 minutes to process a pallet. In this model, the processing time decreased since the number of machines and operators increased. Therefore, the equations defined in chapter 5 need to be multiplied by the throughput factor to determine the throughput.

$$D_{BB} = \frac{W_{BB}}{25} * T_i$$

$$D_{Pa} = \frac{W_{Pa}}{50} * T_i$$

In this model, still $W_{BB} = W_{Pa}$. Moreover, in determining the variance for the effective working minutes, nothing changes. Consequently,

$$Var(W) = Var(W_{BB} + W_{Pa}) = Var(2 * W_{BB}) = 4 * Var(W_{BB})$$

$$Var(W_{BB}) = Var(W_{Pa}) = \frac{Var(W)}{4} = \frac{\sigma_W^2}{4}$$

$$\sigma_{W|BB} = \sigma_{W|Pa} = \sqrt{Var(W_{BB})}$$

Calculating the standard deviation follows the same logic as calculating the throughput as regards the throughput factor. However, the formula derived in chapter 5 should now be multiplied by the square root of the throughput factor since this is a basic rule for working with standard deviations. So,

$$\sigma_{D|BB} = \frac{\sigma_{W|BB}}{25} * \sqrt{T_i}$$

$$\sigma_{\mathrm{D|Pa}} = \frac{\sigma_{\mathrm{W|Pa}}}{50} * \sqrt{T_i}$$

Again, in this model, we assume daily independence. Consequently, the corresponding throughput during the lead time and review period can be calculated using

$$Var(D|T + L|BB) = (T + L) * \frac{\sigma_{D|BB|M}^2 + \sigma_{D|BB|Tu}^2 + \sigma_{D|BB|We}^2 + \sigma_{D|BB|Th}^2 + \sigma_{D|BB|F}^2}{5}$$

$$Var(D|T + L|Pa) = (T + L) * \frac{\sigma_{D|Pa|M}^2 + \sigma_{D|Pa|Tu}^2 + \sigma_{D|Pa|We}^2 + \sigma_{D|Pa|Th}^2 + \sigma_{D|Pa|F}^2}{5}$$

The corresponding standard deviations can be derived by

$$\sigma_{D|T+L|BB} = \sqrt{Var(D|T + L|BB)} = 2 * \sigma_{D|T+L|Pa}$$

In both situations, the lead time and review period is three and one days, respectively. Since the throughput differs per day, the throughput is averaged to determine the throughput during the lead time and review period. So,

$$D_{T+L|BB} = (T + L) * \left(\frac{D_{BB|M} + D_{BB|Tu} + D_{BB|W} + D_{BB|Th} + D_{BB|F}}{5}\right) = 2 * D_{T+L|Pa}$$

The CSL remains 0.95 in both situations. With this, the safety stock can be determined by

$$ss_{BB} = F_S^{-1}(CSL) * \sigma_{D|T+L|BB} = NORMSINV(CSL) * \sigma_{D|T+L|BB} = 2 * ss_{Pa}$$

The equation for the separate reorder points are

$$ROP_{BB} = D_{T+L|BB} + ss_{BB} = 2 * ROP_{Pa}$$

The equation for the mixed reorder point neither changes. So an order should be placed if the following equation holds:

$$\frac{1}{2}X_{BB} + X_{Pa} \leq ROP_{BB}$$

On average,

$$ROP_{BB} = 2 * ROP_{Pa}$$

The operators should try to let the number of blue bins in the storage location be twice as high as the pallets if possible.

6.2.3 – The model – Part 2

The second part in all models is the same and are already explained in chapter 5. Consequently,

$$\text{Amount of haz. sub. in storage location} = 65X_{BB} + 281X_{Pa} + 300X_G + 800X_I + 105X_{DBB} + 180X_N \leq 10{,}000$$

$$\text{Change in hazardous substances} = 65X_{BB|2} + 281X_{Pa|2} - 800X_{I|2} - 105X_{DBB|2}$$

$$\begin{aligned}\text{Predicted amount of haz. sub. at moment of delivery} \\ &= 65\left(X_{BB|1} + X_{BB|2} - \left(D_{T+L|BB} - \sigma_{T+L|BB}\right)\right) \\ &+ 281\left(X_{Pa|1} + X_{Pa|2} - \left(D_{T+L|Pa} - \sigma_{T+L|Pa}\right)\right) + 300(X_G + G_{T+L}) + 800 * I_{T+L} + 105 \\ &* DBB_{T+L} + 180X_N \leq 10{,}000 - S\end{aligned}$$

Working this out would give an equation in the form of the following form:

$$65X_{BB|1} + 281X_{Pa|1} + 300X_G \leq Z$$

6.2.4 – Different situations

The model discussed in this section is applied to two different situations. The difference between the two situations is that the first situation assumes three operators are working, and the second situation assumes four operators are working. The application of the model to the two outlined situations can be found in Appendix F. The important values derived from the model can be found in Table 6.7. In this table, the outcomes of the last situation discussed in chapter 5 are presented as well to show the increase in throughput compared to working with one machine and two operators. All situations have the same working hours.

	Number of operators working	Number of machines used	Mixed reorder point	Reorder point based on hazardous substances	Weekly throughput blue bins	Weekly throughput pallets	Effective working hours
Situation 2 - Chapter 4	2	1	$\frac{1}{2}X_{BB} + X_{Pa} \leq 29$	4,213.83	32.4	16.2	27
Situation 1	3	2	$\frac{1}{2}X_{BB} + X_{Pa} \leq 46$	5,002.11	53.46	26.73	27
Situation 2	4	2	$\frac{1}{2}X_{BB} + X_{Pa} \leq 56$	4,590.05	64.8	32.4	27

Table 6.7 – Important values – Two Machines & No Shifts

It makes sense that the increase in throughput is equivalent to the increase in throughput factors. So, acquiring an extra machine can double the throughput if the number of operators is also doubled. If A.R.T. decides to work with three operators and two machines, it can increase the throughput with 65%. If A.R.T. decides to work with four operators and two machines, the throughput can be doubled compared to working with two operators and one machine.

The increase in situation 2 compared to situation 1 is

$$\frac{(64.8 - 53.46)}{53.46} * 100\% = 21.21\%$$

The effective working hours are the same in every model. As regards the reorder point based on hazardous substances, something strange happens. Until this moment, when the throughput increased, the reorder point based on the amount of hazardous substance also increased. However, now the reorder point decreases for situation 2 compared to situation 1. This is probably because the model behaves strangely when the throughput during the lead time and review period becomes larger than the delivery size. In that case, a new order should be placed before the previous order has arrived. Therefore, the second part of the model seems unreliable and irrelevant.

In principle, the first part of the model is neither applicable. This is because the stock level at the reorder point, which is the lowest position regarding the amount of hazardous substances, is already so high that it would exceed the maximum amount of hazardous substances. However, if A.R.T. builds a second storage location and the order size increases, the model is usable again.

6.2.5 – Reality

Number of operators

The decision to work with three or four operators seems easy. An increase of 21.21% by only acquiring one extra operator seems to be a large increase. However, only if the costs for acquiring a new operator and paying salary are higher than the profit of getting 21.21% extra throughput, we recommend using three operators. An increase of 21.21% will probably lead to so much higher profit that acquiring a fourth operator is, in that case, highly recommended. However, this decision should be made by A.R.T. since other factors can play a role in this.

Number of Suppliers

When A.R.T. and Supplier A made agreements, Supplier A said to be able to feed at least one machine sufficiently. Doubling the aerosol cans to be delivered per time unit is probably impossible for Supplier A to feed. Therefore, if A.R.T. is going to work with two machines at full speed, A.R.T. has to talk with Supplier A or search for a third supplier.

Ordering

As discussed in section 6.2.4, the second part of the model is not reliable anymore since the throughput during the lead time and review period exceeds the order quantity. The reorder point for this situation should be determined again when more data about working with two machines are available and when an extra storage location is built. Moreover, information is necessary about the extra supplier.

Doubling the order quantity from Supplier A is impossible with the current means. This is because an order includes, as researched in section 4.2, approximately 6,316 kg of hazardous substances. Since the storage location may include no more than 10,000 kg of hazardous substances, receiving two loads simultaneously is impossible. A solution for this could be to build an extra storage location, increasing the maximum amount of hazardous substances to be stored to 20,000 kg. This requires an investment and costs time and effort but makes the logistical process easier. Whether this investment is worth it is up to A.R.T.

6.2.6 – Conclusion

The model developed in this chapter is valid but not applicable without building a second storage location and increasing the order size. This is because the throughput during the lead time and review period is so high that it is much larger than the order quantity causing the model is behaving strangely. However, unless the mixed reorder point for the first part of the model is not applicable, it can be applied in case an extra storage location is built and the order size increases. For the mixed reorder point for situation 1, we can use $\frac{1}{2}X_{BB} + X_{Pa} \leq 46$. For the mixed reorder point for situation 2, $\frac{1}{2}X_{BB} + X_{Pa} \leq 56$ can be used. The second part of the model is not applicable anymore and should be revised in the future.

When working with two machines, the throughput is, based on this research, 21.21% higher when working with four operators compared to working with three operators. Acquiring an extra machine has big consequences. First, the machine requires a large investment but can double the throughput. Moreover, working with two machines needs an increase in the number of products delivered. However, the current supplier can probably not provide this. So, in case of working with an extra machine, an additional supplier is necessary, which should be found. To make it easier to stay below the maximum amount of hazardous substances, building an extra storage location is highly recommended.

