Optimizing ramp up speed of packing lines

Koks, T.

Award date:
2018

Department of Industrial Engineering and Innovation Sciences
Operations Planning Accounting & Control Group

Optimizing Ramp up Speed of Packing Lines

Master Thesis

Tom Koks

Supervisors:
Dr. A.E. (Alp) Akay
Prof. dr. ir. I.J.B.F (Ivo) Adan
Ir. A. (Arjan) den Hartog

Eindhoven, Tuesday 18th December, 2018

Abstract

In this research the ramp up phase of the canning line at Company X is analyzed. The aim of this research is to increase the production volume during the ramp up phase. The objective is pursued by evaluating different policies using simulation. In this simulation, a Greedy algorithm is used that serves as a targeted search method, rather than calculating each possible policy. The policy that this Greedy algorithm generates shows a significant increase of approximately 32% of the total production volume during the ramp up period of the packing line.

NOTE: To make this thesis confidential, the name of the company will be "Company X"

Executive summary

Recently the baby milk powder industry was under explicit attention by the media. The insatiable demand for baby milk powder kept increasing, mainly by Chinese customers. This was one of the main reasons for Company X to invest in a new factory in Place Y, where three packing lines and two powder processing lines are hosted. Because the first packing line recently started with commercial production, the packing line is vulnerable and the pressure for performance is high. Moreover, the demand needs to be satisfied as early as possible, so the total production volume during the ramp up phase need to be maximized. Therefore, we aim to maximize the production volume of the packing line during the ramp up phase in this Thesis.

As we observe in many manufacturing industries, the ramp up phase of manufacturing lines is of increasing importance to the manufacturer. The trend can be explained by the growing demand of the markets, which is the case for Company Xs market as well. The three packing lines that Company X hosts in their new factory in Place Y start subsequently with commercial production. Therefore, the first packing line is analyzed thoroughly during the ramp up phase as an example for the two packing lines that will follow.

In this analysis, relations are identified and a model is generated as Figure 1 visualizes. This is a simplified model of reality of the packing line. We chose for a simplification to make the model analyzable, but moreover to enable the creation of a simulation model of the packing line. Timing and values of the input variables influence the total production volume strongly and therefore they need to be chosen carefully. This choice for the set of decision variables is considered the policy of Company X during the ramp up phase. In this policy we consider the adding of teams, hours consumed by Routine Production Activities (RPAs) and Line Speed increase as decision variables that we enter in the system. Table 1 compares the differences in input variables of the policy that Company X is currently uses and the improved policy following our algorithm.

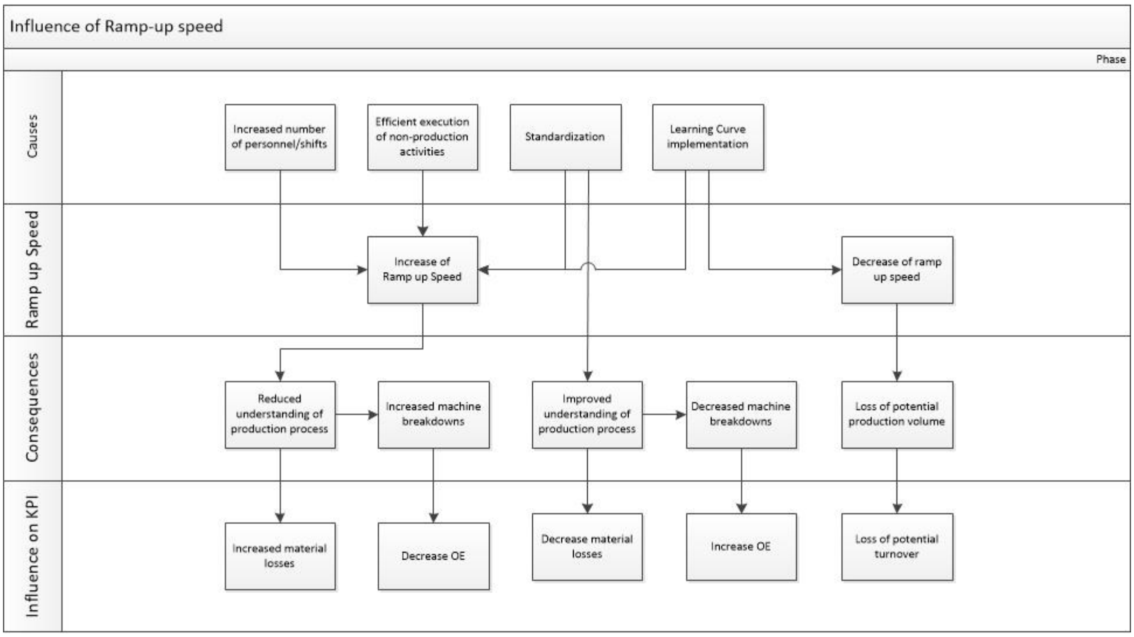

Figure 1: Model of first packing line in the Production facility in Place Y

The current policy that Company X applies on the ramp up of the first packing line is based on experience of other ramp ups of different production facilities in the Company X network. However, these production facilties have different characteristics than the production facility in Place Y. Think of a divers product portfolio in Place Y, while the other production facilities have a limited diversity of products in their product portfolio. The chosen policy is not necessarily the best policy and the aim of this thesis is to find an improved policy that results in an increased total production volume during the ramp up phase of the packing line. To obtain this improved policy we apply the Greedy algorithm on the simulation that represents the packing line. This algorithm checks the impact of a slight change of each decision variable and implements the change with the highest impact. This is iterated until the impact of all changes of decision variables have a negative impact. Then the best result is obtained using this algorithm. Since the characteristics of the three packing lines are similar, we assume that the policy can be applied on the two following packing lines as well. Therefore, the result of the algorithm also serve as a recommendation for the future packing lines.

Decision Variable	Current situation	Improved policy
Adding Teams	week 1,20,24,50	week 1, 20, 24, 28
RPA Pattern	15 + 0.608*week	24 + 0.486*week
Increase Line Speed	week 6, 15, 25	week 6, 12, 18
Standardization	100%	100%

Table 1: Decision variables, obtained after Greedy algorithm

The policy that we recommend Company X to apply on their future packing lines is displayed in Table 1. It shows the importance of any of the decision variables, but the Greedy algorithm shows that the impact of decision variables differ. Standardization is applied in the current policy in the ramp up phase, but in practice Standardization does not get priority to apply during the ramp up phase. Moreover, it can be applied during the Production System Design and Development stage, which occurs far before the start of commercial production. During Factory Acceptance Tests (FATs) and Site Acceptance Tests (SATs) that Company X performs, Standardization should be applied. During ramp up the remaining decision variables were optimized by Greedy. The impact of registering products early has the biggest impact relative to the effort that the decision variables takes. The timing of shifts is the second decision variable with the most impact relative to the effort. Many production hours become available when an extra team is added earlier, but this comes at a price. Moreover, constraints to the timing of adding of teams are set, because the new operators need to understand and control the process sufficiently to be able to execute the processes properly, know how to act in case of machine failure, and teach new operators how to operate properly. The last decision variable Line Speed does not take too much effort to apply, but the downside is that many downtimes occur when the Line Speed is increased. Therefore, the impact is lower relative to the effort when comparing it to the early registration of products and the timing of adding teams.

These adjustments will increase the total production volume by 32.44 % and the net total production volume by even by 33.39%. Besides this increase, it is an environmental conscious decision to implement this policy, for it generates less waste.

	Current situation	Improved policy
Total Production Volume	34986 cans	46334 cans
Material Loss	11.2%	9.42%
Net Production Volume	31462 cans	41969 cans

Table 2: Production volume during the ramp up phase before and after improvement

Preface

The present Thesis is the result of the largest research project that I have conducted during my years as a student. Moreover, it marks the transition for me from a student live to a more civilized one. This transition was not possible without the support of all who supported me during this research that I conducted at Company X in collaboration with TU Eindhoven. In this preface I would like to thank everybody, who made this research a success.

Starting with my first supervisor from the TU/e, Alp Akçay. Your critical view on conducting research and your knowledge regarding simulation helped me significantly improve the scientific value of this research. Especially in the final phase you took extensively the time to review my thoughts and report to improve the quality of the research. Then, Ivo Adan, it was an honor to participate as the first batch of students in the Master you developed. We discussed our shared interest regularly before you agreed on being my second supervisor. During the research you proved your extensive expertise with your critical view and constructive criticism.

Without the extensive support of Company X I would probably have to be asking for data still. Therefore, I would like to thank Supervisor 1 and Supervisor 2 in particular, as my first and second supervisor. Supervisor 1, although you had a tight schedule in a hectic phase, you found weekly time to catch up and discuss what we could improve for both Company X and the research. Moreover, you were an inexhaustible source of data, when I wanted to compare production facilities to each other (once again). Supervisor 2, thank you for being the most optimistic and energetic start up manager that I have met. Not a single question was too much for you and every employee (including me) could always count on your involvement. At last I would like to thanks all employees of Company X that made me feel like one of them instead of another student that needed to finish his Master degree. I value that greatly.

I would like to conclude with thanking my family and friends that supported me in reaching the last hurdle of my student time. I would like to thank Duçibus for making my student time, the best time I could ever imagine. I would like to thank the 52nd board of Industria for an unforgettable year that we experienced intensively together. Finally, I would like to thank my family for their unconditional support in anything I did.

Tom Koks, November 2018

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Motivation

Company x is a leading company in the manufacturing Industry. Recently, Company X invested over €x million to build a new production facility in Place Y. In this new production facility in Place Y three packing lines and two spraydryers are hosted. The first packing line produces cans with baby milk powder and is the main focus of this Master Thesis. In June 2018 this packing line started commercial production. Company X developed a plan to ramp up this packing line based on the experience of production facilities in their network. Recently, vertical ramp up has become a popular topic in the manufacturing performance. Therefore, Company X was curious for policies that optimize the performance of the packing lines during the ramp up phase. The motivation for this research is mainly driven by the practical applicability on the packing lines of Company X.

1.2 Literature Review

The objective of this literature review is to identify possible gaps in the literature, which helps us positioning the present thesis in the literature.

Literature explains that a well organized ramp up is demanded more and more by the rapidly growing manufacturing market (Martin Haller, 2003) and more recently we observe that a "vertical ramp up" is more and more a technique that manufacturers apply on their manufacturing line in ramp up phase (F. Klocke, 2016). With this vertical ramp up Klocke refers to the aim to maximize the output already in the beginning of the ramp up. The "ramp" in the output graph is aimed to be as vertical as possible, which explains the name vertical ramp up. Many frameworks are developed in order to identify important variables that should be investigated during the ramp up (Peter Burggrf, 2016).

We discussed the term ramp up phase, but we did not explicitly define what is meant by this term. Stefanos Doltsinis (2013) stated that the ramp up period is the period between the first commercial production and full volume production. Christian Terwiesch (2001) developed a formal definition of the ramp up phase in their paper and they visualize the ramp up as displayed in Figure 1.1. Their formal definition is the following: "The period between the end of product development and full capacity production is known as production ramp up" (Christian Terwiesch, 2001). Peter Burggrf (2016), Paul Childerhouse (2002) and Martin Haller (2003) refer to the ramp up phase as the time between the first commercial production batch and full capacity production.

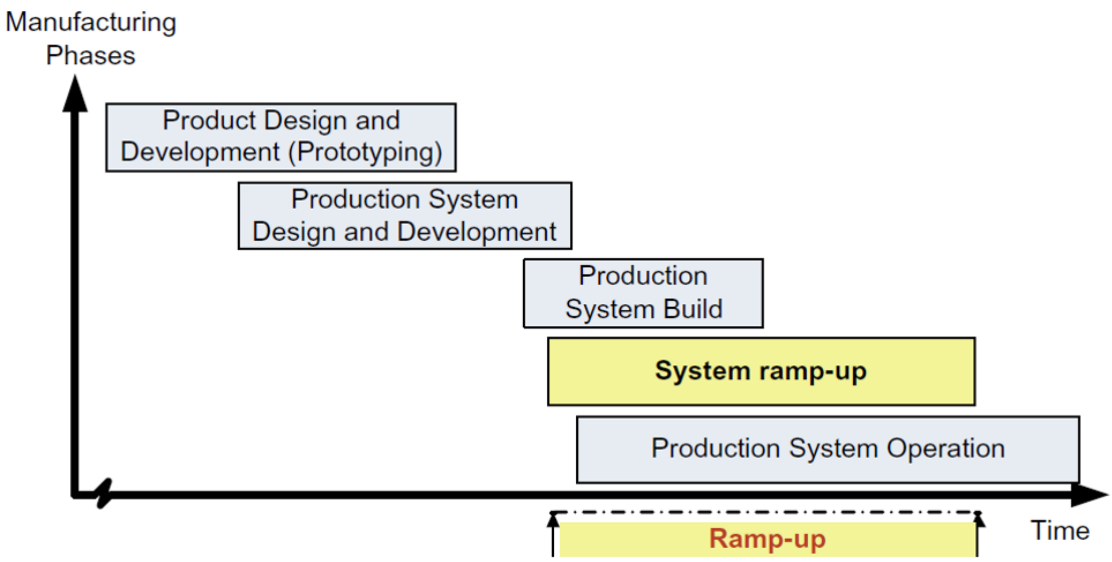

Figure 1.1: Manufacturing phases with ramp up phase highlighted

From these formal definitions we can conclude that at least the product (recipes, cans, etc.) is fully developed before the ramp up phase starts, but it does not necessarily mean that the production facility or in this case, the canning line is fully developed in case of the definition of Stefanos Doltsinis (2013). We are not interested in the part, where the canning line is only partly running. The other definition might be more suitable, but we do want to consider test batches, because in this phase we can measure the initial durations of the Routine Production Activities (RPAs), such as cleaning and changeovers. Therefore, the definition with starting point "first commercial production" does not hold either. In this research the definition of the ramp up period is narrowed to: "The period between the production of the first test batch and full capacity production".

The importance of the ramp up of a manufacturing line and the important variables were revealed in the literature and Achim Kampker (2014) explains in his paper how to increase the performance of a manufacturing line in ramp up by applying gamification. He states that among other variables, the set-up times, operator performance, the manufacturing speed of the production line and introduction of new operators are important variables to consider in measuring the performance of a manufacturing line. However, a clear gap is observed in the literature regarding a policy that guides production facilities to improve manufacturing performance during the ramp up phase. The present thesis will try to answer to this gap in the literature.

1.3 Problem Description

Based on the literature review one could state: "Why not introduce all teams at the start of the ramp up phase?" or "Why not increase the line speed to maximum capacity at the start of the ramp up phase?". However, constraints should be considered and will be revealed when investigating. For example, the introduction of a third team entails night shifts, but supplier assistance during night shifts is not available. The trade-off is then to find a point in time during the ramp up phase, where the loss of production volume is minimized, but the risk is small of a night shift with no or few production due to lack of supplier support or insufficient independence of Company X.

Another important trade-off is the time between introduction of two subsequent teams. When Company X introduces the subsequent team too fast after introduction of the previous one, they run the risk of having operators that not fully understand the process, while teaching new operators about the process. On the other hand production loss is increased when introducing the subsequent team too late.

A trade-off that is less obvious, but certainly not less relevant is the RPA trade-off. RPAs need to be executed, but do not contribute to the production volume. Experience in RPAs can reduce the duration of the RPAs and moreover it will also reduce the downtime, because wrongly executed RPAs cause downtime. Practicing often with RPA in the beginning of the ramp up phase will obtain more experience for the operator, but will consume time that could have been used for actual production. Therefore, the balance in the trade-off between gaining operator experience at the cost of production time in the starting period is interesting to investigate.
The last trade-off that we address in this research is the trade-off regarding the line speed increase. This is a similar trade-off to the trade-off regarding the introduction of two subsequent teams. Postponing the increase of the line speed entails a loss of potential production volume, while not controlling the production line correctly before increasing the line speed again increases the risk of downtime.

Summarizing, the following trade-offs will be addressed in this research.

- Introduction of night shifts
- Timing of subsequent teams
- Introduction of additional RPA hours
- Timing of line speed increase

1.4 Research Questions

As discussed in Section 1.1, the aim of the present report is to investigate policies that improve the performance of packing lines during the ramp up phase. In the literature, we found frameworks regarding the variables that should be considered during performance optimization in manufacturing. However, we missed concrete policies that actually help improving the manufacturing performance. Based on this gap in the literature and the motivation of this research we formulated the main research question:

How to improve the performance of a packing line in ramp up phase?

To support the main research questions, we formulate the following subquestions:

1. How do we define optimal ramp up speed?
2. What techniques should be applied to improve RPAs?

1.5 Methodology

This section describes the methodology used to obtain the final result of this research. The canning line is the first of the packing lines that is producing commercial products. The performance of this packing line serves as analysis model and input for the simulation model. This simulation model uses data from the first packing line in Place Y and other packing lines in the Company X network to develop the optimal ramp up policy for the other two packing lines.

1.5.1 Literature Review

The first step is the literature review. Literature review is performed to obtain background information about manufacturing, ramp ups and other relevant topics, but also to position the thesis in the literature and discover what topics have not been investigated before. Once we discovered this, we determine the research topic in this thesis. Literature will reveal what variables and relations are important in this field of research.

1.5.2 Research Company X Network

Company X has a worldwide network of production facilities. Recently, production facilities in other locations started producing commercially. The objective of this step is to gain insight into data of the ramp ups of these production facilities. This data will support defining the relevant variables and relations between these variables.

