The Impact of a New Filling Line

A Multi-Scenario Discrete-Event Simulation Study at Company X.

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Preface

This master thesis is written as part of my graduation project, which I performed at Company X to finish my master Industrial Engineering and Management. Five years ago, I started the Industrial Engineering and Management bachelor at the University of Twente. During this time, I had the opportunity to learn a lot on multiple different areas. I am really glad that I started this path and I feel very proud and satisfied to present to you the result of my efforts over the last seven months. A period during which I experienced ups and downs, but in the end came out stronger and wiser. I could not have done it without the support of some people I would like to thank.

First, I would like to thank the people at Company X for their collaboration and interest in my research. Your doors were always open for my questions and I sincerely appreciate that. I would especially like to thank Supervisor X for his guidance and the way he has supported me in achieving this great result. Our meetings were an eye-opener for me, since we did not only discuss my research but also other matters. I sincerely hope that the outcome of this research will help Company X in its future endeavours.

Second, I would like to thank my supervisors at the University, Dr. Ir. J.M.J. Schutten and Dr. Ir. L.L.M. Van der Wegen. You gave me well-founded advice, critical feedback, and useful tips to structure my research and this report. The new ideas you came up with, made me critically reflect on my own decisions.

Finally, I thank my girlfriend, my family, and my friends for their love and support. I especially want to thank Jordy for providing feedback on my master thesis.

I wish you a pleasant reading.

Thijs Platenkamp

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Summary

At Company X a new filling line is bought, called SFVision, which can fill both 5L and 10L cans. This new filling line replaces the current 5L and 10L filling lines. The SFVision is faster than the current 5L and 10L filling lines. This has a major impact on the production organization, but also on the flow of materials at the supplying and discharging departments such as mixing and inbound and outbound warehouses. Company X currently does not know what the impact of the new filling line is on the organization. The SFVision asked for an enormous investment and Company X wants to optimally use this filling line in combination with the existing filling lines. Company X has set the goal at 700 tons of production per week on the new filling line. For this research we first define the following research question:

What is the impact of the new filling line on the internal supply chain and how can Company X optimally use the new filling line, considering the available resources?

The second motivation for this research is the urge to grow in the number of tonnages of 5L and 10L liquid cleaning products produced per year. It is unknown what happens to the supporting departments and what should be done to achieve growth when there is an increase in tonnage. This research gives insight into the bottlenecks that arise and how Company X should deal with these bottlenecks. For this research we define the following research question:

How can we identify and elevate the bottleneck that arise, after growth in tonnage production on the new 5L and 10L filling line, considering the internal supply chain?

To find the answers to the questions above, we take a series of steps. First, we analyse the current production process, the planning process, and the new filling line with its modifications. Next, we execute a structured literature study to find out what theory literature offers about finding the bottleneck in a future state at a chemical process plant. Literature indicates that a simulation model can be used to explore alternative future states. We use a Discrete Event Simulation (DES) model to find the impact of the SFVision and the impact of multiple future states. Before we evaluate multiple future states, we create a conceptual model. We verify and validate this model to assure fit between our model and reality.

First Research Question

Company X cannot produce 700 tons a week with 8 shifts of each 8 hours, by just incorporating the new filling line in the simulation model. We conclude that a distribution of shifts where there is at most one consecutive shift results in the highest output and the most even workload for all departments. We do not have to order any extra truck transports. Next, the filling line is not influenced by the transport department, since the AGVs, the pallet wrapper, or the top foil machine do not dictate the overall system throughput. Since the time in which the filling line is waiting for a product (WOP) is 14.50 hours a week, we conclude that the mixing department is the current bottleneck, since mixing dictates the overall system throughput. However, mixing still has spare capacity, since the average utilization of the Mix Kettles (RKs) is 92%. This utilization is already high. However, according to the mix operators, the RKs are never down and can always be used, if there are raw materials and mix operators available. We assume that the raw materials and mix operators are available. So, the mixing department should be able to produce more orders with the current amount of resources.

To reach the 700 tons of production on the SFVision, we analyse multiple future states with one or more interventions. We know that we should unburden the mixing department, since mixing is not able to mix enough 5L and 10L batches with the current way in which orders are started and the current number of resources. Table 1 displays the results of the future states that results in at least 700 tons a week on the SFVision. We display the output in tonnages that can be produced in a week on the SFVision and the other filling lines. Also, we display the total revenues, the WOP, and the number of trucks we need extra or less during a week. Future State 7 is a combination of breaking the shifts of the SFVision and another filling line, called Alwid20L, in half and sharing the Buffer Kettles (BKs) of another filling line, called the GVP, with the SFVision. In Future State 8, we also give the SFVision more priority at the mixing department, so we change the way in which mixing momentarily starts batches. We see that this last intervention results in a lower amount of WOP on the new filling line and hereby a higher output, but the WOP for the other filling lines increases.

Future State	Output SFVision	Output Others	Total Revenues	WOP SFVision (Hours)	WOP Others (Hours)	Extra Trucks	Cancelled Trucks
7	710.6	1,235.1	€ 453,352	2.35	9.60	2.4	0.2
8	737.2	1,226.4	€ 457,506	0.29	14.02	3.0	0.0

Table 1 Results Growth Scenario 1

Since we want to know how Company X can optimally use the new filling line, considering the available resources, we recommend Company X to implement Future State 8. This results in the highest output for the SFVision and the highest revenue per week. By using this future state, we need 3 trucks a week extra in the night shift. This increases the work pressure for the employees in the night shift, therefore we also need one extra FTE in the night shift. With the last future state, the utilization of the most important RKs is almost near the 100%, which shows us that we cannot grow any higher in tonnage with the current resources. Mixing now remains the bottleneck. So, the capacity of the mixing department is just not enough to realize growth.

Second Research Question

To answer the second research question, we first determine the growth scenarios that Company X would like to reach. Second, we use the DES model to give insight in how we can reach the growth scenarios. The growth scenarios Company X wants to reach, provided that the plant is ready, are reaching 800 and 1,000 tons on the new filling line in a week.

We conclude that Company X can produce 800 tons on the new filling line after analysing the future states. On the other hand, the orders for the other filling line are, as expected, decreasing, due to the high utilization of the most important RKs. It is up to the management team if they want to produce less orders on the other filling lines against the same number of resources, while increasing the total revenues. If Company X is willing to do so, then we recommend Company X to use the future state with all three interventions. With this future state we only require 9 shifts. This future state results in the largest profit and the largest KG/Hour. The payback period is 27 weeks. However, if Company X is not willing to let the output decrease over the other filling lines, we require an extra RK. We determined that there is the possibility to build a maximum of 2 10 m^3 RKs at Company X.

After analysing the impact of an extra RK, we conclude that by using broken shifts, using the new routing, and sharing the BKs of the GVP filling line, Company X can produce 800 tons

with 9 shifts. This results in the highest KG/Hour and the lowest WOP over all filling lines and is therefore the most efficient future state. This has no impact at all on the other filling lines, but on a negative, the payback period while producing 800 tons with Future State 8 is 204 weeks. So, we recommend that Company X only uses extra RKs when they find this payback period acceptable and is willing to keep the output of the other filling lines the same. With this future state, we recommend arranging at least 7 extra truck transports in a week and almost 2 extra FTEs in the night. We also recommend hiring one extra FTE in the morning when the new filling line is up.

For the third growth scenario we want to produce 1,000 tons a week on the new filling line. We cannot reach this target without a decrease in orders over the other filling lines, because the utilization of the RKs is 100%. So, mixing is still the bottleneck. The only thing that remains is adding extra RKs at the mixing department. We conclude that, by using 1 extra RK, all future states result in an average output of more than 1,000 tons a week. When Company X wants to produce more than this target, the other filling lines get negatively affected and this is therefore not recommended. We recommend Company X to use broken shifts, give the SFVision more priority at the mixing department, and sharing the BKs while using 12 shifts. This results in an output higher than 1,000 tons and the output for the other filling lines remains the same. For this future state we recommend to arrange 15 extra truck transports per week and two extra FTE for all night shifts. Now, we also need one extra FTE in the morning when the new filling line is up. The increase in profit per week for this future state is €6,670 and the payback period for this future state is 106 weeks.

When Company X builds two extra RKs, they can produce more than 1,000 tons a week without an impact for the other filling lines. The payback period for the most efficient future state, the future state with all three interventions, is 167 weeks. Company X can produce a maximum of 1,247 tons a week on the new filling line when Company X uses the future state with all three interventions and 15 shifts. The payback period for this future state is 129 weeks.

Concluding, we recommend Company X to break the shift of the Alwid20L and the SFVision filling line in half, give the SFVision more priority at the mixing department, and sharing the BKs of the GVP filling line for every growth scenario. The transport department is not a bottleneck, since the AGVs, the pallet wrapper, and the top foil machine do not have an impact on the output of the filling lines. The FGW is a bottleneck, since we need to make sure that we have extra FTEs and extra truck transports. Therefore, we recommend Company X to arrange extra truck transports and extra FTEs for the night and/or morning shift.

Contents

List of Abbreviations

Abbreviation	Description
ABS	Agent Based Simulation
BK	Buffer Kettle
CCR	Capacity Constraint Resource
DES	Discrete Event Simulation
EDC	European Distribution Centre
EPC	European Principal Company
ERP	Enterprise Resource Planning
FGW	Finished Goods Warehouse
FS	Factory Scheduling
FSCO	Factory Scheduling and Call Off
FTE	Full-Time Equivalent
GPL	Group Performance Leader
IBC	Intermediate Bulk Container
JIT	Just in Time
LB	Loading Bay
MCS	Monte Carlo Simulation
MRP	Material Resource Planning
MTO	Make to Order
OEE	Overall Equipment Effectiveness
RK	Roerketel (English: Mix Kettle)
RPT	Remaining Processing Time
SCM	Supply Chain Management
SD	System Dynamics
SKU	Stock Keeping Unit
TFT	Total Filling Time
TPS	Technomatix Plant Simulation
TTC	Time till Close
VSM	Value Stream Map
WIP	Work in Progress
WOP	Wachten Op Product (English: Waiting for Product)

1 Introduction

As part of the completion of the master's degree in Industrial Engineering and Management at the University of Twente, we conduct a research at Company X. The layout of this chapter is as follows. Section 1.1 introduces Company X. Subsequently, Section 1.2 gives the motivation for this research, Section 1.3 describes the problem description, Section 1.4 gives the objective of the research, and Section 1.5 describes the problem approach.

1.1 Company X

Company X is a chemical production plant in Location X. Company X makes a large variety of products. Examples are daily cleaning products, disinfection products, universal cleaners, sanitary cleaning products, detergents, textile care liquids, gloss rinse, strippers/adhesion cleaners, foam cleaners, and carpet care products. The machines at the production site in Location X can produce many different product types and deliver these product types in a large variety of containers. The variety of containers vary from 150ml bottles to 1000L Intermediate Bulk Containers (IBCs). In recent years the amount produced per year is around 90,000 tons of liquid cleaning products. This is divided into 1,200 Stock Keeping Units (SKUs) on basis of 350 different recipes. A recipe in this content is a mixture of materials according to a formula. In terms of resources, Company X possesses 9 mixing tanks, 28 buffer tanks, and 12 filling lines (Supervisors, 2018). The plant is characterized by sharing different resources such as raw material buffer tanks, mixing tanks, and manpower for production. Therefore, the plant is a multipurpose process plant, although the filling layout is product oriented. A filling line can produce a large variety of products, if they are filled in the same type of container.

1.2 Research Motivation

At Company X a new filling line is bought, which can fill both 5L and 10L cans. This new filling line replaces the current 5L and 10L filling lines. The reason to buy this new filling line is twofold. First, the new filling line reduces the operational costs. During the last years, Company X has the task of reducing the operational costs. Several small projects have been conducted to reduce the operational costs; however, those reductions were not large enough. Currently, there are two filling lines that produce 5L or 10L cans. The current filling lines have a combined throughput of 21 cans per minute. This throughput per hour is too low, such that the kilograms produced per hour are too low. The new filling line can realize a throughput of 70 5L cans or 45 10L cans per minute. The goal is to produce 700 tons a week on the new filling line. This has a major impact on the production organization, but also on the flow of materials at the supplying and discharging departments such as mixing and inbound and outbound warehouses. Company X currently does not know what the impact of the new filling line is on the organization and the planning department. The new filling line asked for an enormous investment and Company X wants to optimally use this filling line in combination with the existing filling lines. This research gives a recommendation to Company X on how they can optimally utilize the new filling line to reach the goal, considering the available resources.

The second motivation for this research is the urge to grow in the number of tonnages of 5L and 10L liquid cleaning products produced per year. The growth in tonnage produced will have an impact on all departments within Company X. It is unknown what happens to these departments when there is an increase in tonnage. This research gives insights into the bottlenecks that arise. A bottleneck, in this case, is the department with the longest average active period, and in turn is most likely to dictate the overall system throughput (Roser, Nakano, & Tanaka, 2001).

1.3   Problem Description

Company X does not know how the new filling line should be controlled, in terms of scheduling, in combination with the other filling lines subject to, e.g. the available operators, raw materials, space, time, and capacity. This new filling line fills cans three times faster as the current 5L and 10L filling lines. This means that the output per minute of this filling line is three times as high as the output of the current filling lines. Whenever the new filling line is up and running, other departments are affected, directly or indirectly. To find out what these influences are, we now give a visualization of the relations between the various departments. Subsequently, we describe ways in which the internal supply chain may be or is affected. In this research, the internal supply chain refers to the chain of activities within a company that concludes with providing a product to the customer (Basned, 2013). The internal supply chain has a significant impact on a company's success; operations need to run smoothly to create a harmonized working environment and an efficient workflow. Figure 1-1 depicts the material and information flows between the departments and an explanation of the used terms follows below this figure (Company X, 2012).
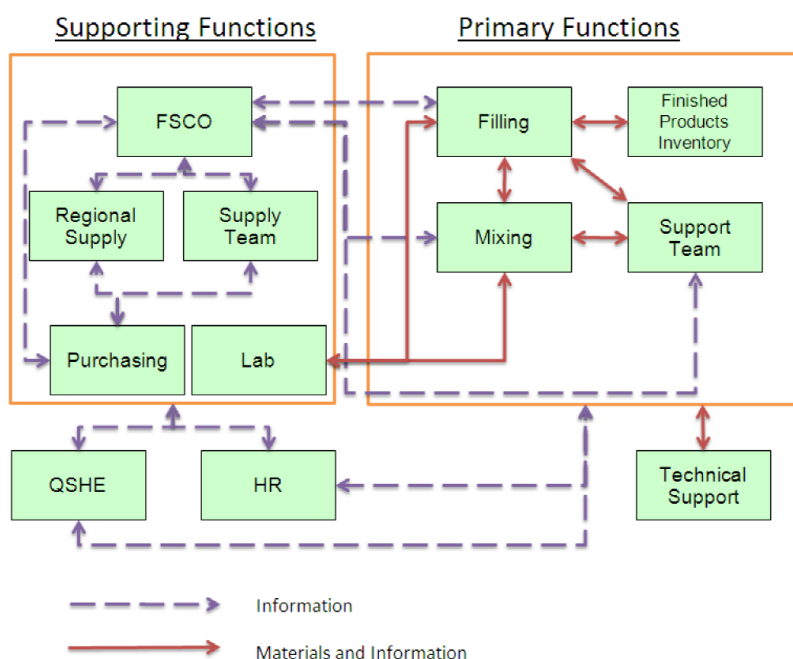
Figure 1-1 Internal Supply Chain Company X (Company X, 2012)

In Figure 1-1 QSHE stands for the Quality, Safety, Health, and Environment department. This department is responsible for leading all aspects of developing, implementing, and maintaining agreed QSHE standards. The Support Team is the department responsible for storing all raw materials in warehouses and HR stands for Human Resources. The Filling department is driven by the Factory Scheduling Call Off (FSCO) department, which is the department responsible for scheduling and rescheduling the week schedule for the Filling department. FSCO starts scheduling whenever Make Planning sends the week plan. This week plan includes all orders that, in an ideal case, are processed in that week. This is not always the case, e.g. due to labels or raw materials that cannot be delivered in time. To check if the required materials are available or can be delivered in time is a task of the Call Off employees, within the FSCO department. The production orders that cannot be produced are put on hold and will ideally be processed in the next week. Nowadays, Factory Scheduling (FS) makes the

day-to-day schedule on basis of information from Call Off, made up agreements, setup times, and experience. The goal that FSCO strives for is minimizing the tardiness and the changeover times by sequencing the planning considering the restrictions. The mixing department has insight into the production schedule of the filling department and aligns its production plan to this schedule.