6.3 – Two Machine – Shifts

This section considers the ultimate expansion case in which an extra machine is assumed and in which the operators work in shifts. To make comparisons, again, two situations are considered. We assume there are four operators in both situations, but both consider a different division of working hours. Section 6.3.1 describes both situations and discusses the assumptions. Next, section 6.3.2 develops the model. Finally, in section 6.3.3, there is a discussion about the different situations, and it is explained why this model is not worked out.

6.3.1 – Assumptions

This model combines aspects from all previously discussed models. In the previously discussed models, either the operators work with two machines or work in shifts, but not both. In this model, both working in shifts and working with two machines are considered. The operators operate between 7:00 AM and 7:00 PM. Every day, one operator starts working half an hour earlier to start up the process, and one operator ends 15 minutes later to shut down the process.

In both situations, it is assumed that all operators work 36 hours a week, excluding half an hour lunch break per day. The lunch break hours are scheduled but are not part of the 36 hours. For example, if an operator works four days a week, he or she is scheduled for 38 hours (36 + 4 * 0.5).

As in the model discussed in section 6.2, throughput factors are used to determine the throughput with a different number of operators. These throughput factors are the same as in the previous model and can be found in Table 6.6.

For simplicity, in both situations, the lunch breaks are assumed to be taken when all operators are working since this is around lunchtime. In reality, if an operator starts working around lunch, his lunch break could fall outside the timeframe all operators are working. However, for simplicity and consistency, this assumption is necessary.

Situation 1

The first situation to which the model in this section is applied considers there are four operators. They all work four days a week and work nine hours a day. In section 6.1.5, we concluded that the operators like to have a day off in their working week instead of having shorter working days. Therefore, the operators are considered to have each a different day off to maximize utilization. The working hours assumed in this situation can be found in Table 6.8.

	Operator 1	**Operator 2**	**Operator 3**	**Operator 4**
Monday	6:30 AM – 4:00 PM	OFF	7:00 AM – 4:30 PM	9:45 AM – 7:15 PM
Tuesday	6:30 AM – 4:00 PM	9:45 AM – 7:15 PM	7:00 AM – 4:30 PM	9:30 AM – 7:00 PM
Wednesday	6:30 AM – 4:00 PM	9:45 AM – 7:15 PM	7:00 AM – 4:30 PM	OFF
Thursday	6:30 AM – 4:00 PM	9:45 AM – 7:15 PM	OFF	9:30 AM – 7:00 PM
Friday	OFF	9:45 AM – 7:15 PM	6:30 AM – 4:00 PM	9:30 AM – 7:00 PM

Table 6.8 Working hours - One machine & shifts - Situation 1

In Table 6.9, the utilization corresponding to Table 6.8 is shown.

	1 operator	2 operators	3 operators	4 operators
Monday	2 hours and 30 minutes	3 hours and 15 minutes	5 hours and 45 minutes	0 hours
Tuesday	0 hours	5 hours	0 hours and 45 minutes	5 hours and 45 minutes
Wednesday	2 hours and 30 minutes	3 hours and 15 minutes	5 hours and 45 minutes	0 hours
Thursday	2 hours and 30 minutes	3 hours and 15 minutes	5 hours and 45 minutes	0 hours
Friday	2 hours and 30 minutes	3 hours and 15 minutes	5 hours and 45 minutes	0 hours
Total	10 hours	18 hours	23 hours and 45 minutes	5 hours and 45 minutes

Table 6.9 Total working hours - One machine & shifts - Situation 1

Situation 2

In the second situation, again, four operators are assumed to be working. However, in this situation, the operators work five days a week. They all have four working days of seven hours and one working day of eight hours. To maximize utilization, for every operator, the longest working day is on a different day. The working hours corresponding to this situation are shown in Table 6.10

	Operator 1	Operator 2	Operator 3	Operator 4
Monday	6:30 AM – 2:00 PM	10:45 AM – 7:15 PM	7:00 AM – 2:30 PM	11:30 AM – 7:00 PM
Tuesday	6:30 AM – 2:00 PM	11:45 AM – 7:15 PM	7:00 AM – 2:30 PM	11:30 AM – 7:00 PM
Wednesday	6:30 AM – 2:00 PM	11:45 AM – 7:15 PM	7:00 AM – 2:30 PM	10:30 AM – 7:00 PM
Thursday	6:30 AM – 2:00 PM	11:45 AM – 7:15 PM	7:00 AM – 3:30 PM	11:30 AM – 7:00 PM
Friday	6:30 AM – 3:00 PM	11:45 AM – 7:15 PM	7:00 AM – 2:30 PM	11:30 AM – 7:00 PM

Table 6.10 Working hours - One machine & shifts - Situation 2

Table 6.11 shows the utilization corresponding to Table 6.10.

	1 operator	2 operators	3 operators	4 operators
Monday	0 hours	8 hours and 15 minutes	1 hour and 15 minutes	2 hours
Tuesday	0 hours	9 hours	45 minutes	1 hour and 45 minutes
Wednesday	0 hours	8 hours	1 hour and 45 minutes	1 hour and 45 minutes
Thursday	0 hours	8 hours	1 hour and 45 minutes	1 hour and 45 mintues
Friday	0 hours	8 hours and 30 minutes	45 minutes	2 hours and 15 minutes
Total	0 hours	41 hours and 45 minutes	6 hours and 15 minutes	9 hours and 30 minutes

Table 6.11 Total working hours - One machine & shifts - Situation 2

6.3.2 – The model

In this section, the model is developed built on the model developed in chapter 5. Since this model is more complex than the model in chapter 5, some additional parameters are necessary. The additional parameters are:

- Y_i: Scheduled working hours if i operators are working excluding breaks (i = 1, 2, 3, 4)
- T_i: Throughput factor in case i operators are working (i = 1, 2, 3, 4)

As in the previous models, half of the processing time is assigned to blue bins, and half of the processing time is assigned to pallets. Subsequently,

$$W = W_{BB} + W_{Pa}$$

$$D_{BB} + 2 * D_{Pa}$$

For calculating the effective working minutes corresponding to the number of operators working on what part of the day, the working hours should be evaluated to the number of effective working minutes assumed in chapter 5. So,

$$W_i = \frac{Y_i}{(9 - 0.5)} * 360$$

The total daily effective working minutes can be calculated using

$$W = \sum_{i=1}^{4} W_i$$

The throughput differs during the day since the number of operators working is not constant in this model. Therefore, the earlier derived throughput factors are necessary for this. This gives the following throughputs.

$$D_{BB|i} = T_i * \frac{W_{BB}}{25} = 2 * D_{Pa|i}$$

The daily throughput can be calculated by adding the throughputs over the day. This can be calculated by using the following equation:

$$D_{BB} = \sum_{i=1}^{4} D_{BB|i}$$

The variances and standard deviations are derived from chapter 5. However, the throughput factor should now be considered since throughput is not constant. Therefore, the variances and standard deviations differ over the day. The variance and standard deviations can be derived using

$$Var(W_i) = (\frac{Y_i}{(9 - 0.5)})^2 * (T_i)^2 * 45^2$$

$$Var(W_i) = Var\left(W_{BB|i} + W_{Pa|i}\right) = Var\left(2 * W_{BB|i}\right) = 4 * Var(W_{BB|i})$$

$$Var\left(W_{BB|i}\right) = Var\left(W_{Pa|i}\right) = \frac{Var(W_i)}{4} = \frac{\sigma_{W|i}^2}{4}$$

$$\sigma_{W|BB|i} = \sigma_{W|Pa|i} = \sqrt{Var(W_{BB|i})}$$

The standard deviations of the throughput can be derived from the standard deviations of the processing time. For this, again, the throughput factor is important. This gives

$$\sigma_{D|BB|i} = \frac{\sigma_{W|BB|i}}{25} * \sqrt{T_i}$$

$$\sigma_{D|Pa|i} = \frac{\sigma_{W|Pa|i}}{50} * \sqrt{T_i}$$

Independence between processing with a different number of operators is assumed. With that assumption, the standard deviation of the daily throughput can be derived by:

$$\sigma_{D|BB} = \sqrt{\sum_{i=1}^{4} (\sigma_{D|BB|i})}$$

$$\sigma_{D|Pa} = \sqrt{\sum_{i=1}^{4} (\sigma_{D|Pa|i})^2}$$

The formula for determining the variances for the throughput during the lead time and review period is the same as in the other models. So,

$$Var(D|T+L|BB) = (T+L) * \frac{\sigma_{D|BB|M}^2 + \sigma_{D|BB|Tu}^2 + \sigma_{D|BB|W}^2 + \sigma_{D|BB|Th}^2 + \sigma_{D|BB|F}^2}{5}$$

$$Var(D|T+L|Pa) = (T+L) * \frac{\sigma_{D|Pa|M}^2 + \sigma_{D|Pa|Tu}^2 + \sigma_{D|Pa|W}^2 + \sigma_{D|Pa|Th}^2 + \sigma_{D|Pa|F}^2}{5}$$

The standard deviations corresponding to this can be derived using

$$\sigma_{D|T+L|BB} = \sqrt{Var(D|T+L|BB)} = 2 * \sigma_{D|T+L|Pa}$$

In this model, the lead time and review period are three and one days, respectively. For calculating the throughput during the lead time and review period, the same equation is used as in the previous models:

$$D_{T+L|BB} = (T+L) * \left(\frac{D_{BB|M} + D_{BB|Tu} + D_{BB|W} + D_{BB|Th} + D_{BB|F}}{5}\right) = 2 * D_{T+L|Pa}$$

The CSL is again 0.95. The safety stock can be determined using

$$ss_{BB} = F_S^{-1}(CSL) * \sigma_{D|T+L|BB} = NORMSINV(CSL) * \sigma_{D|T+L|BB} = 2 * ss_{Pa}$$

The equation for determining the separate reorder points remains the same as well. So,

$$ROP_{BB} = D_{T+L|BB} + ss_{BB} = 2 * ROP_{Pa}$$

An order should be placed if the equation for the mixed reorder point holds:

$$\frac{1}{2} X_{BB} + X_{Pa} \leq ROP_{BB}$$

Since by the model discussed in section 6.2 it appears that the second part of the model is not reliable and relevant anymore, we leave it out in this model.