1.5.3 Model Development

Once we performed both the literature review and the research in the Company X network, we determined the important entities and the relations between them. This enables us to develop a model that enables us to analyze the performance of the canning line and eventually improve this performance.

1.5.4 Performance Measurement

Different levels of data registration are distinguished in a digital landscape. This landscape can not be explained in detail for confidentiality reasons. The data registration regarding the performance of the packing lines happens at Level 3, which is the Manufacturing Execution System (MES) layer. This layer controls the status, location, weight, etc of all materials. Moreover, it contains a module Wonderware, which is the reporting tool. Unfortunately, this module does not function. Therefore, reporting is done, using the method from the factory in Place Z. This method is less accurate, because operators fill in a report after their shift, instead of directly after a failure is resolved. Therefore, mostly estimations are reported instead of actual timestamps, as would be the case in Wonderware.

For Company X it would be valuable to have this reporting insight on an accurate level to base decisions in, such as causes of downtime, durations of RPAs and production volumes. The production volumes are covered by the old tool from Place Z, but the other two insights are rather estimations. Therefore, we aim to gain insight in these two important measures during this research.

1.5.5 Performance Improvement

In the literature we found several techniques, applicable to the packing lines of Company X, that Company X did not implement (sufficiently) yet. This step will address and implement the possibilities for Company X to improve their processes. In this step we emphasize on analysis and reduction of both downtime and other non-production activities such as cleaning and changeover.

1.5.6 Simulation

In order to develop a simulation model, we translate the developed model into a simulation model. This model enables us to evaluate the current situation of Company X. This current situation refers to the chosen policy regarding the set of decision variables. These decision variables are described in the model with the objective. This model is validated by an iterative process, that checks whether the model actually represents the packing line. Once we analyzed and validated the current policy, different policies can be evaluated using this simulation model.

1.5.7 Policy Optimization

In this simulation model we evaluate different policies after which the optimal policy is pursued. This is done by applying a greedy algorithm, which calculates the impact of a slight change in each decision variable. It determines the change with the biggest impact and applies this to the initial situation. This iteration continues until the changes in decision variables solely have negative impact. The best policy using the greedy algorithm is found and serves as an improvement on the initial policy as well as recommendation for the future packing lines.

1.6 Project Environment

The main subject of research in this thesis will be the first packing line in Place Y. This packing line manufactures cans with baby milk powder and is divided into two departments: Blending and Packing. This section explains and visualizes what these departments look like.

The Blending department blends the recipes from different input powders, that we consider raw materials in this thesis. The Packing department is divided in ten departments.

The Packing department is divided in two zones, Low care and High Care, which are separated by a wall and differ in hygiene regime. Because the operators in the High Care zone work with open product, the powder can still escape from the open cans, the risk of contamination is present and therefore strict hygiene rules apply in this zone. The Low care operators do not work with open products. Therefore, the risk of contamination is lower, but still a certain level of hygiene regime applies here.

1.7 Thesis outline

The remainder of this thesis consist of five chapters. In Chapter 2 we define the model that we use to describe situation of the packing line. Chapter 3 explains how the policies using the simulation model are optimized. Chapter 4 analyzes the results and discusses the conclusions of the research and finally the discussion and recommendations are presented in Chapter 5

1.8 Results & Contributions

This research revealed that four decision variables determine the behavior of the packing line, namely timing of adding teams, RPA pattern, timing of line speed and standardization. These variables answer to the trade-offs that we discussed in Section 1.3.

The timing of adding teams addresses the introduction of night shifts, because this is referred to as the introduction of the third team. This decision variable also addresses the timing of subsequent teams. The timing is very important in finding the right balance between potential production volume and enough experience to transfer knowledge to new operators. For each time is evaluated whether it is beneficial or not to introduce this team a week earlier or later.

The RPA pattern addresses the introduction of additional RPA hours. The desired balance in this trade-off is between potential production volume and additional experience of operators. Pattern with additional hours of RPA result in less hours for net production time, but an increase in experience of operators.

Timing of Line speed increases addresses the last trade off. This trade-off balances the potential production volume and the additional downtime due to lack of line control.

Finally, we have the decision variable standardization. This variable describes to what extend standardization is applied on machines throughout the factory. During research we found that 100% of the standardization can be applied before the ramp up phase. Therefore, we assume this variable to be 100% throughout the report.

The policy regarding these decision variables that we recommend Company X to apply on their future packing lines is displayed in Table 1.1. It shows the importance of any of the decision variables, but the greedy algorithm shows that the impact of decision variables differs. Standardization is applied in the current policy in the ramp up phase, but in practice it does not get priority to apply during the ramp up phase. Moreover, it can be applied during the Production System Design and Development stage, as visualized in Figure 1.1. During Factory Acceptance Tests (FATs) and Site Acceptance Tests (SATs) that Company X performs, Standardization should be applied. During ramp up the remaining decision variables were improved by the greedy algorithm. The impact of registering products early has the biggest impact relative to the effort that the decision variables takes. The timing of shifts is the second decision variable with most impact relative to the effort. Many production hours become available when an extra team is added earlier, but this comes at a price. Moreover, constraints on the timing of adding of teams are set, because the new operators need to understand and control the process sufficiently to be able to execute the processes properly, know how to act in case of machine failure, and teach new operators how to operate properly. The last decision variable Line Speed does not take too much effort to apply, but the downside is that many downtimes occur when the Line Speed is increased. Therefore, the impact is lower relative to the effort when comparing it to the early registration of products and the timing of adding teams.

The additional cost for Company X to hire an additional team is zero, because the teams that are newly introduced in Place Y are employees that used to operate in the factory in Place Z. Therefore, teams should be added as soon as possible, while satisfying the constraints that we discovered in this research. This results in the timing of adding teams in Table 1.1. Regarding the RPA pattern, the trade-off was made between reduced net production time due to increased RPA time and loss of efficiency and experience due to decreased RPA time. Linear increasing pattern were compared and the pattern with starting value of 24 hours RPA time per week and an increase of 0.486 hours per week results in the largest total production volume. Finally, the line speed increase pattern is determined by a trade-off as well. This trade-off seeks the balance between production volume loss due to a postponed line speed increase and additional downtime due to an uncontrolled production line at the current line speed.

Summarizing, we recommend to apply the policy as displayed in Table 1.1, for this entails an additional total production volume of over 32%.

Decision Variable	Value
Adding Teams	week 1,20,24,28
RPA Pattern	24+0.486*week
Line Speed Increase	week 6, 12, 18
Standardization	100%

Table 1.1: Decision variables for improved policy

Chapter 2

Model Formulation

In this chapter we present the process towards the development of the eventual simulation, starting with analyzing the Company X network and the current situation of the first packing line at the production facility in Place Y.

2.1 Research Company X network

As discussed in Section 1.1, the ramp up plan for the first packing line is based on the ramp up data and experience of other production facilities in the Company X network. Appendix **??** shows the data of other ramp ups and the initial ramp up plan for Place Y. The data of the ramp ups of other locations are used to develop the ramp up plan for the first packing line in Place Y. The data and experience prevents the managers in Place Y from making mistakes that have been made before. Moreover, this data can also be used to identify relations between the variables in the model. Therefore, we will start with thorough research in the Company X network before developing a model that will represent the packing line.

The following topics are the most important topics to investigate in the Company X network:

- Distribution of Time
- Frequency & Duration of RPAs
- Causes for Technical Downtime
- Timing of shifts
- Ramp up Speed

2.1.1 Distribution of Time

Company X developed a tool called CUTE (Capacity, Utilization, Time & Efficiency) to improve good use of their assets. Company X felt the urge for a centralized way of reporting to enable themselves to compare performance of production facilities in the Company X network. This tool has proved to be efficient in daily performance management and investment decision processes in the past. It describes that time is distributed according Figure 2.1. Later in the simulation part, only the operational time and its distribution are considered. So time will only consist of Net Production Time, Unexpected Stoppages and Routine Production Activities, where Routine Production Activities (RPAs) consist of activities as cleaning, changeovers, etc. The RPAs will be extensively discussed in Subsection 2.1.2.

We can not blindly assume that the distribution of operational time in Place B holds for Place Y as well. Product portfolio, for example, is an important factor that influences the percentage of RPAs. Therefore, this factor, amongst others, should be determined during the research for Place Y.

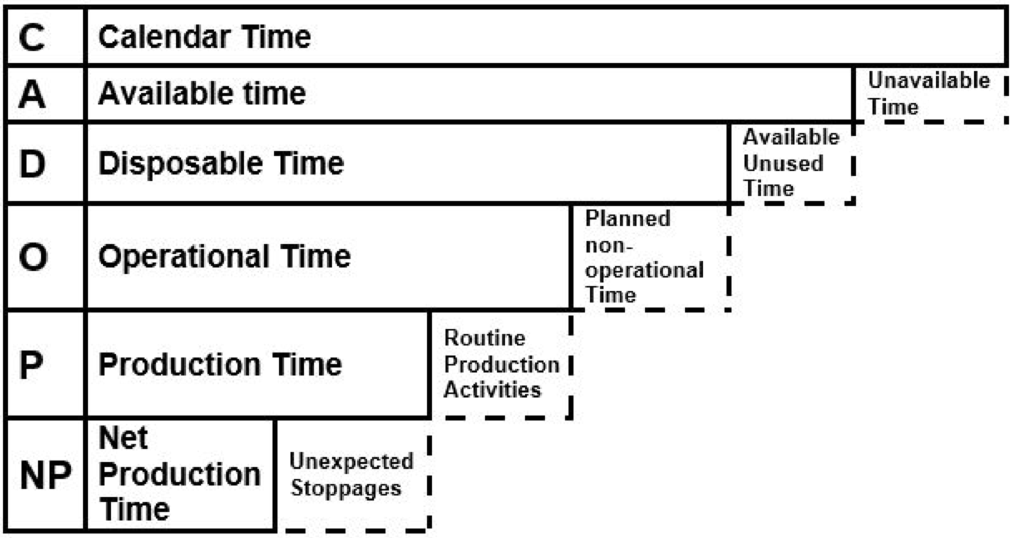

Figure 2.1: Distribution of time according the CUTE-tool

2.1.2 Routine Production Activities

This subsection discusses the following five RPAs that occur at the factories of Company X:

- Line Clearance
- Run to Empty
- Format Changeover
- Powder Free
- Ultra Clean

Line Clearance

The Line Clearance is only performed at the packing department. It is a process, where the line is released per section. The packing department is divided in 10 sections, as visualized in Figure **??**. Whenever a section is released, it means that this section is ready to start with the next Production Order (PO) and the operator confirmed this on a screen in the section.

As soon as Section 1 is released, the cans of the next PO can pass the machines in Section 1. This saves much time compared to waiting until the full line is released and only then starting with putting the cans of the next PO in Section 1. Of course this only holds when only a line clearance is required. In case a format changeover or a cleaning is required as well, the cans can not enter the system immediately after the line clearance.

Run to Empty

The Run to Empty is only performed at the Blending department. The blending department runs all objects, visualized in Figure **??**, completely empty. This means that all powder of the previous PO is released from the system and discarded. As soon as the Run to Empty passed the buffer hopper, the powder of the next PO can enter the dosing station. Following this principle, we consider the Blending department as a department with two sections and after the first section is released, the powder of the next PO can enter Section 1. Notice the similarity with the line clearance here. The difference is that powder enters the dosing station at the Blending department, where cans enter the depalletizer at the Packing department.

Format Changeover

A Format Changeover occurs only at the Packing department. Settings and parts of machines need to be adjusted or exchanged to let the different sized can pass through the system. The format changeover is always preceded by a Line Clearance. Other production facilities were used to adjust the width of the conveyor belt according to the diameter of the cans passing, but in Place Y only two sizes of cans are produces, namely 99 mm (small) and 127 mm (big) diameter cans. The small cans pass the wide conveyor belts without any problem and cans would be able to pass each other on the conveyor belt, because they have more that half the diameter of big cans. Therefore, it would be a waste of time to to adjust the width of the conveyor belts.

Powder Free

Powder Free is a cleaning process that occurs at both departments. A Powder Free cleaning is always preceded by a Run to Empty process. After the Run to Empty has finished the Powder Free cleaning starts at the Blending department. Only when the Powder Free has finished at the Blending department, it can start at the packing department. The essence of a Powder Free is that the powder remainders are removed from the production environment. A special vacuum cleaner and compressed air are used for powder free cleanings.

Ultra Clean

The Ultra Clean is an addition to the Powder Free. Where the essence of a Powder Free is to remove powder remainders from the production environment, the essence of the Ultra Clean is that even Powder haze may not be visible anymore. Therfore, the complete production environment is completely cleaned with alcohol wipes after the Powder Free. Moreover, any valve and machine part is decoupled and cleaned separately with an alcohol wipe.

Occurrence of RPAs

We know what RPAs exist and how RPAs are executed now, but we did not determine when these RPAs occur. RPAs only occur in between POs and Table 2.1 schematically displays when each RPA occurs. We already know that a Format Changeover occurs when the can size of subsequent POs are not equal. Therefore, this RPA is not displayed in Table 2.1. In this Table abbreviations are used for the RPAs according to the following list:

- Line Clearance = L.C.
- Run to Empty = RtE
- Powder Free = P.F.
- Ultra Clean = U.C.

Situation	Recipe	Contamination	Blending	Packing
RPA	Same	No	-	L.C.
RPA	Different	No	RtE	L.C.
RPA	Different	Yes	RtE + P.F. or U.C.	L.C. + P.F. or U.C.

Table 2.1: Occurence of RPAs

Frequency and Duration of RPAs

In addition to the occurences, the frequency and durations of the RPAs are extremely important, for these factors determine the fraction of operational time consumed by RPAs. Knowing this we can estimate how much time can be saved by applying appropriate techniques.

Process	Frequency (/week)	Duration (Minutes)
Line Clearance	8	15
Run to Empty	4	40
Format Changeover	3	30
Powder Free cleaning	2	120
Ultra Clean	1	500

Table 2.2: Frequency of all processes that occur at Blending & Packing

2.1.3 Causes for Technical Downtime

Based on research in the Company X network and the reports of two months in Place Y, we categorized all causes of downtime into five categories. These downtimes have the distribution in Place Y according Table 2.3, but note that these reports were not the first two months of commercial production, because no data was registered then yet. Moreover, the reports are subject to operator interpretation and therefore not 100% accurate.

Category	Total Downtime August & September (h)	Percentage of downtime
Automation	60:00	45,11%
Random Machine Failure	40:00	30,07%
Standardization issues	10:00	7,52%
Operator Failure	8:00	6,02%
Organizational Failure	5:00	3,76%
Lack of Testing	10:00	7,52%
Total	133:00	100%

Table 2.3: Downtime distribution per category

The categories that we distinguish in Table 2.3 are separated based on the experiences and downtimes that occur during the ramp up phase. Automation is the category that covers all MES related downtime. Random machine failure is the tag that covers every downtime with an inexplicable cause. Standardization issues consist of downtime where the machines were not set to the right settings. The category operator failures covers all downtime that is caused by human interaction. Organizational failures are failures due to no powder or empty can inputs and finally Lack of Testing describes the downtime that is caused by the system ending in a situation, that has not been tested before.

This table gives us the opportunity for some interesting observations. To start with the percentage over 45% that is taken by automation. This is a big portion, but when we analyze the data more in depth, we see that the automation problem is two-folded. The downtime is either caused by a connectivity problem or by state changes of the system around PO changes. More general, we can state that with the increase in frequency of PO changes, comes an increase in errors as well. The other factories in the Company X network do not have experience with this type of downtime. However, it is obvious to conclude that the digital environment should be tested more extensively before starting with commercial production, because over 45% of the downtime is caused by automation.

The second interesting observation is the low percentage of ”Lack of Testing”. This category registers downtime caused by insufficient testing of machines and processes during the testphase, which results in downtime during commercial production. Unfortunately, this data does not represent reality. Only data of the last two months of the research was registered, in which hardly any errors occurred, caused by a lack of testing. In the first months of commercial production this percentage must have been significantly higher, but again we do not have data of this period.

The category ”Random Machine Failure” consists of many different failures. These are failures of which the cause is not known yet. The downtime could either be an incident or a problem that occurs more often, but Company X did not find the cause yet. However, the category contains 30% of all errors at the canning line, so it is worth investigating how machine failures can be reduced in general.

The remaining categories seem not extraordinary compared to the benchmarks of the other factories in the Company X network. This statement is made with the side note that the data is only of 2 months in the middle of the ramp up period. An other distribution could have been found when the first two months would have been analyzed.

2.1.4 Timing of new shifts

Operators in the Company X network work in shifts. The number of shifts determines how many hours per week are available for production. During the commercial production the number of shifts can differ from 2 at the start of commercial production to 5, which is the maximum number of shifts that can be scheduled on the packing line.

Every production facility in the Company X network starts with just one team in the test phase and as soon as commercial production is allowed, a second team is introduced. According to the data of Brazil and New Zealand the time to introduce a third shift differs significantly. In New Zealand a third shift was introduced nine months after the start of commercial production, while in Brazil this only lasted four months. This difference could be explained by the fact that New Zealand had an other factory that was still running, while the new factory was ramping up. Therefore, they could not simply hire this number of employees. For the Project A project holds the same. In Place Z the old factory is still running, so we expect the same will happen for Project A as happened in New Zealand. Manufacturing Management of Project A indicated that they should have introduced a third shift already. Therefore, the benchmark time for adding a third shift is up to nine months, as was the case in New Zealand.

