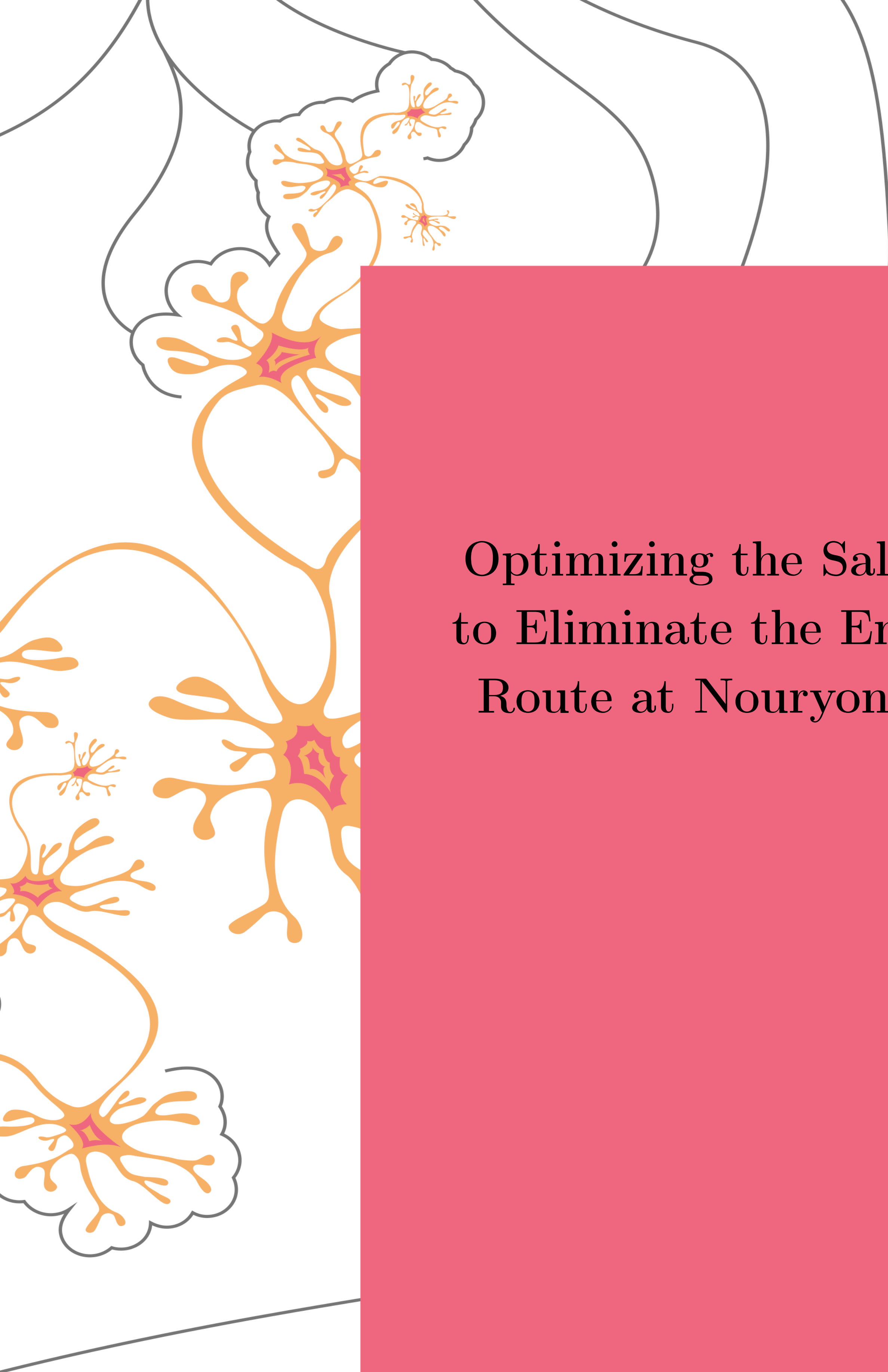

Optimizing the Salt Stream to Eliminate the Emergency Route at Nouryon Hengelo

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Preface

Dear reader,

In front of you, you find my research on optimizing the salt stream to eliminate the emergency route at Nouryon Hengelo. The research is conducted for the purpose of graduating from the bachelor Industrial Engineering and Management at the University of Twente. The research took place in the period from April to August during COVID-19.

I want to thank Nouryon Hengelo for allowing me to perform the research even during these strange times. My supervisors Hans van Gurp and Bart Tabak continued to support me during the entire research. They offered me a lot of information, the right contacts and weekly checkup meetings that allowed me to do the research from home. Besides my supervisors I would like to thank all the other colleagues from Nouryon Hengelo, whenever I came to Nouryon Hengelo I felt very welcome, and everyone tried to help me.

Next I want to thank my first supervisor from the University of Twente, Marco Schutten, for his guidance and elaborate feedback sessions. We did not get to have any face to face conversations, but Marco made time to have online sessions whenever I needed it.

Finally, I would like to thank my family and friends. First, my father and brother who were always there to collaborate with me to understand and write the code for the model. Also Elles and Ian were there to provide me with useful feedback, or cheer me up when I was uncertain about anything.

I hope you enjoy reading my Bachelor Thesis!

Carlijn

Enschede, October 2020

Management Summary

Nouryon Hengelo is a Company that is specialized in salt production. The Librox department is a specific department where unsifted salt is pressed together, to form a desired shape. This department makes use of an emergency silo, which is referred to as the D1 silo, when incoming salt cannot be used immediately. The other departments demand sifted salt, so this salt is sent to as D2 and D3 silo, and these silos fall out of scope for the research.

Nouryon expects that the leftover lifetime of the D1 silo is short. The investment in a new silo is high, so Nouryon is interested in the possibilities of producing without the silo. In the current situation salt is sent to this route on a daily basis, but it not quite clear why the salt cannot be sent to a production line. This rises the following research question:

To avoid capital expenditure, how can the production process be structured to eliminate the emergency silo in the Librox Department?

The Librox department deals with a continuous input stream that has to be used for production at all times. There are 4 different production lines and there is a small bunker within the department that can contain a maximum of 20 tons of salt. The goal of the research is to prove that this bunker is enough to catch the excess salt, and that the D1 silo is unnecessary.

To answer the research question, we need a model that tests all day-to-day situations. Furthermore, it is important that the model helps to bring insight in the process and provides a long term strategy. The state changes in the department can be handled as events. For each state change, a plan is needed, how to prevent an over-stream of the bunker. An example of a state change is a machine failure, or an empty bunker.

First we conducted a literature review to research different production process models. We looked at the relevance of each model for this problem, and choose the most appropriate model through a multi-criteria decision analysis. To give a valid answer with a longer term perspective a discrete-event simulation is used.

Based on a situation and interviews, the production process is modelled in the Plant Simulation software by SIEMENS. Salt flows into the process, and the model involves failures, adjustable inputs and other necessary settings. The model does not include the emergency silo, so a long period of processing without the silo proves that the emergency route is unnecessary.

The Librox Buffer is large enough to catch salt in case of a failure or other state change. To realise production without the emergency route, there is need for control over the choices of the settings of the department. This control can be achieved through system automation, or improved data measurement.

To help the operators with the input choices we include a dashboard that can be used to calculate the dryer input of a certain day. Finally the report includes what steps have to be taken to start the new strategy.

Contents

1. Introduction

The aim of the introduction chapter is the problem identification and description. This chapter provides the company introduction (1.1), the research motivation (1.2) and the research questions (1.3).

1.1 Company Introduction

The research takes place at the department Salt Specialties of Nouryon Hengelo. The Salt Specialties plant is part of the Industrial Chemicals business unit within Nouryon, a multinational company owned by private equity company Carlyle. Besides the plant in Hengelo, Salt Specialties has several locations in Europe (Denmark & Spain). The Hengelo site consists of two plants: the Salt Specialties plant and the Industrial Salt plant. The Industrial Salt plant obtains salt using solution mining from salt layers 500 meters below the surface, removes impurities and finally obtains a very high-quality vacuum packaged salt via a crystallisation process.

The Salt Specialties plant uses about 20% of the total salt volume as feed stock for further processing. This involves drying of the salt, sieving, compacting and packaging. A total of more than 300 salt products (e.g. table salt, water treatment, nitrite salt) are processed at this plant. Salt Specialties and Industrial Salt each have their own management, operations and maintenance teams in place, but share site services like engineering, finance, HR, and HSE (Health Safety and Environment).

1.2 Research Motivation

The Librox department is one specific part of Nouryon Salt Specialties, where salt is compacted, to form any desired shape, such as salt licks for animals, or salt tablets for the dishwasher. The Librox department has 4 different production lines, namely the Broxo-Line, BroxoTablets-Line (also referred to as Broxetten-Line), Lickstone-Line and the Mublo-Line. Three of the production lines can make one specific product, and the Broxo-Line can make multiple products while the line has two parallel processing lines.

In the Librox department there is a small bunker that can intercept the salt that cannot be processed. In case of a jam the first leftover salt goes to the bunker. In any case where salt cannot immediately be processed into an end product, and the small bunker is full, the salt is sent to the emergency silo. The emergency silo is in a poor condition and needs replacing. This leads the company to the following question:

To avoid capital expenditure, how can the production process be structured to eliminate the emergency silo in the Librox Department?

1.3 Research Questions

The research is divided into different stages. The goal of the stages is to provide structure and clarity, and the stages are inspired by the Managerial Problem Solving Method of Heerkens and van Winden [2017].