6.3.3 – Different situations and conclusions

In section 6.2.4, we concluded that the second part of the model is not relevant and reliable in case A.R.T. works with two machines. Moreover, the first part is not easy to apply for the situations two machines are used. This is because, in these situations, a throughput during the lead time and review period is higher than the order size. For that reason, in this situation, it is not worth the effort to apply the model to the outlined situations. However, if A.R.T. decides to build an extra storage location, the first part of the model can be applicable if more batches can be ordered. Therefore, first part of the model is included in this thesis to be used in future work.

The daily throughput for both situations can be found in Appendix G. This is derived using the throughput equation discussed in section 6.2.3. The total throughput for both situations is shown in Table 6.12.

	Situation 1	**Situation 2**
$\boldsymbol{D_{BB}}$ **(Total)**	127.63	120.36
$\boldsymbol{D_{Pa}}$ **(Total)**	63.82	60.19

Table 6.12 - Total throughput - Two machines & shifts

$$\frac{127.63 - 120.36}{120.36} * 100\% = 6.04\%$$

We can conclude that the throughput in the first situation is 6.04% higher than the throughput in the second situation. So it turns out that giving each operator a day off is the best option. Since operators like to have an extra day off, situation 1 only has advantages compared to situation 2.

The shifts composed in the two discussed situations are not the only possible combinations of shifts. A.R.T. can use these examples to find other combinations of shifts. Moreover, if some operators have no favor for having a day off, A.R.T. can use this model to calculate the throughput for that specific scenario. A.R.T. can decide to acquire an extra (part-time) operator who can work at, for example, the days that one of the operators has a day off. We recommend A.R.T. to take a look at this since it can increase the throughput a lot.

7 – Conclusions and recommendations

In this final chapter, in section 7.1, conclusions of the research goal are formed. Then, in section 7.2, recommendations for A.R.T. based on this research are described. Finally, section 7.3 describes possible future research A.R.T. can do if things change in the company.

7.1 – Conclusions

This section forms conclusions of the research goal. The research goal was to design the logistical processes, including the storage location and the order policy, to increase throughput after implementing these designs. The related research question is: "What designs for the logistical processes to implement to increase machine throughput and prevent stockouts?" We first designed the storage location, followed by the order policy. An additional research goal was to consider what happens with the logistical processes and throughput in expansion cases.

Storage location

For the layout of the storage location, five design alternatives have been designed based on observations, the literature review, and common sense. Then, based on the important criteria, these design alternatives are assessed and compared. After that, the highest-rated design alternative is selected.

The design alternative with the highest score uses a system of storing products in lanes. First, it stores blue bins starting in lane 1. Then, it stores blue bins in lane 2 until all blue bins are stored. If all blue bins are stored, the first pallet should be stored in front of the last stored blue bin. Then, the pallets continue to be stored in the next lanes until all pallets are stored. Finally, the blue bins with disapproved aerosol cans should be stored in front of the last stored pallet or in an empty lane.

Processing should be done in reverse order. So, first, the products in lane 5 should be processed. This should be done to create movement space and to make the drip trays in the backside of lanes 4 and 5 accessible. This design alternative has no lost space since the products are stored immediately in front of each other without leaving space between two filled lanes. Moreover, blue bins and pallets are always accessible in this design.

Implementing this design does not require considerable effort since it is just a method the operators must work according to. Of course, they may need some time to become familiar with it, but after using it for a couple of days, we expect no problems.

ROP Model – Current situation

The ROP model developed in this research includes two parts. The first part of the model determines a mixed reorder point based on the number of blue bins and pallets in the storage location. This is determined so that the chance is sufficiently large that the process is not running out of stock. If the mixed reorder point is not triggered, no order should be placed, and the model should be used again at the beginning of the next day. If the mixed reorder point is triggered, the second part of the should be considered.

In the second part of the model, a check is done on whether placing an order results in the amount of hazardous substances staying below 10,000 kg. If, based on the second part of the model, we can conclude that the amount of hazardous substances stay below 10,000 kg, a new order can be placed. On the other hand, if the outcome of the second part of the model is that the amount of hazardous substances will end up higher than 10,000 kg after delivery, no order can be placed. Placing an order is considered at the beginning of each day.

The developed model is applied to three situations represented in Table 7.1. First, the model is applied to the current situation. Next, it is applied to a more optimistic situation, situation 1. Finally, the model is applied to the most optimistic situation, situation 2. Situation 2 is a situation we assume to be feasible in the future, so, therefore, it is considered. This situation is assumed to become a steady future state. For these situations, a mixed reorder point is derived based on the first part of the model, and a reorder point based on the hazardous substances is derived using the second part of the model.

	Mean effective working minutes	**Standard deviation**	**Mixed reorder point**	**Reorder point based on hazardous substances**	**Weekly throughput blue bins**	**Weekly throughput pallets**
Current situation	200	89.31	$\frac{1}{2}X_{BB} + X_{Pa} \leq 20$	3,263.05	18	9
Situation 1	280	65	$\frac{1}{2}X_{BB} + X_{Pa} \leq 24$	3,765.88	25.2	12.6
Situation 2	360	45	$\frac{1}{2}X_{BB} + X_{Pa} \leq 29$	4,213.83	32.4	16.2

Table 7.1 – Important values – Current situation

Based on the daily throughput, A.R.T. can determine where in between these situations it is located. Based on that, A.R.T. can estimate the mixed reorder point and the reorder point based on hazardous substances corresponding to the state it is located.

Currently, A.R.T. should use the $\frac{1}{2}X_{BB} + X_{Pa} \leq 20$ as mixed reorder point and 3,263.05 kg as reorder point based on hazardous substances. However, in the future steady state, A.R.T. should use $\frac{1}{2}X_{BB} + X_{Pa} \leq 29$ as mixed reorder point with a corresponding reorder point based on hazardous substances of 4,213.83 kg.

Expansion – One machine & Shifts

The earlier developed ROP model is adapted and extended for the case in which we assume operators work in shifts and work with one machine. This model is applied to two different situations. First, situation 1, in which the operators work nine hours per day and four days a week. Then, situation 2, in which the operators work seven or eight hours per day and five days a week. In both situations, the operators work the same number of hours per week. Since these are future situations, these situations probably occur when the optimistic situation regarding the working speed is reached. Therefore, the parameters are derived from the optimistic situation discussed in the previous section. The outcomes of the application to the different situations are shown in Table 7.2.

	Mixed reorder point	**Reorder point based on hazardous substances**	**Weekly throughput blue bins**	**Weekly throughput pallets**
Situation 1	$\frac{1}{2}X_{BB} + X_{Pa} \leq 30$	4,418.73	35.27	17.62
Situation 2	$\frac{1}{2}X_{BB} + X_{Pa} \leq 32$	4,595.9	36.9	18.45

Table 7.2 – Important values – One machine & Shifts

Situation 2 generates 4.62% more throughput. However, situation 1 is probably more favorable for the operators since it gives them an extra day off. So, in this situation, there is a trade-off between having a little higher throughput and the well-being of the operators.

The mixed reorder point for situation 1 is $\frac{1}{2}X_{BB} + X_{Pa} \leq 30$, with a corresponding reorder point based on the amount of hazardous substances of 4,418.73. The mixed reorder point for situation 2 is $\frac{1}{2}X_{BB} + X_{Pa} \leq 32$. For the second part of the model, the reorder point based on the amount of hazardous substances is 4,595.9 for situation 2.

Expansion – Two machines & No shifts

For this case of expansion, an extra machine will be acquired. In the model applied to this situation, we assume that the operators do not work in shifts and are always working together. The model has been applied to two situations. Situation 1, in which we assume three operators are working together, and situation 2, in which we assume four operators are working together. Again, since this is a future situation, it is compared to the optimistic situation of the model applied to the current state.

	Number of operators working	Number of machines used	Mixed reorder point	Reorder point based on hazardous substances	Weekly throughput blue bins	Weekly throughput pallets
Situation 2 - Chapter 4	2	1	$\frac{1}{2}X_{BB} + X_{Pa} \leq 29$	4,213.83	32.4	16.2
Situation 1	3	2	$\frac{1}{2}X_{BB} + X_{Pa} \leq 46$	5,002.11	53.46	26.73
Situation 2	4	2	$\frac{1}{2}X_{BB} + X_{Pa} \leq 56$	4,590.05	64.8	32.4

Table 7.3 – Two machines & No shifts

Working with four operators increases the throughput by 21.21% compared to working with three operators. This is a significant difference, and since this probably yields more than it costs, working with four operators is probably the best choice.

Using a second machine has significant consequences for applying the model. It appears to be the case that the current model is not able to handle situations using a second machine. The outcomes for the first part of the model give mixed reorder points of 46 and 56. Since these correspond to a higher number of products than one delivery includes, according to the model, a new order should be placed before the previous one has arrived. Since the number of products corresponding to the reorder points cannot even be reached with the current capacity, this first part of the model would always recommend placing an order. The second part of the model can neither handle a second machine since this is based on the current number of products in the storage location and does not take into account products that are not yet arrived.

To use this model in case of using two machines, an extra storage location should be built to increase the maximum amount of hazardous substances present at the company site. Building an extra storage location requires an investment but would make storage and ordering less complicated. This will probably cause fewer stockouts. Moreover, building an additional storage location makes it possible to order multiple loads to feed the machine during the lead time and review period. However, it is not yet discussed whether Supplier A can feed two machines. So, finding a new supplier should be considered in this case.