In Figure 2.2, we can see a very clear relationship between the number of production hours and the production volume. Each hour enables the production facility to produce around 2.000 kg of production volume. This is in line with the expectation of the positive correlation between adding a shift and the production volume. Therefore the timing of adding extra shifts to a production line, will be a important variable.

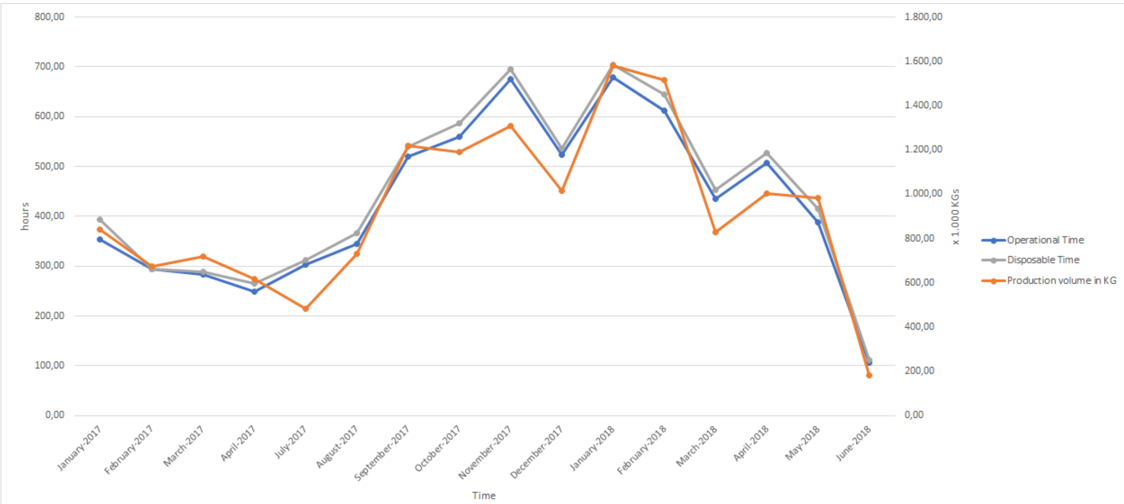

Figure 2.2: A clear relationship between available hours and production volume per month

2.1.5 Ramp up Speed

In section 1.4 we presented the research questions for this thesis. Among the subquestions we posed "How do we define optimal ramp up speed?". In the literature and amongst the managers within Company X, we found many definitions of the ramp up speed. Christian Terwiesch (2001) develops a formal definition of the ramp up phase in his paper and he visualizes the ramp up as displayed in Figure 2.3. Their formal definition is the following: "The period between the end of product development and full capacity production is known as production ramp up" Christian Terwiesch (2001). Paul Childerhouse (2002), Martin Haller (2003) and Peter Burggrf (2016) refer to the ramp up phase as the time between the first commercial production batch and full capacity production.

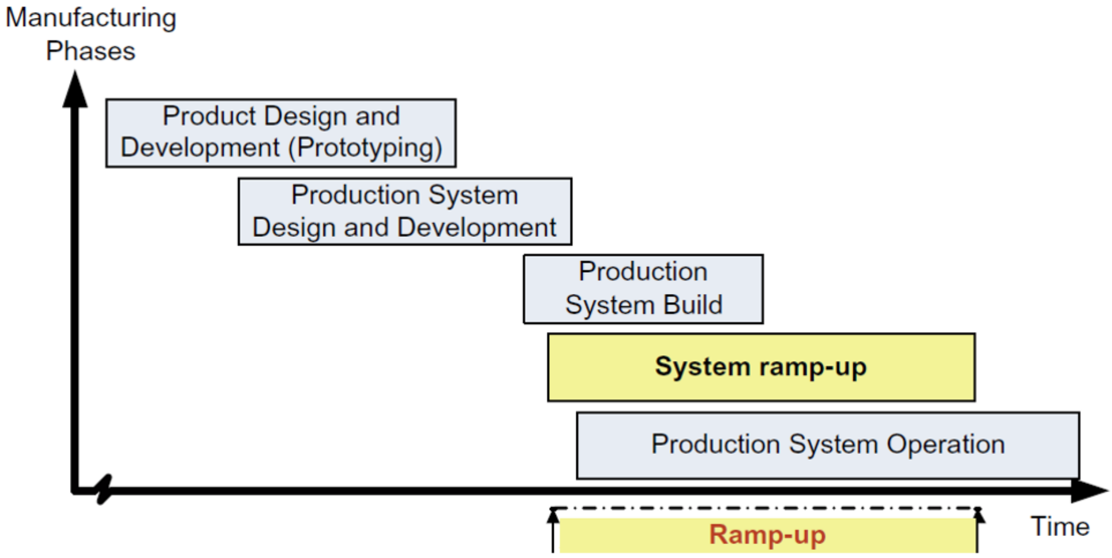

Figure 2.3: Manufacturing phases with ramp up phase highlighted

From these formal definitions we can conclude that at least the product (recipes, cans, etc.) is fully developed before the ramp up phase starts, but it does not necessarily mean that the production facility or in this case the canning line is fully developed in case of the definition of Stefanos Doltsinis (2013). We are not interested in the part, where the canning line is only partly running. The other definition might be more suitable. In this research the definition of the ramp up period is narrowed to: "The period between the production of the first test batch and full capacity production". We do measure the total production volume of merely commercial products. However, the testbatches are measures to initialize the durations of RPAs.

We know what our time frame is now, so we can define the ramp up speed. Ramp up speed is defined as the increase in the production volume per time unit in this report. The ramp up period will be divided in weeks, which will be the time unit. The differences in production volume of two subsequent weeks will define the ramp up speed over these two weeks. When we put this in a formula, it will result in the following:

$$RUS_{i-1,i}(\%) = \frac{P_i - P_{i-1}}{P_i} \cdot 100\%, \tag{2.1}$$

where

$RUS_{i\text{-}1,i}$ = Ramp Up Speed over period *i-1* to period i in percentage
P_i = Production Volume in period i

2.1.6 Other topics

Research in the Company X network revealed other characteristics to consider. Figure **??** shows characteristics of the production facilities such as annual production volume, the maximum line speed, product portfolio and benchmarks for some RPA's. We see that Place Z & Place Y are both producing a complex product portfolio, where other location in the network produces significantly less different products. The benchmarks for "Project A" are estimations for the production facility in Place Y.
It probably relates to each other, but the volume on the other hand is significantly bigger for the other production facilities. More different recipes means more RPA's and therefore less net production time.
An other interesting statistic that we see in Figure **??** is that the production facility in Place Z take less time to perform a cleaning or a format changeover than all others. This is probably, because it is performed more often in Place Z. We could consider this difference as an impact of learning. This effect is very interesting to investigate during the ramp up phase in Place Y.

We still see a big gap between the benchmarks that are denoted in Figure N/A and the initial timings that we saw in Chapter 2.1.2. This has two reasons. The first reason is the numbers mentioned for Project A are estimations rather the calculated indications. The second reason is that much reduction of duration can be obtained in these processes by practicing these processes more often.

The research in the Company X network revealed an other important variable, namely "standardization". By this term we mean to what extend the machines in a packing line and even packing lines in a production facility are tuned to each other in terms of the treatment by the operators. In another location a standardization project reduced the technical downtime in this factory by 5% within a year. This effect has already been proven and therefore we should include this in our model as well. In section 2.3 we elaborate on the effect of Standardization.

2.2 Model development

In this subsection we aim to describe the packing line at Company X as accurate as possible. Using this analysis of the packing line, we translate this into a descriptive model and eventually into a simulation model.

2.2.1 Description of the Packing Line

The canning line at Company X in Place Y consists of twenty machines in series. The input of this canning line is a pallet with empty cans and eventually returns a box with cans. The machines are positioned in series, but two sections are distinguished: Low Care and High Care. The zone defines the risk of contamination of the product. Low care has low risk of contamination and High care has high risk of contamination. The risk in the high care zone is high, because in this zone the operators work with open product. Each section has a clothing regime that fits the risk of contamination.
This packing line is operated by a number of teams that determine the time available for production. During the test phase only one team is operating. This team consists of 8 operators. This is not the bare minimum of operators to keep the line running, but this is to ensure that at the introduction of the second team at least four operators in each team know how to operate the line and are able to teach the new operators how to operate. The introduction of the second team means an introduction of 6 new operators, who are divided over the two teams as well, which results in two teams of 7 operators. With the introduction of each new team the experienced operators and new operators are divided over the new number of teams to maintain all knowledge in each team. Introducing a third team includes the introduction of night shifts as well. A disadvantage of this night shift is that suppliers are not available during this shift to assist or solve a problem in case of downtime. Therefore, a certain state of independence should be reached, before the night shifts will be beneficial.

The time between the introduction of teams, e.g. the time between the introduction of team three and the introduction of team four, should be sufficiently long to enable the new operators to obtain adequate knowledge about all processes. If this constraint is not satisfied, operators will not teach the correct way of working to newly introduced operators. Operators do have a basic level of knowledge about the process, for all operators have worked in the old factory in Place Z and a similar process was executed there. However, not every machine is the same, new machines are introduced in Place Y and more machines are located in the High Care zone compared to Place Z. Unfortunately, the introduction of a new team reduces the efficiency of the teams, for they need time to explain every process to the new operators.

To be able the calculate the output of the production line we need to know the maximum capacity of the production line. We will consider the line as one operating machine. Therefore, the maximum capacity of the line is equal to the bottleneck speed in the line. The bottleneck speed is 10 cans/min. During the ramp up phase the line speed starts at only 70% of the maximum capacity. The production line is not capable of producing at the maximum speed immediately, but this needs to gradually be increased towards the maximum capacity. Unfortunately, an increase of line speed requires tuning of the line. Many downtimes will occur at every increase of the line speed, because the line is not tuned yet. This is an iterative process that the technicians need to face until maximum production capacity is reached.

Recently, the consequences of the enormous demand for baby milk powder reached the international news, for consumers were not allowed to by more that two cans of baby milk powder. This emphasizes the need for production volume improvement to aim for demand satisfaction. Especially, during the beginning of the ramp up phase this will not be possible. Therefore, we can assume that demand is infinite. This implicitly entails that production can not be stopped due to a lack of demand.

The production volume during a week can be assumed to be identically and independently distributed. The production volume of the previous day does not influence the production volume goal for the next day. Moreover, each day the line is emptied and shut down and started up the next day in case one team or two teams are operating. When the third team is introduced the shut down and start up of the line only occur on friday night and monday morning, respectively.

Unfortunately, not all products that enter the packing line result in a commercial product. These products are considered waste. The generation of waste is exogenous to our research. We can not influence the percentage of waste, but we do need to consider waste in our simulation model to ensure that we solely measure the commercial products. Waste can occur as follows:

- The first 50 cans of a batch is discarded, because homogeneous distribution of the powder is not guaranteed in these cans.
- Several cans with powder per PO are taken to the lab for tests. This can is considered waste.
- When a test shows that the powder quality is not sufficient, the batch is completely discarded.
- During the production process cans can get damaged. These cans are discarded as well.

Data about the waste of the first 23 production orders (POs) can be found in Appendix A.3. This figure describes the percentage of material loss relative to the input of products. In other words it describes the percentage of input that did not become commercial product.

When we consider separate machines instead of the packing line as a whole, we observe that the filler is the most important machine for several reasons. Firstly, because it is the bottleneck machine. Secondly, it adds most value to the product and therefore this machine should not be idle due to either downtime or a lack of supply of powder or cans. This is a direct loss of potential product. Therefore, the capacities of the remaining machines are not all used, but they serve to make sure the bottleneck machine is operating as much time as possible. This idea is explained by Hong Chen (2011) using the V-shape model. This model is based on using overcapacity to enable the bottleneck machine to operate a bigger fraction of time (Hong Chen, 2011).

We distinguish four different speeds of the canning line, which are summed below.

1. **Bottleneck speed**: 10 cans/min (small) & 7 cans/min (big)
2. 15 cans/min (small) & 10 cans/min (big)
3. 20 cans/min (small) & 14 cans/min (big)
4. 25 cans/min (small) & 18 cans/min (big)

In Figure **??**, the canning line is visualized in terms of capacities and the four different speeds are returning. We observe the V-shape as intended by Chen & Maldenbaum (Hong Chen, 2011). Before the filler the third capacity speed holds. The filler has a maximum capacity of the bottleneck speed and after the filler the capacity is increasing from the second speed, via the third speed to the fourth speed.

2.2.2 Dependencies in the Packing Line

Based on the research in the Company X network, we developed a model that represents the canning line at Company X, as visualized in Figure A.1. It describes the dependencies between independent variables, ramp up speed, output and KPI's. During the development of this model the central questions were:

- What independent variables apply on the packing line?
- What affects the ramp up speed?
- How does the ramp up speed affect outcomes and KPI's?

The influence diagram quite accurately represents the canning line, but it will never be possible to solve this problem via an exact model, because there are simply to many variables that influence the output. Therefore, we choose to use simulation to aim for an optimal policy. However, the complex model of Figure A.1 will be hard to simulate as well, which revealed the urge for a more simplified model. Some relations are less relevant and can therefore be left out of the model, based on decent assumptions. The remainder of this section is used to discuss what relations should be addressed in the simplified model and what relations can be removed.

The effect of addressing a new team of employees to the canning line on the ramp up speed is not negligible as we saw in Figure 2.2. We should investigate in this research what the influence is of the timing of adding extra shifts on additional downtime, controlling the process and total production volume.

The capacity of the bottleneck machine could be increased to increase the production volume. However, it makes no sense to investigate this during the ramp up period of the factory. The machines are recently purchased, so if more capacity was wanted or needed, other machines should have been purchased. Moreover, during the ramp up phase the machines are not running at full capacity for the largest fraction of time, so it would not lead to an increase of production volume during the ramp up phase. As a third argument to not investigate this bottleneck capacity, Company X states that the same size of land has been purchased next the factory that is ramping up right now. This land can be used in the future to build a second factory of the same size. Therefore such investments are not made, but reserved for this second factory.

The optimal use of buffers in the canning line could also have a positive effect on the production volume, but optimal use of buffers can only be measured when the line is running at full capacity. This should, therefore, not be measured during the ramp up phase of the production facility. For the optimal use of the canning line, the utilization of all machines could be aligned to maximize production, but again it makes no sense to measure this during the ramp up period. For this reason this variable is excluded from the model as well.

Efficient execution of RPAs is very important during the ramp up. The Operational Efficiency (OE) is dependent on the operational time and the net operational time, where the operational time consist of three major parts. The first one is the net operational time, which also determines the fraction for the OE. The second part consists of RPAs, as discussed in Chapter 2.1.2 and the third part is covered by the unexpected stoppages. If we execute the RPA part more efficiently, we can assume that the unexpected stoppages will cover the same absolute time at most. In other words, the downtime will not increase, when RPA hours decrease. We state at most here, because standardization, which helps executing processes more effectively, reduces the unexpected stoppages as well. This means that the fraction net production time is automatically increased when RPA hours are less. This is an important purpose of this variable and therefore we should consider this variable in the model.

The distribution of small and big cans in the production planning does have an impact on the total production volume. However, this impact is not considered in the model that we are developing. The distribution of small and big cans is dependent on the planning of the schedulers. The frequency of RPAs have an impact on the production volume and the OE as well, but we leave this out of the model as well. The frequency is dependent on the demand and production schedulers, which is, once again, out of the scope of this research. Therefore both the distribution of small and big cans and the frequency of RPAs are left out of scope.

The early registration of products has a direct and indirect impact on the ramp up speed. A direct impact, because early registration implies more RPAs during this period. The fraction of the operational time taken by RPAs will be larger and the fraction taken by net production will be smaller. Therefore, the direct impact is that the production volume is reduced. The indirect impact is present, because allowing the operators to learn and understand the process, will eventually help them handle the process better and at higher speed. Moreover, they know how to act when a machine failure occurs, because they will know the machines better.