Figure 1-2 gives an overview of the primary processes within Company X.
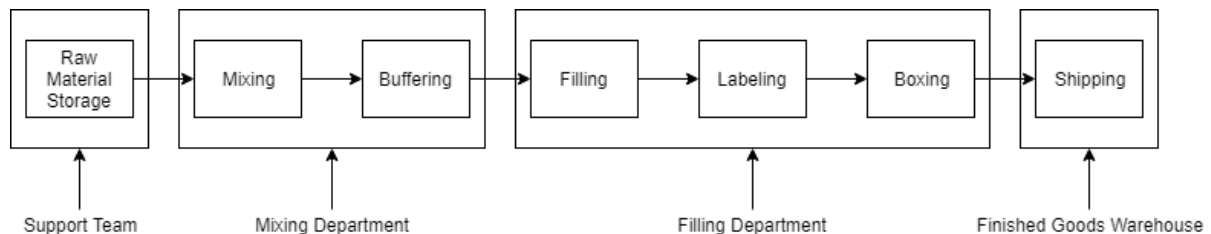
Figure 1-2 Primary Processes within Company X

The first step is the delivery of raw and packaging materials. These materials are stored in raw material kettles or in palletized racks. The products in the palletized racks include materials such as bottles, cans, ingredients for the liquid, and labels. At Company X 9 mixing kettles are used to mix the ingredients. The finished product can be stored in one of the 24 buffer kettles, after mixing is completed. Each of these buffer kettles is connected to one filling line, but a filling line is connected to multiple buffer kettles. The buffer kettles store the finished product until filling can take place. Within the filling department, multiple filling line specific successive steps occur. The general picture is as follows: First, the cans or bottles are manually or by a depalletizer placed on the conveyor belt. Second, these containers are filled with the finished product and a robot mounts the cap on the container. Next, the container is labelled and placed in a box. These boxes get a track-and-trace code and they are placed on a pallet. After a pallet has the required number of boxes stacked on it, an automatic guided vehicle, called Tweety, retrieves the pallet and brings the pallet to the wrapper. After the pallet is wrapped, the pallet goes to the Finished Goods Warehouse (FGW). In the FGW, the employees use a forklift to retrieve the pallet from the conveyor belt. The warehouse employees store the pallets in the warehouse until a truck is available to transport the pallets to one of the five European Distribution Centre (EDC).

Now, it is known how the various departments are related to one another, we analyse the problem. The company supervisor has the presumption that, when FS continues scheduling the way they do now, there is a point where standstills at filling lines occur, since the internal supply chain is not aligned. In the new situation, when the new filling line is up and running, Company X will experience peak loads. These peak loads happen, since the new filling line is three times as fast as the two current filling lines combined. Company X does not know what the implications are of the new filling line. The fact that Company X does not know how the internal supply chain is affected, is part of the causes for rescheduling and this causes a low plan adherence. The plan adherence is the percentage of planned batches that are processed on a given day or week. Over 2018, the plan adherence was on average per week 68.5%. Company X has set the target, for all production facilities, to 90%. Appendix A displays more information about the plan adherence over 2018. The site manager has the presumption that the plan adherence decreases when the new filling line is functional. Concluding, the core

problem is that FS does not know what the implications on the internal supply chain are of the week schedule that they make, since the impact of the new filling line is unknown.

1.4 Research Objective

The research objective is twofold; therefore, we divide this research into two phases. First, we give the FS employees more insight in the implications of the week plan that they can make. We show the impact of several shift distributions, such that a stable flow through the factory is secured, without increasing work pressure for supporting departments. A stable internal supply chain is necessary to get flow through all filling lines. With an internal supply chain, where every department is aligned, one can analyse where, in the internal supply chain, the bottleneck arises. Slack, Brandon-Jones, & Johnston (2013) state that any bottleneck disrupts the smooth flow of items in processes. With a stable internal supply chain, we can analyse which department is the bottleneck and how this bottleneck should be managed to eventually reach the goal of 700 tons a week. Second, we advise Company X on the implications of increasing the production volume on the new filling line. This new situation is later referred to as a growth scenario. We show where bottlenecks occur in the internal supply chain and how they can be resolved such that Company X is able to reach the growth scenarios.

1.5 Problem Approach

Section 1.5.1 states the two research problems. Section 1.5.2 describes the research questions and we exemplify a brief explanation of the problem approach per research question. These research questions reflect the outline of this report. Section 1.5.3 describes the scope of this research.

1.5.1 Problem Statement

We subdivide the research into two phases; therefore, we summarize the knowledge we want to obtain in two research problems.

The first research problem is:

> *What is the impact of the new filling line on the internal supply chain and how can Company X optimally use the new filling line, considering the available resources?*

In the first phase, a Discrete-Event Simulation (DES) model is created of the current processes of the factory, including the new filling line. As indicated in Section 3.2.3, a DES model is most appropriate to simulate the production process of Company X. A DES model simulates a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time (Law, 2015). The model is a digital twin of the current production plant in Location X. We use data from 2018 to simulate the production process of Company X as accurately as possible. This research problem mainly focuses on giving the FS department more insight, such that they can determine a day-to-day schedule that results in a stable flow throughout the plant to reach the goal of 700 tons a week. Thus, on basis of data from 2018, we analyse how the production department is affected by the new filling line. On basis of this information, we give recommendations on how Company X should use the new filling line to evenly level the workload.

The second research problem is:

> *How can we identify and elevate the bottleneck that arise, after growth in tonnage production on the new 5L and 10L filling line, considering the internal supply chain?*

In the second phase of this research, we analyse different future states in which growth of the production volume on the new filling line is incorporated to reach the growth scenarios. A future state is a "to be" business process. We analyse these future states with the DES model of Phase 1. By analysing these future states, Company X can respond quickly to changes in production volume.

1.5.2 Research Design

We present, for each phase, the research questions and their sub-questions that form the backbone of this research. After each research question, we briefly explain the research design.

1.5.2.1 Phase 1

We structure this research according to the simulation project methodology created by Law (2015, pp. 67-70). Figure 1-3 displays this simulation project methodology in a more concise way. In this phase we make the DES model and afterwards experiments are conducted to find out the consequences of the new filling line, considering the current production volume.
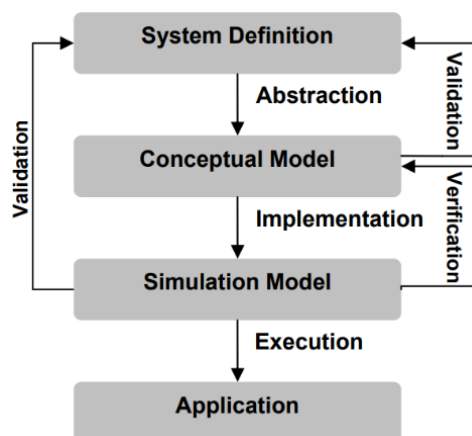
Figure 1-3 Simulation Project Methodology

The research questions that we want to answer, to answer the first research problem, are the following:

1. How is the production and production scheduling organized within Company X and what alters due to the new filling line?
   a. What is the current process flow with its restrictions?
   b. What is the current way of scheduling and what is its current performance?
   c. What changes to the current situation when using the new filling line?

Chapter 2 describes the performance of the current processes within Company X. To do so, we first must know more about the primary processes to get a clear understanding of the production process. Subsequently, we analyse the current way of scheduling and the current performance by conducting interviews with the planning personnel. FS knows restrictions that

are important to this research. Finally, we analyse the changes to the current situation when using the new filling line by conducting interviews with the project team. We also analyse all data available of the new filling line. The current situation with the modifications, due to the new filling line, is important to the DES model, such that the model is an accurate representation of the actual system.

2. What theory offers literature about finding the bottleneck in a chemical process plant?
   a. What is written in literature on the differences between chemical process industries and direct manufacture industries?
   b. What theory offers literature about bottlenecks and finding the bottleneck in a future state?
   c. What is the most suitable way to perform a simulation study?

In Chapter 3 we perform a structured literature search. We describe what is written in literature about finding the bottleneck in a future state or a "to be" business process at a chemical process plant. Next, we give more information on a bottleneck, methods to analyse a production process, and the combination of finding the bottleneck in a future state. Subsequently, we analyse how one can execute a simulation study in the most appropriate way. This research question is of essence to the way in which answers to the next research questions are found.

3. What is an appropriate simulation model design to answer the research problems?
   a. What is an appropriate conceptual model of the production facility of Company X?
   b. What is the experimental design used in this simulation study?
   c. Is the DES model credible?

In Chapter 4 we create an appropriate simulation model design to answer the research problems. First, we describe the conceptual model, i.e. a descriptive model of a production process based on assumptions about its elements, their interrelationships, and system boundaries. Before programming, the problem should be clearly defined. In the conceptual model we first give a general outline of the simulation study. Second, we present the input parameters that we use. Third, we explain the KPIs that we collect after running an experiment. Next, we present the scope and level of detail. In this section we explain the assumptions and simplifications. Finally, we create logic flowcharts that represent the decision processes. We make a conceptual model, because a too extensive model is costly and does not necessarily lead to a higher accuracy of the output (Law, 2015, pp. 249-251). After making the conceptual model we determine the experiments and future states that we should analyse. Together, this defines the simulation model design of the production facility of Company X. Finally, we verify if the programmed model coincides with the conceptual model, by using debugging while creating the DES model. After a credible DES model is created, we validate this model by comparing the results out of the model with real data.

4. What are the results of the experiments conducted with the simulation model?
   a. What are the implications of the new filling line?
   b. How can Company X reach the 700 tons of production per week?

Chapter 5 gives at first the implications of the new filling line on the supporting departments. Next, we analyse multiple future states to find out if and how Company X can reach the 700 tons a week on the new filling line. Eventually, we want to be able to give the FS department

more insight in how they can optimally use the new filling line in combination with the other filling lines to reach 700 tons a week on the new filling line.

1.5.2.2 Phase 2

Now we know what the impact of the new filling line is to reach the predetermined goal, we analyse in Phase 2 what happens with growth of the number of 5L and 10L cans filled per week.

5. What should Company X do when considering growth in the number of tonnages produced per week on the new filling line?
   a. What growth scenarios should be analysed?
   b. What are the bottlenecks that occur in the different growth scenarios and how can these bottlenecks be tackled as efficiently as possible?

Chapter 5 also describes the results of Phase 2. We first describe the possible growth scenarios that are feasible. In combination with the Site Manager, Manager Planning & Logistics, the Manufacturing Supervisor, and the Make Planner these growth scenarios are determined in a brainstorm session. After creating the different growth scenarios, the DES model is altered to find out what bottleneck arise. Third, interventions that solve the bottleneck in these growth scenarios are searched for by consulting literature and holding interviews. We analyse the impact of these alternatives in the DES model and with this model the most desired future state is determined on basis of the KPIs.

The last step in this research is giving the conclusions to the research problems, recommendations to the stakeholders of Company X, and the limitations of this research. Also, we give opportunities for further research. We conclude with some final words.

1.5.3 Research Scope

Our research is focused on the new filling line at the Company X production plant in Location X. Other alterations within supporting departments or other filling lines are not incorporated in this research. No research is executed to find out what happens in the future within these departments. In terms of data collection, we use the data from 2018.

Within this research, we are not making a new planning tool. The focus lies on giving the stakeholders more information on the consequences of the new filling line. However, we use the way in which mixing starts batches in the simulation model.

As said in Section 1.3, the internal supply chain refers to the chain of activities within a company that concludes with providing a product to the customer. So, these are all the processes in Figure 1-2. For our research it is important to incorporate all of these departments in our DES model, since these departments could be the bottleneck after installing the new filling line. At Company X, there are multiple filling lines. There is also an assembly line, called DAS, which assembles semi-finished products into the final product. No filling occurs within this department, so this assembly line is out of scope of this research since it is not affected by the new filling line and the new filling line is also not affected by the DAS.

We limit the study to recommend on the possible available resources at hand. The short-term recommendations include improvements given the available resources, i.e., using the current resources in a more efficient manner. For long-term recommendations, investments may be required. Conducting the implementation of the recommendations is not part of this research.

2 Current Situation

This chapter provides an answer to the research question: "*How is the production and production scheduling organized within Company X and what alters due to the new filling line?*". In Section 2.1 we describe the detailed production process, Section 2.2 describes the planning process of Company X, Section 2.3 describes the alterations due to the new filling line, and we conclude this chapter in Section 2.4.

2.1 Production Process

In Chapter 1 we introduced the production process of Company X broadly. Now, we analyse the production process in more detail. We start by explaining the layout of Company X with their interrelations and then we dive deeper into the production process.

2.1.1 Production Layout

The production layout at Company X is a multi-purpose process layout, Appendix B displays this production layout of the plant with the product flow. The departments displayed in this figure are important for this research. There are 9 mixing kettles that process 1,200 SKUs out of 350 recipes. These mixing kettles can be used interchangeably. So, the plant shares different resources for production (Lyons, Vidamour, Jain, & Sutherland, 2013).

The filling department is arranged as a product layout. Every filling line can fill several types of containers and they do not share resources. Every filling line has its own palletizer, labeller, or filler for example. This has advantages and disadvantages. Advantages of a product layout are amongst others: reduced material handling, lower skill level of operators, and simplified production planning and control. Examples of disadvantages are the following. First, the rate of output for the filling line is controlled by the slowest workstation, the bottleneck. Second, there is duplication of machines, which causes high investments in dedicated machinery. Third, a standstill at any section of the line may lead to a complete shutdown of that line. The filling line currently runs at the speed of its slowest workstation. So, the output per filling line is determined by its bottleneck. The speed is also determined by the type of product. A foaming product is filled at a slower rate than a regular product. This research does not focus on finding the bottleneck of a filling line but uses the output per minute of the filling lines. In the next section, we analyse the interrelations between the various departments.

2.1.2 Production Process

As explained in Chapter 1, the research questions are answered by constructing a simulation model. In the simulation model, we simulate the production process of Company X. The simulation model needs lots of data to represent the actual processes. The remainder of this section explains processes and their restrictions that are used in the simulation model.