Expansion – Two machine & Shifts

For this expansion case, we assume A.R.T. also works with two machines. However, the model designed for this case considers that the operators work in shifts. In this expansion case, again, two situations are considered: situation 1, where all operators have one day off, and situation 2, where all operators work five days. Since the conclusion about the previously discussed model is that with the current resources, the model cannot be applied to working with two machines, effort is saved by not working this model out. However, the throughputs are calculated for both situations, as shown in Table 7.4. Giving all operators a day off and letting them make longer working days seems to give 6.04% higher throughput than if the operators work five days.

	Situation 1	**Situation 2**
$\boldsymbol{D_{BB}}$ **(Total)**	127.63	120.36
$\boldsymbol{D_{Pa}}$ **(Total)**	63.82	60.19

Table 7.4 - Total throughput - Two machines & Shifts

A.R.T. can decide to change the shifts. The considered situations can be used as a basis for getting an indication. Moreover, A.R.T. can decide to acquire an extra operator to increase throughput. This can be a full-timer, but it could also be a part-timer. This probably increases the throughput a lot.

7.2 – Recommendations

Based on this research, some recommendations can be made. In this section, the recommendations are given for every part of the research separately.

Storage location

As regards the storage location, we recommend A.R.T. to implement the design alternative with the highest score, as discussed in the conclusion section. In this design, the products should be stored from lane 1 to lane 5 and processed from lane 5 to lane 1. In short, first, the blue bins should be stored starting in lane 1. After that, the pallets should be stored in front of the last stored blue bin. Finally, the disapproved aerosol cans should be stored in front of the last stored pallet or in an empty lane.

This design is easy to work with for the operators and gives clarity. To implement this design, the operators need to become familiar with the design by explaining them and by practicing. After a couple of days, they are probably used to work with it since the design is not that difficult to understand.

ROP Model – Current situation

For the current situation, we recommend A.R.T. to check the weekly throughput regularly and try to find the state in between which situations A.R.T. is located. Then, the mixed reorder point, and the reorder point based on the amount of hazardous substances can be derived based on the considered situations shown in Table 7.1. For now, we recommend A.R.T. to use $\frac{1}{2}X_{BB} + X_{Pa} \leq 20$ as the mixed reorder point equation. Corresponding to that, we recommend using 3,263.05 kg as reorder point based on the amount of hazardous substances.

Expansion – One machine & Shifts

In case of working with one machine and two operators working in shifts, we recommend A.R.T. to give the operators both one day off and let them work 36 hours in four days. During the days that both operators are working, we recommend maximizing the hours the machine processes. So, we recommend letting the operators work between 6:30 AM and 7:15 PM.

To decide when to place an order, we recommend using the situations this model is applied to, shown in Table 7.2. If it tends to be the case that throughput differs, A.R.T. can change the reorder point based on common sense or changing the parameters in the model.

Expansion – Two machine & No shifts

If the current process with one machine is profitable, we recommend purchasing an extra machine. Purchasing an extra machine doubles the throughput, so it doubles the revenue when the same working hours are assumed, and the number of operators is doubled.

Moreover, in case two machines are used and the operators do not work in shifts, we recommend A.R.T. to work with at least four operators.

Furthermore, we recommend building an extra storage location in case an extra machine is used. This requires an investment but makes storing and ordering less complicated, and the maximum amount of hazardous substances on the company site is doubled.

In case a second machine is used, we recommend thinking about changing the order quantity. Either Supplier A should become able to deliver multiple loads, or an extra supplier should be considered. This is because, otherwise, a new load has to be ordered too often, which makes ordering more complicated and makes the models developed in this research no longer usable.

Expansion – Two machine & Shifts

In case two machines are used and the operators work in shifts, we recommend A.R.T. to work with four operators. We recommend giving all operators one day off and letting them work 36 hours in four days. Additionally, a fifth operator can be acquired, who could be a part-time or a full-time operator. This operator should work when one or two operators are working.

Moreover, we recommend applying the model developed to different situations considering this expansion case. However, some parameters regarding order quantities and storage location capacity should be changed based on future research and decisions.

7.3 – Future Research

Since this research is about a new process, much future research can still be done. For example, the developed models and situations can be revised based on more observations and data. This can be done over a more extended period than in this research.

In the case of using a second machine, possible future research directions are given below:

- Researching whether an extra storage location is possible to build. In this research, corresponding licensing requirements and investments should be considered.
- Researching what storage location will look like and new storage location designs can be created. This thesis can be used as a basis for this.
- Research can be done on the suppliers. For example, the possibility of increasing the order quantity can be researched in this research. Moreover, a new supplier can be considered in this from which the content of deliveries probably differs a lot compared to the content of Supplier A's delivery.
- The research done in this thesis can be expanded and revised in the future if more information is known about how the process is going to look like if there is an extra machine.

If using two machines seems to be a big success, it can be researched whether increasing the number of machines even more is an option and whether becoming a large-scale waste processor is achievable. However, currently, this is not the goal of A.R.T., so this should not be considered soon.

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Appendices

Appendix A – Design Science Research Methodology (DSRM)

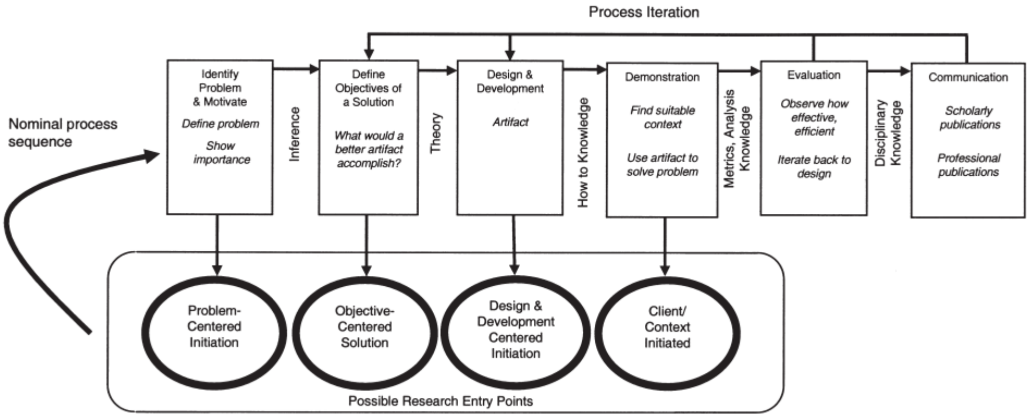

Figure A.1 - Design Science Research Methodology (DSRM)

Appendix B – Performed daily observations

- Number of operators
- Number of effective working hours
- Number of hours the process is not running
- Number of full blue bins
- Number of blue bins with disapproved cans
- Number of blue bins with carton waste
- Number of blue bins with plastic waste
- Number of full pallets
- Full gas tanks
- Full IBCs
- Empty IBCs
- Weight of the dispatched metal
- Number of IBCs dispatched
- Number of empty blue bins dispatched
- Number of blue bins with disapproved aerosol cans dispatched
- Number of blue bins with plastic dispatched
- Number of blue bins with cardboard dispatched.

Appendix C – SPSS input & Descriptive statistics - Pallets and blue bins

Pallets

NetWeightPallets
334,50
340,50
331,50
318,50
542,00
354,50
483,00
365,00
353,50
338,00
327,00
327,00
342,00
344,00
380,50
307,50

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
NetWeightPallets	16	100,0%	0	0,0%	16	100,0%

Descriptives

			Statistic	Std. Error
NetWeightPallets	Mean		361,8125	15,58330
	95% Confidence Interval for Mean	Lower Bound	328,5975	
		Upper Bound	395,0275	
	5% Trimmed Mean		354,8194	
	Median		341,2500	
	Variance		3885,429	
	Std. Deviation		62,33321	
	Minimum		307,50	
	Maximum		542,00	
	Range		234,50	
	Interquartile Range		34,25	
	Skewness		2,273	,564
	Kurtosis		4,787	1,091

Figure C.1 – Descriptive statistics - Pallets

Blue bins

NettoweightBlueBins
100.50
128.50
51.00
116.00
102.50
95.00
120.00
117.50
123.00
101.00
118.50
117.00
113.00
121.50
84.50
123.50
72.50
120.50
121.00
128.00
121.00
125.50
126.00
107.00
126.00

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
NettoweightBlueBins	25	100.0%	0	0.0%	25	100.0%

Descriptives

			Statistic	Std. Error
NettoweightBlueBins	Mean		111.2200	3.77239
	95% Confidence Interval for Mean	Lower Bound	103.4342	
		Upper Bound	119.0058	
	5% Trimmed Mean		113.3722	
	Median		118.5000	
	Variance		355.773	
	Std. Deviation		18.86193	
	Minimum		51.00	
	Maximum		128.50	
	Range		77.50	
	Interquartile Range		21.50	
	Skewness		-1.854	.464
	Kurtosis		3.522	.902

Figure C.2 – Descriptive statistics – Blue bins

Appendix D - Chapter 4 Model

General

Processing time

	Current situation	Situation 1	Situation 2
$W_{MTuWeTh}$	200	280	360
$W_{BB\|MTuWeTh} = W_{Pa\|MTuWeTh}$	100	140	180
W_F	100	140	180
$W_{BB\|F} = W_{Pa\|F}$	50	70	90
$Var(W_{MTuWeTh})$	7,976.28	4,225	2,025
$Var(W_{BB\|MTuWeTh}) = Var(W_{Pa\|MTuWeTh})$	1,994.07	1,056.25	506.25
$Var(W_F)$	1,994.07	1,056.25	506.25
$Var(W_{BB\|F}) = Var(W_{Pa\|F})$	498.52	264.06	126.56
$\sigma_{W\|MTuWeTh}$	89.31	65	45
$\sigma_{W\|BB\|MTuWeTh} = \sigma_{W\|Pa\|MTuWeTh}$	44.65	32.5	22.5
$\sigma_{W\|F}$	44.65	32.5	22.5
$\sigma_{W\|BB\|F} = \sigma_{W\|Pa\|F}$	22.33	16.25	11.25