1.3.1 Stage 1 - Problem Identification and Approach

The first research stage evolves around the problem identification and the approach. The goal is to have full understanding of the current process.

- What is the current production process, and what is the strategy for taking decisions on the salt stream in the Librox department?
- In what occasions is the salt sent towards the emergency silo?
- Who is involved in the decision making process for a new emergency silo?
- What does the company expect from an improved strategy?

After this stage of the research, the current process and the current strategy are explained.

1.3.2 Stage 2 - Theoretical Research and Investigating Optimization Solutions

Stage 2 of the research focuses on the body of existing literature. There is a lot of research available on optimization techniques for production processes. The theories are explained, and the appropriateness of each technique for the specific problem is determined.

- What existing optimization techniques can be used for modeling production processes?
- Which of the found techniques are appropriate for this specific problem?

The goal of the problem analysis stage is to come up with possible techniques to use for further research of this problem. The models are analysed and reviewed, however the decision for a model is in Stage 3.

1.3.3 Stage 3 - Selection of the Approach and Model

After collecting the information in the second stage, an optimization approach is chosen. The third stage involves a multi-criteria decision strategy to decide on the final technique. The following knowledge questions are answered:

- Which model is most appropriate for modelling the production process at the company?
- How can an optimization technique be integrated in the company?

After the problem selection and creation phase, the decision on the final approach is taken.

1.3.4 Stage 4 - Creation of the Model

This stage works towards drawing conclusions from the literary research. If the questions asked before this phase are answered, the limitations of the technique should be clear. During the creation of the model the focus is on answering the following questions:

- To what extent is it possible to produce at the Librox department, without the emergency route?
- What measures have to be taken to start the new strategy?
- What are the expected costs of changing the process to this extent?

The fourth phase has succeeded when a working model is in place, with which we can answer the first two question. After finding the new measures we can answer question three.

1.3.5 Stage 5 - Validation of the Model and Evaluation

In the final stage the outcome validity is proven. Also the results are formed to be deliverables, so that the outcome is understandable.

- To what extent can the validity of the outcome be proven?
- What is the final advice on the future of the emergency route?

After having answered the questions in this last phase, the model is validated, as well as the outcome.

2. Current Situation

The aim of the second chapter is the situation description. We discuss the current process (2.1), the emergency route prediction (2.2), the stakeholders (2.3), the demands and wishes (2.4) and we draw a conclusions from the situation analysis (2.5).

2.1 Current Process

To provide insight in the process the current process and strategy have to be identified. After the explanation of the current production process, the problems of the current process are identified in this chapter. Hereby problems refer to the situations in which salt is sent over the emergency route. To identify the current process, we answer the following question:

What is the current process, and what is the strategy for taking decisions on the salt stream in the Librox department?

Figure 2.1 shows a simplified production process. There are two types of wet salt that come into the process. All salt enters the production process through the dryers. There are three dryers called the D, E and F dryer. After the drying process, the salt can either be sent towards the sieving machine, or the Librox department. For the scope of this research the Librox department is important. So, the part of the process after the sieving is out of scope. As mentioned in Librox department has 4 different production lines. Each production line has a different demand and processing time. The Broxo line has multiple processing speeds as it contains two parallel lines, the throughput then depends on the product that is chosen.

2.1.1 Priority Strategy

In the current process, the Librox department receives salt from one of the three dryers found in Figure 2.1. The salt of the other two dryers is sent towards the sieve department, which falls out of the scope of the research. Which of the three dryers is allocated to the Librox department differs, but for the scope of the research it is interesting to assume there is a continuous input of one dryer. So, the dryer can never be turned off. The dryers have a corresponding throughput capacity with each a minimum of 20 ton per hour and a maximum of 32, 34 and 36 for the D,E and F dryer, respectively. The salt that flows to the dryer originates from another department of Nouryon, which is called Industrial Salt.

The salt that is dried should be used for one of the four production lines of the Librox department. If it cannot be sent to one of these lines it is saved in the Librox bunker within the department, which can contain a maximum of 20 tons of salt. Whenever this bunker is full, the salt is sent to the emergency route and it ends up in the emergency silo, which is also referred to as the D1 silo.

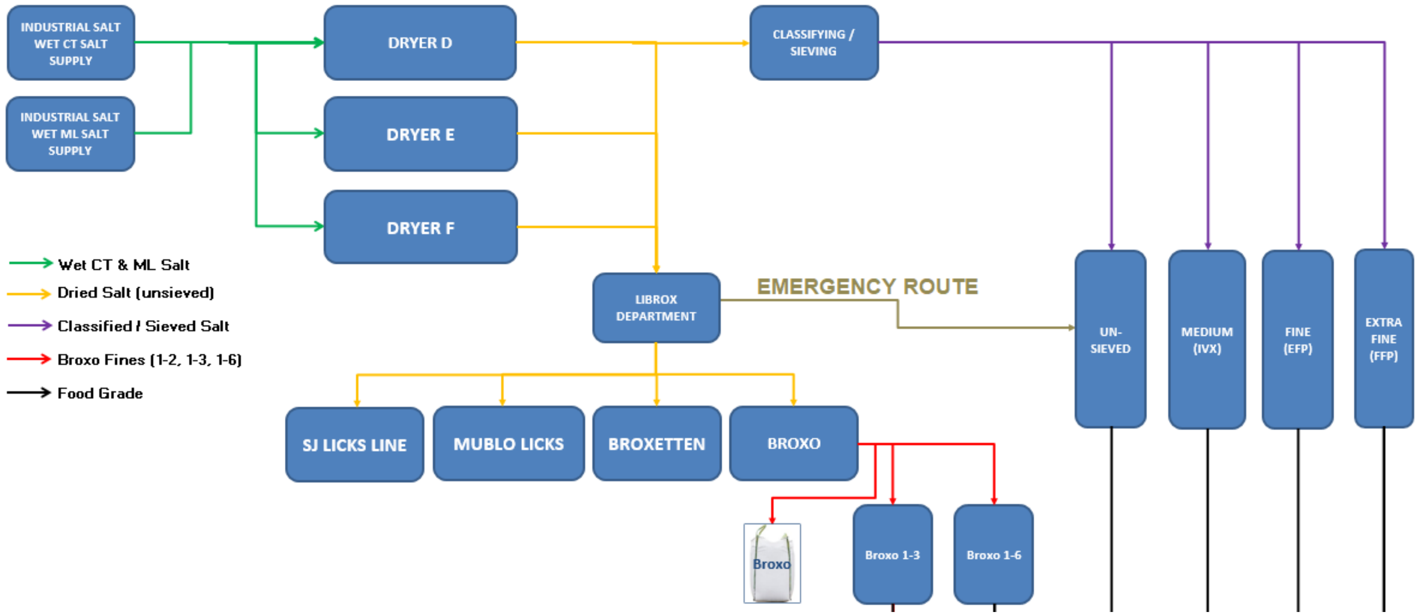

Figure 2.1: Process Flow

The current strategy within the department is to follow the priority that is given to the products on a daily basis by the planners. The planners provide a list of production plans for one day, and the production employees at Librox start producing according to the provided priority. This strategy is very clear, but it turns out that it is not followed by the operators in production. The production plan is met some of the time, but it is not held as main focus in the department. So, a first problem within the production process is that the strategy is currently not followed.

Another loss is that through this strategy there is no focus on using the incoming stream of salt in the most efficient manner. The planners decide what product is prioritized through the demand. There is little to no track kept of the best throughput of the Librox department. This means that even if the strategy is followed perfectly, the salt will still be sent to the emergency route at times. To prevent this the strategy should take into account the throughput of the dryer, or test whether steering with the input of the dryer is possible.

2.1.2 Utilization Production Lines

The current view is that all lines can run at the same time, however there are many situations in which this is not the case in practice. There are situations in which production lines are turned off due to lack of manpower or idleness. There are multiple reasons why production lines are unnecessarily turned off. For example the lack of interest in preventing the stream towards the D1 silo, and the lack of control by management.

The other two dryers are constantly drying salt to provide the other departments. As mentioned before, the other departments demand sieved salt. After the salt is sieved the salt that cannot be used in production immediately is sent to other emergency silos, namely D2 and D3 silo, so this is no longer a problem for the D1 silo. This is why the sieved salt is out of the scope of this research.

		kg/productunit	Norm OEE [productunit/min]	Norm OEE [ton/dienst]	Doel OEE [%]	Doel OEE [ton/dienst]	Doel OEE [productunit/min]	Norm OEE [ton/dag]
	BSF2,2	2,2	100	105,6	52%	54,9	52,00	316,8
BigBags	BB1000	1000	0,396	190,0	39%	74,1	0,15	570
	BB1250	1250	0,396	237,6	39%	92,7	0,15	712,8

Figure 2.2: Production Plan Example

2.2 Emergency Route Prediction

To come up with a new strategy it is important to understand why the production process does not run without waste salt. In this case waste salt refers to salt that is not used in production and hence ends up in the emergency silo. This rises the following question:

In what occasions is the salt sent towards the emergency silo?

2.2.1 Production Plan

In the current situation the planners decide how much of each product has to be produced in one day of 24 hours, and based on that information the operators know how much to produce in one shift (8 hours). The salt production process is continuous, so there is a constant stream of dried salt. An example of a production plan can be found in Figure 2.2 This figure shows the specific plan for the product called BigBags. The operators can find information how many tons of salt of this product they have to produce during their 8 hour shift. The production plan takes into account the overall equipment effectiveness (OEE). The planning method with the use of OEE is based on the expected efficiency of the machines including the availability and quality measures. This planning method strives to a realistic output goal as the variances are taken into the measure. One can assume that this ensures an accurate production plan. With OEE the production plan is planned realistically and specifically for each product.