Summarizing these assumptions leaves us with the eventual model, that we will analyze. This model is visualized in Figure 2.4. Because of the simplification of the model to make it more analyzable, we observe that several other relationships are not considered anymore. Detailed quantitative relations are described in detail in Section 2.4

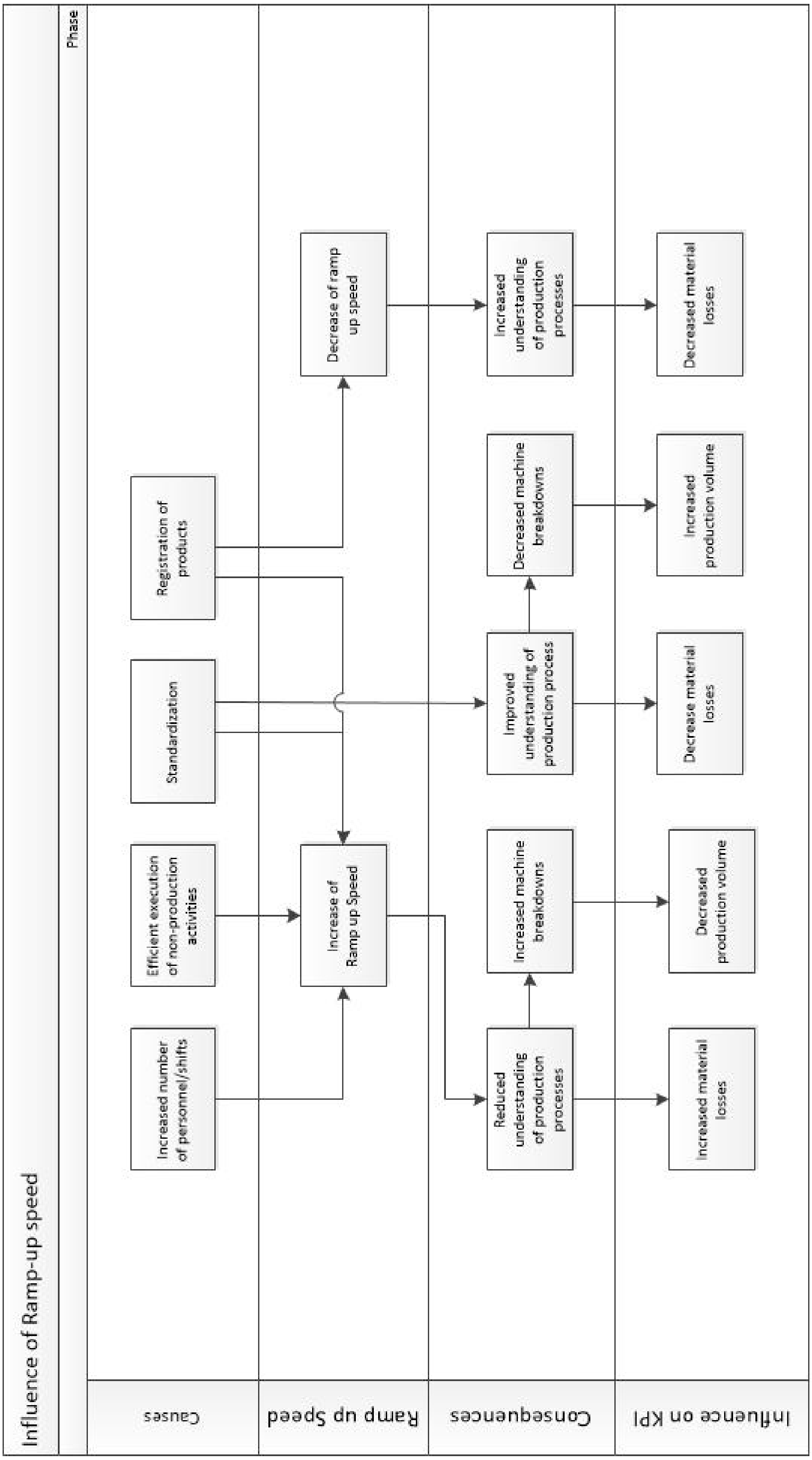

Figure 2.4: Simplified Ramp up Speed model after revision of relations

2.3 Performance Improvement

Performance improvement of the packing line can be obtained by various techniques. Two techniques that we discuss in this section are Standardization and SMED. Standardization was discovered as an important variable during the research in the Company X network and SMED is a technique that was revealed in the literature regarding manufacturing performance. Both are discussed in the following subsections.

2.3.1 Standardization

We briefly discussed standardization before, but now we will discuss it more in detail. Technical downtime registration in Place Z reveals that many downtimes occurred due to incomplete or wrong format changes. A solution might be to apply standardization on the machine, which makes it easier for operators to execute RPAs. In another location, such a standardization process already took place, which reduced the technical downtime with 5% within a year

Another impact of standardization is the increased flexibility for Company X. New operators can more easily be introduced to the process. Therefore, temporary workers can take over jobs in case of sickness of employees. Moreover, employees will be exchangeable between packing lines, which makes Company X even more flexible.

In consultation with the supervisor of this thesis, we will apply standardization on the machines in Place Y as well. The module Wonderware from MES would have provided data of technical downtimes and what these downtimes were caused by. Unfortunately, the software experienced many issues and did not have enough priority in this phase of the ramp up, because the entire digital environment experienced many issues. To compensate for this, the old data registration method, that was used in Place Z, is introduced in Place Y. This method is less accurate than Wonderware would have been, because operators have to fill in a form now, in which they indicate how much time was lost and due to what cause. This is done only after the shift, which makes it vulnerable for interpretation errors. However, this insight will help analyzing how we should prioritize problem solving in order to reduce the technical downtime.

Introduction of standardization

Standardization can be introduced in various ways. Based on the failures in Place Z and the improvement success in the other location we decided to prioritize the standardization for machines that seemed to benefit most from standardization. These machines and the steps that need to be performed are described in Table 2.4.

Standardization Object	Packer	Labeller	Capper	Filler	Bottom Supply
Step numbers for format changeover	x	x	x	x	x
Rulers for format changeover	x	x	x	x	x
Color indication of exchange parts	x	x	x	x	x
Process descriptions	x	x	x	x	x
Counters	x	x	x	x	x
Fix settings that need no change	-	-	x	-	-
Shadowboards	-	x	x	x	x
Zoning	x	x	x	-	-

Table 2.4: Standardization objects at five priority machines

Unfortunately, the data registration only started after most of standardization objects were implemented. Therefore, it is hard to say what the exact effect in this situation is. However, the operators experienced this standardization as a very pleasant way of working and they had the idea that they were less vulnerable of making mistakes. Moreover, the management team sees added value of a standardized way of working throughout the factory. This way of working makes it easier to exchange employees between packing lines in case of shortage of personnel.

2.3.2 SMED

SMED (Single Minute Exchange of Die) is a technique developed by Shigeo Shingo, who wrote a paper about this revolution in the manufacturing world Shingo (1985). This method aims to reduce durations of manufacturing processes. Literature X caught the essence of the SMED methodology in their own literature DaMaWay (2018), but in the original paper, the SMED methodology is elaborated on more extensively Shingo (1985). To fully understand the methodology, Shingos book provided all information, but the DaMaWay library is sufficient to just execute the methodology. Both literature pieces will be used to reduce the duration of RPAs of the canning line.

Summarizing the two subsections in this section; two techniques, standardization and SMED are used, which will lower the risk for machine failures due to operator mistakes and reduce the durations of RPA, respectively. Both techniques are applied during the ramp up phase of the canning line.

2.4 Simulation

In this section we describe the simulation model. We translate the developed model of Figure 2.4 into a simulation and explain what assumptions were made.

2.4.1 Simulation description

As we see in Figure 2.4, we divided all entities in four categories. For the simulation we will treat the entities as only three different categories. The first category is the decision variables, the second category is the mediators and the last category is the output entities. Therefore, we have four input variables, six mediators and two output variables.

Decisions variables

1. Number and timing of shifts
2. Frequency of RPAs
3. Standardization
4. Line Speed

These decision variables are measured as follows:

1. Number and timing of shifts (Sh)
The number and timing of shifts is the first decision variable in the policy that we will determine. This decision variable starts with 2 shifts and ends with 5 shifts, which are the lower and upper bound, respectively. Moreover, the timing of adding a shift is important, because this will influence the trade-off that we investigate in this research. This decision variable is easily measurable, because any additional shift that is planned to produce at the canning line increases this variable with 1.

2. Execution of RPAs (RPA)
This variable is measured as the absolute time that is consumed per week by the execution of RPAs. This tells us about the experience that operators gained with executing RPA processes. The higher this number, the more RPAs are executed, the more experience the operators gained. This decision variable can be influenced by assuring that more production have been registered at the start of the ramp up phase. Products need to be registered before commercial can start. When Company X registered more products, more RPAs will occur, because more PO changes are needed.

3. Standardization (St)
In Chapter 2.3.1, we defined a number of activities that need to be performed to standardize the canning line. Standardization can be measured by assessing what percentage of these activities have already been performed and, if applicable, what percentage of each activity has been performed yet. E.g. for 40% of the machines the steps are clearly indicated by number and color. The lower and upper bound are 0% and 100%, respectively.

Standardization is a factor still in the current simulation model of Company X, because standardization was not applied before the start of commercial production. This will be one of the recommendations and therefore we set this factor to 100% at the start of the ramp up phase in the simulation model.

4. Line Speed (LS)
The last decision variable is the line speed. Before the start of commercial production the line speed was 7 cans/min, which is 70% of the maximum speed. This is taken as the lower bound of this decision variable and 10 cans/minute is the maximum speed of the canning, which is automatically the upper bound. For the line speed, the speed of the filler is considered, because this is the bottleneck speed of the serial packing line.

For all of these decision variables we need to decide how they behave during the ramp up phase. The set of decisions for all four variables is considered the policy of this model. During the simulation different policies will be compared to the benchmark policies and evaluated to determine the optimal ramp up policy.

Mediators

A mediator is a variable that is influenced by at least one decision variable and it influences either another mediator or an output entity. In other words, this variable describes that there is no direct influence between decision variables and output entities, but it rather describes the connection.

1. Efficient Execution of RPAs (EE) This variable is measured as 1 over the factor of the duration of the process with respect to the benchmark. E.g. the benchmark for the Big Bag Hoisting process is 7 minutes and the actual duration of the process in a certain period is 9 minutes. Then the variable is determined by 1 over $\frac{9}{7}$, which results in an efficiency value of 0.78.

As described by Christian Terwiesch (2001), one could consider the experience increase as the loss of potential production. However, we consider the experience increase as benefit for Total Production Volume, for on the mid- and long-term, practicing more often in early stages results in more total production. We made this choice, because experience of an operator increases the percentage of the efficient execution of RPAs.

2. Technical Downtime (TD)
Technical Downtime is downtime that is caused by technical failure. Technical Downtime consists of the categories mentioned in Table 2.3. This mediator is only measured as absolute value.

3. Net Production Time (NPT)
Net Production Time is the time that remains when the time for RPAs and Technical Downtime is subtracted from the operational time. This is the time that is fully used for production.

4. Quality of Product (Q)
The quality of the products is always checked at Company X. The products are consumed by extremely vulnerable customers, who demand perfect products. The products that are rejected on one of the tests are rejected and the complete batch is immediately removed from the production area. Depending on the test the product is either discarded or sold as animal food. This mediator is measured is percentage of the total production.

Output entities

We observe only three output entities. Total Production Volume, Operational Efficiency and Material Loss. The Total Production Volume is the objective to improve in this research.

1. Total Production Volume (TPV) The Total Production Volume is measured as the number of cans that are produced by the canning line and are ready to be sold as commercial product.
2. Material Losses (ML) The Material Loss is measured as the percentage of cans that has entered the manufacturing line, but did not leave the manufacturing line as a commercial product. Although the objective of this research is regarding the TPV, Company X values the Material Loss as well, for they have a strong interest in operating environmental consciously.

3. Operational Efficiency (OE) Operational Efficiency is measured as the fraction of Operational Time that is used for Net Production. This output entity is also very important for Company X, for this measure is used in the Company X network to compare performance of different production plants to each other.

Using these entities and model that we already developed, we visualize the simulation model according Figure 2.5. This visualization of the simulation model uses three forms. The first one is a circle and it announces a decision variable. The second form is a trapezoid and is used to announce a mediator. The third form is a rectangle and this form denotes an output variable.

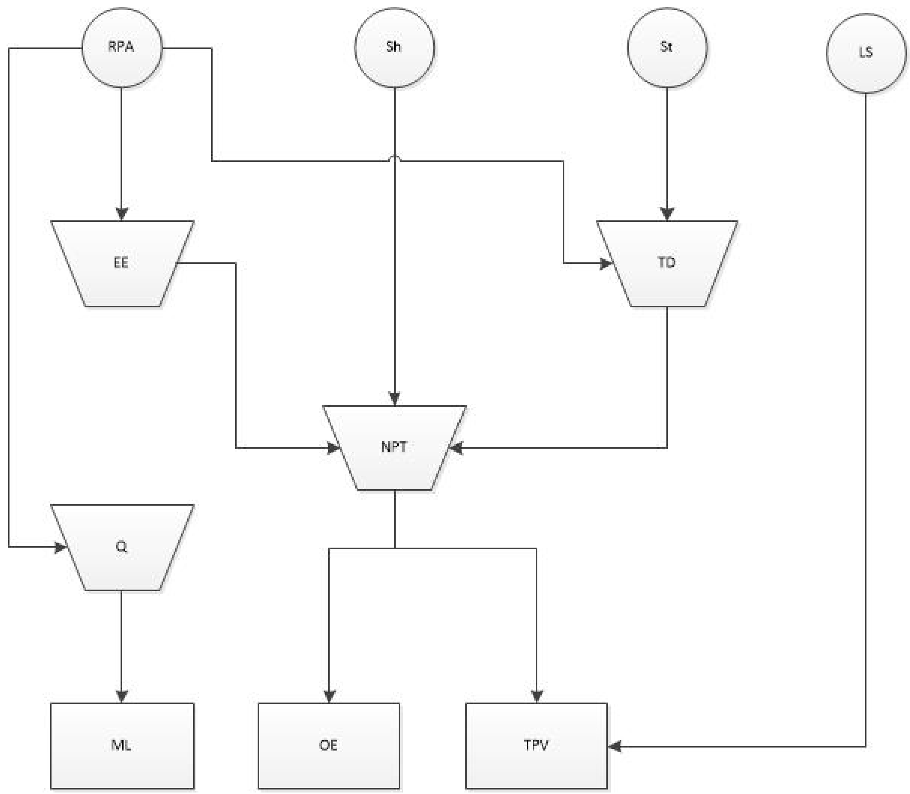

Figure 2.5: Visual representation of the entities in the simulation model

Using this simulation model we aim to improve the trade-offs that we discussed in Section 1.3. In other words, our objective is to increase the production volume, while minimizing the impact of the downsides of the trade-offs. Using the relations of the simulation model, the objective function can be formulated as follows:

Total Production Volume = function(RPA, Sh, LS, St)

2.4.2 Simulation Logic

The simulation model is based on Discrete Event Simulation logic. This means that the simulation model is responsive to events. The first step in our simulation model is stating the policy that will be used in the ramp up phase. This ramp up phase is divided in 75 weeks, which are considered the periods. Based on this policy each period is replicated 2000 times to compensate for the variability in the system. The variability is a result of the high unpredictability of downtimes and its durations. On these 2000 replications the chosen policy is applied and because variability is found in downtime distribution, the simulation will have different downtimes as output. The downtime affects the Net Production Time, which eventually affects the Production Volume. Because of this relations we execute the following: When downtime occurs the duration of this downtime is subtracted from the total remaining operational time of the week. The durations of this downtime also follows a distribution, which we will explain in 2.4.5. This is repeated until the remaining operational time is zero. Then the next replication starts. When 2000 replications were performed for week 1, the average Net Production Time and Production Volume are determined. This process is repeated for the other 74 weeks, which results in an overview of production volumes per week and the sum registers the Total Production Volume in the ramp up phase.

2.4.3 Solution Spaces of Decision Variables

Each variable has its own solution space, which we will define below. We will both discuss theoretical solution spaces and the constraints from reality that we need to consider, which results in a practical feasible solution space.

Introduction of night shifts

The introduction of night shifts is an important trade-off concerning the third shift. Theoretically, the third shift can be added after the introduction of the second shift, considering a certain interarrival time. This interarrival time is to be determined as one of the other trade-offs. However, this is not the only constraint to consider. As stated in the assumptions list for the simulation model, Company X needs a state of independence before the night shifts will be beneficial. Until Company X is independent of the supplier assistance for downtimes, the risk of running no or few production during night shifts is too high. Based on the expertise of the manufacturing manager in Place Y this independence is reached at the earliest in week twenty. One could state that this independence can be prepared and all settings of all machines can be registered from the beginning of the ramp up phase. However, many settings change during the beginning of the ramp up, so it does not hold to store these settings at the beginning. This leads to a feasible solution space for the introduction of the third team of week 20. The interarrival time is respected when this value is smaller than 19 weeks, which we can easily assume.

Timing of subsequent teams

In the previous paragraph we discussed the interarrival time between introduction of two subsequent teams. This interarrival time could theoretically vary from one week to 75 weeks. However, 75 weeks will not be considered, because this is not realistic in the ramp up phase of 75 weeks. We will consider the solution space of 1 to 10 weeks for this trade-off.

Introduction of additional RPA hours

The introduction of additional RPA hours entails an increased experience for the operators, which leads to a more efficient execution of RPAs, but also to a reduced risk of downtimes. We quantify this reduced risk in the simulation model by modelling that each additional hour of experience increases the mean of the interarrival time distribution for downtime by 0.1 hours. This means that on average the time between two unexpected stoppages takes on average 6 minutes longer. The downside is that RPA hours take time that could have been used for actual production. The amount of time taken by RPAs up a certain point in the ramp up phase determines the experience of the operators at that point. Eventually, approximately 36% of the operational time is consumed by RPAs. This 36% is based on 60 hours of RPAs on a workweek of 168 hours. The trade-off here is either to start with a larger fraction of RPA time and then increase gradually or to start with a smaller fraction and increase rapidly. Figure 2.6 shows reasonable RPA patterns up to a starting fraction of 0.5 with respect to the operational time. This means that the solution space is narrowed down to linear function with starting values between 15 and 36 that end up to the 60 RPA hours at the end of the ramp up phase.