Figure 2-1 displays the detailed visualization of the current production process. In this figure we display almost all operations within the production plant of Company X. An explanation of the used terms and the production process follows below this figure.
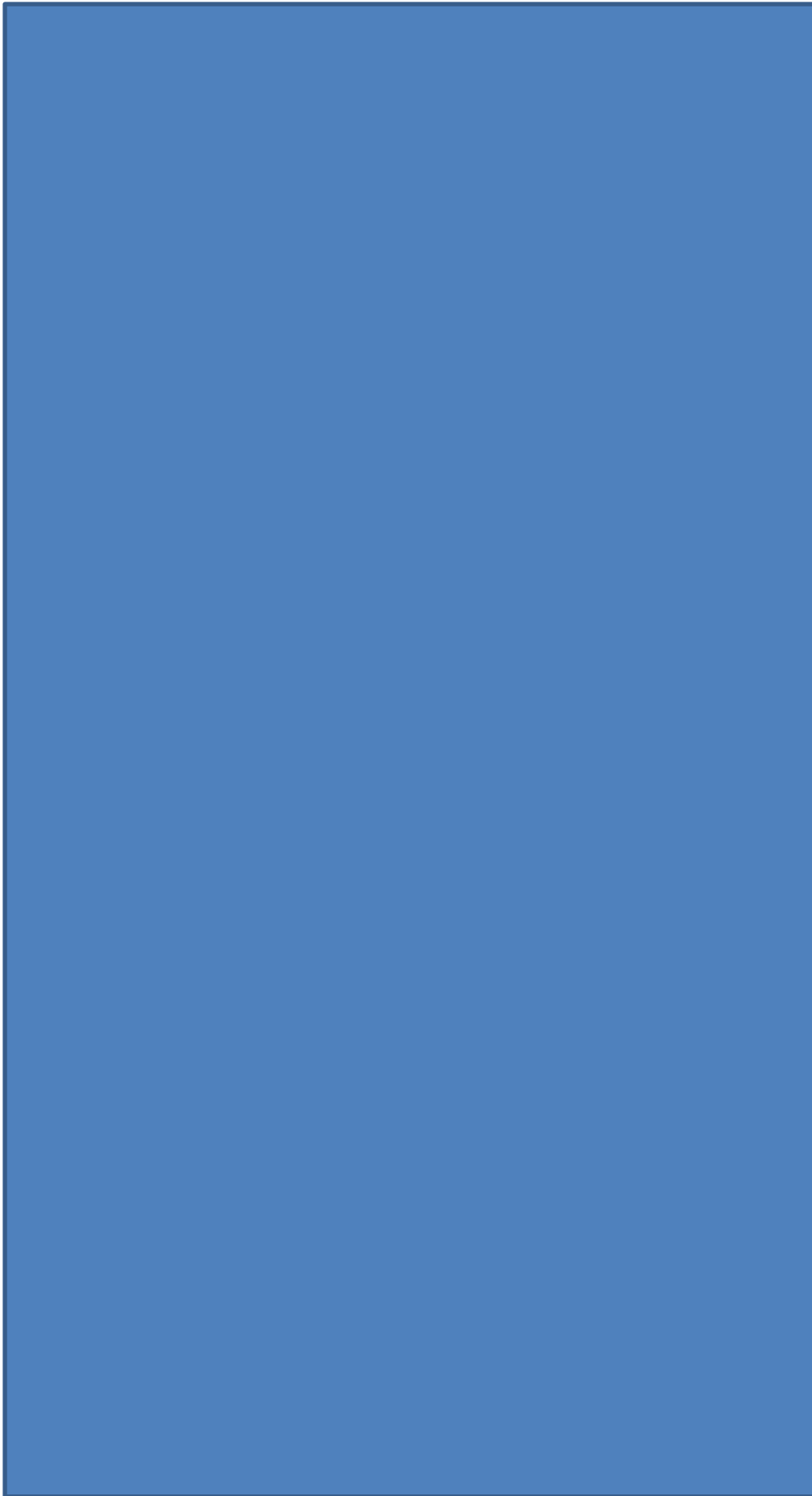
Figure 2-1 Visualization of the Production Process of Company X

Support Team

The Support Team at Company X is responsible for bringing the desired materials Just in Time (JIT) to the mixing or filling department. They prepare the raw materials of the batches, such as labels, sleeves, carton boxes, caps, and containers. Appendix B displays the layout of the plant with the warehouses. These warehouses are:

- *Canhal.* At the canhal, 5L, 10L, and 20L cans are stored. In this department, constantly one employee is available to make sure that the cans are delivered to the desired filling lines.
- *Packaging warehouse.* The packaging warehouse makes use of three distinct types of storage methods: adjustable pallet racking for carton boxes and caps and open bin-shelving and paternosters for labels. According to Koster (2018), the utilization is on average 72% for adjustable pallet racking and 91% for the paternosters.
- *Warehouse A.* In this warehouse, the non-ADR ingredients for mixing are stored. ADR is a French term that indicates if a material is hazardous or not.
- *Warehouse B/C.* In these warehouses, the ADR ingredients are stored.
- *Mezzanine.* The mezzanine is not displayed in the layout of the plant in Appendix B, since the mezzanine is an attic. Above the production line, there is a floor with storage space for flasks and caps used in four filling lines. These are fed to their respective stations through dosing bunkers (flasks) and cap hoppers (bottle caps).

Mixing

There are two mixing departments: Jupiter and Hypo. Production at Company X takes place on a Make to Order (MTO) basis. We explain in Section 2.2 how these orders arrive at the Location X production plant. Orders will only be processed when there is demand from the market. The variety in orders is large, there is no week alike. The production process at Company X is done in different batches of different sizes. For mixing, the batch size, has no influence on the total mixing time, but every batch has several characteristics which should be considered. These characteristics are for example the minimum number of tonnages that needs to be mixed. Make planning tries to make the batch sizes as large as possible, but the production of a SKU may not exceed more than three months of demand. On average, 80% of the batches have a size of 10 tons, which is the largest batch size possible since the largest mix kettle (RK) is 10 tons. Another important characteristic of a batch is the type of batch. There are eight distinct types of batches to distinct.

1. *Regular batches.* Characteristics of the batch has no influence on other batches. Around the 65% of all batches are regular batches.
2. *Fill-only batches.* For two filling lines, the Breitner and the Multivuller, there is the option to fill containers with liquids that were made by a third-party manufacturer. These batches are not mixed at Company X, but they are filled and transported by Company X. Only 0.5% of the orders are Fill Only Orders.
3. *Bulk batches.* Batches mixed at Company X and filled directly into tank cars. On average, 7 batches per week are directly filled into tank cars.
4. *Acid batches.* These are batches that have a low pH value. It is important that no batch is scheduled before or after a hypo batch, because chlorine gas can arise when those two batches make contact. Almost 19% of the batches are acid batches.

5. *RK104 batches.* These are batches that must be mixed on mix kettle 104. This mixing kettle has a stronger stirring mechanism. The percentage of all batches that is mixed in 2018 and should be mixed on this RK is almost 6%.
6. *Hypo batches.* Batches that contains hypochlorite ingredients. 10% of the batches are Hypo batches.
7. *ADR 3 batches.* Batches that may not, due to safety reasons, be in the FGW during the weekend.
8. *'Weekend overstaan' batches.* These are batches that are mixed on Friday and wait in the buffer kettle during the weekend. In this case, the air can go out of the semi-finished product and the filling department will not experience hindrance when filling the containers. A semi-finished product is in this research, for clarity, the batch after mixing.

Table 2-1 and Table 2-2 display the connection between buffer kettles (BKs), filling lines, and mix kettles (RKs) for the Jupiter and Hypo department, respectively. Not every RK is connected to a BK, so for our research it is important to consider this when modelling. In these tables, we also display the size of the RKs. There is a special mixing department for the hypo batches, since hypochlorite products are highly corrosive and cannot be mixed in steel kettles.

Filling

Every filling line is connected to 2 buffer kettles. Only the SF Vision, the filling line filling the 5L cans and in the future also the 10L cans, has 4 buffer kettles. Table 2-1 displays the information, for the Jupiter department, on which buffer kettle is connected to which filling line. Table 2-2 displays the connections between the BKs and the filling lines for the Hypo department. At the Hypo department there is only one RK. This information is a strict restriction for our simulation model. The simulation model incorporates this information.

Connections RK-BK (Jupiter)		RK and volume							
		101	102	103	104	106	107	110	111
Filling Line	BK	10m³	10m³	10m³	10m³	5m³	5m³	10m³	10m³
Bulk	101	x	x	x	x			x	x
Bulk	102	x	x	x	x			x	x
GVP / Rauenberg10L	103	x	x	x	x	x	x	x	x
GVP / Rauenberg10L	104	x	x	x	x	x	x	x	x
A.B.L.	105	x	x	x					x
A.B.L.	106	x	x	x					x
Multivuller	107	x	x	x				x	x
Multivuller	108	x	x	x				x	x
Kugler	109	x	x	x				x	x
Kugler	110	x	x	x				x	x
Pouch	111				x			x	x
Pouch	112				x			x	x
SFVision5L	113	x	x	x	x	x	x	x	x
SFVision5L	114	x	x	x	x	x	x	x	x
SFVision5L	115	x	x	x	x	x	x	x	x
SFVision5L	116	x	x	x	x	x	x	x	x
Safepack	117	x	x	x	x			x	x
Safepack	118	x	x	x	x			x	x
Alwid20L	119	x	x	x	x			x	x
Alwid20L	120	x	x	x	x			x	x
Breitner	121	x	x	x	x			x	x
Breitner	122	x	x	x	x			x	x
Flexlijn	123	x	x	x	x	x	x	x	x
Flexlijn	124	x	x	x	x	x	x	x	x

Table 2-1 Connections RK-BK for Jupiter

Connections Hypo		RK: 22
Filling Line	**BK**	10m³
GVP/Rauenberg10L,	40	x
Bulk, SFVision5L,	41	x
Alwid20L, Breitner,	42	x
Safepack & Kugler	43	x

Table 2-2 Connections RK-BK for Hypo

As said, the filling department is product oriented. Currently, there are 12 filling lines. Table 2-1 displays 11 of those 12 filling lines. Appendix C displays the layout of the filling department. Bulk production is not seen as a filling line, because these liquid cleaning products are directly filled from the buffer kettles into tank cars. The 12th filling line, the cGMP filling line, is not connected to a BK, since mixing transfers the semi-finished product into IBCs. At the cGMP filling line, the containers are filled directly out of these IBCs when the filled IBCs have waited for a week.

The semi-finished products can be filled on almost all filling lines, but a batch is scheduled just for one filling line. So, if the same semi-finished product needs to be filled on two different filling lines, two batches need to be mixed since the BKs are dedicated to filling lines. However, the semi-finished product can be filled in different containers when this is done on the same filling line. When this happens, setup time occurs during a batch.

Table 2-3 displays, from left to right, the filling lines with the corresponding container types, the production volumes over 2018, the number of orders in 2018, the average quantity in kilograms per order, the average filling time per batch, the average mixing time per batch, the number of boxes per hour, the number of boxes/cans on a pallet, and finally the number of pallets per hour considering the pallet load and the number of boxes per hour. This information gives an idea of the production capacity of Company X. The average filling time per production line, for example, gives us an indication that there are filling lines that, on average, take a longer time to fill a, on average, larger batch than others. The filling lines filling a larger container take, on average, fewer time to complete a batch. This information is used while creating the way in which we start orders at mixing. When looking at the mixing times over 2018, we see, except for the cGMP mixing process, not much variation. This number is although deceptive, since there is a variation in mixing times between batches. There are batches that need 8 hours of mixing, while there are also batches that only need 1 hour of mixing. The information out of the table is particularly convenient when modelling and for validating the simulation model. For example, by analysing the number of orders per week, we make various production plans, such that the model is filled with enough batches.

Over 2018 a total of 88,000 tons of liquid cleaning products was filled by the 12 filling lines into containers and by bulk batches into tank trucks. The variation in tonnage at the different filling lines is due to demand of the market and the difference in filling rates per filling line. Some filling lines are scheduled more often than others. To go from one container to another, setup time is required. Appendix E displays the setup matrix. This information is necessary to model the production process of Company X as accurately as possible.

Filling Line	Container in which batch is filled	Tonnage (KG)	Number of Orders	Average Qty. in KG per order	Average of Filling Time (hrs)	Average of Mixing Time (hrs)	Quantity per hour (Boxes)	Number of Boxes on a Pallet	Number of Pallets per hour
Flexlijn	1.4L SD	353,042.88	70	4,799.78	11.75	3.34	280.00	190	1.47
	1.5L Jflex	174,905.69	43	4,205.07	7.87	3.43	280.00	175	1.60
	2 x 1.4L SD	102,453.12	18	5,675.51	15.44	4.00	125.00	100	1.25
	4 x 1.3L GHC	390,753.16	87	4,449.67	7.27	5.36	120.00	80	1.50
	5L BPC	10,770.00	2	5,385.00	5.61	4.00	160.00	96	1.67
	5l cub	281,251.17	61	4,744.06	6.44	3.39	240.00	120	2.00
	5l flex	73,756.30	16	4,584.78	21.78	3.50	75.00	69	1.09
	5L MIC standalone	16,927.06	4	4,231.77	2.08	4.13	360.00	104	3.46
	6 x 1L Urnex	154,284.48	19	8,120.24	14.22	3.00	85.00	80	1.06
Pouch	2 x 1.5L Pouch	1,509,855.38	215	6,882.65	5.38	3.33	400.00	195	2.05
	2 x 2.5L Pouch	722,413.42	76	7,104.13	3.84	3.39	330.00	128	2.58
	4 x 1.5L Pouch	4,057,119.67	426	9,660.34	7.56	4.30	206.25	75	2.75
SFVision	2 x 5L can	15,204,165.86	1,622	9,364.65	1.81	3.92	396.00	80	4.95
Multivuller	6 x 0.75L trigger bottle	6,795,425.57	746	9,044.60	5.56	3.28	370.00	95	3.89
Safepack	10L Safepack	11,281,926.90	996	11,324.80	3.90	3.30	242.25	57	4.25
Breitner	2 x 2L KH	11,759.94	3	6,996.65	2.69	3.17	354.29	124	2.86
	6 x 2L KH	5,007,807.89	465	10,716.36	3.86	3.38	206.25	55	3.75
	6 x 2L Schotte	2,133,299.90	127	16,699.70	6.40	3.88	243.00	52	4.67
cGMP	24 x 0.25 L bottle	511,238.22	109	4,781.51	10.93	9.36	70.00	72	0.97
	28 x 0.3 L bottle	506,569.00	103	4,803.25	9.20	8.62	60.00	60	1.00
Alwid20L	20L can	17,109,660.20	1,567	10,901.90	1.89	4.00	245.00	24	10.21
Bulk	Bulk	3,089,013.80	353	8,707.65	2.11	4.14	4,000.00	Bulk	N.A.
Kugler	12 x 1L LG	1,218,571.60	118	10,308.80	4.95	3.69	164.00	56	2.93
	6 x 1L DB	315,745.44	44	6,988.79	5.64	3.39	203.00	56	3.63
	6 x 1L FB	79,645.25	13	6,126.56	4.75	3.15	210.00	105	2.00
	6 x 1L SRS	3,543,859.70	390	9,027.38	4.31	3.49	330.00	120	2.75
ABL	6 x 750 ml angled neck	1,231,592.82	144	8,778.63	11.14	3.88	223.00	130	1.72
Rauenberg10L	10L core bottle	8,718,274.30	839	10,416.55	2.74	4.06	330.00	60	5.50
GVP	200 L drum	2,221,828.00	332	7,298.11	1.80	4.20	16.00	4	4.00
	60L drum	136,056.00	20	7,049.59	3.21	5.09	15.00	9	1.67
	IBC	1,017,892.00	111	7,267.05	2.04	4.05	5.00	1	5.00
Grand Total		87,981,864.72	9,139	9,596.07					

Table 2-3 Data over 2018

Finished Goods Warehouse

When the boxes are stacked on the pallet, the AGV is called and brings, depending on the filling line, the pallet to the buffer track or to the wrapper. Besides, every filling line has a buffer track of 2 pallets, such that filling can continue for a brief period when the AGV is busy or down. Figure 2-1 shows two AGVs. The AGV for the filling lines that produce smaller volumes brings the pallets to the buffer track, whereas the other AGV collects the pallets from this buffer track, the Safepack, the SFVision5L, the Rauenberg10L, the Alwid20L, and the GVP. The latter AGV will put the pallets on a conveyor belt that goes through three workstations before entering the FGW. First, the pallet gets a plastic foil on top and hereafter the pallet goes to the wrapper. At the wrapper, the pallets will be wrapped with plastic foil, to make sure that boxes will not fall off during transport. The last workstation is a scanner, to make sure that the Enterprise Resource Planning (ERP) system knows that a part of the order is produced. Now, the conveyor belt transports the pallet to the warehouse. At the warehouse, there is a buffer track for 12 pallets. These pallets are picked up by a forklift truck and transported to its designated Loading Bay (LB). The last pallet of a batch is a 'rest pallet'. This pallet is not fully stacked and is therefore not wrapped by the wrapper. The employees of the warehouse need to do this by hand, which takes around the 5 minutes per pallet.

The warehouse can store no more than 504 pallets, due to safety reasons as specified in PGS 15 (Rijkswaterstaat, 2019). The PGS 15 is a storage directive regarding fire safety, occupational safety, and environmental safety. At the warehouse, there are 11 LBs where 33 pallets can be stored. On the floor, there is also space dedicated for another 100 pallets. On a day, a maximum of 19 trucks of each 33 pallets transports the finished goods to the EDC. When the number of pallets in the warehouse is below 80, a transport is cancelled. There is a restriction on which type of pallets are scheduled for one truck, because some pallets are heavier than others. A truck cannot transport more than 24.5 tons, when going to the central warehouse in Belgium. After analysing the data out of 2018, we find that in total 396 trucks are cancelled, since it happens that there are not enough pallets ready in the FGW. On average, Company X cancels 8 trucks per week. There is variation in the number of pallets per truck that are transported to the EDC. Sometimes only 24 pallets are transported, but when we look at the average over 2018, we found an average of 31.79 pallets per truck. We use this information for modelling the production process of Company X and for verifying the model.