A new strategy can also help to make the output more efficient. If the new strategy focuses on using the salt streams in the department, instead of planning from the demand perspective, the continuous stream is used most efficiently. If the dryer is set to a throughput of 20 ton/hour, the strategy should focus on using these 20 tons completely.

2.2.2 Production Control

After looking at the strategy it is interesting to analyse the realisation of the production plan. It turns out that the production plan is often not met. As discussed before in Chapter 1.3.5, it turns out that the operators in production do not stick to the plan. In order to predict the output of the Librox department there has to be more control on the choices that are made within the department. Also, when the shift changes after 8 hours, there is little responsibility for keeping up with the continuous stream. It is a common situation that the first few tons of salt go to the emergency silo, instead of through production even though it should be possible to use this salt.

Next to the output control, it can also help to improve the overall control in the department. There are many situations in which the operators are unfamiliar with the fact that salt streams towards the emergency silo.

There are alarm bells for different situations in the process, for example when the Librox bunker is nearly out of salt. However there is no emergency bell, for the situation in which the bunker is almost full. When the bunker is completely full, the salt is automatically sent to emergency silo. In this case it might take quite some time before the operators change the settings of the production lines to stop the flow towards the D1 silo.

The control over the output can be improved once the salt stream is measured in the right places. At this moment it is not possible to accurately measure the percentage of salt that is lost at the Librox department. If the outflow of the Librox department and the input of the D1 silo are measured and controlled it is easier to improve the strategy.

2.3 Stakeholders

For a solution to be implemented, it must be agreed with by every stakeholder. The focus is on the stakeholders that have a say in decisions regarding the D1 silo. In this section we answer the following question:

Who is involved in the decision making process?

The stakeholders will be presented and introduced, and an identification on the stakeholders needs and expectations is elaborated.

Function	**Influence on Job**	**Influence in Decision**	**Expectations**	**Strategy for Enhancing**
Plant Manager	low	medium	Low investment	Inform about all scope changes
Production Manager	high	high	Long term solution	Stay in touch about progress
Shift Leaders	low	medium	Easily adaptable strategy	Update every once in a while
Operators	high	low	Clear guidelines accurate work expectations	Listen to their struggles, clear guidelines
Capital Expenditure	low	medium	Only necessary investment	Provide a long-term plan

Table 2.1: Stakeholders Analysis

Figure 2.1 shows the stakeholders that are involved in the decisions of the emergency route.

2.3.1 Introduction of Stakeholders

The plant manager at Nouryon Hengelo has medium influence in the decision and is not influenced highly by changing the strategy. He will be informed when the scope of the research is changed. He has no personal interest in changing the system.

From the table we see that the production manager has both high interest and influence on the decision of the emergency silo. So, he is highly interested in finding a solution, and holds quite some power over the decision to implement the research.

The shift leaders have low interest in changing the process, while the influence on their job is low. For them it is important that the renewed strategy is easily adaptable and understandable, while they have to monitor the realisation of the changes.

The operators are the people that work in the factory. They have low influence on changes of the system, however their daily routine is highly influenced by these changes. The new strategy can only be implemented by them. The strategy towards success is to listen to their struggles and provide clear guidelines on any changes. The operators have no personal interest in changing the production strategy as they are used to the current methods. They are of high importance for receiving the right inputs of the model, but they do not believe that production is possible without the use of the emergency silo.

The final stakeholder is Capital Expenditure. They will only be involved if the investment on the new strategy exceeds the maximal spending of 5000 euros. They have interest in changing the system if the investment in a new silo can be prevented.

2.4 Demands and Wishes

To find a suiting solution it is important that the company's expectations are clear. There are certain constraints that a new strategy must abide by. This rises the following question:

What does the company expect from an improved strategy?

The expectations are divided over two categories: demands and wishes. There are certain constraints for the solutions that cannot be exceeded. These constraints can be referred to as demands, and they have to be separated from any constraints that fall under wishes regarding the solution.

2.4.1 Demands

The first and most important demand is to gain insight into the current situation. Over the years the process at the Librox department has run without analysing all historical data about when and why salt is sent to the emergency route. There is need for an overview on when and where salt is lost through the process. This is the first demand of the company.

The next demand is to bring conclusions regarding the long term horizon. The conclusion of the research will recommend or dissuade a huge investment. To give an appropriate advice in favor of, or against the investment in a new silo the long term perspective has to be considered.

Finally, the company specifically asked for an advice on the production strategy. As there is little knowledge on the process in the current state.

2.4.2 Wishes

Other than the constraints that fall within demands there are also some wishes identified. The greatest wish is to find a solution with a low investment. The research is conducted in order to find out whether the investment of an entirely new emergency silo can be prevented. This does not fall under demands as the outcome of the research may be that the investment cannot be prevented. However it is important to keep this wish in mind. When the outcome allows it, the costs have to be identified.

For the company it is also important that the new strategy is easily adaptable. There is little sight on the production process, so the new strategy must be easy to follow for the employees in the factory without too much extra effort. This requires practical solutions and clear guidelines.

2.5 Conclusions from the Stage Identification

In the situation identification there are several conclusions.

The conclusion that is drawn is that there is little insight in the current process of salt that streams from the Librox department to the D1 silo. There is no control on when the salt is sent towards this route, why the salt is sent there and how many tons of salt are sent there. From this research it has been concluded that the salt stream towards the D1 silo can be decreased, and it is to be researched whether this stream can reach zero.

3. Literature Review

The literature research stage focuses on the body of existing literature on production processes planning and answers the following question:

What existing optimization techniques can be used for modeling production processes?

As mentioned there is a continuous inflow of salt. To prove that the emergency route can be eliminated, we have to prove that the entire input of the department can be used for production. The salt that cannot be placed in either production or the Librox bunker, is usually sent to the emergency route, so it can be referred to as waste for this research. We discuss the models that have showed to be relevant for planning production processes. The search strategy can be found in Appendix B.

This chapter provides the possible techniques (3.1), the eligibility of each technique (3.2) and the conclusions of the systematic literature research (3.3).

3.1 Techniques

A model refers to a simplification of a real system which facilitates understanding, controlling and predicting a system. In this case the model can mainly be used to predict the future of the system when using a new strategy.

Based on the systematic literature review we conclude that there are several techniques available to optimize production processes. The reviewed techniques are identified and explained shortly. An overview on the search strategy for the exploratory literature research, the inclusion and exclusion criteria and a concept matrix of the final articles can be found in Appendix B

3.1.1 Fuzzy Programming

The first mathematical optimization model is fuzzy programming. Fuzzy programming is a model that deals with optimization problems under uncertainty. Fuzzy programming can be used in combination with an EOQ (Economic Order Quantity) model. [Kumar and Goswami, 2015] The EOQ model focuses on the order quantity, and evolves around inventory costs. The inventory costs are irrelevant for this problem, so the EOQ model is not a good fit.

However fuzzy programming might be an interesting feature. The main benefit of fuzzy programming is that the objectives' uncertainty can be included. As this research confines within uncertain parameters, this aspect of fuzzy programming is interesting.

3.1.2 Linear Programming

In linear programming the main purpose is to pursue one goal and find the right strategy to reach this goal. An example of such a goal is to minimize costs or maximize profit. Linear programming can be used in various research fields. The linear programming problems always consist of the following three parts: [Edgar and Himmelblau, 1988]

e.g.

a linear function to be maximised

$$f(x_1, x_2) = c_1x_1 + c_2x_2$$

problem constraints

$$a_{11}x_1 + a_{12}x_2 \leq b_1$$

$$a_{21}x_1 + a_{22}x_2 \leq b_2$$

$$a_{31}x_1 + a_{32}x_2 \leq b_3$$

non-negative variables

$$x_1 \geq 0, x_2 \geq 0$$

This problem can then be presented in matrix form

$$max\{c^T x | Ax \leq b \wedge x \geq 0\}$$

Linear programming models can be used for manufacturing problems. It often evolves around maximizing profit in this case, but it is possible to choose a different goal. In a manufacturing problem the constraints can for example be the material availability or production rate.

Linear Programming is often used in planning and scheduling issues through Mixed-Integer Linear Programming. Mixed-Integer Linear Programming is introduced when some of the variables are non-discrete, and this provides a way to program a continuous process. [Castro et al., 2009]

3.1.3 Simulated-Annealing

Simulated-Annealing is an algorithm method for optimization problems. The Simulated Annealing algorithm is based upon Physical Annealing in real life. Physical Annealing is the process of heating up a material until it reaches an annealing temperature and then it will be cooled down slowly in order to change the material to a desired structure. When the material is hot, the molecular structure is weaker and is more susceptible to change. When the material cools down, the molecular structure is harder and is less susceptible to change.

Simulated Annealing (SA) mimics the Physical Annealing process but is used for optimizing parameters in a model. This process is very useful for situations where there are a lot of local minima such that other algorithms get stuck. [Hajek, 1988]

3.1.4 Simulation Models

Finally, a simulation model can be used in a production process. In this case, a computer model can be used to analyse a system and experiment with it. Simulation models can vary between simplistic and very detailed.