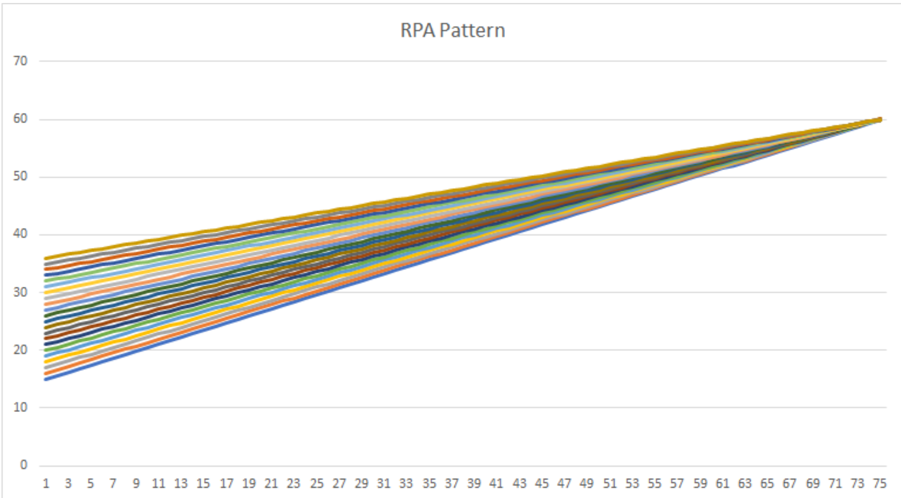

Figure 2.6: Possible policies regarding introduction of additional RPA hours

The direct effect of increasing the fraction of RPA time is of course that actual production in reduced. However, the indirect effect of the experience increase and downtime risk is not clearly noticeable in the total production volume. Figure 2.7 shows this indirect effect. The brown shaded area is the additional total time consumed by RPAs, which represents the additional gained experience of the operators.

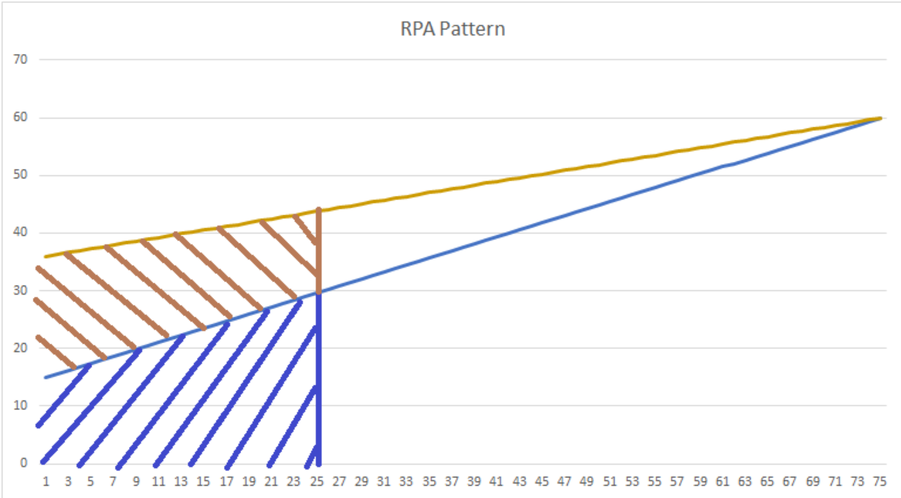

Figure 2.7: Effect of starting with a larger fraction of RPA time

Timing of line speed increase

The line speed is starting at 70% of the maximum capacity of the production line and each increase consists of 10% of additional line speed. This means that we have to have to schedule three increases to run the canning line at 100% of the maximum capacity. Similar to the interarrival times between the subsequent teams.

2.4.4 Relations to mediators and output entities

Figure 2.5 already shows how entities in this model are connected, but it is not clearly stated how mediators and output entities depend on the decision variables. This subsection will describe these dependencies.

Net Production Time

As assumed in Subsection 2.1.1, the operational time is the only time available for production and is divided in three parts: RPA time, Downtime and Net Production Time (NPT). Therefore, the NPT is easily calculated by Formula (2.2).

$$NPT = OT_i - RPA_i - D_i, \tag{2.2}$$

where
OT_i = Operational Time in week i
RPA_i = RPA time in week i
D_i = Downtime in week i

Exogenous influences

We also have to deal with exogenous influences, that have impact on our production volume. The two exogenous influences that we have to deal with are material loss and downtime.

Material loss is a direct reduction of the production volume. 2.2.1 already described the causes for this reduction and that they are exogenous. However, this material loss should be considered to let the model represent the reality correctly. The same holds for downtime, but the RPA pattern that is chosen as decision variable influences the parameters of the downtime distribution and the experience of the operators. The interarrival time of unexpected stoppages can be modelled by a Weibull distribution. The process towards this conclusion is explained in Subsection 2.4.5, but for now we assume this is given. We model the relation between the operator experience and influence on the downtime by stating that each hour of RPA experience increases the scale parameter of the Weibull distribution by 0.1. This means that more RPA experience lengthens the average time between two unexpected stoppages. The start value of this scale parameter is 2.09, which will again be proved in Subsection 2.4.5.

Production Volume

The Production Volume ($\mathrm{P_i}$) is calculated by Formula (2.3)

$$P_i = NPT_i \cdot LS_i \cdot ML_i, \tag{2.3}$$

where
NPT_i = Net Production Time in week i
LS_i = Line Speed in week i
ML_i = Material Loss in week i

Total Production Volume

The Total Production Volume is simply calculated by summing the production volumes of each week in the ramp up phase, as stated in Formula (2.4).

$$TPV = \sum_{i=1}^{75} P_i \tag{2.4}$$

2.4.5 Real data input

To accurately determine parameter settings we used real data as input. We used data of the last two months about downtime durations and the interarrival times of downtime. To be able to generate data for the longer term, a distribution was fitted to this data by Matlab. We found, based on the histogram in Figure 2.8, that we could fit a Weibull distribution on the data. Moreover, Alexander Schmig (1985) wrote a paper on the suitability of a Weibull distribution to approximate machine failures.

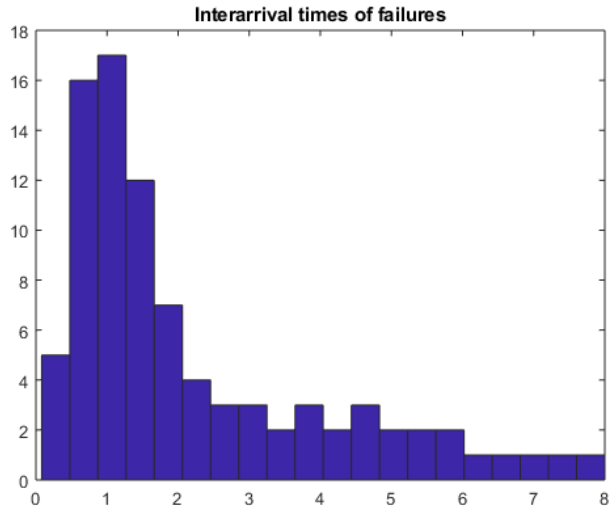

Figure 2.8: Histogram of the interarrival times between downtimes

Based on this knowledge we fitted the Weibull distribution to the data of August and September. Fitting a Weibull distribution, we were looking for the scale and shape parameters that we need to define the Weibull distribution. These values are 2.09 and 1.48, respectively, which were used to simulate the downtime interarrival time distribution. We can only use these parameter values, when we validated them. We did this by performing the Lilliefors test, which is a modification of the Kolgomorov-Smirnov test. This test is applied on continuous distributions of the normal distribution family, where the Weibull distribution belongs to. This Lilliefors test is build in Matlab and it validates whether the data set comes from a distribution of the "normal distribution family" with a 5% significance level.

The same method is applied to fit the durations of the downtimes, which resulted in Figure 2.9

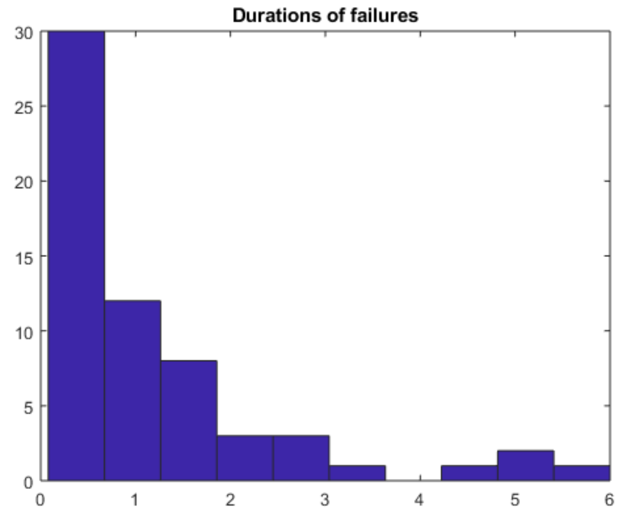

Figure 2.9: Histogram of the durations of downtimes in hours

When fitting a distribution to this data, we found that an exponential distribution is the most suitable one. This resulted in a exponential distribution with parameter value 0.33 hours for λ, which means that E[X] of this distribution is equal to 3.0. Again we need to validate this before using it in our simulation. The same Lilliefors test offered a solution. The exponential distribution needs the Lilliefors adjustment to the Kolgomorov-Smirnov test as well.

2.4.6 Assumptions

- The ramp up duration is fixed to 75 weeks. For every packing line this is different, but based on the planning for the first packing line this is a reasonable assumption.
- In all situations holds an infinite demand of the customers. This means that in case of an early introduction of shifts, no production due to lack of POs, does not occur
- Commercial production always starts with 2 shifts. This is the starting point of the ramp up phase in this investigation.
- Time is distributed only in three parts; Net Production Time, Unexpected Downtime and Routine Production Activities. Planned non-operational time, Available unused time and unavailable time are not considered in this research.
- The time between the adding of teams should be at least 4 weeks. E.g. if team three is added in week 20, team 4 can only be added in week 24 or later. An interarrival time is new teams shorter than 4 weeks will not be sufficient to practice all RPAs and experience different downtimes for the new operators, who are assumed to teach the next team already how to operate.
- Employees have 65% understanding of the production process at the start of the ramp up period. This is assumed, for the operators could already practice with the equipment, before the ramp up period has started and instructions per machine are developed by assigned operators. Moreover, almost every employee has experience from the factory in Place Z. Many machines in Place Y are similar to the machines in Place Z.
- Standardization is assumed to be applied in the design phase. This is a recommendation for any future packing line. Therefore, it is not considered a decision variable in the simulation
- Material loss is defined as a percentage of the total production based on the policy instead of calculated exactly. The data available about the material loss for the ramp up phase in Project A is not sufficient, See Appendix A.3.
- Adding a shift and the efficient execution are related as can be seen in Figure 2.5. Adding a shift leads to an efficiency reduction of 5%, because experienced operators need to guide and explain the new operators about the processes
- Increasing the Line Speed entails an increase of the downtime. The line has to be tuned for a smooth product flow again. This is applied in the simulation model as an additional 10% downtime in the two weeks after a line speed increase.
- The transition from 2 to 3 teams entails the adding of night shifts. Concerning a large fraction of the downtimes, Company X is dependent on suppliers to solve the problems. However, these suppliers will not be available during night shifts. However, we assume that these suppliers are available during night shifts in this simulation.
- The downtimes are dependent on the hours of experience with RPAs of the operators. The more hours of RPA execution, the lower the chance of machine failures. Therefore, the parameters of the downtime distribution differ according the experience of the operators.

2.4.7 Validation

The model that we created needs validation to enable Company X to use this model for decision-making purposes. Validation is performed in three steps. First, we should ensure that the model appears reasonable to model users and experts on the packing line. This high degree of realism is called high face validity (Banks, 1998). The second step is validating the model assumptions. Again expert knowledge is used here to verify data reliability for example. We discussed that report for the first packing line are vulnerable to operator interpretations, but the estimations are sufficient as model input. The third step is the validation of Input-Output transformation. This is done by looking at the model as a black box that has values for the decision variables as input and generates values for the output variables. This third step is executed by comparing the production volume from the simulation with the actual production volume. In both cases the input variables are equal under the assumptions made. Unfortunately, only data regarding production volume is available starting in week 9. Figure 2.10 compares the actual production volumes of week 9 to 19 with the production volume results of the simulation model that uses the input parameters of the current policy. We observe that the graphs are similar and the small fluctuations are results of the downtime distribution. The larger differences are identified at week 12, 13 and 14. In these weeks Company X produced solely the same product so no changeovers and hardly any cleaning was necessary. Therefore, the production volume is higher than the simulation predicts. The significant lower production volume in week 21 is caused by the introduction of the third team. This includes night shifts and Company X was not fully independent of their suppliers in case of downtime. Therefore, no production was generated during night shifts from the point a failure occurred.

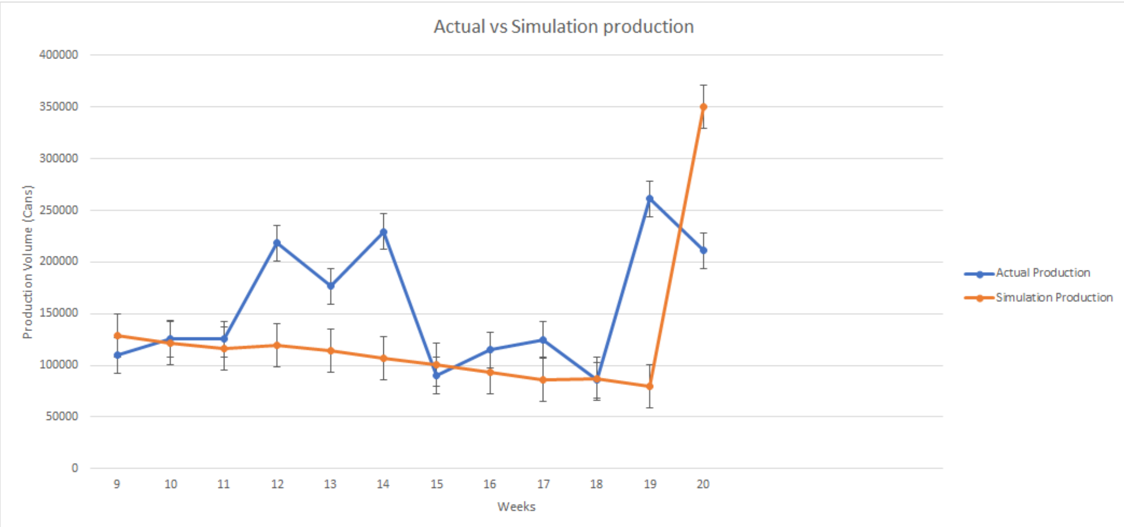

Figure 2.10: Validation of actual and simulation results

Disregarding the large differences we see a pattern that the simulation results tend to be lower than the actual results. This can be explained by the fact that RPA times, that are not executed weekly in reality, are distributed equally over the weeks in the simulation. We perform a students t-test with a significance of 5% and the 11 observations on simulation results. Based on the results of the students t-test, we can conclude that our model is validated. The process of validation is stated in the remainder of this section.

The students t-test is calculated by Formula 2.5

$$t_0 = |\frac{\bar{Y} - \mu_0}{\frac{S}{sqrt(n)}}|, \tag{2.5}$$

where
$\overline{Y}$ is the average of production of the simulation
μ is the average of the actual production
S is the standard deviation of the sample population
n is the number of observations

Therefore, we need the average of both the simulation results and the actual observations of week 9 to 19. Moreover, we need to calculate S, which is done by the following formula:

$$S = \sqrt{\frac{\sum (Y_i - \bar{Y})^2}{n - 1}}, \tag{2.6}$$

where
Y_i is producion of simulation in week i

Based on the data of Table 2.5, we can perform the necessary calculations. We find that S = 67766 and t_0 = 1.9916. When we compare this with the value for $t_{\alpha/2,n-1}$ and t_0 is lower than $t_{\alpha/2,n-1}$, we can conclude that our simulation model is validated. As stated, we choose alpha=5% and n = 11. $t_{\alpha/2,n-1}$, which represent the test value for a two sided confidence interval of 5% and 11 observations is equal to 2.201. Therefore, we can conclude that our model is valid to represent reality. There is still room for improvement in terms of accuracy, but this model sufficiently represents reality.

Actual Production (cans)	Simulation Production (cans)	$(Y_i-\overline{Y})^2$ ($cans^2$)
109505	128613	$7.53 * 10^8$
125607	121426	$1.20 * 10^9$
125244	115899	$1.61 * 10^9$
218351	119018	$1.37 * 10^9$
176404	114322	$1.74 * 10^9$
229534	107079	$2.40 * 10^9$
90133	100564	$3.08 * 10^{10}$
114818	93174	$3.95 * 10^9$
125000	86301	$3.95 * 10^9$
85759	86680	$4.81 * 10^9$
261106	349979	$3.76 * 10^{10}$

Table 2.5: Actual observations vs simulation results

Chapter 3

Policy Improvement

In this chapter we aim for a policy that improves the production volume during the ramp up phase. This is done by applying the Greedy algorithm on the developed simulation model.

3.1 Initial policy

The initial solution in the solution space is chosen as the policy that is currently used at Company X. This is done to easily demonstrate what the impact of a different policy is on the total production volume in the ramp up phase compared to the current policy. Moreover, we will be able to validate the simulation model by comparing the actual output with the simulation output. This current policy partly consist of the policy that has already been executed and partly the planning that still has to be executed. The original plan experienced delay due to various reasons. Therefore, the remaining part of the policy has been adjusted to this delay.