2.2 Planning Process

In Chapter 1 we gave a brief introduction to the planning processes at Company X. In short, the FS department makes the day-to-day schedule on basis of information from Call Off, made up agreements, setups between batches, and experience. The goal of FS is to minimize the tardiness. Now, we go into more detail. This information is used when modelling the production process. Figure 2-2 visualizes the planning process of Company X.
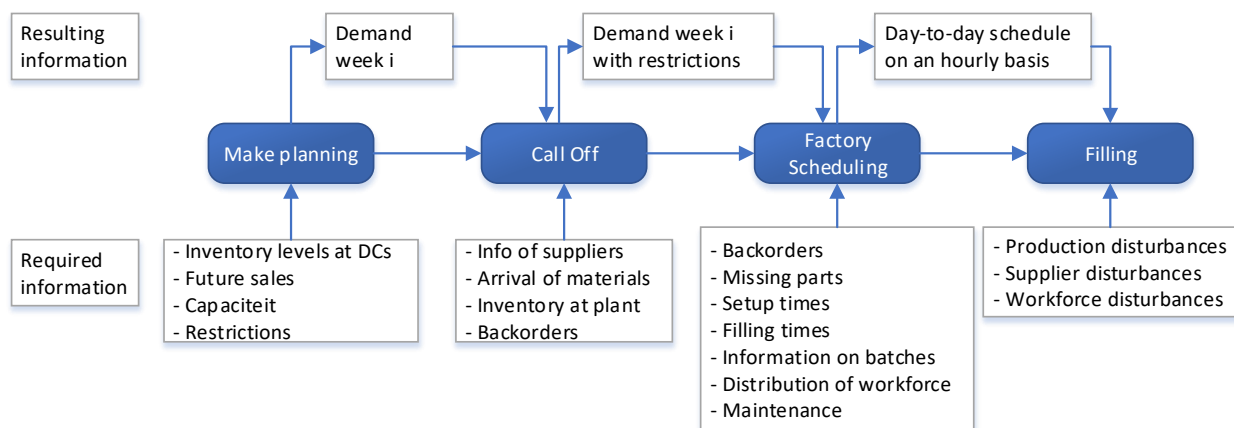
Figure 2-2 Planning Process at Company X

Make Planning

Planning at Company X starts with the make planner. The make planner has insight into the forecasts that sales put in SAP. SAP is a full ERP software helping with financials, distribution, manufacturing, project management, and customer relationship management. First, the make planner determines the demand per filling line over the next thirteen weeks. Next, the make planner allocates the capacity in kilograms for these thirteen weeks. The make planner determines how many shifts there will be needed for the upcoming thirteen weeks to level the difference between capacity and demand for these thirteen weeks. This is done on a daily basis. At every Monday and Tuesday of the week, the make planner determines the orders that should, in an ideal case, be processed in the next week. At Tuesday the make planner sends the orders to the Call Off team.

Call Off

The Call Off team consists of two team members who look at the orders that should be processed and the backorders of the previous weeks. They consult the ERP system to find out what the current inventory levels of the required raw materials, ingredients, and packaging material are. Together with the moment that materials arrive at the plant, they give restrictions to the FS team. So, the Call Off team runs a Materials Requirements Planning (MRP) run. An example of a restriction is the following: Make planning determined that SKU A should be processed in week 7. Call Off finds out that the supplier cannot deliver until week 8, hence SKU A cannot be processed in week 7. This restriction is given to FS, such that they know that they cannot plan SKU A in week 7. Call Off has a direct connection with the suppliers. They monitor the situation of the deliveries on a continuous basis. When a deviation in delivery time occurs, Call Off consults FS, such that the production schedule can be altered. Call Off also reports this deviation, such that performance leaders can contact the supplier to come to a solution.

Factory Scheduling

At Wednesday, FS gets the restrictions from the Call Off team and knows which orders can be processed in the given week. FS looks at 'Time for filling' of the orders that they must schedule and determines a day-to-day schedule for the filling department on basis of these and other restrictions. The day-to-day schedule is visualized in a Qlikview tool. Qlikview is a software tool for business intelligence and data visualization. Out of one mix order, multiple fill orders exist. As said in Chapter 1, FS looks at the restrictions of Call Off when scheduling. The restriction of Call Off is as follows, they first display the date before the batch can be processed and second, they display the material code that is not available. There are more restrictions that are important to FS, these are:

- *Hypo and acid batches.* A hypo and an acid batch may not be processed after each other, because chlorine gas can arise when those two batches make contact.
- *Capacity.* Capacity of filling lines in available hours/day/shift.
- *Prioritization of batches.* Some batches are more urgent than others.
- *Setup:* Between batches, setup may be needed. FS tries to minimize setup times.
- *Maintenance plan.* Every week, all filling lines have preventive maintenance. The line is in this time not available for production.
- *Run rate.* FS uses the run rate for a filling line to determine the estimated filling time of the batches.
- *Prio lines.* Two filling lines are prio lines. These filling lines can be scheduled for 24 hours a day, while other filling lines are scheduled for 22 hours a day to incorporate breaks of operators.
- *ADR3 Batches.* ADR3 batches may not be scheduled on Friday, since these batches may not be stored in the warehouse during the weekend.
- *'Weekend overstaan' batches.* Some batches are 'Weekend overstaan' batches, these should ideally be mixed on Friday afternoon and filled on Monday.

Mixing

At Company X, mixing is subordinate to filling, therefore this department is not included in Figure 2-2. Mixing has insight into Qlikview and aligns its mixing schedule. The mixing department has the goal to start producing the batch four hours in advance, such that the semi-finished product is mixed before needed at filling. A batch should constantly be available in

one of the buffer kettles, so that an operator in a shift can produce quickly after completing a batch. So, the mixing operators constantly analyse the batches at the filling lines, the batches in the RKs, and the batches in the BKs. So, they make an own prioritization of the filling lines, such that they could start up the batch with the highest priority. The mixing operators do not only look at the total filling time, they make the prioritization by also considering the characteristics of the batches to mix, and the shift distribution of the filling lines. The characteristics of the batches are the mixing times and on which RK the batch could be made, because not every batch can be made on every RK as explained before. Filling is dependent on mixing. If mixing has no batches ready, so-called WOP (Waiting for Product) occurs. Table 2-4, Table 2-5, and Table 2-6 display the logic for when orders are started at the mixing department. In these tables we display the number of batches that are currently in a BK or RK and the constraint if we start the batch at a RK. If there is currently one batch in a BK, then it could be the case that this batch is processed on the filling line. This BK becomes available after the Remaining Processing Time (RPT). An explanation of the used terms follows below the tables.

	Situation 1		Situation 2	
BK	1. RK	1. Starting batch?	2. RK	2. Starting batch?
0/1	0	Always	1	MixTime > RPT & TTC > RPT
2	> 0	Never	0	MixTime > RPT & TTC > RPT

Table 2-4 Current way in which Mixing starts an Order for all Filling Lines

	Situation 1		Situation 2	
BK	1. RK	1. Starting batch?	2. RK	2. Starting batch?
0/1	< 3	Always	3	MixTime > RPT & TTC > RPT
2	< 2	Always	2	MixTime > RPT & TTC > RPT
3	0	Always	1	MixTime > RPT & TTC > RPT
4	> 0	Never	0	MixTime > RPT & TTC > RPT

Table 2-5 Current way in which Mixing starts an Order for the SFVision5L

BK	RK	Starting batch?
0/1	2	MixTime > RPT + (Processing Time RK / 2)) & TTC > (RPT + (Processing Time RK / 2))
2	1	MixTime > (RPT + BK Processing Time) & TTC > (RPT + BK Processing Time)

Table 2-6 Current way in which Mixing starts an Order for the Alwid20L

For all filling lines, mixing starts a batch if the number of batches in the adjoined BKs is zero or one as displayed in Table 2-4. If there are two batches in the BKs and zero batches in the RK, the mixing departments checks if the mixing time is larger than the RPT and if the time until the line becomes inactive, the Time Till Close (TTC), is larger than the RPT. The same check is performed when there is zero or one batch in the BKs and one batch in the RK. Table 2-5 shows the restrictions that are applicable to the SFVision5L, because this filling line has four BKs.

For the filling line with a low filling time, the Alwid20L, mixing uses the same rules as in Table 2-4 with additional constraints. Table 2-6 shows the restrictions that mixing uses for this filling line. Mixing also starts a batch if the number of batches in the adjoined BKs is zero or one, the number of batches in the RK is 2, and the mixing time is larger than the remaining processing time plus the filling time of one batch that is currently in the RK. We also start a batch if there is one batch in the BK and one batch in the RK, we check if the mixing time is larger than the RPT plus the filling time of the batch in the BK, and if the time until the line becomes inactive

is larger than the remaining processing time. So, concluding, the mixing department is only starting a batch when they know for sure that the batch can directly be moved to the BK.

Filling

FS makes the day-to-day schedule for the filling department. When no disturbances occur, filling could produce according to plan. Unfortunately, disturbances occur. Due to these disturbances, the plan adherence is lower than expected. Appendix A shows the plan adherence over 2018. The process of rescheduling takes place when disturbances within the primary process or the supply chain occurs. Disturbances within the primary process are e.g. reprocessing of batches at the mixing department due to bad quality, batch cycle time and setup times variability, variations in recipes, and equipment failures. Disturbances within the supply chain are e.g. supplies not delivered or delivered too late, changes in product orders or changes in priority, changes in forecasts, and order cancellations. These disturbances are considered when modelling the production process of Company X.

2.3 The New Filling Line

This research is focused on the consequences of the new filling line, such that Company X knows what to do to reach a growth scenario. In the new situation, the SFVision5L and the Rauenberg10L are merged to one new filling line, the SFVision. For visualization, Figure 2-3 displays the new filling line with the production steps. Appendix D displays the new layout of the filling department of Company X. This new filling line has financial advantages, according to the project leader. The personnel costs are reduced by €250,000; the electricity costs are reduced by €3,600, and the maintenance costs are reduced by €50,000. The line is designed such that production can even be 100 or 60 cans per minute for the 5L and 10L cans, respectively. The time to finish one batch of 5L cans and 10L cans is estimated respectively at 28 minutes and 22 minutes. In this time, cleaning and setup time is not incorporated. The time to clean the filling line and to setup the filling line for a new batch takes 20 minutes.
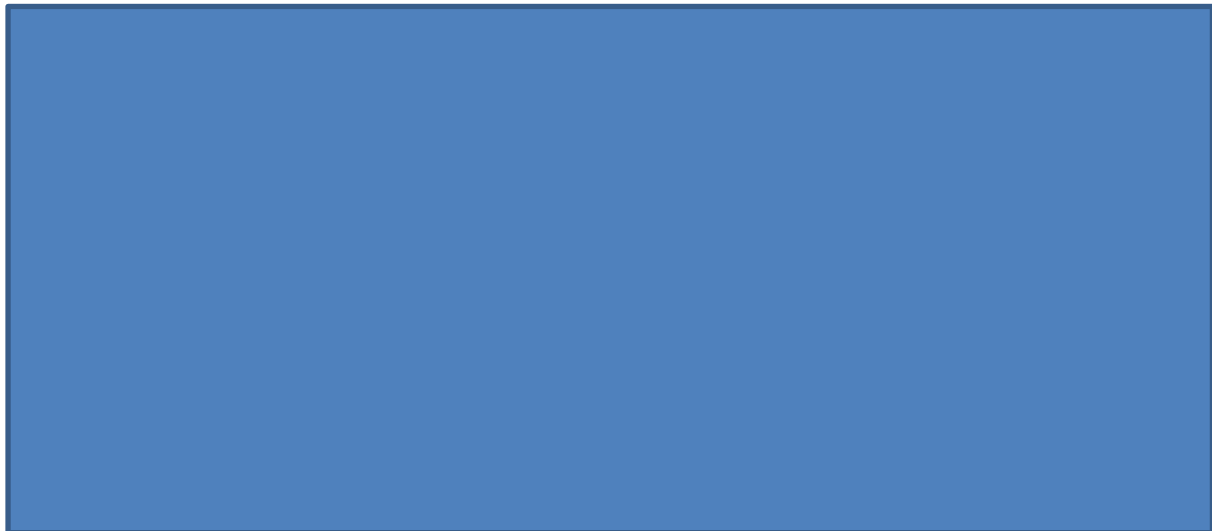
Figure 2-3 Production Line Layout

The production steps of the two cans differ. Table 2-7 displays the production steps of the two cans. In the new situation, the cans still undergo these steps. The main distinction is that the 10L cans are not placed in a box. Thus, in the new situation, the filling line has two routes. In the current situation, the filling lines could run in parallel. In the new situation, this is not possible. To convert the filling line from 5L to 10L or vice versa is estimated at 2 hours. The

Manager Planning and Logistics thinks that during a week, one setup is required. The new filling line is connected to the 4 BKs that are currently adjoined to the SFVision5L filling line. The 2 BKs for the Rauenberg10L and GVP filling lines are in the future situation adjoined to the GVP filling line. When profitable, these two buffer tanks can be adjoined to the SFVision.

Production step	5L Cans	10L Cans
Depalletizer	YES	YES
Sleever	YES	YES
Filler/capper	YES	YES
Labeller	YES	YES
Box erector	YES	NO
Packing machine	YES	NO
Tape machine	YES	NO
Box labeler	YES	NO
Track and trace labeler	YES	YES
Palletizer	YES	YES

Table 2-7 Production Steps for the 5L and 10L Cans

When considering the rate of boxes per hour that FS uses for scheduling, there is a gap between the current and future situation. In the current situation, when the two filling lines are up and running simultaneously, the number of cans per minute is 18.7. In Chapter 1 we noted that the average number of cans per minute in the future situation is 70 and 45 for a 5L and 10L batch, respectively. These numbers are determined by Company X via a simulation study, we assume that these numbers are well-founded and therefore accurate. Table 2-8 displays some more facts of the gap, such as the boxes/cans per hour, the pallet load, the number of pallets per hour, the minutes until a new pallet, and finally the number of shifts required per week. The number of shifts for the new filling line is determined for a product portfolio of 40 5L batches and 30 10L batches. It is estimated that we need a daily production time of 12 hours to make sure that these batches are produced during a week. Therefore, 8 shifts should be enough. The consequences of the new filling line on the supporting departments, if the 8 shifts are enough, and the way in which Company X can optimally utilize this new filling line is currently not known.

Situation	Cans per minute	Boxes/cans per hour	Pallet load	Pallets per hour	Minutes till new pallet	Number of shifts
5L New	70	1400 Boxes	80	17.5	3.4	8
10L New	45	1800 Cans	60	30	2	
5L Old	13.2	396 Boxes	80	5	12.1	15
10L Old	5.5	330 Cans	60	5.5	10.9	10