3.1.4.1 Discrete-Event Simulation

In the chemical industry process simulation plays an important role in decision-making. Chemical industries often produce continuously. In this case, a simulation can help to experiment different strategies. In specific discrete-event simulation supplies the missing link between aspects of the process and their effect on the bottom line by providing a method to quantify the interactions. [Cope, 2010] The discrete-event simulation distinguishes itself from other simulation methods as each event occurs at a particular instant in time and marks a change of state in the system.

3.1.4.2 System Dynamics

A continuous simulation approach is the system dynamics simulation. This approach represents the world in a set of stocks and flows in which stocks are accumulations (items, people, money) and flows adjust the level of stock. [Poles, 2013] This model focuses on information feedback in a system, and it often includes fuzzy aspects.

Typically, system dynamics is used for supply chains to find strategic policies. This type of simulation is useful for planning issues and can help provide insight over the long-term of a process.

3.1.4.3 Monte-Carlo Simulation

Another relevant example of simulation is Monte-Carlo Simulation. The result of the simulation is a distribution that presents the range of outcomes that are possible. This type of simulation is often used when there is a set of input distributions, and it is used to simulate the outcome at some future point or series of time periods. This type of simulation is not involved in studying the progression of a system over time, so it is not the best fit for a long-term strategy consideration.[Bunday et al., 2006]

3.2 Eligibility of the Models

The next step of this chapter is to verify whether each of the models mentioned above is suitable for the salt production process. After analyzing each model in this chapter, the model that is used is concluded in Chapter 4.

3.2.1 Suitability of Fuzzy Programming

In this Literature Review the fuzzy programming strategy was combined with the Economic Production Quantity model (EOQ). However the EOQ model focuses on the inventory of a certain process. This involves a process that can be started and stopped easily. In the process at Nouryon we are dealing with a continuous input. There is a continuous inflow stream which has to be used at all times. If it cannot be sent to one of the production lines it will result in a salt flow towards the emergency route. The conclusions of the EOQ model would lead to optimal order quantities which are not relevant for this type of problem.

However, the literature review revealed the possibility of fuzzy programming. Fuzzy programming can also be combined with linear programming. This is suitable for the salt stream while some machines are outdated and therefore not as accurate as they used to be. The lack of accuracy results in fuzzy inputs.

3.2.2 Suitability of Linear Programming

Linear programming focuses on maximizing or minimizing one goal. So, the first question to ask when finding out the suitability of linear programming is whether there is one specific goal to the problem, such as maximization of profit. In the case of the emergency route there is such a goal, namely to minimize the salt that is not used by the Librox department after drying. The salt that cannot be placed at a production line, is the salt that is sent to the D1 emergency route. The next step in a linear programming formulation is to set up the constraints.

The linear function to be minimized is the salt that is dried minus the salt that is used by one of the production lines on the department. An example of a constraint could then be that the salt that is dried for the Librox department can not exceed 45 tons per hour. The next aspect is to write down the non-negative variables. In this case the through puts of each of the production lines are non-negative.

All in all, the linear programming model seems like a possible fit for the salt production process. The final model will be chosen in Chapter 4.

3.2.3 Suitability of Simulated-Annealing

In case of the salt process the goal of the annealing algorithm is to minimize the leftover salt. The annealing process jumps from possibility to possibility to find the optimal equation of production lines to match the incoming salt stream. It is possible to model this as a continuous process. Hence we see simulated-annealing as a suitable optimization technique for the problem.

3.2.4 Suitability of Simulation

First of all Nouryon is familiar with simulation processes. This can help with the implementation phase and the insight.Also, to find a suitable new strategy for the process, it is useful to experiment with different strategies.

The discrete event simulation is known to move from event to event. This would mean that we would look at the process as the steady state, and the events are the changes to a system. Examples of such changes are failures, input changes and an empty bunker. This is a possible technique for this problem, so the approach will be identified further in Chapter 4.

The system dynamics simulation focuses on continuous processing. The technique relies on information feedback. The input consists of the relations between different variables, however the system lacks live data input to use for the system dynamics simulation, so this technique is not ideal.

Finally, the Monte-Carlo simulation might also be possible for this problem, however it is more convenient to simulate from event to event. Turning on and off the machines is an expensive and time-consuming action, so we are looking for a steady state result with little events. The salt production process is more similar to a discrete-event simulation.

3.3 Conclusion from the Literature Review

There are many models available to provide insight for planning production processes. The six models that are found through systematic literature review are: multi-objective modelling, fuzzy programming, linear programming, stochastic programming, non-linear programming and simulation. After further research, it was found that there are three types of models that match the salt production process which are, linear programming, system dynamics and Monte-Carlo simulation. So, from this chapter, we can conclude that both questions at the beginning of the chapter are answered. In the next chapter we choose the model for answering the main research question.

4. Selection of the Approach

The aim of this chapter is to find a suitable technique to substantiate the answer to the main research question:

To avoid capital expenditure, how can the production process be structured to eliminate the emergency silo in the Librox Department?

To answer this question we first select the right model (4.1) and then we discuss the model integration (4.2.

4.1 Model Selection

The models that are found to be usable for this research are (mixed-integer) linear programming, Discrete event Simulation and Simulated Annealing. To make sure the right model is chosen, a multi-criteria decision analysis is used. The decision criteria can be found in Figure 4.1, and are based on research constraints and the company's demands and wishes.

The decision is made as follows. Each of the three methods is ranked on each criteria by assigning a score of minimal 1 and maximal 10 points. This score gives an indication of the performance of this method on the criteria. The performance can be based on both subjective and objective factors, so the assigned score will be substantiated.

The four decision criteria are weighted based on their relative importance for Nouryon. For the research it is most important that the model leads to a valid conclusion. That is why this is the highest ranked criteria with 35% of the weight. Then the expected development and limitations are both weighted with 25%. The model has to be created within the time span and also the model cannot include limitations that make the outcome less realistic, hence they are both rated as 25%. Finally the insight is weighed 15%. The model has to be understood, so this is reflected here, however this is not of main importance as one expert on the model can be enough to use it, so not everyone is obligated to understand it. Then the final model is selected by the highest weighted sum of scores.

4.1.1 Validation - 35%

The ability to answer the main research question is one of the foremost important criteria. Before building the model completely we cannot be sure that the question can be answered through all of the models. With the criteria validation, we weight the certainty that the model will return the answer to the main question.

It is uncertain whether the linear programming model can calculate the continuous process. This decreases the validation of the final answer whether or not to eliminate the emergency route, so the linear program scores a 5 on the criteria validation.

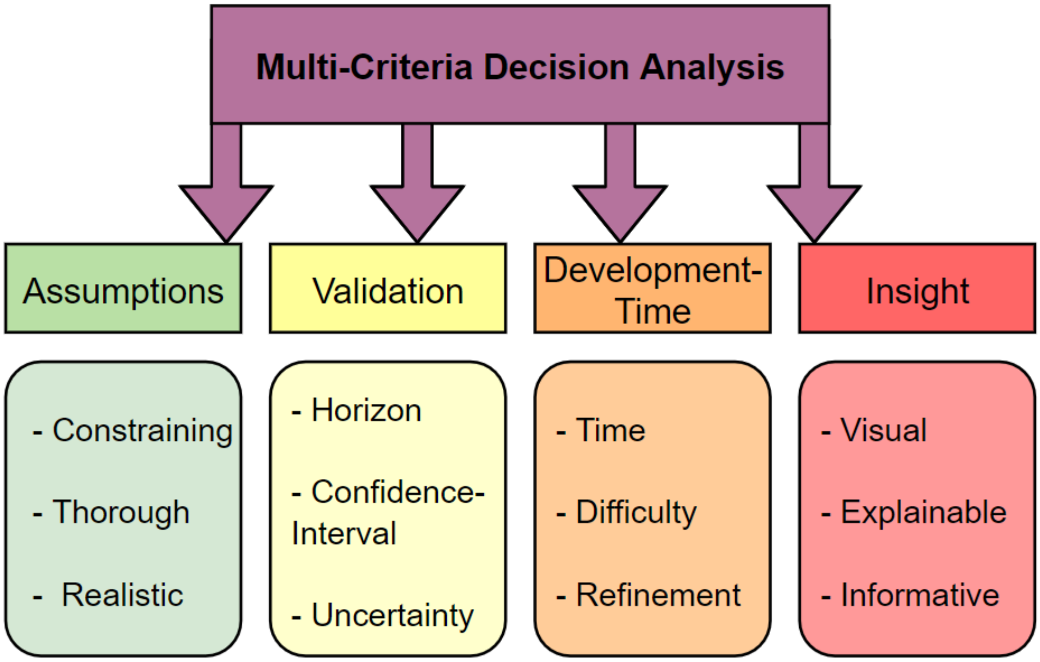

Figure 4.1: Decision Criteria

With Simulated-Annealing it is the least certain that we can find an answer. After the literature research we cannot be 100% sure that the model is appropriate for finding a new strategy for a continuous production process. Simulated annealing is often used for other type of problems, so it is hard to validate the possibilities. So, the Simulated Annealing method scores a 4 on validation.

Simulation models include long term feedback within a system, while it is possible to do a long run that relies on . This makes the result valid for long-term horizons while the information that is gained during a long run is used for further decisions. Furthermore the variability can be included, so the simulation model scores an 8 on the criteria of bringing us towards a valid result.

4.1.2 Undesired Limitations - 25%

We stated that a model is an imitation of the real system. With an imitation there are certain assumptions that have to be made. Each type of model comes with its own set of assumptions. Some of these assumptions are more limiting for the outcome as others, so the models will be rated on their performance on assumptions.