The entire policy is schematically displayed in Table 3.1. It states that the ramp up period starts with 2 teams, as assumed in subsection 2.4.6. Furthermore, teams 3, 4 and 5 start in week 20, 24 and 50, respectively. When a team is added, the experienced teams need to explain everything to the new operators, which takes additional time. This is modelled by a 5% loss of efficiency and then following the pattern again. The RPA hours is following a linear pattern that we will explain in detail in Subsection 2.4.3. The Line Speed is determined as the fraction of the maximum capacity. So in this case the canning line is producing at maximum speed from week 25. The only decision variable that differs from the current situation is the standardization variable. This is set to 100%, which means that standardization is already executed before the ramp up phase started. This is one of the recommendations, because it can already occur in the System Design and Development phase, see Figure 2.3.

Decision Variable	Value
Adding teams	week 1, 20, 24, 50
RPA Pattern	Linear function: 15 + 0.608 * week
Line Speed Increase	week 6, 15, 25
Standardization	100%

Table 3.1: Decision variables for benchmark of current policy

When we apply this policy in the Matlab script the following results are obtained:

Total Production Volume	34986 cans
Material Loss	11.2%
Net Production Volume	31462 cans

Table 3.2: Results for benchmark of current policy

The production volume per week is distributed as follows in Figure 3.1. We observe a obvious growth when a shift is added. The fluctuations are declared by the downtime. This is unpredictable and therefore variability is inevitable. However, we see a clear decrease in amplitude of the variability. This is because throughout the ramp up phase Company X controls the processes more and recognizes failures and know how to act these failures.

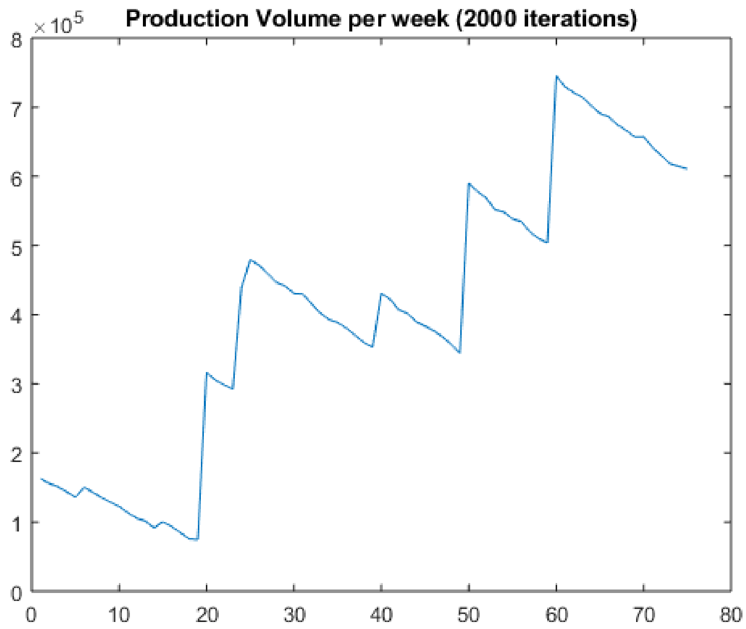

Figure 3.1: Production volume displayed per week using the current policy

This graph will be generated for every policy and it shows the production volume per period under the chosen policy. One would find the total production volume produced in the ramp up period by calculating the surface under the line in the graph. This is of course the output entity that we need to measure. When we apply the Greedy algorithm we evaluate the impact on the total production volume. This production graph is the average of 2000 replications. The ramp up phase is extremely vulnerable for variability in downtime, so this amount is replications is necessary to filter this variability. Because the RPA time is linearly increasing, it can be observed that the total production volume is decreasing at some periods in the ramp up phase. In reality this decrease is not that strongly present, but on average it represents the reality, as proved in Subsection 2.4.7

3.2 Benchmarking

In this section we will explore behavior of decision variables and their influence on the total production volume of the canning line.

3.2.1 Benchmark policies

In this subsection we discuss several benchmark policies, based on several patterns of the decision variables that we discussed in subsection 2.4.3. The extreme values of decision variables are respected when choosing the patterns. Based on the benchmark policies results in terms of total production volume are shown. This helps us validate whether the obtained results from the improved simulation are realistic. Moreover, we will be able to explore the behavior of the total production volume when changing decision variables that imply the trade-offs mentioned in Section 1.3.

Early Shift Policy

We start with the policy, that increases the number of shifts as soon as possible.

Decision Variable	Value
Adding teams	week 1, 2, 3, 4
RPA Pattern	Linear function 15 + 0.608 * week
Line Speed Increase	week 6, 15, 25
Standardization	100%

Table 3.3: Benchmark policy with earliest possible shift increase

The difference that we observe in this policy is the introduction of all teams in the first four week of the ramp up period. Due to this difference the hours available increases, but another important difference is that the efficiency of the execution of RPAs decreases very fast in the beginning. Therefore, the first part the ramp up period is not very efficient, but as we observe in Table 3.2, the weekly production starting at week 30 is, on average, 20.000 cans larger. However, the total production using the "Early Shift" policy is lower than the current policy of Company X, as displayed in Table 3.4. This can be understood by the fact that the operators were not able to control the processes sufficiently in the beginning and therefore were not able to teach the new operators properly. Another observation in the graph confirms that an early introduction of production teams is not beneficial. Namely the fluctuations in downtime have the same amplitude throughout the ramp up phase, where the fluctuations in the current policy are decreasing.

Total Production Volume	45407 cans
Material Loss	16.93 %
Net Production Volume	37719 cans

Table 3.4: Results for benchmark of current policy

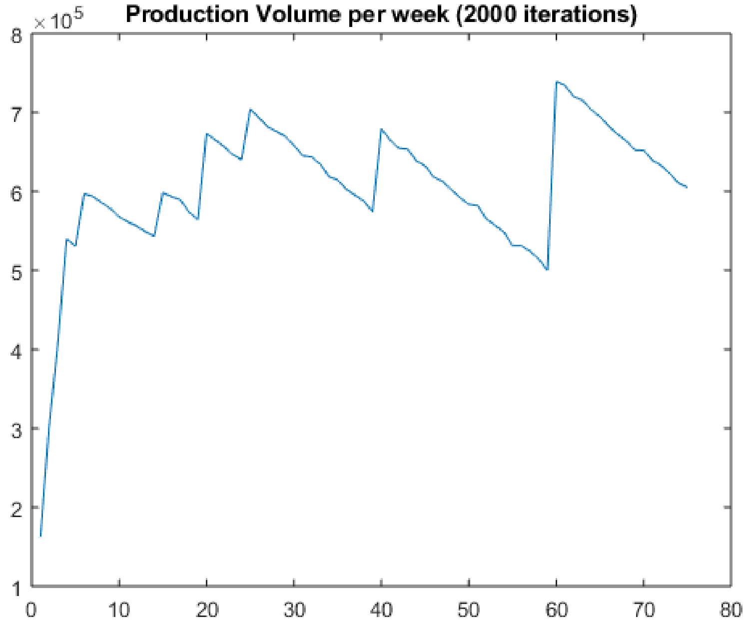

Figure 3.2: Production volume displayed per week using the "Early Shift" policy

Figure 3.2 shows the production volume per week using the "Early Shift" policy. In this policy we introduce all shifts in the first four weeks. The explosive ramp up speed is easily explained by the hours that become available due to the availability of more teams. However, this entails an increase in downtime as well. In the beginning of the ramp up , the processes and failures are not as controlled as they would be later in the ramp up. Therefore, we expect the ideal ramp up policy to be in between this extreme early policy of adding of new shifts and the current policy regarding adding shifts. Moreover, the weekly production volume that could be achieved in not nearly achieved using this policy.

Early Line Speed Policy

Because we increase the line speed in this benchmark policy as soon as possible, we will experience more downtime. During the beginning of the ramp up phase, downtime is experienced anyway, because employees need to get to know the line and random errors occur more often, during this part of the ramp up phase. This could be an advantage, because the additional downtime because of the line speed increase is relatively less, compared to the situation in which the line speed is increased later in the ramp up phase. The disadvantage might be that some errors do not come to light, because the line is not running very often. However, in case of an increase in line speed, the line immediately experiences trouble or at least congestion at the potential trouble points. The disadvantages are negligible compared to the additional production volume and considering the downtime that is already experienced in the begin of the ramp up phase. Therefore, Company X should aim for the fastest increase of line speed, without losing control over the line, because than more downtime could occur than necessary. The amount of RPA time is taken here as the time that is used for the current policy of Company X as well.

Decision Variable	Value
Adding teams	week 1, 20, 24, 50
RPA Pattern	linear function: 15 + 0.608 * weeknumber
Line Speed Increase	week 2, 3, 4
Standardization	100%

Table 3.5: Benchmark policy with maximum Line Speed increase

Total Production Volume	36321 cans
Material Loss	14.87%
Net Production Volume	30920 cans

Table 3.6: Results for benchmark of Early Line Speed Policy

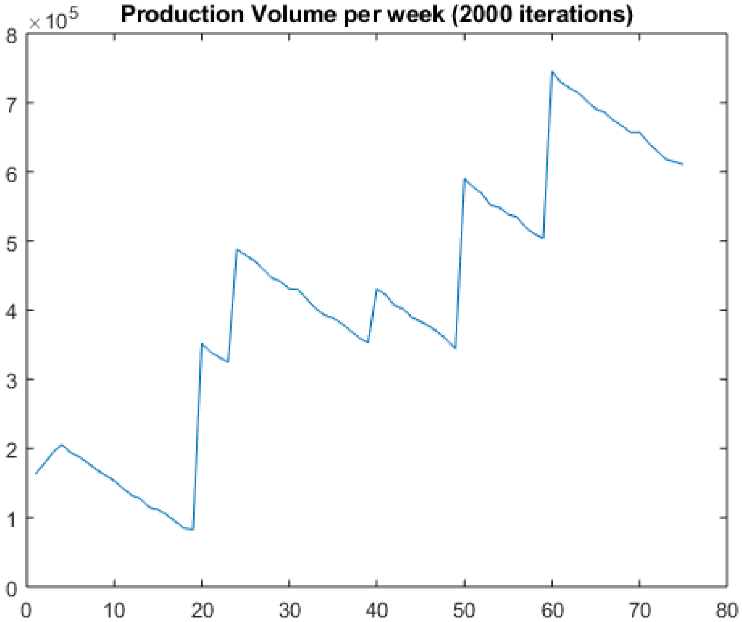

Figure 3.3: Production volume displayed per week using the "Early Line Speed" policy

Figure 3.3 shows the production volumes per week using the Early Line Speed policy. We observe a growth in the beginning of the ramp up period due to the Line speed increase, but we also recognize a bigger amplitude in this period. This is due to the additional downtime caused by the line speed increase. After this starting period, we observe a similar progress of production volume compared to the current policy.

Early Registration Policy

The last policy that we will evaluate as a benchmark policy is the "Early Registration" policy. The main difference is that the operators have more RPAs to execute in the first part of the ramp up phase due to more product registrations. More registered products means more tests and opportunities to produce commercial product and therefore more RPAs. The Net Production Time could have been higher in the first part of the ramp up phase, but the experience of the operators increased early and therefore they are able to perform RPA more efficiently.

Decision Variable	Value
Adding teams	week 1, 20, 24, 50
RPA Pattern	root-function: 36 + 0.324 * week
Line Speed Pattern	week 6, 15, 25
Standardization	100%

Table 3.7: Benchmark policy Early Registration

Total Production Volume	39918 cans
Material Loss	0.1307 %
Net Production Volume	34701 cans

Table 3.8: Results for benchmark of Early Registration Policy

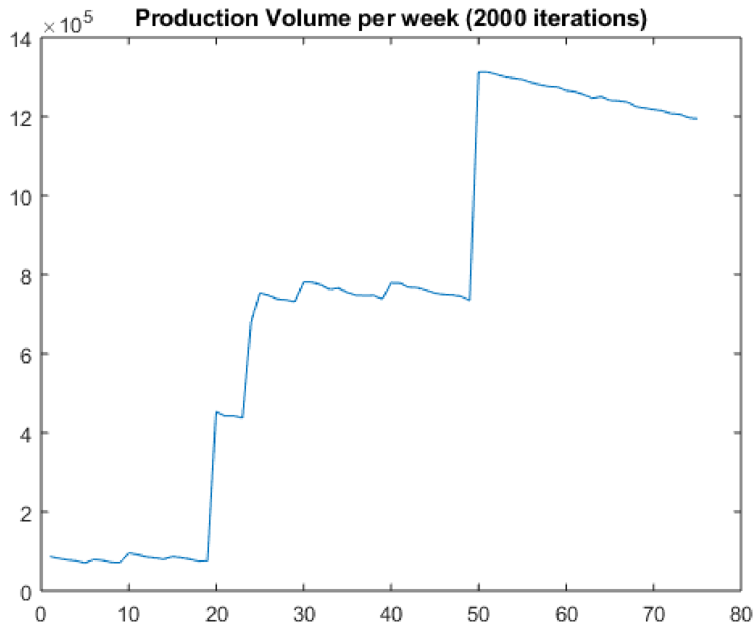

Figure 3.4: Production volume displayed per week using the "Early Regsitration" policy

Figure 3.4 shows several weeks with very little production at the beginning of the ramp up phase. However, the production volume at the end of the ramp up speed is larger than any of the other policies. An early introduction of more RPAs due to early product registrations has a positive effect on the production volume at the end of the ramp up phase. Moreover, the effect of a less steep increase of RPA hours is clearly visible in Figure 3.4. The decrease of production volume over weeks is less, because the RPAs are increasing more slowly. Weighing these two influences should results in the best solution of this decision variable. Therefore, a trade-off should be implemented in the simulation that maximizes this influence.

3.3 Improved policy

We already discussed the greedy algorithm as the improvement methodology to improve the policy. In this section we will explain the greedy algorithm in detail. A greedy algorithm is often used in projects for improvement of performance and is also applicable on manufacturing problems. It assumes that the decision variable that has the most impact on a certain initial situation is the direction to go in aiming for the best solution using this algorithm. This process is iterated until the impact of the variables is lower than a predetermined value Thomas A. Feo (1995). The lower this predetermined value is chosen, the closer the outcome is to the eventual solution. In this chapter we use solution and policy alternating, because each policy that we provided is a solution of the solution space. The improved policy is found by applying the Greedy algorithm on the current policy of Company X.

We check the impact of expediting and postponing of:

- adding an extra team
- increasing the line speed
- registering new products

For all independent variables the impact is observed and the slight change with the largest impact will be implemented and than the algorithm starts again. These slight changes depend on the decision variables. Therefore, postponing and expediting the introduction of teams by a week is measured, postponing and expediting line speed increase by a week is measured and the RPA patterns are measured by increasing and decreasing the start value of the linear function by one hours and adjust the slope accordingly. The algorithm stops repeating itself, when the impact is below a certain threshold. This threshold is chosen to be 1, because a positive impact is beneficial for the production. The process of this improvement is visualized in Figure 3.5

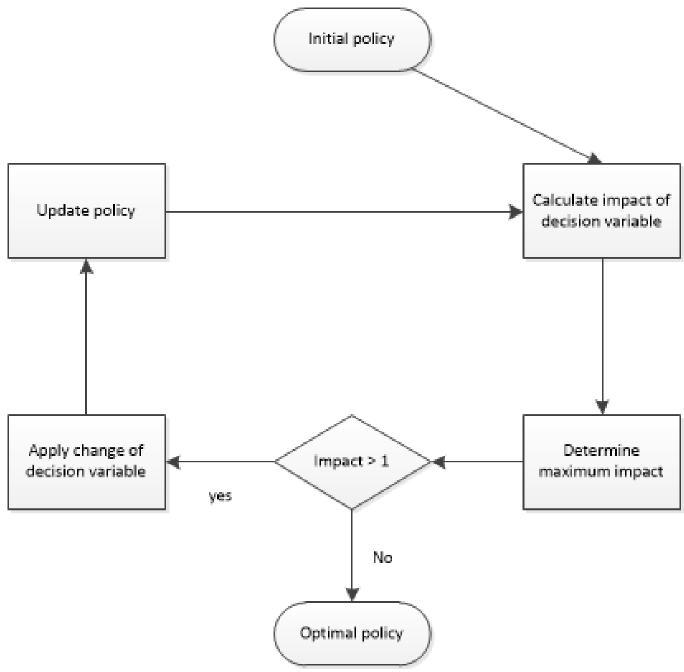

Figure 3.5: Visualization of Greedy Algorithm applied on policy optimization

When all steps for improvement are determined, the difference in policy with the initial situation will be evaluated, whether the effort is worth the benefit. Table 3.9 shows the improvement steps based on the optimization cycle. In the last step we see that the impact of changing decision variables has a maximum impact of 0.9981. This impact is negative for the total production volume and therefore this change is not applied on the policy. The previous changes optimized the initial situation.

Applying all these steps leads to the best policy using the Greedy algorithm. Table 3.10 shows this best policy that leads to the total production volume as calculated in Table 3.9. The differences between the initial policy and the improved policy are obvious. Only the addition of team 5 is expedited. This is explained by the fact that the third team can only be added, when Company X is (nearly) independent of suppliers during downtimes. The fourth team can only be added 4 weeks after the addition of team 3. Team 5 was added initially 26 weeks after team 4, therefore many improvement space is found here. The addition of this team is expedited by 22 weeks to only 4 weeks after team 4.