Table 2-8 Production Rate per Filling Line

The new filling line has consequences that can be predicted, but the magnitude of those consequences is not known. When the new filling line is up and running, this results in peak demand at supporting departments. These supporting departments are all subordinate to the filling department. Figure 2-4 displays the problem cluster. A problem cluster is usually created to identify the core problem (Heerkens & Van Winden, 2012). This method gives more insight into the problems that occur at this moment and the problems that can occur when the new filling line is up and running. In the grey box "After buying the new filling line" we display the possible worst-case scenarios that can occur when the new filling line is up and running. Since the new filling line is currently not producing at the designed speed, these are foreseeable problems and are due to the fact that FS does not know how the internal supply chain, in the

future situation, is affected by the day to day plan that they make. Below the figure, we indicate per supporting department the consequences.
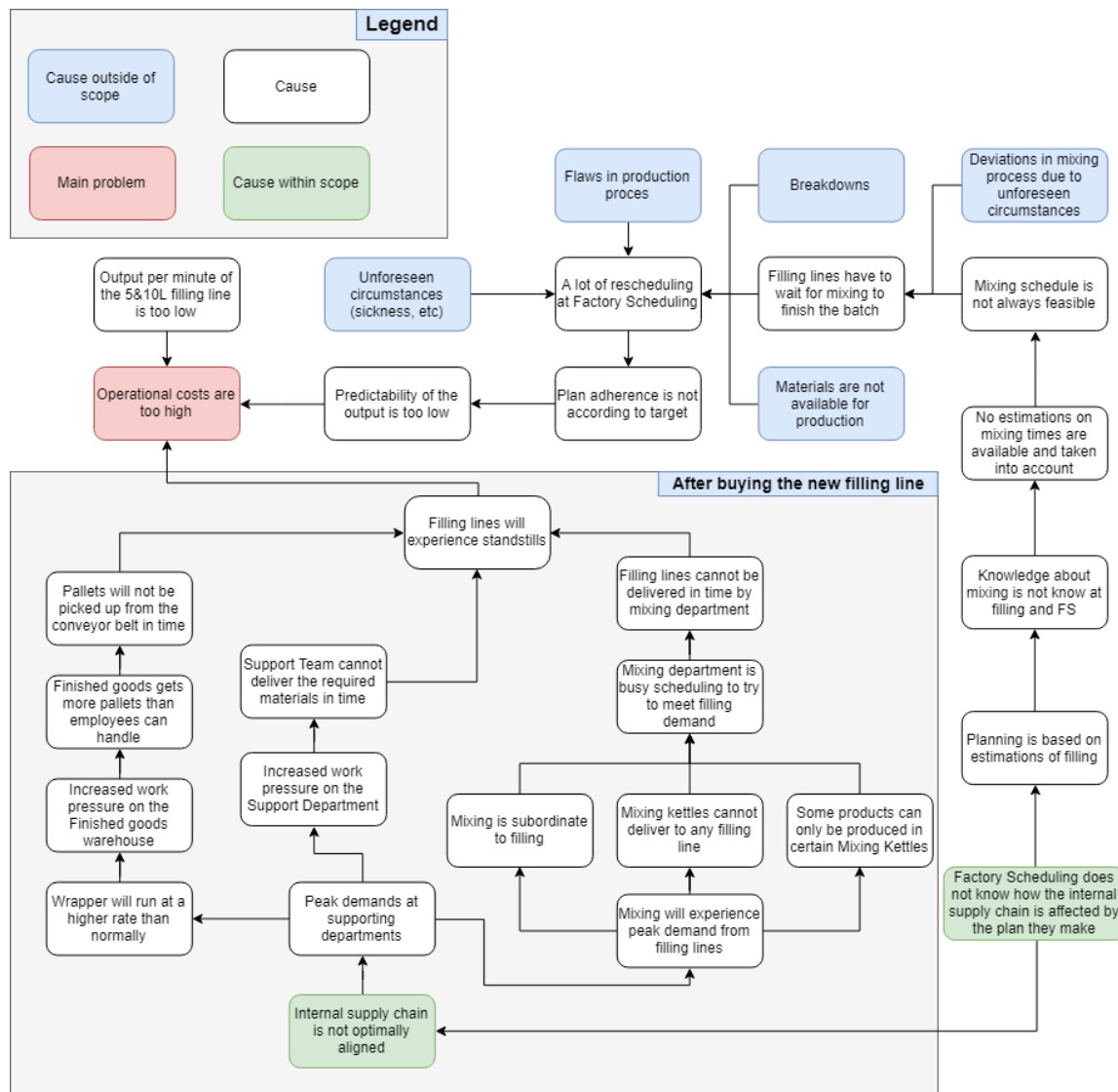
Figure 2-4 Problem Cluster

Support Team

When the new filling line is up and running, the filling line needs more cans, cartons, labels, etc. per hour for production. Thereby, the work pressure on the Support Team increases. This can result in the fact that the employees cannot deliver the materials in time. Also, the storage of the materials in the warehouse could be a problem in the future, since the materials needed at a certain moment will increase.

Mixing

The second department taken into consideration is the mixing department. Filling can start when the semi-finished product is in the buffer kettle and is stirred for some minutes. When the new filling line is up and running, this line demands more batches from mixing than mixing can manage. Currently, mixing is busy scheduling to try to meet demand of the filling department. With the new filling line, this will intensify.

Filling

The third department taken into consideration is the filling department. This new filling line can negatively influence other filling lines, when mixing is busy trying to meet the demand of this new filling line. Therefore, we incorporate all filling lines in our simulation model to make sure that the right number of batches are filled on all filling lines.

Transport and Finished Goods Warehouse

For the FGW, there are multiple locations where standstills can occur, all resulting into the fact that the pallets will not be retrieved from the buffer in time. These locations are for example the AGV or the pallet wrapper. It could also be that there are more incoming pallets than pallets leaving the warehouse, using the fixed transport schedule. As the warehouse cannot store more than 504 pallets, pallets will be blocked before entering the warehouse. This could all result in a standstill at one or more of the 11 filling lines. It is therefore necessary to analyse what the impact is on these supporting departments.

Company X does not know when, where, and to what extent those problems arises, using a configuration in production. Company X wants to know how they can use this new filling line as optimally as possible, considering multiple future states. The remainder of this research gives answer to this question.

2.4 Conclusion

In this chapter we answered the following research question: "*How is the production and production scheduling organized within Company X and what alters due to the new filling line?"*. First, we analysed the production process of Company X. Company X first mixes multiple raw materials into a batch. The batch is later filled into a specific type of container at one of the filling lines. Every filling line is connected to 2 BKs, except for the new filling line, which is connected to 4 BKs, therefore Company X uses buffers to make sure that a filling line never has to wait for a product. Not every filling RK is connected to a BK, so the existing connections are of importance in the DES model. We divide the batches, that are processed at Company X, into eight types of batches according to their characteristics. We use the following characteristics of a batch: regular, fill only, bulk, acid, RK104, hypo, ADR 3 and 'weekend overstaan' batches. After a batch is filled in containers, the pallets go to the FGW. In the FGW at most 504 pallets may be stored and there are daily 19 truck transports of each 31.79 pallets on average to the EDCs.

Second, we explained the way in which batches are started at Company X. The scheduling process gives us more information on the restrictions within the production process, such that the simulation model starts batches in the most accurate way. The FS department considers multiple important restrictions, such as capacity of the filling lines, the run rate of a filling line, the maintenance plan, and the setup times. At Company X mixing is subordinate to filling. The FS department schedules the batches at filling, while mixing needs to adjust its plan to this schedule to mix the batches in time. Table 2-4, Table 2-5, and Table 2-6 display the logic for when orders are started at the mixing department.

Finally, we explained the modifications due to the new filling line. Now we summarize the most important findings that we incorporate in the simulation model. The line is designed such that production can even be 100 or 60 cans per minute for the 5L and 10L cans, respectively. The time to finish one batch of 5L cans and 10L cans is estimated respectively at 28 minutes and

22 minutes. In this time, cleaning and setup time is not incorporated. The time to clean the filling line and to setup the filling line for a new batch takes 20 minutes. To convert the filling line from 5L to 10L or vice versa is estimated at 2 hours. The new filling line is connected to the 4 BKs that are currently adjoined to the SFVision5L. Finally, Company X estimated the required number of shifts at 8, when producing 700 tons. Due to the new filling line, we expect peak loads at the supporting department.

Now we know what alters in the production process of Company X and thereby what we should incorporate in our DES model. It is unsure how the production process of Company X is affected by the new filling line. Company X wants to know how they can use this new filling line as optimally as possible, considering multiple future states. More research still needs to be done into the production process of Company X, because more data is needed for the DES model. We describe this information in Chapter 4. In Chapter 3, we perform a literature analysis to gain more information on possible ways in which we can analyse the consequences of a future state.

3 Literature Study

This chapter provides an answer to the research question: "*What theory offers literature about finding the bottleneck in a chemical process plant?*". Section 3.1 introduces the chemical process industry. Section 3.2 describes what is written in academic literature about analysing the bottleneck in a future state. Section 3.3 describes the way in which a simulation study should be executed to describe the production process on hand as accurately as possible. Finally, Section 3.4 summarizes the most important findings.

3.1 Chemical Process Industries

Company X is a chemical process plant, as concluded in Chapter 2, therefore the first subject we analyse is the chemical process industry to gain some background information on the characteristics of such a plant. The process industry produces measurable products. This means the products that are made are often in liquid or gas state and therefore not countable, but measurable in e.g. volumes (Lyons, Vidamour, Jain, & Sutherland, 2013). A definition of process manufacturing is given by the 12th edition of the APICS dictionary: "Production that adds value by mixing, separating, forming and/or performing chemical reactions. It may be done in either batch or continuous mode" (Blackstone, 2008). For the rest of this research we use this definition when referring to the process industry. Companies that produce mostly in batch mode often must deal with a high variety in products. This results in long lead times, complex routings, and many production steps. Continuously producing companies must deal with long setup times and a limited number of different products that are made (Lyons *et al.,* 2013). Lyons *et al.* (2013) give various characteristics on discrete and process industries. Table 3-1 depicts the characteristics applicable to Company X.

Factor	Discrete manufacturing	Process manufacturing
Product and product structure	Solid	Liquid
	Assembled bill-of-materials	Blended formula or recipe
	Countable	Measurable
	Many input raw materials/components	Few input raw materials
	Primarily convergent product flow	Primarily divergent product flow
Manufacturing processes	Predictable material grade	Variable material grade
	Process sequence precedence constraints	Flexible process plans with fewer precedence constraints
Production planning and control	Item tracking and control	Batch tracking and control
	Predictable yield expected	Often variable yield

Table 3-1 Discrete and Process Industries – a Comparison (Lyons *et al.* (2013))

When considering these characteristics, some notable facts can be determined. In addition to the countable versus measurable products, we note that discrete manufacturing has a primarily convergent product flow, while the process industry has a divergent product flow. This means that the discrete manufacturing industry often uses many raw materials for one product only. The process industry can process a liquid into a wide range of chemicals. At Company X, the mixing department produces measurable products, while the filling department makes countable products. Therefore, Company X cannot be qualified as a chemical process industry. At mixing, Company X is a process manufacturer, while at filling Company X has the characteristics of a discrete manufacturer. For the remainder of this research, we still use the

term chemical process industry for clarity, and we take the difference between both industries into account.

3.2 Analysing the Bottleneck in a Future State

In this section, Section 3.2.1 elaborates more on bottlenecks and its impact on the internal supply chain. Section 3.2.2 describes the Lean Manufacturing methodology and describes if Lean Manufacturing tools are useful in a process industry environment. Finally, Section 3.2.3 describes literature on finding bottlenecks in a future state in a process industry environment.

3.2.1 Bottleneck in a Process Plant

Bottleneck is a term with multiple definitions, we use the definition by Roser *et al.* (2001). Roser *et al.* (2001) state that the machine with the longest average active period is considered to be the bottleneck and in turn is most likely to dictate the overall system throughput. We chose to use this definition since we want to find the department that is responsible for the overall system throughput in a discrete event system by examining the average duration of a machine or FTE being active in a department. The longest average active period is in our case displayed as the department with the highest utilization and the greatest impact on the total output. The bottleneck has a negative impact on the entire internal supply chain and thus on the total output.

According to King (2009), identifying bottlenecks and potential bottlenecks is more important for process manufacturing operations. In process plants, throughput in most manufacturing steps is limited by equipment capability, not by labour. Many of these manufacturing steps operate around the clock or at or near full capacity. There is no extra time available to create additional capacity. Furthermore, equipment tends to be expensive and relatively inflexible. Replacing or upgrading equipment is often not a viable option. This means that improving performance of the bottleneck step is critical (King, 2009). According to King (2009) managing the bottleneck is a matter of optimizing the performance of the bottleneck resource itself, protecting the bottleneck from upstream and downstream problems, and optimizing bottleneck scheduling. King (2009) states the most significant characteristics of bottlenecks found in process plants. These are:

1. The root cause is generally in equipment capacity and performance, not labour staffing;
2. Root causes include yield losses and reliability problems as well as inherent capacity;
3. Non-bottlenecks can become bottlenecks due to variability in Overall Equipment Effectiveness (OEE) factors;
4. Plants often run around the clock, so additional shifts are not a feasible solution;
5. Bottlenecks can move with product mix;
6. Bottlenecks may not be obvious – the resulting inventory and other waste is frequently hidden from sight.

Now that the importance and characteristics of the bottleneck in a process plant is clear, we want to resolve this bottleneck, such that we could strive for flow. The Theory of Constraints is an iterative process of eliminating bottlenecks to improve the process during each cycle (Goldratt, 2013). The methodology consists of five steps:

1. Identify the bottleneck;
2. Decide how to exploit the bottleneck;
3. Subordinate everything to the bottleneck;

4. Eliminate the bottleneck;
5. Start again at step 1.

To identify the bottleneck, multiple issues can occur. Two issues are the following. First, in many process plants the Work in Progress (WIP) is not visible. It is stored in a location somewhat removed from the main process flows, in kettles for example. Therefore, it is invisible and does not give clues to possible bottlenecks. Second, the bottleneck may be at different processes. The bottleneck can be at a different process step for one material being produced than for another material. So, the bottleneck may be invisible or moving.

King (2009) states five reasons why a specific step may be the bottleneck. So, there are five causes why a bottleneck is the bottleneck. To eliminate the bottleneck, one must look at those potential causes. These five reasons are:

1. Inherent equipment capacity limitations;
2. Long changeovers;
3. Mechanical reliability problems;
4. Yield losses;
5. Inappropriate scheduling, i.e. Capacity Constraint Resources (CCRs).

A distinction can be made between Bottleneck Resources and CCRs. A Bottleneck Resource is when throughput is limited by factors related to a piece of equipment and its performance, either its inherent processing rate or losses due to downtime or poor yield. A CCR is a resource which, if not properly scheduled and how well its flow is synchronized with upstream and downstream process steps, is likely to cause the actual flow of product through the plant to deviate from the planned product flow (King, 2009).

3.2.2 Lean Manufacturing Methodology and the Process Industry

Lean Manufacturing, hereafter Lean, is a well-known term within the production environment, with the goal of reducing waste through the value chain. The Lean theory offers many approaches to identify and solve the bottleneck in a production process, but Lean is more than just implementing improvements. It is a philosophy, or a 'state of mind'. This philosophy comprises three goals. First, an organization should create value for its customers. Second, an organization should eliminate all kinds of waste. Third, an organization should include the employees in the process to get a successful implementation.

Out of this philosophy, steps are made to implement Lean. According to Womack and Jones (1996), there are five steps for implementing Lean Thinking in an organization: 1) Define Value from the perspective of the customer, 2) Identify the Value Streams, 3) Achieve Flow, 4) Schedule production using Pull, and 5) Seek perfection through Continuous Improvement. This research is part of the second and third step. According to Rother and Shook (1999) a value stream is a collection of all actions value added as well as non-value added that are required to bring a product or a group of products that use the same resources through the main flows, from raw material to the customers. For our research, we need to visualize the value stream of Company X.

To implement Lean, techniques and tools are required. Figure 3-1 shows the House of Lean and visualizes the key techniques (Bicheno & Holweg, 2016). In the House of Lean there are some techniques that can be used to find the root cause of a problem, such as 5 Whys. Also, there are techniques to solve the root cause, such as Standard Operating Procedures. Out of

these techniques, Value Stream Mapping (VSM) can be used as a guiding framework for Lean transformation and to visualize the value stream. We explain this method later in more detail.
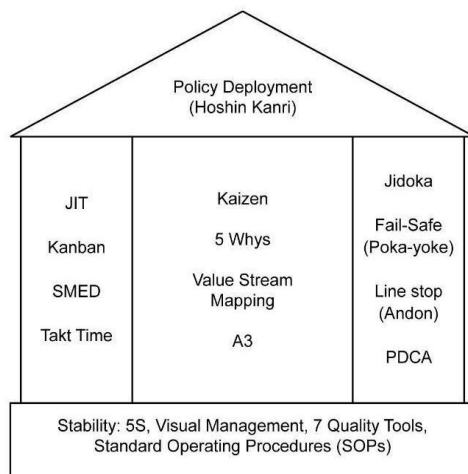
Figure 3-1 House of Lean (Bicheno & Holweg, 2016)

Lean in the process industry

Now we know what Lean is, we need to know if Lean is also applicable in a process industry environment, because Lean thinking finds its origin in the discrete manufacturing industry (Lyons *et al.,* 2013). Section 3.1 showed the differences between the two types of industries. Although, there are some major differences between discrete manufacturing and the process industry, Lean can be applied nearly the same way for both industries. Value enhancement, waste reduction, people involvement, and increasing flow - the philosophies behind Lean - is not bound to one industry alone (Panwar, Jain, & Rathore, 2015). Nevertheless, on some points the Lean application differs. Since a process industry produces mostly in batches, other techniques, such as quick changeover techniques become more important. Concluding, Lean is perfectly implementable in a process industry environment, although the focus is different.

Value Stream Maps

A VSM is a visualization of the entire production process, representing both material and information flow. The goal is to identify all types of waste in the value stream and to take steps to try to eliminate them (Rother & Shook, 1999). The VSM technique exists out of two steps. The basic idea is to go to the workplace and define the current state of the production process. The future state is the "to be" business process. Value Stream Mapping is a powerful tool; its real purpose is to design the future state. Before one begins mapping, the aim and the scope of the map should be clearly defined. The current state VSM gives clues to possible bottlenecks by looking at the inventory values, but the real give-away are steps with utilization values near 100%.