The linear programming model cannot contain fuzzy aspects (chapter 3.2.1). This is an assumption which decreases the value of the outcome. Another assumption that is made, is that the constraints in Linear Programming have to be linear. The prognosis is that this is true, but we cannot be sure yet. So, the Linear Programming model scores a 4 on the criteria of assumptions.

With Simulated Annealing the outcome is referred to as a local optimum. So we cannot be 100% sure that the result is the best strategy. So the Simulated Annealing model scores a 5.

To initiate the simulation model the parameters of each of the entities should be based on real-data. As Nouryon has little data to provide, there are assumptions made such as how often one production line jams. However, even the possibility to implement these assumptions is an advantage, so the simulation scores a 7.

4.1.3 Expected Development Time - 25%

For the scope of this research it is important to take into account the development time. The more time is spent on the creation of the model, the less time is left to make the model more accurate and work out the conclusions.

The Linear Programming model is quite time consuming to build. The constraints and recurrence relation have to be formed specifically for this problem. It is difficult to check whether the system is complete and this might cause some delay, so it scores a 5 on the development time.

The Simulated Annealing is not the most complex system, but still might take extra time as this type of model has not been used very widely in production problems. It was hard to find a comparable problem through literature research. It might be that this is a rather new way of application, while there are no similar examples found yet. Hence the Simulated Annealing system scores a 7.

Simulation involves building the simulation which costs quite some time, however this type of model is relatively simple. It involves the process flow without the fine details of a system such as people and raw materials, so the simulation model scores a 6.

4.1.4 Expected Insight - 15%

One of the main problems has turned out to be the lack of insight into the current process. One of the main objectives of this research is to provide this insight. A more visual model which looks relative to the process flow diagram, brings more insight into the strategy of the solution. The models have different expected added values when it comes to the term of contributing insight into the process. This is a minor criteria for selection, while insight can also be obtained through process mapping or drawing well constructed conclusions.

The Linear Programming model brings the least insight into the current situation. The outcome of the linear program is the least visual, so the process mapping has to be realised through other measures. The score of Linear Programming is a 4.

The Simulated Annealing model provides little insight, but the production lines with their inputs can still be recognizes from the model, so the score is a 6.

Finally, the simulation has a visual aspect. When this model is used by the operators it is likely that it looks familiar. This makes it easier to understand the model, so the simulation scores an 8.

4.1.5 Conclusion Model

When applying the multi-criteria strategy calculation the following scores can be derived using the following formula.

$$max\, v = 0,35 * x_1 + 0,25 * x_2 + 0,25 * x_3 + 0,15 * x_4$$

	Linear-Programming	**Simulated-Annealing**	**Simulation**
Validation (x_1) - 35%	5	6	8
Assumptions(x_2) - 25%	4	5	7
Development Time (x_3) - 25%	5	7	6
Insight (x_4) - 15%	4	6	8

Table 4.1: Multi-Criteria Decision Analysis

The Linear Programming model scores 4.6 the Simulated Annealing model scores 6 and the simulation model scores 7.25 points, so the simulation model scores the highest. From table 4.1 we see that the simulation model also scored the highest score on three out of four criteria. So we conclude that the Discrete-event Simulation is the most appropriate model for this research.

4.2 Model Integration

Now that the model choice for a model is made, we can define how the model should be integrated in the current process. We will answer the following research question:

- How can an optimization technique be integrated in the company for making a simple production plan?

First of all the model lay-out must be close to the reality. The model is supposed to bring insight for the managers as well as the operators. If the model is understood by everyone, it can be used in both the office and the factory. All adjustable inputs in real life must be visual in the model and adjustable to the right standard. For example the dryer can have a processing speed of 20 to 32 tons per hour. The model must have the option to change this processing time. In case this is fully included in the model, the integration stage becomes easier.

The model can be used by the planning department to see what production capacity the Librox department should have. This way the model is integrated in the planning completely. However when the model is used by the means of the planners, there is still need for big changes in the operators working culture.

The model should also bring insight in long term measures. It can be used to test certain new strategies. Nouryon must be able to try different inputs and line settings. For example, if they are interested in turning on a production line for a longer period, they can test the possibilities through the model.

5. Simulation Model

In this chapter we discuss the creation and functionalities of the simulation model. The subjects that are covered in this chapter are the type of simulation (5.1, the conceptual model (5.2), the final model (5.3) and the validation of the final model (5.4).

5.1 Simulation Type

The model is built in the Plant Simulation software. The goal of this simulation study is different from a classic simulation study. In a classic simulation study we aim to improve a certain KPI through different experiments. The goal of this model is solely to visualize and test the possibilities with the current production set up. Therefor the description of the model and conclusions are different than in other simulation studies.

The main objective is to create insight through building a simulation, we aim to prove the functionality of the current production process, and the possibility of producing without the emergency route. This insight can be gained through building a serious game. Clearly, gaining acceptance for a solution is essential to get the system implemented, especially when a lot of independent (and even competing) actors are involved. [Douma et al., 2012]. In this case the implementation of the system refers to eliminating the emergency route.

A serious game is a specific type of simulation with the specific aim of convincing all concerning parties.

5.2 Conceptual Model

The conceptual model is a specific parameter description about a simulation model that will be developed afterwards. A conceptual model contains the objectives, inputs, outputs, simplifications and assumptions of the model. [Robinson, 2008]. Before stating these parameters, a concept flow model is explained. During the development of the simulation model, the conceptual model serves as a guideline.

5.2.1 Concept Flow Model

Figure 5.1 shows the process of salt entering and leaving the Librox department. After the salt is dried, it is sent to the Librox bunker or immediately to the production lines. From the bunker it is then sent to one of the production lines. At the moment the input of the Librox bunker is higher than the output of the bunker, the bunker fills up. If the buffer then exceeds 20 ton of salt, the salt flows to the emergency silo.

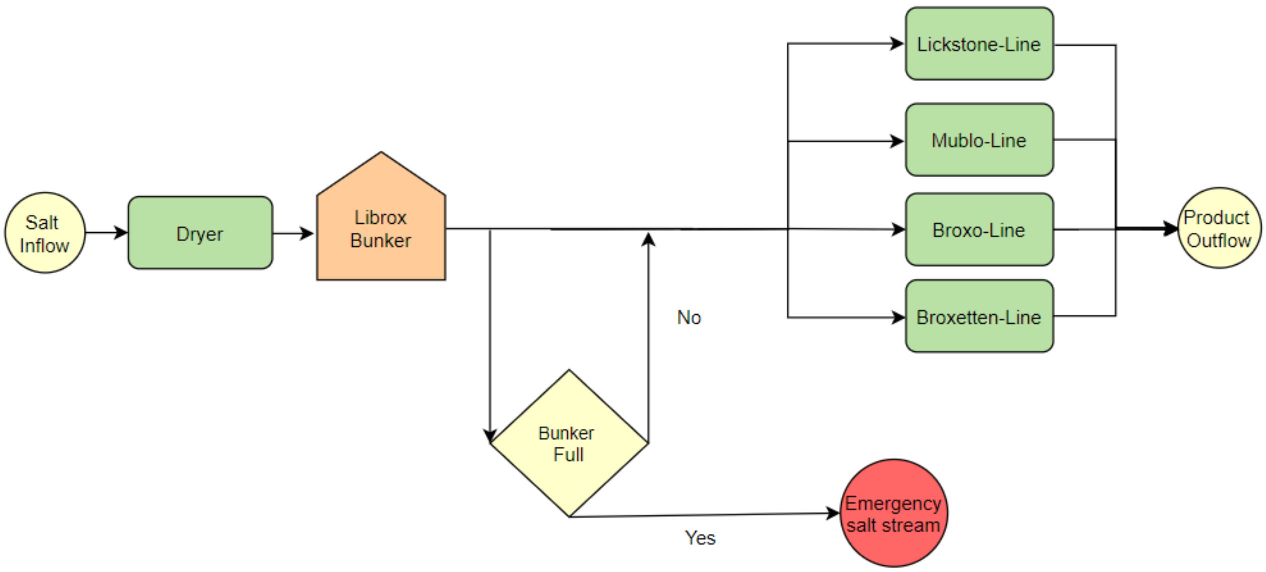

Figure 5.1: Concept Simulation Model Flow

5.2.2 Objectives

The first and main objective is to find out whether the Librox department can process without the use of the emergency route over a long-horizon. A second objective is to make the simulation model represent the Librox department to such an extend that the operators can recognize the production lines so that the model can be used for testing strategies and production planning.

5.2.3 Concept Inputs

- The deterministic throughput capacity of the Broxo-Line, the Broxetten-Line, The Likstenen-Line and the Multiblok-Line.
- The minimum and maximum capacity of the Librox-Bunker and the capacity options of the Dryer.
- The priority of production planning for a specific day.

The inputs of the final model are all the values that we put into the model after the completion of the conceptual model. These values can easily be changed without destroying the logic behind the simulation model. Therefore the model inputs are the experimental factors. If the company decides to allocate one of the other two dryers, the input of the dryer can be changed to the throughput capacity of this dryer.

5.2.4 Outputs

The outputs of the model are variables that we aim to measure within the model.

- Buffer Fill Rate: The main objective is the fill-rate of the Librox bunker which is continuously measured.
- Output per line: The output flow is measured for every line.

5.2.5 Simplifications

For the research there are a few simplifications. These consist of aspects that are relevant in the real situation, however these aspects do not add value towards finding the solution to this specific problem.