Mean throughput

	Current situation	Situation 1	Situation 2
$D_{BB\|MTuWeTh}$	4	5.6	7.2
$D_{BB\|F}$	2	2.8	3.6
$D_{Pa\|MTuWeTh}$	2	2.8	3.6
$D_{Pa\|F}$	1	1.4	1.8
D_{BB}(Total)	18	25.2	32.4
D_{Pa}(Total))	9	12.6	16.2

Standard deviation throughput

	Current situation	Situation 1	Situation 2
$\sigma_{D\|BB\|MTuWeTh}$	1.79	1.30	0.90
$\sigma_{D\|BB\|F}$	0.89	0.65	0.45
$\sigma_{D\|Pa\|MTuWeTh}$	0.89	0.65	0.45
$\sigma_{D\|Pa\|F}$	0.45	0.33	0.23

Current situation – Part 1

$\boldsymbol{Var(D\|T+L\|BB)}$	$(1+3)*\frac{1.79^2+1.79^2+1.79^2+1.79^2+0.89^2}{5}=10.85$
$\boldsymbol{\sigma_{D\|T+L\|BB}}$	$\sqrt{10.85}=3.29$
$\boldsymbol{Var(D\|T+L\|Pa)}$	$(1+3)*\frac{0.89^2+0.89^2+0.89^2+0.89^2+0.45^2}{5}=2.71$
$\boldsymbol{\sigma_{D\|T+L\|Pa}}$	$\sqrt{2.71}=1.65$
$\boldsymbol{D_{T+L\|BB}}$	$(1+3)*\left(\frac{4+4+4+4+2}{5}\right)=14.4$
$\boldsymbol{D_{T+L\|Pa}}$	$(1+3)*\left(\frac{2+2+2+2+1}{5}\right)=7.2$
$\boldsymbol{ss_{BB}}$	$F_S^{-1}(0.95)*3.29=1.645*3.29=5.42$
$\boldsymbol{ss_{Pa}}$	$F_S^{-1}(0.95)*2.77=1.645*1.65=2.71$
$\boldsymbol{ROP_{BB}}$	$14.4+5.42=19.82$
$\boldsymbol{ROP_{Pa}}$	$7.2+2.71=9.91$
Mixed ROP	$\frac{1}{2}X_1+X_2\leq 20$

Current situation – part 2

$\boldsymbol{D_{T+L\|BB}-\sigma_{D\|T+L\|BB}}$	$14.4-3.29=11.11$
$\boldsymbol{D_{T+L\|Pa}-\sigma_{D\|T+L\|Pa}}$	$7.2-1.65=5.55$
$\boldsymbol{G_{T+L}}$	$\frac{\frac{125}{5}*(1+3)}{300}=\frac{1}{3}$
$\boldsymbol{I_{T+L}}$	$\frac{(1+3)*200}{310}=2.6$
$\boldsymbol{DBB_{T+L}}$	$(1+3)*\frac{1}{10}=0.4$

$$\text{Predicted amount of haz. sub. at moment of delivery} = 65\left(X_{BB|1}+X_{BB|2}-\left(D_{T+L|BB}-\sigma_{T+L|BB}\right)\right) + 281\left(X_{Pa|1}+X_{Pa|2}-\left(D_{T+L|Pa}-\sigma_{T+L|Pa}\right)\right)+300(X_G+G_{T+L})+800I_{T+L} + 105DBB_{T+L}+180X_N\leq 10{,}000\ -\ S$$

Filling in the discussed variables and parameters corresponding to this situation, it would result in

$$Amount\ of\ haz.sub.at\ moment\ of\ delivery = 65\left(X_{BB|1}+28-11.11\right)+281\left(X_{Pa|1}+16-5.55\right)+300(X_G+\frac{1}{3})+800*2.6 + 105*0.4+180*1 = 65X_{BB|1}+1{,}097.85+281X_{Pa|1}+2{,}936.45+300X_G+100+2{,}080+42+180 = 65X_{BB|1}+281X_{Pa|1}+300X_G+6{,}436.95\leq 9{,}700$$

Arranging this gives

$$65X_{BB|1}+281X_{Pa|1}+300X_G\leq 3{,}263.05$$

Situation 1 – part 1

$\boldsymbol{Var(D\|T+L\|BB)}$	$(1+3)*\frac{1.30^2+1.30^2+1.30^2+1.30^2+0.65^2}{5}=5.75$
$\boldsymbol{\sigma_{D\|T+L\|BB}}$	$\sqrt{5.75}=2.40$
$\boldsymbol{Var(D\|T+L\|Pa)}$	$(1+3)*\frac{0.65^2+0.65^2+0.65^2+0.65^2+0.33^2}{5}=1.44$
$\boldsymbol{\sigma_{D\|T+L\|Pa}}$	$\sqrt{1.44}=1.20$
$\boldsymbol{D_{T+L\|BB}}$	$(1+3)*\left(\frac{5.6+5.6+5.6+5.6+2.8}{5}\right)=20.16$
$\boldsymbol{D_{T+L\|Pa}}$	$(1+3)*\left(\frac{2.8+2.8+2.8+2.8+1.4}{5}\right)=10.08$
$\boldsymbol{ss_{BB}}$	$F_S^{-1}(0.95)*2.40=1.645*2.40=3.94$
$\boldsymbol{ss_{Pa}}$	$F_S^{-1}(0.95)*1.20=1.645*2.02=1.97$
$\boldsymbol{ROP_{BB}}$	$20.16+3.94=24.1$
$\boldsymbol{ROP_{Pa}}$	$10.08+1.97=12.05$
Mixed ROP	$\frac{1}{2}X_{BB}+X_{Pa}\leq 24$

Situation 1 – Part 2

$\boldsymbol{D_{T+L\|BB}-\sigma_{D\|T+L\|BB}}$	$20.16-2.40=17.76$
$\boldsymbol{D_{T+L\|Pa}-\sigma_{D\|T+L\|Pa}}$	$10.08-1.20=8.88$
$\boldsymbol{G_{T+L}}$	$\frac{\frac{125}{5}*(1+3)*1.4}{300}=0.47$
$\boldsymbol{I_{T+L}}$	$\frac{(1+3)*280}{310}=3.61$
$\boldsymbol{DBB_{T+L}}$	$(1+3)*\frac{1}{10}*1.4=0.56$

$$\begin{aligned}&\text{Predicted amount of haz. sub. at moment of delivery}\\&\quad=65\left(X_{BB|1}+X_{BB|2}-\left(D_{T+L|BB}-\sigma_{T+L|BB}\right)\right)\\&\quad+281\left(X_{Pa|1}+X_{Pa|2}-\left(D_{T+L|Pa}-\sigma_{T+L|Pa}\right)\right)+300(X_G+G_{T+L})+800I_{T+L}\\&\quad+105DBB_{T+L}+180X_N\leq 10{,}000\ -\ S\end{aligned}$$

Filling in the discussed variables and parameters corresponding to this situation, it would result in

$$\begin{aligned}&Amount\ of\ haz.sub.at\ moment\ of\ delivery\\&\quad=65\left(X_{BB|1}+28-17.76\right)+281\left(X_{Pa|1}+16-8.88\right)+300(X_G+0.47)+800\\&\quad*3.61+105*0.56)+180*1\\&\quad=65X_{BB|1}+665.6+281X_{Pa|1}+2{,}000.72+300X_G+141+2{,}888+58.8+180\\&\quad=65X_{BB|1}+281X_{Pa|1}+300X_G+5{,}934.12\leq 9{,}700\end{aligned}$$

Arranging this gives

$$65X_{BB|1}+281X_{Pa|1}+300X_G\leq 3{,}765.88$$

Situation 2 – Part 1

$\boldsymbol{Var(D\|T+L\|BB)}$	$(1+3)*\frac{0.90^2+0.90^2+0.90^2+0.90^2+0.45^2}{5}=2.75$
$\boldsymbol{\sigma_{D\|T+L\|BB}}$	$\sqrt{2.754}=1.66$
$\boldsymbol{Var(D\|T+L\|Pa)}$	$(1+3)*\frac{0.45^2+0.45^2+0.45^2+0.45^2+0.23^2}{5}=0.69$
$\boldsymbol{\sigma_{D\|T+L\|Pa}}$	$\sqrt{0.69}=0.83$
$\boldsymbol{D_{T+L\|BB}}$	$(1+3)*\left(\frac{7.2+7.2+7.2+7.2+3.6}{5}\right)=25.92$
$\boldsymbol{D_{T+L\|Pa}}$	$(1+3)*\left(\frac{3.6+3.6+3.6+3.6+1.8}{5}\right)=12.96$
$\boldsymbol{ss_{BB}}$	$F_S^{-1}(0.95)*1.66=1.645*1.66=2.73$
$\boldsymbol{ss_{Pa}}$	$F_S^{-1}(0.95)*0.83=1.645*0.83=1.37$
$\boldsymbol{ROP_{BB}}$	$25.92+2.73=28.65$
$\boldsymbol{ROP_{Pa}}$	$12.96+1.37=14.33$
Mixed ROP	$\frac{1}{2}X_{BB}+X_{Pa}\leq 29$
Weekly throughput blue bins	$7.2+7.2+7.2+7.2+3.6=32.4$
Weekly throughput pallets	$3.6+3.6+3.6+3.6+1.8=16.2$