The RPA pattern is changed from a start value of 15 to 24. The main difference is found in the start value that determines the time consumption of RPAs during the begin phase of the ramp up. This start value is now 25 instead of 15 and the root function ensures that during the ramp up speed the RPA hours reach a certain limit, which is desired in this case

The line speed increase to 90% of the maximum capacity is pulled forward by 3 weeks. The increase to 100% is pulled forward by 7 weeks. Apparently it is useful to increase the line speed early in the process. We would expect this already based on the benchmark policy regarding the line speed, but it also makes sense to produce already at maximum capacity before adding a new team. The first two teams can then fully control the process at maximum speed, before they teach the third time how to operate.

	Total Production Volume (TPV)	Max Impact	Variable	New TPV
Iteration 1	34986	1.0130	RPA increase	35441
Iteration 2	35441	1.0087	Sh5 earlier	35749
Iteration 3	35749	1.0025	Sh5 earlier	35839
Iteration 4	35839	1.0067	Sh5 earlier	36079
Iteration 5	36097	1.0080	RPA increase	36367
Iteration 6	36367	1.0075	Sh5 earlier	36640
Iteration 7	36640	1.0063	RPA increase	36871
Iteration 8	36871	1.0071	Sh5 earlier	37133
Iteration 9	37133	1.0026	Sh5 earlier	37229
Iteration 10	37229	1.0083	RPA increase	37538
Iteration 11	37538	1.0041	Sh5 earlier	37692
Iteration 12	37692	1.0093	LS70 earlier	38043
Iteration 13	38043	1.0056	Sh5 earlier	38256
Iteration 14	38256	1.0043	Sh5 earlier	38420
Iteration 15	38420	1.0053	RPA increase	38624
Iteration 16	38624	1.0095	Sh5 earlier	38991
Iteration 17	38991	1.0074	LS70 earlier	39279
Iteration 18	39279	1.0042	Sh5 earlier	39444
Iteration 19	39444	1.0059	Sh5 earlier	39677
Iteration 20	39677	1.0073	RPA increase	39967
Iteration 21	39967	1.0049	RPA increase	40162
Iteration 22	40162	1.0048	Sh5 earlier	40355
Iteration 23	40355	1.0016	Sh5 earlier	40419
Iteration 24	40419	1.0072	LS70 earlier	40711
Iteration 25	40711	1.0062	Sh5 earlier	40963
Iteration 26	40963	1.0040	RPA increase	41127
Iteration 27	41127	1.0073	Sh5 earlier	41427
Iteration 28	41427	1.0053	Sh5 earlier	41647
Iteration 29	41647	1.0069	LS70 earlier	41934
Iteration 30	41934	1.0035	Sh5 earlier	42081
Iteration 31	42081	1.0074	RPA increase	42392
Iteration 32	42392	1.0023	Sh5 earlier	42498
Iteration 33	42498	1.0038	LS70 earlier	42659
Iteration 34	42659	1.0067	LS70 earlier	42945
Iteration 35	42945	1.0132	Sh5 earlier	43512
Iteration 36	43512	1.0088	Sh5 earlier	43895
Iteration 37	43895	1.0071	LS70 earlier	44206
Iteration 38	44206	1.0103	Sh5 earlier	44662
Iteration 39	44662	1.0134	LS70 earlier	45260
Iteration 40	45260	1.0126	LS70 earlier	46334
Iteration 41	46334	0.9981	LS80 earlier	46246

Table 3.9: Greedy steps towards policy policy improvement

Applying the final result of the greedy algorithm results in the policy, described in Table 3.10. This policy shows an improvement that is summarized in Table 3.11.

Decision Variable	Value
Adding teams	week 20, 24, 28
RPA Pattern	Linear function: 24 + 0.487* week
Line Speed Increase	week 6, 12, 18
Standardization	100%

Table 3.10: Decision variables for improved policy

When we consider the weekly production volume of this policy and compare this to the current policy if Company X we see a more balanced increase of production volumes and the RPA hours are more smoothly increasing. This policy leads then to an increase of approximately 32%, . Therefore, it is absolutely worth implementing this improved policy.

Total Production Volume	46334 cans
Material Loss	9.42%
Net Production Volume	41969 cans

Table 3.11: Results for the improved policy

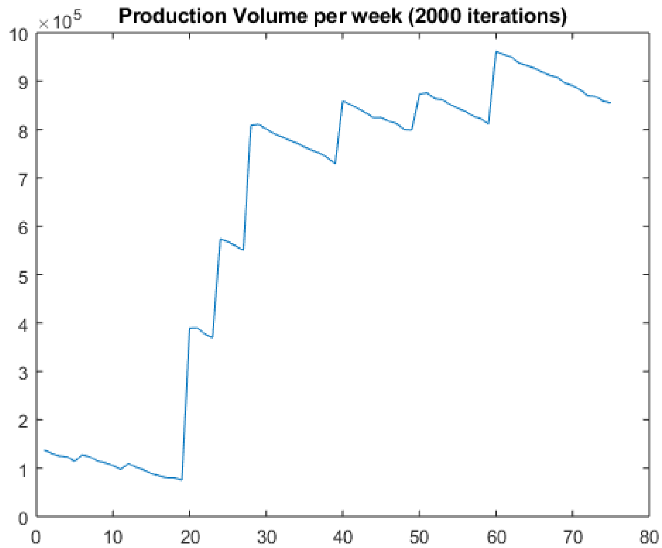

Figure 3.6: Production volume displayed per week using best greedy policy

This policy is again the average of 2000 replications. Still error bars should be added, because it is still a simulation. However, this distracts from the behavior of the actual policy in terms of production volume. Therefore, we decided to shows both graphs. The graph with the error bars is shown in Figure 3.7. These error bars are calculated as the standard deviation of the production volume, measured over 2000 replications.

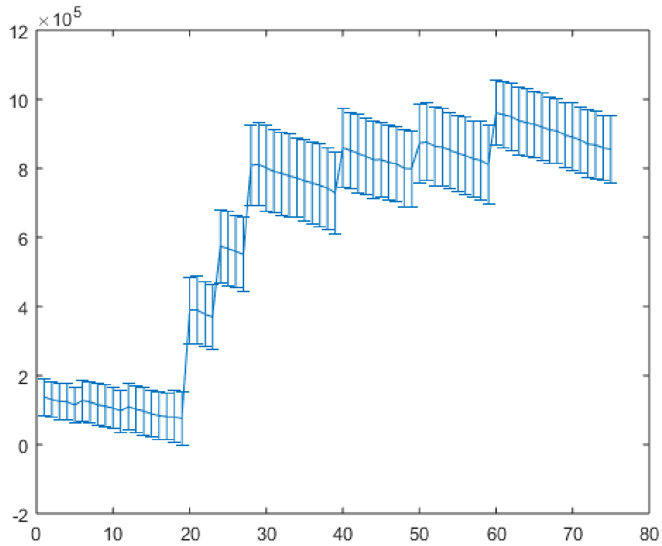

Figure 3.7: Production volume displayed per week using best greedy policy with error bars

Chapter 4

Results & Conclusion

Results of the simulation and improvement of the policy will be highlighted first in this chapter. Afterwards, the conclusion will be discussed, while the discussion and recommendations will only be treated in Chapter 5.

4.1 Results

Improving the performance of a packing line in ramp up phase is achieved via two main techniques, that are central in this Thesis.

The first technique is policy improvement that is done by applying the Greedy algorithm on the simulation model that we developed. Applying this Greedy algorithm revealed that the early registration of products has the largest impact compared to the effort. This registration should and can be done very early in the process, for all recipes are known in the Company X network. The effect of this early registration will be that every operator experiences many RPAs, which eventually leads to an increased overall production. The second largest impact relative to the effort is the timing of adding new operator teams. Many production hours become available when an extra team is added earlier, but this normally comes at a price. In this specific case of Company X, this does not hold. The operators that will work in the production facility in Place Y, are operators in Place Z. Therefore, the salary for the operators is not additional for Company X. However, the operators need to be trained in the new environment. Moreover, constraints to the timing of adding of teams are set, because the new operators need to understand and control the process sufficiently to be able to execute the processes properly, know how to act in case of machine failure, and teach new operators how to operate properly. Then Line Speed also has its impact on the production volume. It is easy to implement, but increasing the line speed also entails an increase of downtime, which makes the impact less large as the other decisions variables. However, it is very important to increase the line speed to maximum capacity before the third team is introduced in the production facility. The first reason for this need of increase is that downtime due to line speed increase is experienced anyway, regardless of the timing, while every expedited week of a line speed increase, results in additional production volume. The second reason to do so is to enable operators to fully control the process before teaching the processes to new operators. Experienced operators draw attention for mistakes that they have made and will therefore less likely happen again.

The second technique is reducing the non-production time. In this case we considered non-production time as unexpected stoppages and RPAs. Reducing downtime is achieved by prioritizing problem solving regarding unexpected errors. The digital environment caused 61% of the unexpected downtime, which logically leads to the recommendation for Company X to fully test the digital environment, before the start of commercial production.

Disregarding the automation downtimes and standardization downtimes, as we defined in Chapter 2.1.3, we observe that the main part of the reminder is random machine failures. Downtimes should be prioritized on their impact on the production. This means that when a downtime of 10 minutes does not affect the production, because it can be covered by a buffer, there is no priority to solve the issue immediately.

When prioritizing problems that affect the actual production, we recognize a clear pattern. The closer the machine that causes the failure is located to the filler, the bigger the impact on the production. This is intuitively, because less buffer will be located in between the filler and the machine that is causing the trouble. Therefore, we should prioritize downtime, using the V-shape model as visualized in Figure **??**.

Reducing the time consumed by RPAs is achieved by both Standardization and SMED. Standardization should be implemented during the Production System Design and Development phase. Which takes place before the actual ramp up of the packing line. During the FATs and SATs that Company X performs Standardization should be one of the requirements towards the suppliers. SMED reduces the RPA durations by approximately 45% on average. Moreover, the operator failures will be reduced because of the structured way of working.

Therefore, the optimization of RPAs should be pursued by first apply standardization throughout the factory. This is preferably taken care of during the design phase of the manufacturing line. Secondly, SMED should be applied on the RPAs that reduces the individual activities and aims for parallel execution of these individual activities during an RPA.

Using those two techniques, we found the best policy by Greedy that increased the total production volume during to ramp up speed with 32%. This is displayed in Table 4.1

Decision Variable	Value
Adding Teams	week 1,20, 24, 28
RPA Pattern	root-function: 24 + 0.486 * week
Line Speed Increase	week 6, 12, 18
Standardization	100%

Table 4.1: Decision variables for best policy using the Greedy algorithm

In this policy we recognize the early registration of RPAs, for the RPA pattern shows more RPA hours in the beginning of the ramp up phase compared to the initial situation. Moreover, the RPA hours remain roughly constant throughout the ramp up phase, which results in a net increase of production time, for the operational time increases during the ramp up phase.

We also recognize an improved pattern in the adding of teams. The fifth team is added to the canning line amply earlier compared to the initial situation. The third and fourth team remain constant relative to the initial policy. The third team can not be expedited, because the additional night shift will not be beneficial, while Company X is dependent on her suppliers in case of machine failures. The fourth shift can not be expedited, because the third team needs time to control the processes before having the ability to teach the fourth team about these processes.

Regarding the Line Speed is chosen for the fastest policy to increase to the maximum capacity, that gave the operator time to control the process at higher speed, recognize the machine failures and still operate at maximum speed before the third team is added. Although the Line Speed has the least impact on the total production, the Line Speed should be increased before the adding of team three to be able to adjust and tune the line before the introduction of this team.

Implementing the new policy of Table 4.1 will generate a total production volume of $5.5*10^6$. This is an increase in production volume of 34% compared to the current policy used at Company X. This means that huge potential for the production facility is available, when choosing a ramp up policy. Besides the optimization of the production volume, the material loss is reduced as well. Where the initial policy generated a waste of 10.2% material loss, the optimal policy only generates 9.4%. In absolute terms, the optimal policy generates more waste, but per can the waste is reduced significantly using the optimal policy. Table 4.2 summarizes the results of the optimal policy.

Total Production Volume	46334 cans
Material Loss	9.42%
Net Production Volume	41969 cans

Table 4.2: Results for the improved policy

The ramp up pattern will than look according to Figure 4.1. We observe an steady growth, where the current situation shows a capricious pattern. Both this difference and the early availability of production hours effectuate an increase of the total surface under the graph, which means an increase of total production volume.

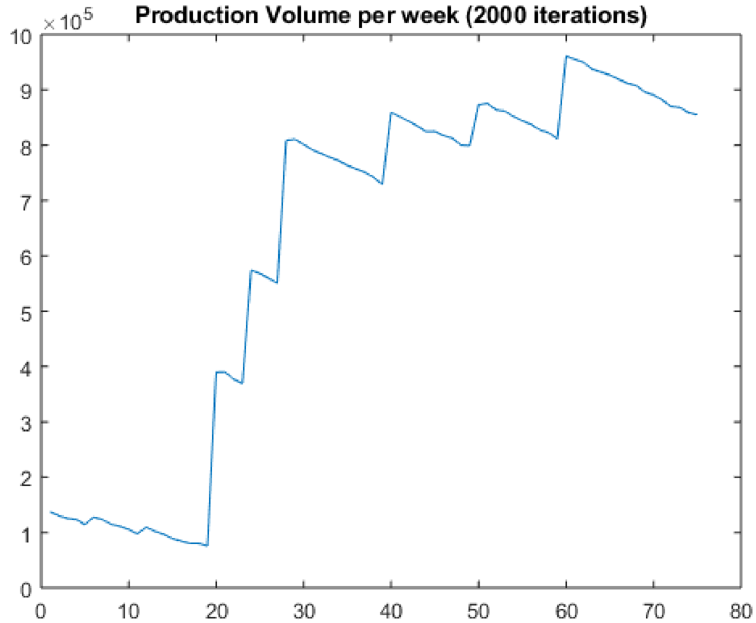

Figure 4.1: Production volume per week using the improved policy

4.2 Conclusion

The conclusion of this Thesis is two-fold. The first part of the conclusion is regarding the best policy for Company X to implement on their future packing lines. The second part is a more general conclusion for manufactures. This addresses the policy structure and what influences impact the manufacturing performance most.

The best policy for Company X to improve the performance of a packing line in ramp up phase has been displayed in Table 4.1. The most important differences that we observe are the number of hours taken by RPAs and the timing of adding new teams to the packing line.

Applying this improved policy on the future packing lines of Company X will not necessarily generate the optimal result for Company X, but aiming for the optimal result will not be beneficial in this situation. The ramp up phase is highly sensitive for uncertainty, such as downtimes due to information system breakdowns that we can not control. Therefore, an easy to implement improvement that generates a 10% increase is more relevant for Company X than the optimal solution. This optimal solution would generate e.g. 11% improvement, but this additional 1% will not be worth the investment.

The second part of this conclusion is more generally applicable. The experience of operators is investigated as a rather qualitative but important variable in the manufacturing industry. It is known that this expertise of operators is important to reduce machine failures and improve efficiency. This research proves this quantifying this influence. We discovered a much larger influence on the performance, both direct and indirect, than we expected. Therefore, manufacturers should never underestimate the value of experienced operators.

Another, often underestimated factor, is standardization. Research is conducted for over decades to the influence of standardization in factories. This research proves again that standardization both generates more production output during the ramp up phase, but also that operators value the attention of management to invest in making their work easier to perform.

Chapter 5

Discussion & Recommendations

The conclusion of this Thesis consists of the reflection on the limitations and the recommendations for future research.

5.1 Limitations

This sections explains the disadvantages of assumptions or techniques used in during this Thesis. The main limitations hide in the use of the Greedy algorithm, because the Greedy algorithm starts at a random initial situation and from this situation decision variables are slightly changed until the change of a decision variables does not effect the total production anymore. This seems a valid way of reasoning, but solutions that do belong to the solution space might not be considered following this algorithm. Therefore, we can not state that the optimal solution was found using the Greedy algorithm, however, the best policy is found using this algorithm.

Greedy assumes a certain rank in decision variables that should be optimized, but no order should be applied when optimizing the decision variables. Each of the decision variables should be optimized in the end.

The RPA pattern in each policy is described as a linear function, while this is not exactly the case. The simulation can be further improved be assigning RPAs that are usually executed less than once a week to specific weeks instead of distributing the downtime equally over the several weeks. This also supports the assessment of changing the RPA variable in the Greedy algorithm. The impact can then be measured more accurately. The total accuracy of the simulation model will then be even higher as well.

5.2 Recommendations for future packing lines of Company X

The first recommendation for Company X is to assure that the digital environment around the packing lines is ready before the start of the first batch. As we saw in Table 2.3, Company X should prioritize problems in this environment, because the line will not run if errors occur in the digital environment. A second reason why the digital environment's readiness is very important, is the potential to reduce waste. A perfect working digital environment reduces the number of rejected blends significantly.

Secondly, standardization should be considered during the design and development phase as indicated in Figure 2.3. The effect is clear and it saves Company X much time and money, when applying this in the design and development phase. No adjustments have to done during the ramp up phase, in which one wants to reserve time for more urgent matters and more important it gives you a head start. Moreover, no tailored parts have to be purchased. Instead the manufacturer of machines is forced to meet all requirements that now include standardization. Applying this standardization earlier in the manufacturing stage, would also perfectly fit in the Company X mindset: First Time Right.

The third recommendation is to apply the SMED methodology, as soon as possible. Not only the is a reduction of duration of the RPAs obtained, but the employees appreciate the attention and involvement of management on the workfloor. They acknowledge the effect of SMED and suggest ideas to make the activities even more efficient. Moreover, applying SMED as soon as possible emphasizes the ”First Time Right” attitude at Company X. The greatest advantage of this attitude is the absence of confusion about the way of working in the production facility. Every employee knows from the beginning how tasks should be executed and this knowledge is communicated to new employees as well.