- There are no actual employees in the simulation model. The assumptions state that all production lines can run active at once, so there is no added value in including workers.
- The Librox works with one fixed dryer. In the actual process the dryer that is used can change over time. However the minimal throughput of the dryers is exactly equal and the maximal throughput of the dryers only deviates 2 ton/hour. So, we consider one of the dryers as the input.
- The idleness of operators or unwillingness to turn on production lines is not considered. The goal of the research is to test whether producing without the D1 silo is possible if we filter out human errors. The human errors are described in the second chapter, and we discuss these further later.
- Instead of calculating the amounts to kilograms, the amounts are all presented as liter units. The model is meant to provide insight, and when converting the salt to kilograms within the model, the input and output seem to be different. This might decrease the understanding. For clarity the unit is set to liters through the entire process.
- Full factory shut downs are not taken into consideration.

5.2.6 Assumptions

- There are enough employees to work on all four lines at once.
- There is no storage maximum. In order to answer the question whether we can produce without the emergency route, we will assume that the inventory of each of the products is infinite.

5.3 Final Model

After configuring the conceptual model, the actual simulation is set-up. Figure 5.2 shows the simulation model. The layout of the model is the same as the conceptual model, only the emergency route is excluded, as this is the goal of the assignment. A visual demonstration of the functionalities can be found on:

Link: https://youtu.be/UMVeiuCSJRQ

5.3.1 Functionality Model

The moment the simulation starts, the input from Industrial Salt, which is referred to as BolkInput, starts to flow according to the chosen processing speed. The salt flows to the dryer and the buffer starts to fill. The lines can then be turned on and off to keep the buffer level available. The goal is to prevent the buffer from exceeding 20,000 liters, while this initiates the emergency route. After drying the salt, it is sent to the production lines. Salt can only be received when the production lines are turned on in the settings at "Machine Running", see Figure 5.2. If the production lines demand more salt than is available, through both the buffer and the dryer, the production lines are turned off automatically in reverse priority. If a line is turned on the warm-up period starts and the line keeps producing until the next event. So, reasons for a line to stop are a failure, a manual turnoff or a shortage of input.

The goal is to manage the settings so that the input from the dryer and the output from the production lines is equal. This way the buffer fills up slowly and the process requires minimal changes. The settings differ every day as the priority changes, which makes the optimal production quantity different. Furthermore the failures require that the settings are changed as well. The steering takes place from both the input side (dryer setting) and the production lines by turning them on and off. The system is not stable as the buffer content changes constantly. This way there is not one correct answer to the sequence, so the system has to be controlled continuously. The main code behind the model can be found in Appendix C

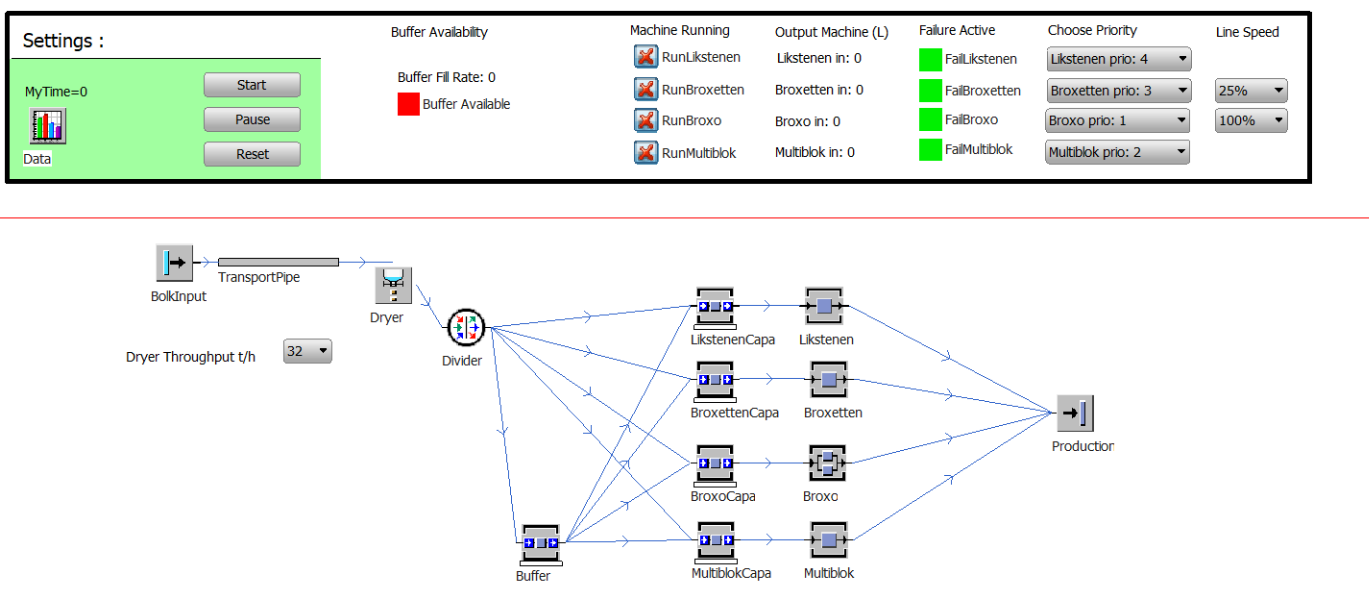

Figure 5.2: Simulation Model

5.3.2 Inputs

Table 5.1 shows the inputs of the production lines, this refers to the time it takes to process one liter on this line. The column speed alt, defines whether a production line can be alternated in terms of throughput speed.

From Table 5.1 we can see that both the Broxetten and Broxo line are adjustable in speed. So, for both these lines the speed can be set using a drop down menu with the choice of a speed of 25, 50, 75 and 100 percent. Finally the Broxo line is actually a Parallel Station. This is a station with two parallel lines as we can see in Figure 5.2, while there are two small rectangles within the station. The parallel lines mean that two products can be made simultaneously, so the processing time of 0.36 seconds means that there are two liters processed within this time span.

Other adaptable inputs are the dryer throughput, the priority and the failures. The dryer has a minimum throughput of 20 tons per hour and a maximum throughput of 32 tons per hour. The dryer throughput is often set in advance of a production run, as the response time is slow. In case of dryer changes the operators have to call Bulk to change their outflow stream. If the dryer speed is changed in the simulation model there is a delay of 30 minutes to imitate the response time.

The priority is chosen in the settings below "Choose priority" and in these settings the highest priority is seen as the highest number. So in Figure 5.2, the Likstenen-line has the highest priority. It is important that neither lines have the same priority. Furthermore the failures can be initiated by pressing the green buttons next to the line-failures. This makes it possible to research extreme situations such as three simultaneous failures.

Processing Time	**1 liter**	**Speed Alt**
Likstenen	0.45 sec	no
Broxetten	0.30 sec	yes
Broxo	0.36* sec	yes
Multiblok	0.36 sec	no

Table 5.1: Input Processing Time

5.3.3 Testing Situations in Model

To answer the core research question on eliminating the emergency route, all extreme situations require analysing. With the serious game model it is possible to test regular day situations, to see whether the use of the emergency route is necessary. There are different situations that require testing.

5.3.3.1 Regular Day

The first situation to test without the emergency route is a regular day. This is a day without extraordinary failures or maintenance. The goal of a regular day is to follow the priority to make minimum amounts of the given products. In the example in Figure 5.2 the highest priority is the Likstenen. Hence the first machine to turn on is the Likstenen line. The next priority is the Broxetten machine. Depending on the chosen dryer throughput the Multiblok line can be turned on and off every few hours. The buffer availability button turns red when the buffer is filled for 80% . When the buffer availability button turns red there is enough time to turn on a third production line to avoid the use of the emergency route. If the combination of priority lines is too low for the throughput of the dryer, the dryer throughput can be turned down to make the number of adjustments lower.

5.3.3.2 Decreased Start Capacity

In some situations a shift start with decreased capacity. This is possible if one production line is unavailable through a failure or maintenance. In this case the priority of the unavailable line is set to the lowest and the day can be treated as a regular day, while it is never necessary to have all four lines available to prevent the use of the emergency route. This does require quick response when the buffer availability turns red, while the buffer can be emptied with one production line only, however three lines is enough to handle the entire dryer throughput.

5.3.3.3 Multiple Line Fails

A possible case is the situation in which multiple production lines fail simultaneously. To test this to the extreme we look at the situation in which the two fastest lines fail, namely the Broxo line and the Broxetten line. In this specific case there are multiple responses possible. If only two production lines are available it is smart to set the dryer throughput to it's minimum, as the total capacity is reduced by the failures. In the rare situation where the dryer setting is at 32 tons of salt per hour when the Broxetten and Broxo line fail, the dryer should be set to 20 ton/hour. The response time of the dryer is 30 minutes. The summation of the capacity of the two working lines adds up to 20 tons per hour which means that the buffer fills itself 12 tons per hour. With the response time of 30 minutes the buffer fill rate will increase with 6 tons. From this we can conclude that producing without the emergency route in this extreme failure case is possible if the buffer does not exceed a fill rate of 14 tons. Hence a possible new strategy should include an alarm as the buffer exceeds 14 tons of salt.

5.3.3.4 Conclusions from the Situations

Through testing all different day to day situations, we conclude that the emergency route can be eliminated from the current production process. The different situations and the functionality of the model needs validation. After validating we can write an advice and conclusions for the future. From the situation tests we concluded that all emergency route situations can be prevented if only the dryer throughput is accurately set. To fully integrate a new strategy we need still to find a way to find the right dryer throughput. More details on the throughput choices can be found in Chapter 5.5

5.4 Validation Model

Another important step during a simulation study is validation of the simulation model. With the validation of the simulation model it is checked if the simulation model correctly represents the real-life situation. The validation aims to check if the simulation model introduced during this chapter accurately represents the salt production process.