Situation 2 – Part 2

$\boldsymbol{D_{T+L\|BB}-\sigma_{D\|T+L\|BB}}$	$25.92-1.66=24.26$
$\boldsymbol{D_{T+L\|Pa}-\sigma_{D\|T+L\|Pa}}$	$12.96-0.83=12.13$
$\boldsymbol{G_{T+L}}$	$\frac{\frac{125}{5}*(1+3)*1.8}{300}=0.6$
$\boldsymbol{I_{T+L}}$	$\frac{(1+3)*360}{310}=4.65$
$\boldsymbol{DBB_{T+L}}$	$(1+3)*\frac{1}{10}*1.8=0.72$

$$\begin{aligned}&\text{Predicted amount of haz. sub. at moment of delivery}\\&=65\left(X_{BB|1}+X_{BB|2}-\left(D_{T+L|BB}-\sigma_{T+L|BB}\right)\right)\\&+281\left(X_{Pa|1}+X_{Pa|2}-\left(D_{T+L|Pa}-\sigma_{T+L|Pa}\right)\right)+300(X_G+G_{T+L})+800I_{T+L}\\&+105DBB_{T+L}+180X_N\leq 10{,}000\ -\ S\end{aligned}$$

Filling in the discussed variables and parameters corresponding to this situation, it would result in

$$\begin{aligned}&\text{Amount of haz. sub. at moment of delivery}\\&=65\left(X_{BB|1}+28-24.26\right)+281\left(X_{Pa|1}+16-12.13\right)+300(X_G+0.6)+800\\&*4.65+105*0.72+180*1\\&=65X_{BB|1}+243.1+281X_{Pa|1}+1{,}087.47+300X_G+180+3{,}720+75.6+180\\&=65X_{BB|1}+281X_{Pa|1}+300X_G+5{,}486.17\leq 9{,}700\end{aligned}$$

Arranging this gives

$$65X_{BB|1}+281X_{Pa|1}+300X_G\leq 4{,}213.83$$

Appendix E - Section 5.1 Model

Effective working minutes

	Situation 1	**Situation 2**
$\boldsymbol{W_{MF\|1}}$	$\frac{9}{(9-0.5)} * 360 \approx 381$	$\frac{9.5}{(9-0.5)} * 360 \approx 402$
$\boldsymbol{W_{BB\|MF\|1}} = \boldsymbol{W_{Pa\|MF\|1}}$	$\frac{W_{MF\|1}}{2} = \frac{381}{2} \approx 191$	$\frac{W_{MF\|1}}{2} = \frac{402}{2} \approx 201$
$\boldsymbol{W_{MF\|2}}$	0	$\frac{2.75}{(9-0.5)} * 360 \approx 116$
$\boldsymbol{W_{BB\|MF\|2}} = \boldsymbol{W_{Pa\|MF\|2}}$	0	$\frac{W_{MF\|1}}{2} = \frac{116}{2} \approx 58$
$\boldsymbol{W_{TuWeTh\|1}}$	$\frac{6.5}{(9-0.5)} * 360 \approx 275$	$\frac{10.5}{(9-0.5)} * 360 = 445$
$\boldsymbol{W_{BB\|TuWeTh\|1}} = \boldsymbol{W_{Pa\|TuWeTh\|1}}$	$\frac{W_{TuWTh\|1}}{2} = \frac{275}{2} \approx 138$	$\frac{W_{TuWTh\|1}}{2} \approx 222$
$\boldsymbol{W_{TuWeTh\|2}}$	$\frac{5.75}{(9-0.5)} * 360 \approx 244$	$\frac{1.75}{(9-0.5)} * 360 \approx 74$
$\boldsymbol{W_{BB\|TuWeTh\|2}} = \boldsymbol{W_{Pa\|TuWeTh\|2}}$	$\frac{W_{TuWTh\|2}}{2} \approx 122$	$\frac{W_{TuWTh\|2}}{2} \approx 37$
Total weekly effective working minutes	$381 + 519 + 519 + 519 + 381 = 2{,}319$	$518 + 519 + 519 + 519 + 518 = 2{,}593$
Total weekly effective working hours	$\frac{2{,}319}{60} = 38.65$	$\frac{2{,}593}{60} = 43.22$

Variances Processing time

$\boldsymbol{Var(W_{MF\|1})}$	$(\frac{9}{(9-0.5)})^2 * 0.65^2 * 45^2 = 959.18$	$(\frac{9.5}{(9-0.5)})^2 * 0.65^2 * 45^2 = 1{,}068.71$
$\boldsymbol{Var(W_{BB\|MF\|1})} = \boldsymbol{Var(W_{Pa\|MF\|2})}$	$\frac{Var(W_{MF\|1})}{4} = \frac{959.18}{4} = 239.79$	$\frac{\boldsymbol{Var(W_{MF\|1})}}{4} = \frac{1{,}068.71}{4} = 267.18$
$\boldsymbol{Var(W_{MF\|2})}$	0	$(\frac{2.75}{(9-0.5)})^2 * 45^2 = 211.96$
$\boldsymbol{Var(W_{BB\|MF\|2})} = \boldsymbol{Var(W_{Pa\|MF\|2})}$	0	$\frac{Var(W_{MF\|2})}{4} = \frac{655.15}{4} = 52.99$
$\boldsymbol{Var(W_{TuWeTh\|1})}$	$(\frac{6.5}{(9-0.5)})^2 * 0.65^2 * 45^2 = 500.31$	$(\frac{10.5}{(9-0.5)})^2 * 0.65^2 * 45^2 = 1{,}305.55$
$\boldsymbol{Var(W_{BB\|TuWeTh\|1})} = \boldsymbol{Var(W_{Pa\|TuWeTh\|1})}$	$\frac{Var(W_{TuWTh\|1})}{4} = \frac{500.31}{4} = 125.08$	$\frac{Var(W_{TuWTh\|1})}{4} = \frac{1{,}305.55}{4} = 326.39$
$\boldsymbol{Var(W_{TuWeTh\|2})}$	$(\frac{5.75}{(9-0.5)})^2 * 45^2 = 926.67$	$(\frac{1.75}{(9-0.5)})^2 * 45^2 = 85.83$
$\boldsymbol{Var(W_{BB\|TuWeTh\|2})} = \boldsymbol{Var(W_{Pa\|TuWeTh\|2})}$	$\frac{Var(W_{TuWTh\|2})}{4} = \frac{926.67}{4} = 231.67$	$\frac{Var(W_{TuWTh\|2})}{4} = \frac{85.83}{4} = 21.46$

Standard deviation processing time

$\boldsymbol{\sigma_{W\|MF\|1}}$	30.97	32.69
$\boldsymbol{\sigma_{W\|BB\|MF\|1} = \sigma_{W\|Pa\|MF\|1}}$	15.49	16.35
$\boldsymbol{\sigma_{W\|MF\|2}}$	0	14.56
$\boldsymbol{\sigma_{W\|BB\|MF\|2} = \sigma_{W\|Pa\|MF\|2}}$	0	7.28
$\boldsymbol{\sigma_{W\|TuWeTh\|1}}$	22.37	36.13
$\boldsymbol{\sigma_{W\|BB\|TuWeTh\|1} = \sigma_{W\|Pa\|TuWeTh\|1}}$	11.18	18.07
$\boldsymbol{\sigma_{W\|TuWeTh\|2}}$	30.44	9.26
$\boldsymbol{\sigma_{W\|BB\|TuWeTh\|2} = \sigma_{W\|Pa\|TuWeTh\|2}}$	15.22	4.63

Mean throughput

	Situation 1	**Situation 2**
$\boldsymbol{D_{BB\|MF\|1}}$	4.96	5.23
$\boldsymbol{D_{BB\|MF\|2}}$	0	2.33
$\boldsymbol{D_{BB\|MF}}$	4.96 + 0 = 4.96	5.23 + 2.33 = 7.56
$\boldsymbol{D_{BB\|TuWeTh\|1}}$	3.58	5.78
$\boldsymbol{D_{BB\|TuWeTh\|2}}$	4.87	1.48
$\boldsymbol{D_{BB\|TuWeTh}}$	3.58 + 4.87 = 8.45	5.78 + 14.8 =7.26
$\boldsymbol{D_{Pa\|MF\|1}}$	2.48	2.62
$\boldsymbol{D_{Pa\|MF\|2}}$	0	1.16
$\boldsymbol{D_{Pa\|MF}}$	2.48 + 0 = 2.48	2.62 + 1.16 = 3.78
$\boldsymbol{D_{Pa\|TuWeTh\|1}}$	1.79	2.89
$\boldsymbol{D_{Pa\|TuWeTh\|2}}$	2.44	0.74
$\boldsymbol{D_{Pa\|TuWeTh}}$	1.79 + 2.44 ≈ 4.22	3.63