The VSM technique has some drawbacks. First, a VSM is a snapshot in time, so it is not usual to pick up vital variation information. Second, the performance of the future state map is not guaranteed by just mapping. The future state map cannot be analysed by mapping. Third, an accurate VSM of the current state clearly defines any static bottleneck, but bottlenecks that move with product type, as is often the case in process industries, may be harder to see, even on a well-constructed VSM. We analyse the possibilities in literature to overcome these downsides of the VSM technique.

3.2.3 Finding the Bottleneck in a Future State

After an extensive literature study, multiple articles indicate that a simulation model can be used to explore alternative future states (Abdullah, 2003) (King, 2009) (Kikolski, 2016). McDonald, Van Aken, and Rentes (2002) use simulation for a manufacturing system to demonstrate that simulation can be a crucial tool in assessing different future state maps. They demonstrate that simulation can provide and examine different scenarios. Xia and Sun (2013) demonstrate, in a tubular machining facility, that simulation is not a replacement but an enhancement of the VSM method. They concluded that a simulation goes further than VSM and a future state can be better analysed with simulation.

Law (2015, pp. 3-4) gives the following definition for simulation: "In a simulation we use a computer to evaluate a model numerically, and data are gathered in order to estimate the desired true characteristics of the model". Alternatives for a simulation model are experimenting in reality or using an analytical model. Experimenting is more realistic, but also expensive, not repeatable, impossible, dangerous, and/or it takes too long. Analytical models are faster, optimization is easier and better, but the models are often not applicable due to dynamic effects and random events. We use simulation due to the complexity of the systems of interest and of the models necessary to represent them in a valid way.

Simulation is not a snapshot in time; therefore, simulation is an extension of the VSM technique that includes variability. Figure 3-2 shows the steps in a conventional and a digital VSM process (Trebuna, Perkarcikova, & Edl, 2019). In addition to evaluating a future state, simulation can also assist organizations that consider implementing Lean to quantify the benefits they can expect from applying Lean (Abdullah, 2003). Abdullah (2003) state that simulation is adaptable to the specific circumstances of the organization and can generate resource requirements and performance statistics for both the current and future situation. The information provided by the simulation model would enable management to assess the performance of the system in absolute terms, relative to the system it is designed to replace. According to King (2009), a discrete event simulation model of a manufacturing process can identify which steps are bottlenecks or near-bottlenecks and how the situation changes with each specific product in the overall mix. Also, King (2009) indicates that a simulation model of the manufacturing process helps with the covert inventory and moving bottleneck issue.
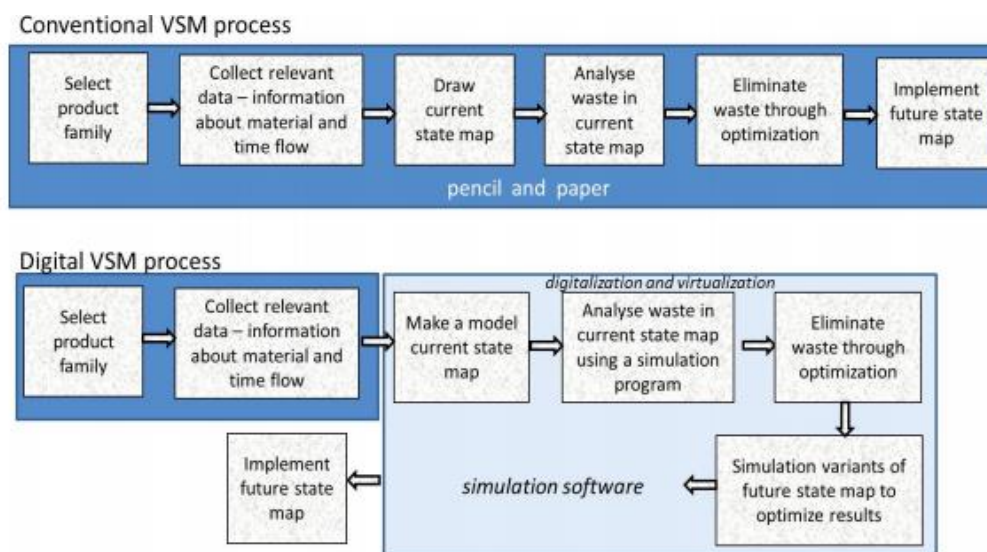
Figure 3-2 Conventional VSM Process vs. Digital VSM Process (Trubuna *et al.* (2019))

Furthermore, simulation is a uniquely powerful approach to decision making. By building and running a virtual representation of the production system, the simulator can identify missing or unclear processes, find where resources or equipment are constraining productivity, see where queues are building up, evaluating the impact of system changes, and many other types of issues. Kikolski (2014) states that a simulation model is a fine tool for verifying the functioning of processes and allows for clear visualization of selected assumptions. The interactive ability to view and change the model as it runs sets simulation apart from other methods, such as those using Excel or Linear Programming. Concluding, we use simulation to analyse multiple future states. Via simulation we follow the steps of the Theory of Constraints. Using simulation, we first identify bottlenecks which we will than resolve by following an iterative process to improve the process during each cycle.

3.3 Executing a Simulation Study

In this section, we analyse the most popular simulation techniques, hereafter we choose one technique. Next, we analyse the steps that need to be taken to execute a simulation study in the most accurate way. Finally, we describe the way in which we can find the bottleneck in a simulation study.

3.3.1 Simulation Applications

There are many popular simulation techniques. Some examples of techniques are: Discrete Event Simulation (DES), System Dynamics (SD), Agent Based Simulation (ABS), and Monte Carlo Simulation (MCS). All techniques have their own advantages and disadvantages. Jahangirian, Eldabi, Naseer, Stergioulas, & Young (2010) find that DES is used in over 40% of the papers they reviewed. The researchers reviewed the simulation applications published within peer-review literature to provide a picture of the role of simulation techniques within manufacturing and business. Results show that DES is the most widely used technique in manufacturing and business. DES is useful for tactical and operational decision making. Also, DES tends to be convenient for detailed process analysis, resource utilization, queuing, and relatively shorter-term analysis.

SD is the second most widely applied simulation technique, with a popularity rate of over 15%. Its use has been focused on policy and strategy development, project management, Supply Chain Management (SCM), and knowledge management. SD is closely related to DES. SD often includes fuzzy or qualitative aspects of behaviour.

ABS or bottom-up modelling addresses the modelling of human agents' behaviour as well as the communications inside an organization. Simulation is driven by the smallest entities. Finally, MCS uses random generators and are static. No time dimension is considered. Mostly useful in static problems or to solve numerical problems with a stochastic nature. These two simulation techniques are not applicable to answer our research questions.

For our research, the most useful simulation model is the DES model, since DES is, amongst the simulation techniques, the most appropriate to model resource utilization. Resource utilization is an important indicator to find the bottleneck. MSC and ABS are not applicable to model resource utilization. SD is mostly used for strategy verification, while DES is more operational and tactical. Since our research is operational and tactical oriented, we choose DES as our simulation technique.

There are multiple software models that use DES. We use Technomatix Plant Simulation (TPS) software developed by Siemens PLM software. The TPS software is a computer application for modelling, simulating, analysing, and visualizing logistic operations allowing to run experiments and what-if scenarios without disturbing existing production systems or long before the real production systems are installed.

3.3.2 Executing a Simulation Study in the Most Accurate Way

In Section 3.2 we explained some background on simulation studies. We chose to make a DES model. Law (2015, pp. 6-11) state that a discrete system is one for which the state variables change instantaneously at an event. Examples of events are a mixing kettle is done mixing the raw materials or a filling line has finished all liquids into containers. To execute a sound simulation study, attention must be paid to a variety of concerns, such as validity, modelling system randomness, statistical analysis of simulation output data, and project management. Figure 3-3 shows the steps that makes up a typical sound simulation study (Mes, 2018).
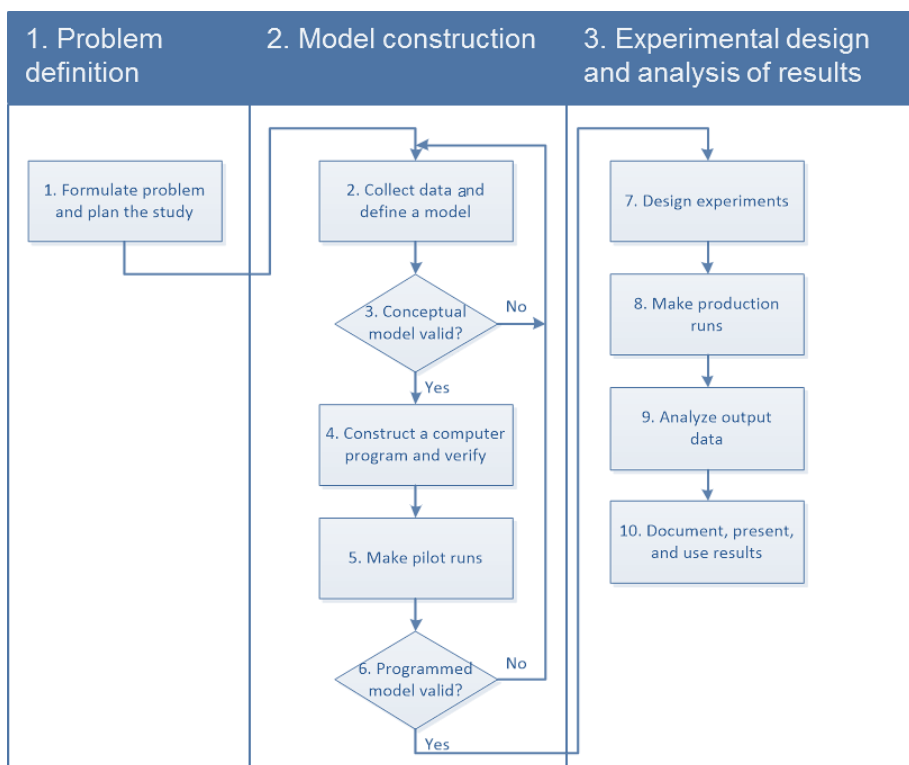
Figure 3-3 Steps in a Simulation Study (Mes, 2018)

There are three phases in a simulation study. The first phase is the problem definition phase. In this phase the problem is formulated, and the goals of the simulation study are defined. Next, the experimental factors are chosen and the scope and level of detail of the model is determined in this phase. Finally, a project specification should be made that includes the basis for the simulation study.

Now in the second phase, after the problem is clear, the model is constructed. The logic steps are first to describe the model in a documentation, second to code the model in software, and finally to check the validity and verification of the model. This is an iterative process, meaning these steps occur during the entire time that the model is constructed. In the documentation phase, flow charts are convenient to represent decision processes in the documentation phase

where time is standing still. When programming, documenting the code is important for re-use and communication. When programming, a stepwise approach is convenient according to Mes (2018). The steps are:

1. Identify main objects;
2. Construct a first model with default functionality;
3. Add basic logic;
4. Add detailed logic;
5. Finish model.

During programming the model, we need to use verification, i.e. to check if the programmed model coincides with the paper model. After the model runs, we need to check if the simulated model is valid, i.e. if the model represents reality well enough. These two concepts together make sure that a model is credible, e.g. that the manager and other key project personnel accept the model and its output as correct (Law, 2015, pp. 255-260). Figure 3-4 displays the steps needed to establish model credibility.
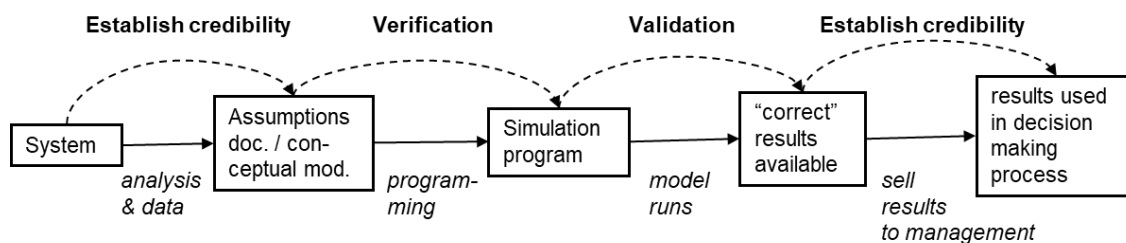
Figure 3-4 Establishing Model Credibility (Law, 2015)

There are different types of simulations regarding output analysis. The options available in designing and analysing simulation experiments depend on the type of simulation at hand. Simulations may be either terminating or non-terminating. A terminating simulation is one for which there is a natural event that specifies the length of each experiment (Law, 2015, pp. 493-497). A non-terminating simulation has no such event. A non-terminating simulation is often used when designing a new system and information on the behaviour of the system in the long run is asked for. Another distinction between simulations can be made on basis of the initial conditions of the simulation. If performance depends on the initial conditions, we have a transient system. Else, we have a steady state behaviour, where performance does not depend on initial conditions (Mes, 2018). Furthermore, at Company X the system is never empty, therefore literature suggests making use of initial conditions and thus a warm-up period. This means that we need to delete observations form beginning of simulations that depend on initial conditions.

In the third and last phase, the simulation model is an accurate representation of the reality and experiments can be conducted to answer the problems out of phase one. First, experiments are to be designed, second production runs need to be executed, output data needs to be analysed, and finally, the results should be documented and presented. A decent experimental design is situation dependent. An experimental design is for example the simulation-based optimization technique. In this case, a combination of input factors is searched for which optimizes a key output performance measure with the least number of evaluations. The idea is to sequentially decide on the system configuration to simulate based on the results from earlier simulated configurations. This continues until a stop criterion is reached.

3.3.3 The Bottleneck in a Simulation Study

First, as said, a bottleneck is the station with the longest average active period and in turn is most likely to dictate the overall system throughput (Roser et al., 2001). This bottleneck limits the production efficiency of the entire process. This can lead to a situation, in which a workstation before the bottleneck completes processing, but it cannot forward materials. Or a situation in which the workstation after the bottleneck is waiting for products. In a simulation study, the bottleneck can be found by looking at the workstations. Second, Kikolski (2016) shows and verifies that TPS can find the true bottleneck when creating a twin model of the current process. This is done by looking at the resource statistics of the workstations. The resource statistics shows, amongst others, what fraction of time the workstation is working, waiting, blocked, and failed. The use of a computer simulation tool allows to predict the work of the production line and provide some of the behaviour of systems (Kikolski, 2016). By using TPS, we analyse the current and future state of Company X to answer our research problems.

3.4 Conclusion

In this chapter we answered the following research question: "*What theory offers literature about finding the bottleneck in a chemical process plant?".* By analysing the characteristics of the chemical process industry, we got a better view on the production plant of Company X. By analysing the theory of LM and bottlenecks we came across the VSM technique. The VSM technique visualizes the entire production process, representing both material and information flows. Its real purpose is to analyse the current state and use the results to make a future state. A VSM is a snapshot in time, so it cannot be used to pick up vital variation information. Therefore, the performance of the current and future state map is not guaranteed by just mapping. To overcome this drawback, multiple articles indicate that a simulation model can be used to explore alternative future states. This is called a Digital VSM process and Figure 3-2 shows the subsequent steps while performing this technique. Multiple simulation techniques were discussed. We choose to make use of the DES technique. Next, we analyse the best way to execute a sound simulation study and how we can find the bottleneck.

4 Simulation Model Design

This chapter provides an answer to the research question: *"What is an appropriate simulation model design to answer the research problems?"* In Section 4.1 we address the project specification of this research. In Section 4.2 we discuss the experimental design of this research. In Section 4.3 we elaborate why the conceptual model is an accurate representation of the production process of Company X. We conclude this chapter in Section 4.4.

4.1 Conceptual Model

In this section we describe all aspects of the conceptual model by answering the first question of research question 3: *"What is an appropriate conceptual model of the production facility of Company X?".* First, we give a general outline to introduce the simulation study. Second, we discuss the input parameters of the simulation model. Third, we describe the output that we collect after running an experiment. Fourth, we describe the level of detail of the simulation model, since a too detailed simulation model is often time consuming. Yet, a more compact simulation model could also simulate the production process in an accurate way. Finally, we describe the logical flowchart of the routings used in the DES model.

4.1.1 General Outline of the Simulation Study

The simulation model has the goal to reach the targets as specified in Chapter 1. So, we would like to know the impact of the new filling line on the production process of Company X. This means that we create a simulation model that is scenario-based instead of improvement-based. Important in a scenario-based simulation study is to make sure that one simulates the system such that one is able to analyse different future states. When we know the consequences of a future state, we analyse how FS should deal with these consequences to get a stable flow through the factory. For FS it is of importance to know how the new filling line should be scheduled in collaboration with the other filling lines, such that the workload over a week is evenly distributed for all departments. When the consequences are known for the current product portfolio, we analyse the impact of some future states. The future states are scenarios in which we incorporate growth in tonnage production for the 5L and 10L cans. We show where bottlenecks arise in the production process. This is called a digital VSM process. We use the steps of Figure 3-2 to be able to analyse the results of a future state where variability is taken into consideration. The bottleneck or bottlenecks that we find are either due to capacity related problems or due to inappropriate scheduling.