5.4.1 Theory of Validation

There are several ways of validating a model. The two most common types of validation are white and black-box validation. In black-box validation a researcher compares the output of the model to the output of the actual process. [Law, 2010] This method relies mainly on data. White box testing focuses on comparing the internal behaviour of a system with the behaviour on the model. This type of validation relies on experts in a system. The real-life data of this specific system is not complete. It was not possible to attain accurate live data of salt that is sent to the emergency route. This way the output of the actual process will never be the same as the output of the model. Furthermore it is most important that the internal structure of the model is accurate, as the parameters might change, but the functionality does not change, so White-box validation is most appropriate.

5.4.2 White-Box Validation

In order to execute the white box validation, an expert panel of 5 people was put together. The expert panel includes 3 managers with each their own perspective and two operators with experience in the Librox department. After explaining the full model the panel filled in a survey with questions on the visual representations, the inputs, the availability (completeness of options) and the result. The interviews were held separately, or in pairs, due to COVID-19. The respondents rated the statements from 1 to 5 with;

1 = completely disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 = completely agree.

The received comments are used to improve the research.

5.4.2.1 Validation Survey

The survey received very positive responses. The first important statement that the panel ranked is:

- The model gives a correct visualization of the process flow.

From the responses, it became clear that the buffer is not positioned accurately. However, for the answer to the research questions the respondents argued that the position does not make a difference. In the real life situation all salt flows through the bunker before entering the production lines, but the steering of the salt is the same in both situations. Furthermore the average score of the question was a 4, which means the panel agrees that the model gives the correct visualization of the process flow.

The next important statement is:

- All adjustable input buttons are clear and complete.

To give a realistic advice it must be certain that all options are available. In the real process the operators have control through many different settings, and all these options must be present in the model. From the interviews it was found that two out of the four production lines are adjustable in speed. After this interview the speed alteration buttons are added to the model. Furthermore the question scores an average of four points, so the panel agreed with the statement.

- The model can include all real-life situations

Furthermore it is important that the model has the option to simulate every situation that the operators have to face during their shift. The majority of the respondents agreed with this statement, however the operators did not agree fully. Their perspective on the model is quite negative, as they have little experience with this type of technology. They were sceptic about whether or not the model can cover all situations. From this interview we discovered that there are situations in which all production lines stop simultaneously. This was not in the scope of the current research, so this topic continues in the conclusions.

Finally the panel was asked to answer questions on the results.

- The model enlarges the insight in the current process
- The model can help to answer the question: To avoid capital expenditure, how can the production process be structured to eliminate the emergency silo in the Librox Department?

Every single respondent agreed with these statements. The statements scored a rounded 4 as well, so the panel agrees with the results that the model provides. All recommendations that followed from the interviews are included in either the results or the recommendations. Generally speaking, the management interviews had a positive outcome. The model was rated valid and the result was appreciated. The operators were more sceptic as they feel slightly violated by the advice to change the process. However the operators did agree on the functionality of the model.

5.5 Operators Integration

Now that the model is validated, we must find a way to make use of it. The validation phase shows that the operators had a harder time understanding the model. Nouryon seeks a way to make use of the findings in the future. The model is made in the Plant Simulation software by SIEMENS, but at this moment this can only be reached through a University license. Nouryon can choose to invest in a business license to open the model.

Nouryon is considering to invest in software, or rebuild the model in available software. However the model is still quite difficult to understand for the operators, so we need a way to use this new information to increase their insight.

To improve the insight of the operators a small excel dashboard is built. In this dashboard the operators can practice with the impact of turning lines on and off. Figure 5.3 shows the front face of the dashboard. The operators can adjust all blue cells. In the column "aan/uit" they choose whether the production line is turned on (aan) or off (uit), the cells show a drop-down menu when they are pressed. If the Broxo or Broxetten line is turned on, the speed column cell turns blue as the speed of these two lines can be adjusted. The most optimal dryer setting is then showed on the right. The cell is now red, while the dryer needs a minimum throughput of 20 tons of salt, but when the turned on line capacity adds up to a dryer setting of between 20 and 32 tons the cell turns green.

All input data is located in different sheets, and the cells that cannot be changed in real-life are locked with a password. This dashboard can be used to determine the most appropriate dryer settings for a day or shift. The inputs can be changed if necessary, but the dashboard is now locked to decrease the complexity.

Furthermore the visual demonstration, which can be found in Chapter 5.3, is made to help the operators through their educational period. With the video and the excel dashboard they can increase their insight of the Librox department.

Lijn	Snelheid	aan/uit
Likstenen	100%	uit
Broxo	75%	aan
Broxetten	100%	uit
Multiblok	100%	uit

Droger stand in ton	9

Figure 5.3: Excel Dashboard

5.6 Conclusions from Building the Model

After finding out what type of simulation is the best fit for solving the problem, we build the serious game with the goal of gaining acceptance for the answer of the main question. The game is built to approach the actual production process, and the real life situations can now show to be possible without the use of an emergency route. Furthermore the model has showed to be valid by the experts of Nouryon and finally the chapter ends with an explanation on how the solution can be implemented.

6. Conclusions

This chapter covers the conclusions from the model. Now that the model is proved to be a true representation of the Librox department, we can work towards a new strategy. To do so, an answer is discussed on the possibility of eliminating the emergency route (6.1), we measure the strategy measures (6.2 and we measure the expected costs (6.3.

6.1 Eliminating the Emergency Route

The first and main question to answer in the conclusion is:

To what extent is it possible to produce at the Librox department, without the emergency route?

Since the emergency route is used, it has become quite uncertain whether producing without an emergency route is possible.

The model proves that it is definitely possible to produce at the Librox department, without the emergency route.

The model does not include the emergency silo, so a long period of processing without the silo proves that the emergency route is unnecessary. The Librox Buffer is large enough to catch salt in case of a failure. The input stream is even met when there is maintenance in one line and a failure in another. As long as there are at least two lines running, the buffer fills very slowly. If the operators respond when the buffer availability turns red, they are still in time to turn on an extra production line. The model shows that the production process can run for infinity as long as there is continuous control.

6.1.1 Emergency Plan

The model shows that the regular emergency initiations are unnecessary. However there is still one situation in which all production lines stop simultaneously. If all lines fail simultaneously, the buffer has a maximum fill span of 1 hour. However when the buffer is filled up to 80% at the moment of the failure, it will fill within minutes. In order to eliminate the emergency route there is need for extra research on the possibilities during an actual emergency situation. An example of a solution can be to have a truck waiting at all times to catch the salt in case of an emergency. With all simplifications in order, we have proven that the emergency route is unnecessary, however there can still be an actual emergency that needs different solving.

6.2 Strategy Measures

The production process is currently dependent on the emergency route. As defined in Chapter 2.2 the salt is sent to the emergency route for several reasons. To eliminate the emergency route there are measures that have to be taken. With use of the model we advise what measures have to be taken to adapt a new strategy. The question that is answered is as follows:

What measures have to be taken to start the new strategy?

6.2.1 Data Measurement

In order to improve the management of production, the data measurement within the department can use some improvement. The department lacks real-life data measurements. The operator that is responsible for controlling the settings receives an alarm when the Librox bunker is nearly empty. This helps to stay in control over the salt stream. However the operators should also receive an alarm when the buffer is nearly full. The model includes an alarm when the buffer is filled up to 80%. With this alarm we have proven that a flooding of the buffer can be prevented. Furthermore the new strategy can only succeed when there is a certain extent of control. If the data is measured and used in the right places, the managers in the office have automatically more control and insight.

6.2.2 Automation

The current situation has proven that the operators do not steer the settings in order to avoid the initiation of the emergency route. The first change to realise is to create control over the settings. Settings involve turning on and off production lines. The current strategy is used for a long period, so it involves big changes for the operators. The model shows that human steering is a possibility however it does involve continuous control and a big change from the current strategy. A possibility to assure success is to make the process automatic. The simulation model can be turned into a stand alone model. This way the turning on and off of the production lines is no longer the responsibility of the operators.

6.2.3 Awareness

Now that it is proven that a normal production day does not need to include the emergency route, the planning strategy should be followed better. During the final interviews the people with management positions really started to brainstorm why the route is currently used, and how to prevent this. The insight that the route is not needed helps to realise an improved planning. The people in the office have to prioritize change to realise a new production culture. They can take back the control and improve the monitoring over the Librox department.

6.3 Expected Costs

What are the expected costs of changing the process to this extent?

The first change to adapt is to insert an alarm when the buffer reaches a certain fill rate. This is a relatively low investment. The alarm system is already used, this specific alarm only needs to be added. If Nouryon decides not to change the entire strategy, it would be even better to improve the receive stage of this alarm system. The operators receive a text message to notify an alarm, but they do not look at their cell phones all the time. A small investment can be made into bracelets that turn red in case of an alarm. This way the alarms cannot be missed, and the level of human steering mistakes can decrease.

The improvement of data measures is also a valuable investment. Nouryon is already working on improving these measures, so it is a small initiative to include an accurate measurement of the Librox buffer.

Full automation is a bigger investment. There are companies that are specialized in automating processes like the Librox department. For example Viro in Hengelo is interested in changing the process to realise automation. Viro is a multi-disciplinary engineering company, so they can realise the change from the software to full-implementation. The costs of automation are estimated to be about one ton. This is quite a lot of money, however the estimated costs of a new silo are much higher.