The fourth recommendation is to arrange product registration in an early stage. Close to the end of the ramp up phase of the canning line, we experienced a suddenly low production volume at the canning, because only then products were registered and could be tested. When these products would have been registered earlier, these tests and validations of recipes could have been done in the beginning of the ramp up phase. This would result in both more production during the ramp up period, but also many RPA practice opportunities for the employees, which would benefit their learning curve. Moreover, the recipes would be controlled better (learning curve) and therefore less mistakes will be made in the Blending department, which entails a waste reduction.

The fifth recommendation is regarding the starting point of the commercial production as well. It will be beneficial over the whole ramp up phase to let the operators experience RPAs as early as possible in the ramp up phase. This results in less production in the beginning of the ramp up phase, but because the operators experienced many RPAs, they are familiar with these activities and will be able to explain it better to the new operators that will follow. This means that the execution of these processes takes less time and because these processes occur more frequently later in the ramp up phase, more time is gained by reduction of processing time later in the ramp up phase, which automatically leads to more net production time. This recommendation will mainly follow from applying the fourth recommendation, but operators can also practice with RPAs during the test phase.

In the policy that Company X used for their canning line, the time between the adding of the next shift was at one point only one month (between adding the third and fourth shift). In this month the third shift operators are supposed to be able to transfer knowledge to the fourth shifts as well. A month is short to fully understand all processes and machines. Therefore, it is recommended to reserve at least six weeks in between the adding of new shifts.

The last recommendations is to strive for independency on suppliers as soon as possible. This independency allows Company X to solve problems that occur during night shifts, where otherwise the night shifts would have been vulnerable for long production stops due to unavailability of suppliers. This independency can be achieved by document every setting of every machine. In case of a crash, where machines settings are reset, Company X can enter the correct settings from their documentation

5.3 Recommendations for future research

A fruitful area of research would be the construction of the learning curve. Instead of lowering the operating speed of the production line, it might be beneficial to assign time for operators to gain experience with the production line at the maximum production speed. This could for example be done by lengthen the test phase. By this mean less variables change for the operator and the line does not have to be adjusted with every change of operating speed.

In the problem definition we already discussed handling change management. This will be an issue to consider, because it is in the nature of humans to resist to change. Achim Kampker (2014) provides a solution to handle change management and improve the performance during the ramp up. He suggests to implement a gamification approach during the ramp up phase to motivate operator to perform better. This should, however, have been set up before the installation of the line already. An option might be to implement this for the two EazyPack lines, which would be an interesting Thesis subject.

Bibliography

Achim Kampker, Christoph Deutskens, K. D. A. M. A. H. (2014). Increasing Ramp-Up Performance by implementing the Gamification Approach. Master's thesis, . 3, 57

Alexander Schmig, O. R. (1985). On the suitability of the Weibull Distribution for the Approximation of Machine Failures. Master's thesis, . 33

Banks, J. (1998). Handbook of Simulation. Master's thesis, Georgia Institute of Technology. 36

Christian Terwiesch, R. B. (2001). Learning and process improvement during production ramp-up. Master's thesis, . 2, 16, 27

DaMaWay, D. (2018). SMED, Standard Description. Master's thesis, . 25

F. Klocke, J. Strauder, P. M. J. M. (2016). Modeling of manufacturing technologies during ramp-up. Master's thesis, . 2

Hong Chen, A. M. (2011). Discrete Flow Networks: Bottleneck Analysis and Fluid Approximations. Master's thesis, . 20

Martin Haller, Andreas Peikert, J. T. (2003). Cycle time management during production ramp-up. Master's thesis, . 2, 16

Paul Childerhouse, James Aitken, D. T. (2002). Analysis and design of focused demand chains. Master's thesis, . 2, 16

Peter Burggrf, Matthias Dannapfel, H. V. (2016). Potentials of factory standards in production ramp-ups. Master's thesis, . 2, 16

Shingo, S. (1985). A revolution in manufacturing: the SMED system. Master's thesis, . 25

Stefanos Doltsinis, Svetan Ratchev, N. L. (2013). A Framework for performance management during production ramp up of assembly stations. Master's thesis, . 2, 16

Thomas A. Feo, M. G. R. (1995). Greedy Randomized Adaptive Search Procedures. Master's thesis, . 46

Appendix A

Additional Information

A.1 Format Changeover

The machines that need to be adjusted in case of a format changeover with their location.

Machine	**Location**
Bottom Supplier	Low Care
Case Packer	Low Care
Filler	High Care
Labeler	High Care
Capper	High Care

Table A.1: Machines with need of adjustment during Format Changeover with their location

A.2 Influence Diagram

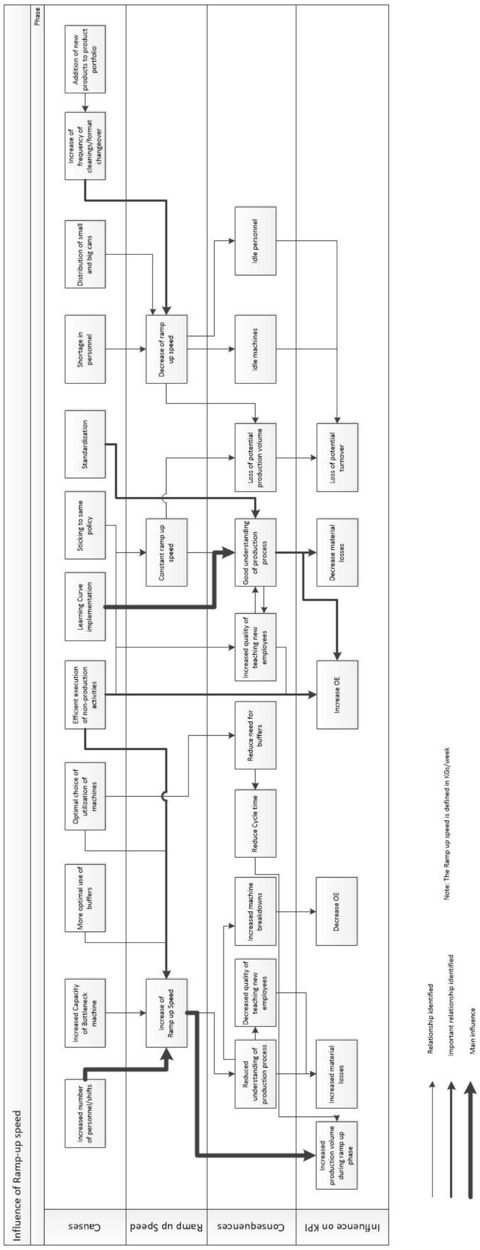

Figure A.1: Influence and dependencies of entities of the canning line

A.3 Material Loss

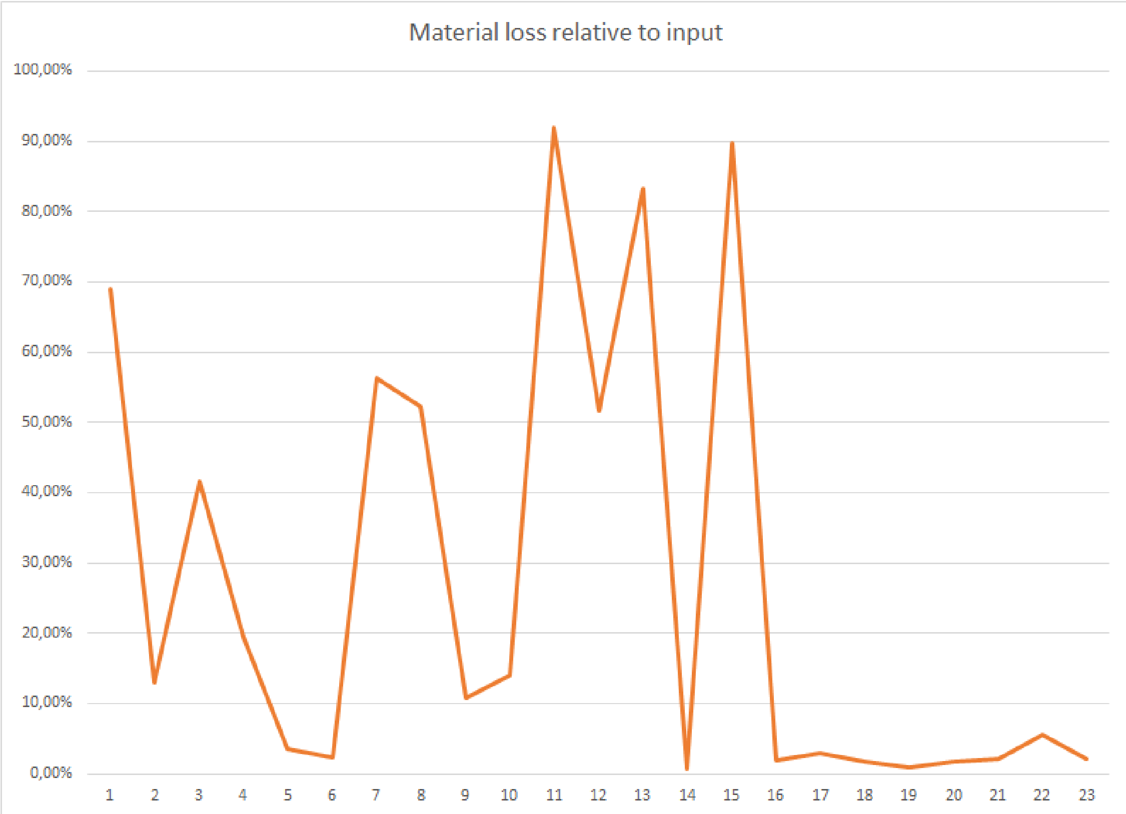

Figure A.2: Material loss relative to input per Production Order

A.4 Impact per step

Figure A.3 shows the impact of the change of each variable on the total production volume. The maximum impact of the variable change is chosen to apply on the policy for each step.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.0338	1.0165	1.0372	1.0247	1.0504	1.0326	1.0399	1.0263	1.0387	1.0220	1.0507	1.0348
2	0.9977	0.9813	1.0010	0.9838	1.0087	0.9840	0.9909	0.9774	0.9898	0.9733	1.0024	0.9861
3	0.9891	0.9728	0.9924	0.9752	1.0025	0.9793	0.9900	0.9766	0.9889	0.9725	1.0014	0.9852
4	0.9942	0.9780	0.9975	0.9804	1.0067	0.9859	0.9950	0.9817	0.9940	0.9776	1.0064	0.9903
5	0.9952	0.9791	0.9984	0.9814	1.0080	0.9865	0.9959	0.9826	0.9949	0.9786	1.0072	0.9912
6	0.9947	0.9787	0.9979	0.9810	1.0075	0.9835	0.9953	0.9822	0.9943	0.9782	1.0066	0.9906
7	0.9945	0.9787	0.9977	0.9810	1.0049	0.9886	0.9952	0.9821	0.9941	0.9781	1.0063	0.9905
8	0.9968	0.9811	1.0013	0.9834	1.0071	0.9837	0.9903	0.9762	0.9892	0.9722	0.9974	0.9855
9	0.9898	0.9742	0.9943	0.9765	1.0026	0.9826	0.9904	0.9764	0.9893	0.9724	0.9974	0.9856
10	0.9943	0.9787	0.9988	0.9810	1.0083	0.9829	0.9948	0.9808	0.9938	0.9769	1.0018	0.9901
11	0.9930	0.9775	0.9974	0.9798	1.0041	0.9870	0.9935	0.9796	0.9924	0.9757	1.0004	0.9888
12	0.9958	0.9804	1.0002	0.9827	1.0093	0.9862	0.9962	0.9824	0.9952	0.9786	1.0032	0.9916
13	0.9934	0.9781	0.9978	0.9804	1.0056	0.9827	0.9937	0.9801	0.9927	0.9763	1.0006	0.9891
14	0.9946	0.9794	0.9989	0.9816	1.0043	0.9850	0.9948	0.9813	0.9938	0.9775	1.0017	0.9903
15	0.9969	0.9818	1.0012	0.9840	1.0053	0.9918	0.9971	0.9836	0.9961	0.9798	1.0040	0.9926
16	0.9982	0.9831	1.0025	0.9853	1.0095	0.9910	0.9983	0.9849	0.9973	0.9811	1.0051	0.9938
17	0.9951	0.9802	0.9994	0.9824	1.0074	0.9849	0.9952	0.9819	0.9942	0.9781	1.0019	0.9907
18	0.9941	0.9792	0.9983	0.9814	1.0042	0.9857	0.9941	0.9809	0.9931	0.9772	1.0008	0.9896
19	0.9961	0.9813	1.0003	0.9835	1.0059	0.9892	0.9961	0.9829	0.9951	0.9792	1.0027	0.9916
20	0.9964	0.9817	1.0005	0.9839	1.0072	0.9886	0.9963	0.9832	0.9953	0.9795	1.0029	0.9919
21	0.9952	0.9807	0.9994	0.9828	1.0062	0.9853	0.9951	0.9821	0.9942	0.9785	1.0017	0.9907
22	0.9950	0.9805	0.9991	0.9827	1.0040	0.9886	0.9948	0.9819	0.9939	0.9783	1.0014	0.9905
23	0.9969	0.9825	1.0010	0.9846	1.0073	0.9886	0.9967	0.9838	0.9957	0.9802	1.0032	0.9923
24	0.9954	0.9811	0.9995	0.9832	1.0053	0.9889	0.9951	0.9824	0.9942	0.9788	1.0016	0.9908
25	0.9958	0.9816	0.9999	0.9837	1.0069	0.9859	0.9955	0.9828	0.9946	0.9792	1.0019	0.9912
26	0.9946	0.9805	0.9986	0.9826	1.0035	0.9888	0.9942	0.9816	0.9933	0.9781	1.0006	0.9900
27	0.9967	0.9826	1.0007	0.9847	1.0074	0.9861	0.9963	0.9837	0.9953	0.9801	1.0026	0.9920
28	0.9948	0.9808	0.9988	0.9829	1.0025	0.9876	0.9943	0.9818	0.9934	0.9783	1.0006	0.9901
29	0.9816	0.9676	0.9739	0.9739	0.9739	0.9739	0.9918	0.9793	0.9909	0.9758	0.9981	0.9876

Figure A.3: Impacts per variable change of every step in the Greedy algorithm

Appendix B

Relevant information for Company X

B.1 Big Bag Hoisting Analysis

The first step to apply the SMED methodology on the hoisting of big bags is the identification and timing of activities in the Big Bag Hoisting Process. In Figure **??**, all activities are identified and the duration of each activity is measured.

Two subprocesses were identified, which are separated by the horizontal bar in Figure **??**. Firstly, individual activities need to be reduced. E.g. "driving AGV" can be reduced, by moving the rest location of the AGV closer to the warehouse station. Many steps include communication with the MES system. This takes much time, because the MES system is not working optimal yet. Once improved these kinds of activities take less time. Other activities like "BB hoisting" (the actual hoisting) are dependent of speed of the hoist, in this case. Due to safety reasons the speed of the hoist can not be increased. Then the activities are checked for possible parallel execution. Both individual activity reduction and the parallel execution of process can only be obtained, provided that the quality of the product and the safety of the operators is not reduced. Figure **??** shows that the set of activities did not change, but by applying the SMED methodology, we reduced the total process time for subprocess 1 from 96 seconds to 54 seconds, which is a reduction of 40%.

We saw that the frequency of this process is 100 times per week. This means that not only some activities, but the process itself can be executed parallel. When we visualize this, it would look according to Figure **??**. Here we see that parallel execution of processes reduces the total duration even more. The hoisting process would take 56 seconds per Big Bag after applying SMED, so hoisting 4 Big Bags would take 4 * 56 = 224 seconds. When we execute the processes parallel it would only take 131 seconds, which is another reduction of 23,25 seconds per Big Bag. This is equivalent to another 42% time reduction. Applying the SMED methodology and the parallel execution eventually results in 61,25 seconds, which is a 65% reduction with respect to the initial measurement.

B.2 Small Recommendations

To help the canning line improve in various factors, such as efficiency, quality, etc., the following small recommendations are proposed for the canning line:

- Between the printer and the labeler is a buffer located, but also a long conveyor belt. Reducing the length of this conveyor belt, would reduce the time of production per can.
- Finding a set up of a cap with an integrated scoop, would help to improve on both efficiency and quality aspect. The scoop inserter is not needed any more in the process and regarding hygiene it is preferable to store the scoop in a cap, rather than in the powder.
- In the begin of the ramp up phase everybody took a break at the same time and the line needed to be stopped as well. The start up time after a break was significant with several additional errors. Therefore, the suggestion is to introduce a shifted break schedule from the beginning of the ramp up phase. By this mean unnecessary stops and start are avoided, moreover employees are forced to learn about all machines, instead of leaving it to the same employee. The learning curve should be stimulated for every operators individually from the beginning.
- For the same reason as the previous suggestion the overlap of shifts, that took 2 hours during the first part of the ramp up period, should be reduced to 30 minutes as soon as possible. 30 minutes would still allow for the shift transfer between assigned operators, but optimizes the available time for production and the need for employees to get to know their machines. Moreover, there is no need stop the line, because not all operators need to attend the shift transfer. The new shift members can easily substitute the current shift members