Standard deviation throughput

	Situation 1	**Situation 2**
$\sigma_{\vert D\vert BB\vert MF\vert 1}$	$\left(\frac{15.49}{25} * \sqrt{0.65}\right) = 0.50$	$\left(\frac{16.35}{25} * \sqrt{0.65}\right) = 0.53$
$\sigma_{\vert D\vert BB\vert MF\vert 2}$	0	$\left(\frac{7.28}{25}\right) = 0.29$
$\sigma_{\vert D\vert BB\vert MF}$	$\sqrt{0.40^2} = 0.50$	$\sqrt{0.53^2 + 0.29^2} = 0.60$
$\sigma_{D\vert BB\vert TuWeTh\vert 1}$	$\left(\frac{11.18}{25} * \sqrt{0.65}\right) = 0.36$	$\left(\frac{18.07}{25} * \sqrt{0.65}\right) = 0.58$
$\sigma_{D\vert BB\vert TuWeTh\vert 2}$	$\left(\frac{15.22}{25}\right) = 0.61$	$\left(\frac{4.63}{25}\right) = 0.19$
$\sigma_{D\vert BB\vert TuWeTh}$	$\sqrt{0.36^2 + 0.61^2} = 0.71$	$\sqrt{0.58^2 + 0.19^2} = 0.61$
$\sigma_{D\vert Pa\vert MF\vert 1}$	$\left(\frac{15.49}{50} * \sqrt{0.65}\right) = 0.25$	$\left(\frac{16.35}{50} * \sqrt{0.65}\right) = 0.26$
$\sigma_{D\vert Pa\vert MF\vert 2}$	0	$\left(\frac{7.28}{50}\right) = 0.15$
$\sigma_{D\vert Pa\vert MF}$	$\sqrt{0.25^2} = 0.25$	$\sqrt{0.26^2 + 0.15^2} = 0.30$
$\sigma_{D\vert Pa\vert TuWeTh\vert 1}$	$\left(\frac{11.18}{50} * \sqrt{0.65}\right) = 0.18$	$\left(\frac{18.07}{50} * \sqrt{0.65}\right) = 0.29$
$\sigma_{D\vert Pa\vert TuWeTh\vert 2}$	$\left(\frac{15.22}{50}\right) = 0.30$	$\left(\frac{4.63}{50}\right) = 0.09$
$\sigma_{D\vert Pa\vert TuWeTh}$	$\sqrt{0.18^2 + 0.30^2} = 0.35$	$\sqrt{0.29^2 + 0.09^2} = 0.31$

One machine / Shifts – Version 1 – Part 1

$Var(D\vert T + L\vert BB)$	$(1 + 3) * \frac{0.50^2 + 0.71^2 + 0.71^2 + 0.71^2 + 0.50^2}{5} = 1.60$
$\sigma_{D\vert T+L\vert BB}$	$\sqrt{1.60} = 1.27$
$Var(D\vert T + L\vert Pa)$	$(1 + 3) * \frac{0.25^2 + 0.35^2 + 0.35^2 + 0.35^2 + 0.25^2}{5} = 0.40$
$\sigma_{D\vert T+L\vert Pa}$	$\sqrt{0.40} = 0.63$
$D_{T+L\vert BB}$	$(1 + 3) * \left(\frac{4.96 + 8.45 + 8.45 + 8.45 + 4.96}{5}\right) = 28.22$
$D_{T+L\vert Pa}$	$(1 + 3) * \left(\frac{2.48 + 4.22 + 4.22 + 4.22 + 2.48}{5}\right) = 14.11$
ss_{BB}	$F_S^{-1}(0.95) * 1.27 = 1.645 * 1.27 = 2.08$
ss_{Pa}	$F_S^{-1}(0.95) * 0.63 = 1.645 * 0.63 = 1.04$
ROP_{BB}	$28.22 + 2.08 = 30.30$
ROP_{Pa}	$14.11 + 1.04 = 15.15$
Mixed ROP	$\frac{1}{2}X_{BB} + X_{Pa} \leq 30$
Weekly throughput BB	$4.96 + 8.45 + 8.45 + 8.45 + 4.96 = 35.27$
Weekly throughput Pa	$2.48 + 4.22 + 4.22 + 4.22 + 2.48 = 17.62$

One machine / shifts – version 1 – part 2

$\boldsymbol{D_{T+L\|BB} - \sigma_{D\|T+L\|BB}}$	$28.22 - 1.27 = 26.95$
$\boldsymbol{D_{T+L\|Pa} - \sigma_{D\|T+L\|Pa}}$	$14.11 - 0.63 = 13.48$
$\boldsymbol{G_{T+L}}$	$\frac{\frac{125}{5} * (1+3) * \frac{28.22}{14.4}}{300} = 0.65$
$\boldsymbol{I_{T+L}}$	$\frac{(1+3) * 200 * \frac{28.22}{14.4}}{310} = 5.06$
$\boldsymbol{DBB_{T+L}}$	$(1+3) * \frac{1}{10} * \frac{28.22}{14.4} = 0.78$

$$\text{Predicted amount of haz. sub. at moment of delivery}$$
$$= 65\left(X_{BB|1} + X_{BB|2} - \left(D_{T+L|BB} - \sigma_{T+L|BB}\right)\right)$$
$$+ 281\left(X_{Pa|1} + X_{Pa|2} - \left(D_{T+L|Pa} - \sigma_{T+L|Pa}\right)\right) + 300(X_G + G_{T+L}) + 800I_{T+L}$$
$$+ 105DBB_{T+L} + 180X_N \leq 10{,}000 - S$$

Filling in the discussed variables and parameters corresponding to this situation, it would result in

$$Amount\ of\ haz.sub.at\ moment\ of\ delivery$$
$$= 65(X_{BB|1} + 28 - 26.95) + 281(X_{Pa|1} + 16 - 13.48) + 300(X_G + 0.65) + 800 * 5.06 + 105 * 0.78) + 180 * 1$$
$$= 65X_{BB|1} + 68.25 + 281X_{Pa|1} + 708.12 + 300X_G + 195 + 4{,}048 + 81.9 + 180$$
$$= 65X_{BB|1} + 281X_{Pa|1} + 300X_G + 5{,}281.27 \leq 9{,}700$$

Arranging this gives

$$65X_{BB|1} + 281X_{Pa|1} + 300X_G \leq 4{,}418.73$$

One machine / Shifts – Version 2 – Part 1

$\boldsymbol{Var(D\|T+L\|BB)}$	$(1+3)*\frac{0.60^2+0.61^2+0.61^2+0.61^2+0.60^2}{5}=1.48$
$\boldsymbol{\sigma_{D\|T+L\|BB}}$	$\sqrt{1.48}=1.22$
$\boldsymbol{Var(D\|T+L\|Pa)}$	$(1+3)*\frac{0.30^2+0.31^2+0.31^2+0.31^2+0.30^2}{5}=0.37$
$\boldsymbol{\sigma_{D\|T+L\|Pa}}$	$\sqrt{0.37}=0.61$
$\boldsymbol{D_{T+L\|BB}}$	$(1+3)*\left(\frac{7.56+7.26+7.26+7.26+7.56}{5}\right)=29.52$
$\boldsymbol{D_{T+L\|Pa}}$	$(1+3)*\left(\frac{3.78+3.63+3.63+3.63+3.78}{5}\right)=14.76$
$\boldsymbol{ss_{BB}}$	$F_S^{-1}(0.95)*1.22=1.645*1.22=2.00$
$\boldsymbol{ss_{Pa}}$	$F_S^{-1}(0.95)*0.61=1.645*0.61=1.00$
$\boldsymbol{ROP_{BB}}$	$29.52+2.00=31.52$
$\boldsymbol{ROP_{Pa}}$	$14.76+1.00=15.76$
Mixed ROP	$\frac{1}{2}X_{BB}+X_{Pa}\le 32$
Weekly throughput BB	$7.56+7.26+7.26+7.26+7.56=36.9$
Weekly throughput Pa	$3.78+3.63+3.63+3.63+3.78=18.45$

One machine / shifts – version 2 – part 2

$\boldsymbol{D_{T+L\|BB}-\sigma_{D\|T+L\|BB}}$	$29.52-1.22=28.3$
$\boldsymbol{D_{T+L\|Pa}-\sigma_{D\|T+L\|Pa}}$	$14.76-0.61=14.15$
$\boldsymbol{G_{T+L}}$	$\frac{\frac{125}{5}*(1+3)*\frac{29.52}{14.4}}{300}=0.68$
$\boldsymbol{I_{T+L}}$	$\frac{(1+3)*200*\frac{29.52}{14.4}}{310}=5.29$
$\boldsymbol{DBB_{T+L}}$	$(1+3)*\frac{1}{10}*\frac{29.52}{14.4}=0.82$

$$\text{Predicted amount of haz. sub. at moment of delivery} = 65\left(X_{BB|1}+X_{BB|2}-\left(D_{T+L|BB}-\sigma_{T+L|BB}\right)\right) + 281\left(X_{Pa|1}+X_{Pa|2}-\left(D_{T+L|Pa}-\sigma_{T+L|Pa}\right)\right)+300(X_G+G_{T+L})+800I_{T+L} + 105DBB_{T+L}+180X_N\le 10{,}000\ -\ S$$

Filling in the discussed variables and parameters corresponding to this situation, it would result in

$$\begin{aligned} &Amount\ of\ haz.sub.at\ moment\ of\ delivery\\ &= 65(X_{BB|1}+28-28.3)+281(X_{Pa|1}+16-14.15)+300(X_G+0.68)+800\\ &*5.29+105*0.82)+180*1\\ &=65X_{BB|1}-19.5+281X_{Pa|1}+421.5+300X_G+204+4{,}232+86.1+180\\ &=65X_{BB|1}+281X_{Pa|1}+300X_G+5{,}104.1\le 9{,}700 \end{aligned}$$