To determine the consequences of the new filling line, the simulation model is a twin model of the current production process of Company X. The simulation model reflects the production process as accurately as possible to make sure that the conclusions are also applicable in the real world. The DES model simulates multiple weeks of production by simulating the flow of batches through the production process. We create multiple lists with orders by using the data out of Table 2-3 and the orders from 2018. We use a VBA code to determine multiple lists with orders. Now, a list with orders is available and we create logic to process the right batch at the mixing department. We explain this logic later in more detail. When the batch is ready at the mix kettle (RK), the batch is sent to a buffer kettle (BK) and waits until the designated Filling Line is ready to process the batch. The model contains all Filling Lines available at Company X. The pallet is subsequently moved to the FGW by AGVs. At the FGW, the pallets leave the simulation by means of truck transports to the EDCs.

After we validated the simulation model, we incorporate the new filling line and execute experiments to get the data required for answering our research questions. We show what Company X should do to reach 700 tons of production in a week on the new filling line.

After we analyse the simulation model for the number of tonnages for which the SFVision is bought and a stable flow can be ensured, we alter the simulation model. We then enter Phase 2 of our research. The list with orders, i.e. the production plan, is now different than before. The production plan incorporates more orders for the new filling line than in Phase 1. After altering the input of the simulation model, we perform experiments to determine the impact of growth. We translate these conclusions into guidelines for the FS department. After all, this research tries to give FS more insight in the consequences of the plan that they make.

4.1.2 Input

The simulation model does not run without the use of input data. The input data should be representative such that the simulation model is an accurate representation of reality.

General

A production week starts Sunday night at 22:00 and ends Friday at 22:00. A day is divided into 3 shifts. Table 4-1 displays the start and end times of these shifts. If a filling line is up and running for the whole week, 15 shifts are planned. In total, 9 filling lines may be scheduled simultaneously in a shift in the current situation. This means that in total, 135 shifts are to be divided over the twelve filling lines in one week. In a shift, the operators have breaks of in total 40 minutes. So, in total there are 7 hours and 20 minutes available for production in one shift.

Shifts	Start Time	End Time	Breaks
Shift 1	22:00	06:00	24:00-00:10; 02:00-02:20; 04:00-04:10
Shift 2	06:00	14:00	08:00-08:10; 10:00-10:20; 12:00-12:10
Shift 3	14:00	22:00	16:00-16:10; 18:00-18:20; 20:00-20:10

Table 4-1 Distribution of Shifts

We use data from 2018 to model the production as realistically as possible. We translate this historical data in multiple production plans, such that we could model various situations. The production plans contain the orders that FS already scheduled in 2018. In this way, we can simulate the process of Company X as accurately as possible. Figure 4-1 displays an example of a production plan table. In this table, we display various important attributes that we use in various sections of the simulation model. In the production plan we display the kilograms, the quantity, and the litres of all batches. We use this data to calculate the number of pallets for example. We also display the filling and the mixing time of a batch in seconds. We determined this data in consultation with FS. Finally, in Chapter 2 we concluded that not every batch can be mixed on all RKs, therefore we need to consider the characteristics of a batch. In the production plan we display the type of batch at 'Remarks' to make sure that the batch is also started on a suitable RK.

	object 1	integer 3	real 4	string 5	string 6	real 7	string 8	real 9	real 10	real 11
string	MU	Priority	Quantity (KG)	Filling Line	Product	FillingTime (sec)	Remarks	MixTime (sec)	Quantity (pcs)	Quantity (l)
3	.MUs.Batch	3	10344.84	Multivuller	6 x 0.75L trigger bottle	21833.00	0	14400.00	2244.00	10098.00
4	.MUs.Batch	4	12446.00	Alwid20L	20L can	7200.00	0	10800.00	490.00	9800.00
5	.MUs.Batch	5	3044.47	Flexlijn	1.4L SD	28632.00	0	10800.00	2227.00	3117.80
6	.MUs.Batch	6	11882.20	Rauenberg10L	10L core bottle	10712.00	RK 104	21600.00	982.00	9820.00
7	.MUs.Batch	7	12321.10	Alwid20L	20L can	7155.00	0	10800.00	487.00	9740.00
8	.MUs.Batch	8	9944.80	Kugler	6 x 1L SRS	17498.00	Hypo	14400.00	1604.00	9624.00

Figure 4-1 Example of a Production Plan in TPS

Mixing

The production process starts at the mixing department. We use the data that the FS department uses. We cannot say with certainty that the time used is completely accurate, because according to the operators the mixing time is variable. More accurate data is unfortunately not available, so we cannot fit a probability distribution. In consultation with the mixing operators, we determine to vary the mixing times by using a uniform distribution of minus half an hour and plus half an hour to incorporate variability. After the batch is mixed, the batch goes to a BK, if there is an empty BK. To incorporate the time needed for transferring the batch to a BK and to make sure that the last amount of water is added, we take half an hour as transfer time. The simulation model contains the connections between RKs, BKs, and filling lines as displayed in Table 2-1 and Table 2-2, such that we do not start up a batch for a specific filling line on the wrong RK. When the batch is leaving the RK, we should make sure that the RK is cleaned. After consulting the operators at the mixing department, we found that cleaning the RK takes, on average, half an hour. Next, the way in which mixing starts orders is important for the DES model. In a later section we explain via a flowchart how and when we start an order for a specific filling line at mixing. This way is related to the logic as explained in Table 2-4, Table 2-5, and Table 2-6.

Filling

Now we know what kind of input we use for mixing the orders; the orders are going to the next step in the production process: the filling lines. We describe later how and when an order arrives or leaves the filling line via flowcharts.

- *Product data.* Some filling lines can fill multiple containers. So, the number of litres on a pallet varies according to the number of boxes on a pallet and the number of containers in a box. Table 2-3 displays these input parameters.
- *Shifts.* Multiple filling lines in the simulation model are not up for 15 consequent shifts. Some filling lines are only up for 6 shifts in a week for example, since the demand out of the market is not high for those filling lines. To make sure that we use the right number of shifts, we consulted the Group Performance Leader (GPL). The GPL is responsible for making sure that the right number of shifts are allocated in a week. Fortunately, the GPL has a document where he updates the shifts allocated in a week. For this simulation study, we choose six weeks of production out of 2018 and use the shift distributions used in these weeks of all filling lines. These six weeks are determined such that we do not have weeks with vacation days or weeks in which overtime did take place. Appendix G displays these shift distributions for all filling lines.
- *OEE Rate.* Company X does not store failure data for the filling lines or for any other machine, therefore we need to find another way in which we can incorporate disruptions

in the production process. We determined a so called OEE Rate per filling line per week. Table 4-2 displays this OEE Rate. We calculate this OEE Rate by first dividing the total number of filling hours and setup times by the number of shifts that the line was active in that week. Then, we divide this number by the total number of hours available in a shift to get the disruption fraction. We analyse this data per filling line and found that we can use a normal distribution. We calculate the mean, the standard deviation, the minimum, and the maximum for every filling line. TPS is capable to include the minimum and the maximum while using a normal distribution. This allows us to make sure that we do not get unreasonable outliers in production times. In consultation with the project leader of the new filling line, we determined that the OEE Rate for the new filling line is not equal to the OEE Rate of the SFVision5L. For the situation with the new filling line, we use a discrete empirical distribution, since data for creating a theoretical distribution is not available. In consultation with the production manager and the planning and logistics manager we determine the following discrete empirical distribution. In 50% of the batches, the filling line produces as described in Chapter 2. In 10% of the batches, the filling line produces 10% faster, while in 20% of the batches the production line produces the batch 10% slower. In 10% of the batches, the production line produces 20% slower. Finally, in 10% of the batches, the production line produces 30% slower.

	SFVision5L	R'berg10LGVP	Safepack	Kugler	Breitner	Multivuller	ABL	Pouch	Flexlijn	Alwid20L
Mean	0.84	0.99	0.89	0.76	0.76	0.91	0.64	0.97	0.72	0.95
Stdev	0.13	0.14	0.14	0.16	0.16	0.10	0.16	0.11	0.17	0.13
Min	0.67	0.60	0.58	0.41	0.55	0.67	0.39	0.70	0.41	0.84
Max	1.12	1.25	1.13	1.04	1.10	1.06	0.92	1.22	1.04	1.31

Table 4-2 OEE Rate per Filling Line

- *Processing times.* For the filling times, we use the data used by FS. FS makes use of a so called, demonstrated run rate. The demonstrated run rate is the number of containers that the filling lines can process in an hour. This demonstrated run rate comes from the operators at the filling line. For this research, we converted this demonstrated run rate in the production time for one pallet. We make a distinction between the last pallet and the others, since the last pallet is a, so called, 'restpallet'. This pallet has a shorter processing time than the other pallets, since less containers need filling for this last pallet. Finally, we divide the time needed for processing a pallet by the OEE Rate to make sure that we incorporate disruptions.
- *Setups.* There are two kinds of setups. First, there are regular setups when the filling line does not have to change the filling line to another setup. A regular setup takes 30 minutes, within this setup time the filling line is cleaned and prepared for the next batch. The new filling line has a cleaning time of 20 minutes. This setup time is verified with the operators at the filling lines. Second, there are moments when the filling line needs a setup from one type of container to another. If the filling line needs to switch to a different container for a filling line, we need more setup time. Appendix E displays these setup times. For the new filling line we use one setup per week as stated in Chapter 2.
- *Line capacities.* We know that a pallet is 1.2 meters wide; therefore, we calculate the line capacities by taking the length of a conveyor belt and divide this length by 1.2. With this logic, we see that at each filling line a maximum of two stacked pallets can be stored and that the filling line can still fill the third pallet.

Transport

When a pallet is fully stacked, the AGV is called to transport the pallet to the warehouse. This needs some input data. First, we determine the distances between the various filling lines by consulting the CAD-drawing of the production plant of Company X. Second, we determine the time to load and unload a pallet by the AGV from or on the conveyor belt by clocking the time. To load a pallet or to unload a pallet takes 12 seconds. Third, we determine the speed of the AGV also by clocking the AGV at various moments in time. The speed of the AGV is 0.8 meters per second.

Finished Goods Warehouse

After the pallet is stacked with the right number of boxes and the AGV brought the pallet to the conveyor belt, the pallet enters the FGW. Now we explain the input data. We need to incorporate this data, since the various objects can all affect the output of the filling lines.

- *Top foil.* After 200 pallets have entered the warehouse, the top foil needs to be replenished. According to operators, this takes on average 10 minutes. To put a top foil on the pallet takes half a minute.
- *Pallet wrapper.* After 75 pallets have entered the warehouse, the wrap foil needs to be replenished. This takes on average 5 minutes. Sometimes it takes somewhat longer since the operators are busy with other activities. To wrap a pallet takes 38 seconds.
- *Transport schedule.* Currently, there are 19 truck deliveries per day. These trucks transport a maximum of 33 pallets to the EDCs. Some trucks are cancelled when the number of pallets in the warehouse is at a low level. We do not consider the destination of a specific pallet, since the make planner determines the destination of a batch after making the week plan. The pallet is positioned in one of the LBs and waits until a truck is available to transport the content of this LB to an EDC. Since it is not always the case that we transfer 33 pallets to the EDC due to tonnage restrictions, we take a uniform distribution between 31 and 33 pallets. We determined this uniform distribution by analysing data of every week of 2018.
- *Loading a truck.* For loading a truck, we consulted the warehouse employees. On average, loading a truck, takes 45 minutes.
- *Handling a pallet.* For handling one pallet, the warehouse employees indicated that it takes on average 2 minutes to get a pallet and store it in a designated loading bay. Within this time also unforeseen circumstances are considered.
- *'Restpallet'.* The warehouse employees need to wrap the 'restpallet' themselves. This takes according to the warehouse employees, on average, 6 minutes.
- *Cancelling a truck.* When the number of pallets in the FGW is below 80, we cancel the truck. We assume that no truck can be fully loaded, since the pallets are divided over multiple LBs.
- *Extra Truck.* Due to safety reasons, the warehouse cannot contain more than 504 pallets. If a truck is not scheduled at some moment, but the number of pallets in the warehouse is larger than 350, we make sure that an extra truck is arranged. When the warehouse contains more than 350 pallets, the warehouse is getting crowded and this is not desirable.
- *Starting quantity.* We set the starting quantity of the warehouse in the first week at 200 pallets, since this is, according to the warehouse employees, the average number of pallets in the warehouse at a Sunday night.

4.1.3 Output after Running an Experiment

During and after running an experiment, we collect data. First, we want to analyse the consequences of the new filling line on the internal supply chain. With the generated data we identify the bottleneck. As Chapter 3 explained, the bottleneck disrupts the smooth flow of processes. To resolve this bottleneck, we should find ways to exploit this bottleneck. So, the output that we also want is focused on getting knowledge on the impact of a future state, such that we see if Company X is able to reach the targets. Concluding, the KPIs in Table 4-3 are collected for analysing the consequences and the performance of a future state. The KPIs for the filling department are first generated for the SFVision and second for all other filling lines combined. In this research, we only show the implications for the FGW of an experiment. So, we do not let allow the system to be influenced by the FGW. We know that by adding FTEs or truck transports the FGW gets spare capacity and hereby the FGW can meet the supply of the filling department. The data is, in addition to answering the research questions, used to verify and validate our simulation model.

KPI	Description
General	
1. Total Revenues	1. The production plant in Location X is selling its product to the EPC for €233 per ton. We show per future state the revenues that are generated per week.
2. Profit	2. The profit is used to analyse the payback period of a future state. The profit is calculated by subtracting the total revenues by the total costs. The total costs are calculated by multiplying the average tonnage per week by €219. This amount is the target costs per produced ton. According to the Production Manager, this amount remains equal with an increase in tonnage.
Mixing	
1. Utilization	1. The utilization shows, on average over all RKs, the percentage in which the RKs are mixing a batch or cleaning the RKs compared to the total time available for mixing. This gives an indication if the RKs still have spare capacity or that we need an extra RK.
2. Number of Orders	2. We calculate at the end of every shift how many orders are finished at the mixing department.
3. Variance	3. The variance shows us the spread of the number of orders that are mixed in a shift. When the variance is high, then the workload is not evenly distributed over the weeks.
Filling Line (SFVision – Others)	
1. KG/Hour	1. At Company X the kilograms per working hour is a KPI often used to show the performance of a filling line over a longer period. The kilograms per hour is calculated as the total number of kilograms produced in a week, divided by the number of hours in which the filling line was active. In our research we use this KPI to analyse the impact of a future state.
2. Tonnage per Week	2. This variable shows the number of tonnages that are produced for the SFVision and the other filling lines. With this variable, we analyse if the model produces 'enough' number of tonnages.
3. Revenues	3. For the SFVision and the other filling lines, we calculate the revenues that a future state generates over a 5-week period.
4. WOP	4. The WOP is the total time that a filling line must wait for a batch to arrive over a 5-week period. If the 'WOP' is high, we would expect that mixing is not capable to mix enough batches due to capacity related problems or an inadequate routing.

Transport	
1. Time Blocked	1. This variable shows for how long the filling line is blocked, because the pallets cannot be moved any further in the production process.
Finished Goods Warehouse	
1. Cancelled Trucks	1. This variable shows how many trucks are cancelled during the run length.
2. Extra Trucks	2. This variable shows how often it is required to arrange extra trucks, due to peak loads at the warehouse.
3. Number of shifts above 7 hours	3. This variable shows in how many shifts the FTEs had a workload over 7 hours.
4. Average number of incoming pallets	4. This variable shows, on average, how much pallets arrive at the FGW during a shift. The higher this number, the more pallets arrive at the FGW.

Table 4-3 Output after Running an Experiment

4.1.4 Scope and Level of Detail

In Chapter 1 we already narrowed down our project scope. As said, the simulation model does not cover every aspect of the production process of Company X. To come to adequate solutions to the research questions, the level of detail is not more extensive than needed.