7. Advice and Recommendations

After drawing the conclusion, there has yet to be given an advice towards the company. We will first give the advice (7.1) and then provide some recommendations for further research (7.2).

7.1 Advice

From Chapter 6 we conclude that the advice is to increase the control over the Librox department. There are two ways to increase the control over the Librox department. Now that it is proven that the department can process without the use of an emergency route, the summarized advice of this report is as follows:

- Invest in an automated control system.

Change this model to a controlled system that takes away the responsibility of the settings of the department. This way the operators can do their shifts without extra responsibility and the D1 route can be eliminated without extra stress.

Before the company is willing to automate the system completely, the control can also be improved through:

- Implement extra alarms.
- Improve the responsibility.

The Librox can run without the D1 silo, however the human steering currently results in a large salt loss for the department. These two changes can help to change the current strategy to a process without emergency route. The control can be improved through implementing the alarm messages to operators. This is a simple change that can have great consequences. Secondly, improved control from the managers can help to prevent the salt from going to the emergency route. Now that there is a lack of responsibility the salt streams toward D1 constantly, but if there is a person that feels responsible for preventing the D1 salt stream, it can be prevented completely.

7.2 Recommendations

During the research we came across some interesting opportunities for Nouryon. In this section the recommendations for further research are explained.

7.2.1 True Emergency Situations

It has yet to be researched what effect an emergency situation has on the Librox department. An emergency situation hereby refers to a situation in which all production lines stop simultaneously. The prognoses is that the Librox buffer fills up within half an hour, if not faster. The research should involve questions such as: "How often does such a situation occur?" and "What are the options of storing the incoming salt?".

7.2.2 Automation Options

From this research we concluded that automation is a good option for Nouryon. There is an advice regarding expected costs and sourcing options as mentioned in the conclusions.

Furthermore, there is an option of assigning another graduation assignment on changing the model to a stand-alone model, Nouryon can invest in their own license of a simulation tool, or the automation can be outsourced to a company specialized in this.

7.2.3 Control Improvement

Finally it is valuable to do further research into the control problem. From the perspective of an outsider we see a structural control and motivational problem. The planning is not followed accurately on a daily basis. This problem might be caused by motivational issues or strategy misunderstandings. A lot of improvement can be realised by researching and changing this culture. Even with the new strategy it is likely that there will be a lot of mistakes due to the control issues, so it is recommended to dig deeper into this problem.

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A. Appendix: Non-Suiting Literature

A.1 Multi-Objective Modelling

Multi-Objective Modelling, also known as Multi-Objective Programming concerns a research area where multiple variables are taken into consideration. It is a mathematical programming method that enables to optimize multiple variables simultaneously. An example of use is a problem with the goal of minimizing costs while maximizing comfort of a certain product, in contrast to the linear programming model that is discussed later, that aims to optimise one variable only.

Multi-Objective optimization can be used in different research fields, but it is often used for economic problems and is rising in interest in the chemical engineering research field. The main reason for this is multiple-variable consideration allows to take into account energy consumption. This research model is introduced in an article by Fu et al. [2019] as a fit for a chemical engineering problem.

The problem can be formulated as follows:

$$min(f_1(x), f_2(x), ..., f_k(x))$$

$$s.t. x \in X$$

$$k \geq 2$$

Where k is the number of objectives and the set X is the feasible set of decision vectors.

This research model is introduced in an article by Fu et al. [2019] as a fit for a chemical engineering problem.

A.1.1 Suitability of Multi-Objective Modelling

The multi-objective model seemed valid at first. The literature review revealed the rising interest in the Chemical Engineering field. However the model was specifically valid when energy consumption is of concern. In the salt production process energy consumption is not one of the variables. More specific the multi-objective model is only relevant when multiple variables are equally important. For the to be created model there is only one variable considered, so it can be concluded that the multi-objective model is not a good match.

A.2 Non-Linear Programming

Non-linear programming models are useful when some constraints or objectives are non-linear.[Cay et al., 2019] Non-linear expressions include relationships in which variables are squared, cubed, taken to powers other than one, or multiplied or divided by each other. Generally speaking non-linear models are harder to solve for several reasons.

A.2.1 Suitability of Non-Linear Programming

Non-linear programming distinguishes itself from linear programming as the constraints are non-linear. The constraints of the problem have not been formulated completely, but until now there has not yet been signaled a non-linear constrained. If there are constrains that are found to be non-linear later, it will come back to linear-programming.

B. Appendix: Systematic Literature Review

B.1 Motivation

In this phase of the research, the goal is to understand all possibilities of learning more about the process. There is insight in the parameters and constraints of the research problem, and it is time to find out all possible ways to learn more.

Number	**Criteria**	**Reason for Exclusion**
1	Pre 1984 articles	Process Simulation was first introduced in 1984. To compare different methods I have to start researching in a period where both simulation and alternatives are an option.
2	Not written in English	The research is conducted in English, the articles have to be understood by both me and my supervisors.
3	Too mathematical	If the research is too mathematical with too many formulas it is not interesting for my research.
4	Multi-depot/Multi-site	Studies about multi-site or multi-depot are not comparable to my research of one site.
5	Climate	There are surprisingly many articles about climate change, which is not relevant for the research.

Table B.1: Exclusion Criteria

Number	**Criteria**	**Reason for Inclusion**
1	Subject Area: Mathematics, Engineering or Management	The research will be most likely to be useful when it originates from one of these fields.
2	Fluctuation or varying or uncertain	It is useful to include articles who struggle with uncertain demand, as this is the case for this research.
3	Chemical Industry	It is useful to include articles who focus specifically on chemical industry issues as they deal with the same uncertainties.

Table B.2: Inclusion Criteria

Search String	Scope	Date Range	Entries
Search Protocol for Scopus			
"production process" AND "supply" AND "Demand" AND ("Uncertain" OR "Fluctuating")	TITLE-ABS-KEY	1984-present	193
"Production process" AND "supply" AND "Demand" AND ("Uncertain" OR "Fluctuating") AND "Optimization"	TITLE-ABS-KEY	1984-present	80
"Model" AND "Production Process" AND ("Uncertain" OR "Fluctuating") AND "Optimization"	TITLE-ABS-KEY	1984-present	84
Search Protocol For Web of Science		1984-present	
"Production process" AND "Supply" AND "Demand"AND ("Uncertain"OR "Fluctuating") AND "Optimization"	Topic	1984-present	5
("Production Process"AND ("Uncertain"OR "Fluctuating") AND "Optimization" AND "Model"	Topic	1984-present	37
Total in Mendeley			399
Removing Duplicates			-78
Applying Inclusion Criteria			-123
Applying Exclusion Criteria			-168
Total Selected for Review			30

Table B.3: Article Search Strategy

Title	**Year**	**Author(s)**	**Model**	**Demand S/D**
Stochastic multi-objective modelling and optimization of an energy-conscious distributed permutation flow shop scheduling problem with the total tardiness constraint	2019	Fu, Y.a, Tian, G.b,cEmail Author, Fathollahi-Fard, A.M.d, Ahmadi, A.d, Zhang, C.e	Multi-Objective Modelling	S
A fuzzy random EPQ model for imperfect quality items with possibility and necessity constraints	2015	Kumar, R.S., Goswami, A.	Fuzzy Programming (EPQ)	D
Integration of Production Planning and Scheduling Based on RTN Representation under Uncertainties	2019	Tao Zhang, Yue Wang, Xin Jin	Discrete-time Linear Programming	D
Genetic optimization of order scheduling with multiple uncertainties	2008	Z.X.Guo, J.T.Fan, W.K.Wong, S.F.Chan S.Y.S.Leung,	Stochastic Programming	S
Operational decisions for multi-period industrial gas pipeline networks under uncertainty	2019	Cay, P, Mancilla, C, Storer, RH, Zuluaga, LF	Non-Linear Programming	D
Consider discrete event simulation	2010	Cope, D	Discrete-event Simulation	S

Table B.4: Final Concept Matrix

C. Simulation Code

```
-> integer

var successors : any[]

successors.append(.Models.Frame.LikstenenCapa)
successors.append(.Models.Frame.BroxettenCapa)
successors.append(.Models.Frame.BroxoCapa)
successors.append(.Models.Frame.MultiblokCapa)

var maxPrio := -1

for var index := 1 to  successors.dim
    if (successors[index].NumMU <= (successors[index].Capacity - 1)) and not (successors[index].Stopped or (successors[index].Pause =
        maxPrio := max(maxPrio,successors[index].myPrio)
    end;
next;

for var index := 1 to  successors.dim
    if successors[index].myPrio = maxPrio
        return index + 1
    end;
next;

-- buffer is on exit 1
return 1
```

Figure C.1: Divider Code

```
if .Models.Frame.LikstenenCapa.ContentsList.yDim = 0
    .Models.Frame.RunLikstenen.Value := false
end
```

Figure C.2: Line Entrance Code

```
if ?.Value
    .Models.Frame.Likstenen.Stopped := false
    .Models.Frame.Likstenen.startPause(?.startupTime)
    .Models.Frame.LikstenenCapa.Stopped :=false
    .Models.Frame.LikstenenCapa.startPause(?.startupTime)
else
    .Models.Frame.Likstenen.Stopped := true
    .Models.Frame.LikstenenCapa.Stopped :=true
end
```

Figure C.3: Run Button Code