Arranging this gives

$$65X_{BB|1} + 281X_{Pa|1} + 300X_G \leq 4{,}595.9$$

Appendix F - Section 5.2 Model

General

	Situation 1	Situation 2
$W_{MTuWeTh}$	360	360
$W_{BB\|MTuWeTh} = W_{Pa\|MTuWeTh}$	180	180
W_F	180	180
$W_{BB\|F} = W_{Pa\|F}$	90	90
$Var(W_{MTuWeTh})$	2,025	2,025
$Var(W_{BB\|MTuWeTh}) = Var(W_{Pa\|MTuWeTh})$	506.25	506.25
$Var(W_F)$	506.25	506.25
$Var(W_{BB\|F}) = Var(W_{Pa\|F})$	126.56	125.56
$\sigma_{W\|MTuWeTh}$	45	45
$\sigma_{W\|BB\|MTuWeTh} = \sigma_{W\|Pa\|MTuWeTh}$	22.5	22.5
$\sigma_{W\|F}$	22.5	22.5
$\sigma_{W\|BB\|F} = \sigma_{W\|Pa\|F}$	11.25	11.25

Mean throughput

	Situation 1	Situation 2
$D_{BB\|MTuWeTh}$	11.88	14.4
$D_{BB\|F}$	5.94	7.2
$D_{Pa\|MTuWeTh}$	5.94	7.2
$D_{Pa\|F}$	2.97	3.6

Standard deviation throughput

	Situation 1	Situation 2
$\sigma_{D\|BB\|MTuWeTh}$	1.16	1.27
$\sigma_{D\|BB\|F}$	0.58	0.64
$\sigma_{D\|Pa\|MTuWeTh}$	0.58	0.64
$\sigma_{D\|Pa\|F}$	0.29	0.32

Situation 1 – Part 1

$\boldsymbol{Var(D\|T+L\|BB)}$	$(1+3)*\frac{1.16^2+1.16^2+1.16^2+1.16^2+0.58^2}{5}=4.58$
$\boldsymbol{\sigma_{D\|T+L\|BB}}$	$\sqrt{4.58}=2.14$
$\boldsymbol{Var(D\|T+L\|Pa)}$	$(1+3)*\frac{0.58^2+0.58^2+0.58^2+0.58^2+0.29^2}{5}=1.14$
$\boldsymbol{\sigma_{D\|T+L\|Pa}}$	$\sqrt{1.14}=1.07$
$\boldsymbol{D_{T+L\|BB}}$	$(1+3)*\left(\frac{11.88+11.88+11.88+11.88+5.94}{5}\right)=42.77$
$\boldsymbol{D_{T+L\|Pa}}$	$(1+3)*\left(\frac{5.94+5.94+5.94+5.94+2.97}{5}\right)=21.38$
$\boldsymbol{ss_{BB}}$	$F_S^{-1}(0.95)*2.14=1.645*2.14=3.52$
$\boldsymbol{ss_{Pa}}$	$F_S^{-1}(0.95)*1.07=1.645*1.07=1.76$
$\boldsymbol{ROP_{BB}}$	$42.77+3.52=46.29$
$\boldsymbol{ROP_{Pa}}$	$21.38+1.76=23.14$
Mixed ROP	$\frac{1}{2}X_{BB}+X_{Pa}\leq 46$
Weekly throughput BB	$11.88+11.88+11.88+11.88+5.94=53.46$
Weekly throughput Pa	$5.94+5.94+5.94+5.94+2.97=26.73$

Situation 1 – Part 2

$\boldsymbol{D_{T+L\|BB}-\sigma_{D\|T+L\|BB}}$	$42.77-2.14=40.63$
$\boldsymbol{D_{T+L\|Pa}-\sigma_{D\|T+L\|Pa}}$	$21.38-1.07=20.31$
$\boldsymbol{G_{T+L}}$	$\frac{\frac{125}{5}*(1+3)*\frac{42.77}{14.4}}{300}=0.99$
$\boldsymbol{I_{T+L}}$	$\frac{(1+3)*200*\frac{42.77}{14.4}}{310}=7.66$
$\boldsymbol{DBB_{T+L}}$	$(1+3)*\frac{1}{10}*\frac{42.77}{14.4}=1.19$

$$\text{Predicted amount of haz. sub. at moment of delivery} = 65\left(X_{BB|1}+X_{BB|2}-\left(D_{T+L|BB}-\sigma_{T+L|BB}\right)\right) + 281\left(X_{Pa|1}+X_{Pa|2}-\left(D_{T+L|Pa}-\sigma_{T+L|Pa}\right)\right)+300(X_G+G_{T+L})+800I_{T+L} + 105DBB_{T+L}+180X_N \leq 10{,}000\ -\ S$$

Filling in the discussed variables and parameters corresponding to this situation, it would result in

$$Amount\ of\ haz.sub.at\ moment\ of\ delivery = 65\left(X_{BB|1}+28-40.63\right)+281\left(X_{Pa|1}+16-20.31\right)+300(X_G+0.99)+800 * 7.66+105*1.19)+180*1 = 65X_{BB|1}-820.95+281X_{Pa|1}-1{,}211.11+300X_G+297+6{,}128+124.95 + 180 = 65X_{BB|1}+281X_{Pa|1}+300X_G+4{,}697.89\leq 9{,}700$$

Arranging this gives

$$65X_{BB|1} + 281X_{Pa|1} + 300X_G \leq 4{,}455.61$$

Situation 2 – Part 1

$\boldsymbol{Var(D\|T+L\|BB)}$	$(1+3) * \frac{1.27^2+1.27^2+1.27^2+1.27^2+0.64^2}{5} = 5.49$
$\boldsymbol{\sigma_{D\|T+L\|BB}}$	$\sqrt{5.49} = 2.34$
$\boldsymbol{Var(D\|T+L\|Pa)}$	$(1+3) * \frac{0.64^2+0.64^2+0.64^2+0.64^2+0.32^2}{5} = 1.39$
$\boldsymbol{\sigma_{D\|T+L\|Pa}}$	$\sqrt{1.39} \approx 1.17$
$\boldsymbol{D_{T+L\|BB}}$	$(1+3) * \left(\frac{14.4+14.4+14.4+14.4+7.2}{5}\right) = 51.84$
$\boldsymbol{D_{T+L\|Pa}}$	$(1+3) * \left(\frac{7.2+7.2+7.2+7.2+3.6}{5}\right) = 25.92$
$\boldsymbol{ss_{BB}}$	$F_S^{-1}(0.95) * 2.34 = 1.645 * 2.34 \approx 3.85$
$\boldsymbol{ss_{Pa}}$	$F_S^{-1}(0.95) * 1.18 = 1.645 * 1.17 \approx 1.93$
$\boldsymbol{ROP_{BB}}$	$51.84 + 3.85 = 55.69$
$\boldsymbol{ROP_{Pa}}$	$25.92 + 1.93 = 27.85$
Mixed ROP	$\frac{1}{2}X_{BB} + X_{Pa} \leq 56$
Weekly throughput BB	$14.4 + 14.4 + 14.4 + 14.4 + 7.2 = 64.8$
Weekly throughput Pa	$7.2 + 7.2 + 7.2 + 7.2 + 3.6 = 32.4$

Situation 2 – Part 2

$\boldsymbol{D_{T+L\|BB} - \sigma_{D\|T+L\|BB}}$	$51.84 - 2.34 = 49.5$
$\boldsymbol{D_{T+L\|Pa} - \sigma_{D\|T+L\|Pa}}$	$25.92 - 1.17 = 21.75$
$\boldsymbol{G_{T+L}}$	$\frac{\frac{125}{5} * (1+3) * \frac{51.84}{14.4}}{300} = 1.2$
$\boldsymbol{I_{T+L}}$	$\frac{(1+3) * 200 * \frac{51.84}{14.4}}{310} = 9.29$
$\boldsymbol{DBB_{T+L}}$	$(1+3) * \frac{1}{10} * \frac{51.84}{14.4} = 1.44$

$$\begin{aligned}\text{Predicted amount of haz. sub. at moment of delivery}\\ &= 65\left(X_{BB|1} + X_{BB|2} - \left(D_{T+L|BB} - \sigma_{T+L|BB}\right)\right)\\ &+ 281\left(X_{Pa|1} + X_{Pa|2} - \left(D_{T+L|Pa} - \sigma_{T+L|Pa}\right)\right) + 300(X_G + G_{T+L}) + 800I_{T+L}\\ &+ 105DBB_{T+L} + 180X_N \leq 10{,}000 - S\end{aligned}$$

Filling in the discussed variables and parameters corresponding to this situation, it would result in

$$\begin{aligned}Amount\ of\ haz.sub.at\ moment\ of\ delivery\\ &= 65\left(X_{BB|1} + 28 - 49.5\right) + 281\left(X_{Pa|1} + 16 - 21.75\right) + 300(X_G + 1.2) + 800 * 9.29\\ &+ 105 * 1.44) + 180 * 1\\ &= 65X_{BB|1} - 1{,}397.5 + 281X_{Pa|1} - 1{,}615.75 + 300X_G + 360 + 7{,}432 + 151.2 + 180\\ &= 65X_{BB|1} + 281X_{Pa|1} + 300X_G + 5{,}109.95 \leq 9{,}700\end{aligned}$$

Arranging this gives

$$65X_{\mathrm{BB|1}} + 281X_{\mathrm{Pa|1}} + 300X_{\mathrm{G}} \leq 4{,}590.05$$

Appendix G – Section 5.3 Model

Mean throughput

	Situation 1	Situation 2
$D_{BB\|M}$	24.38	24.26
$D_{BB\|Tu}$	30.11	23.27
$D_{BB\|We}$	24.38	24.36
$D_{BB\|Th}$	24.38	24.36
$D_{BB\|F}$	24.38	24.11
$D_{Pa\|M}$	12.19	12.13
$D_{Pa\|Tu}$	15.06	11.64
$D_{Pa\|We}$	12.19	12.18
$D_{Pa\|Th}$	12.19	12.18
$D_{Pa\|F}$	12.19	12.06
D_{BB} (Total)	127.63	120.36
D_{Pa} (Total)	63.82	60.19