4.1.4.1 Scope

In consultation with the company supervisor we determined the following scope for the simulation model. We look at the production process, so the transport of raw materials to the departments is not considered. The Support Team is subordinate to the mixing and filling department. Nowadays, the Support Team delivers the materials JIT to mixing and the filling lines. In the situation with the new filling line and with the current product portfolio, this remains the same. The only thing that changes is the intensity of orders that needs to be delivered to the filling lines if the new filling line is up and running. We choose to disregard the Support Team. Second, we model the filling line as simple as possible. The steps that are normally taken from filling a container until placing a box with some containers on a pallet are excluded in our simulation model. These production steps could have an impact on the total output, since each of these production steps could break down. Since we use the OEE Rate, we incorporate the failures in another way. Third, the batches, that were normally processed on the Rauenberg 10L, are in the future situation divided over the SFVision and the Alwid20L filling lines. For our research, we exclude the processing of 10L batches on the Alwid20L, since Company X momentarily does not know what kind of batches are processed on this filling line. Company X estimates that only a few SKUs are filled in the future on the Alwid20L filling line. So, we make sure that all batches that are filled in 10L containers are filled on the SFVision.

4.1.4.2 Level of Detail

According to Law (2015), choosing the level of detail of the model is an art and should depend on the following: project objectives, performance measures, data availability, credibility concerns, computer constraints, opinions of SMEs, and time and money constraints. This section explains the simplifications and the assumptions that we make.

General

- *Workforce.* We do not model the workforce in the simulation model. For some aspects of the production process it may be needed to get some information on the utilization

of the workforce. We obtain this data by counting the number of actions needed in a shift. Later, we divide the total amount of production time by the number of FTEs available in the shift, such that we can still analyse what the utilization of these FTEs is. For the mixing department it is not feasible to determine the utilization, since one mix operator operates multiple RKs.

- *Raw materials.* Since the Support Team is outside our scope, we do not model the transportation of raw materials to the mixing or filling departments. We assume that there are enough raw materials available for the production process. This simplification is made, since the arrival of raw materials is demand oriented and highly fluctuates between weeks. As explained, we do incorporate the delivery of cans to the new filling line, since this is a potential bottleneck.

Mixing

- *Specifications of a batch.* To produce batches at the mixing department it is important to consider the specifications of the orders. As said in Chapter 2, there are different types of batches to distinguish. These batches cannot be processed on all RKs; therefore, in our simulation model we incorporate some specifications. The specifications we incorporate are: Hypo, RK104, Fill Only, and Acid. If a batch does not have one of these specifications, a zero is given as attribute. When the batch has specification Fill Only, we set the mix time to 0 and these batches will directly be moved to the filling line, since these batches are mixed elsewhere.

- *RKs.* Not all RKs are connected to all Raw Material Kettles. We make the simplification to not consider the raw materials of a batch, since it would otherwise be infeasible to create an acceptable list of orders. With the current list of orders, we can always start a batch, provided that the specifications of the batch are correct, which is also the case in reality. Second, we make the simplification that a utilization of 100% for a RK is feasible.

- *cGMP mixing process.* We do not simulate the cGMP mixing process, since there is one RK dedicated to this filling line. From now on, we exclude RK106, since this RK is dedicated to the cGMP orders. Mixing of these orders is not influenced by the new filling line. We only simulate the impact of the cGMP filling line on the transport department and FGW by analysing the number of pallets produced when the filling line is up and running.

- *Bulk orders.* The bulk orders are important to the mixing department, but it is not important to the other departments. So, when the bulk orders are mixed, these orders are pumped into a designated BK. They remain in the BK for a specified number of minutes, to simulate the pumping out process. This time is specified by the FS department.

- *'Weekend overstaan' batches.* In our simulation model we exclude the 'Weekend overstaan' specification for particular batches. We make this simplification, because in the simulation model there are always orders in a BK on Friday evening. These orders stay in the BK during the weekend and are filled on Monday. So, with this reasoning there are 'Weekend overstaan' batches, but these could be any kind of batches.

Filling

- *Output.* We model the output of the filling lines as pallets leaving the filling line containing the containers.

- *Prio lines.* Usually, two filling lines are, during a week, prio lines. These filling lines can be scheduled for 24 hours a day, while other filling lines are scheduled for 22 hours a day to incorporate breaks of operators. Since it is not possible to determine the prio lines for a specific situation, we do not take prio lines into account.
- *Products.* We exclude the rejection of products in our simulation model. In the real situation, products may be rejected, but this has hardly an impact on the total number of pallets produced. Therefore, it has no impact on the filling time and on the conclusions.

Transport

For the transport department, we make some simplifications. The pallet arrives at a buffer and this is a signal that a pallet is available to be transported to the warehouse. If there are multiple pallets available for transportation, the AGV chooses the first arrived pallet to transport. Also, the two AGVs on the tracks are never down, since no data on downtimes are available.

Finished Goods Warehouse

For the FGW, we make some simplifications. To transport the pallets to the EDC, we used the current transport schedule. Every half an hour a check is performed to see if a truck is available for transportation. If this is the case, a specified number of pallets leaves the simulation. For our simulation model it does not matter to what EDC the pallet goes to, because it does not deliver any extra value to the results of a simulation run.

4.1.5 Logical Flowcharts

In this section, we explain the most important decision processes per department in words and in flowcharts. The methods used in the model make sure that the batches move through the system in the right manner. So, the logic flowcharts form the heart of our simulation.

Mixing

Order Buffer Check. Figure 4-2 displays the flowchart of this method. In this method we prioritize the filling lines on basis of the Total Filling Time (TFT). The TFT is the total filling time of all batches that are at some point at some stage in the production process. On basis of this TFT we prioritize the filling lines and we sort the table with the filling lines on basis of the lowest TFT. By determining the TFT, we make sure that the most desired batch is started up as is also done in reality. The filling line with the lowest TFT is the filling line that first comes to a standstill. We calculate the TFT for a filling line as follows:

$$Total\ Filling\ Time = Filling\ Time\ Of\ Batches\ In\ RK +$$
$$Filling\ Time\ Of\ Batches\ In\ BK + RemainingProcessingTimeAtFillingLine$$

If the filling line is, at the moment, not active, then we add the time until the filling line becomes active to the TFT. When the TFT is higher than the time until the filling line becomes inactive, when the filling line is active, we add the time that the filling line is closed to the TFT. In reality only batches are started that are required in a short period of time such that the time in the BKs is minimal, therefore we make sure that we only start batches when we are certain that the batch can directly be transferred to a BK and filled in a short period of time.
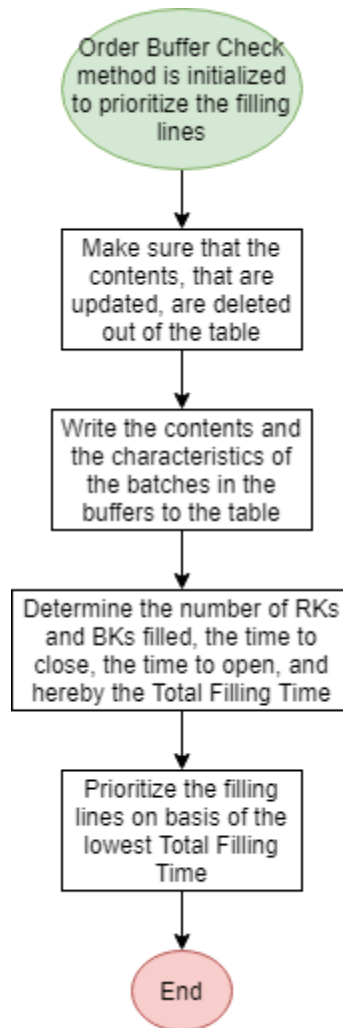
Figure 4-2 Method: Order Buffer Check

Ask New Product. Figure 4-3 displays the flowchart of this method. This method is executed after a RK is cleaned and makes sure that a new batch is called from the list with orders. Before executing this method, the *Order Buffer Check* method is executed. As can be seen in the figure, we check if we can start the batch. We exclude the specific criteria for clarity, but this check corresponds with the way in which the mixing department is currently starting batches, as explained in Chapter 2. In short, we first look at the filling line that has the smallest TFT. For this filling line we try to find an order out of the production plan that suits the RK. We only analyse the first 20 orders to make sure that the computational time stays reasonable. Also, when we do not find a suitable batch out of 20 batches, it is likely that there is no batch available in the production plan that will suit. If such an order cannot be found out of 20 orders in the list of orders, we look at the next filling line in the list until we find an order that suits the RK or until we analysed 5 filling lines. We only analyse 5 filling lines to make sure that we do not start a batch for a filling line that has no priority at all. This could happen when for example the time until the line is active again is taken into consideration when calculating the TFT.
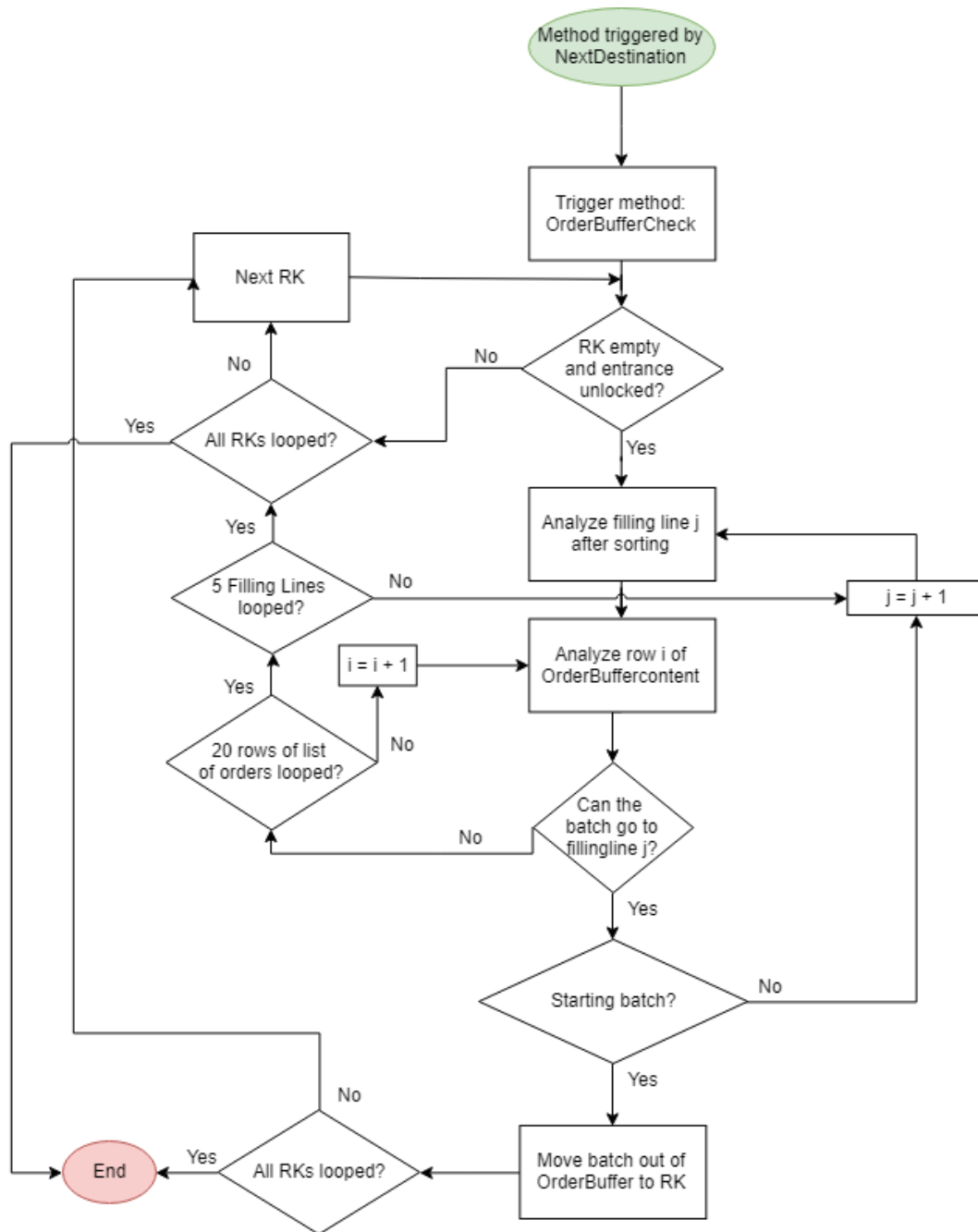
Figure 4-3 Method: Ask New Product

Next Destination. Figure 4-4 displays the flowchart of this method. This method makes sure that after a batch is mixed, the batch is moved to a BK. Besides, the method also considers the other RKs to make sure that batches that could not be sent to a BK at the time they were finished, due to unavailability of a BK, are also sent to their designated BKs. To make sure that a batch does not keeps a RK unnecessary occupied, we also run this method after a BK becomes available. Finally, the method makes sure that a new batch is started at the RK, after the RK is cleaned, by calling the previous explained method: *Ask New Product.*
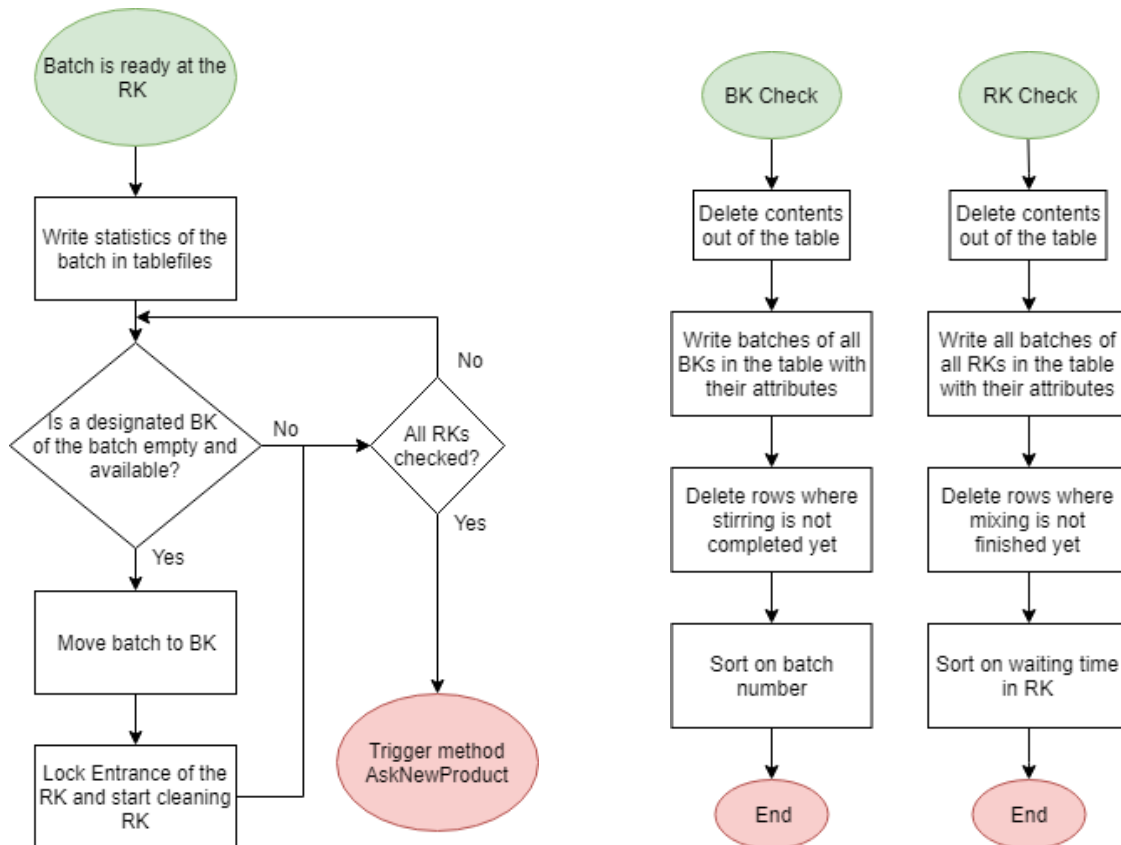
Figure 4-4 Methods: Next Destination, RK Check, and BK Check

RK Check/BK Check. Figure 4-4 also displays the flowchart of these methods. These methods are called while executing the *Next Destination* and *Check Exit Filling Line* methods. It makes sure that the model knows which batches are available at a RK or a BK. This makes sure that the model is not sending batches that still have some processing time to the next stage.

Filling

Check Exit Filling Line. Figure 4-5 displays the flowchart of this method. In this method we check if the last pallet is processed. If this is the case, we make sure that the filling line is cleaned and, if available, a new batch is pulled from a BK. If the last pallet has not been processed, data is written to tables such that we can analyse the performance of the filling lines.
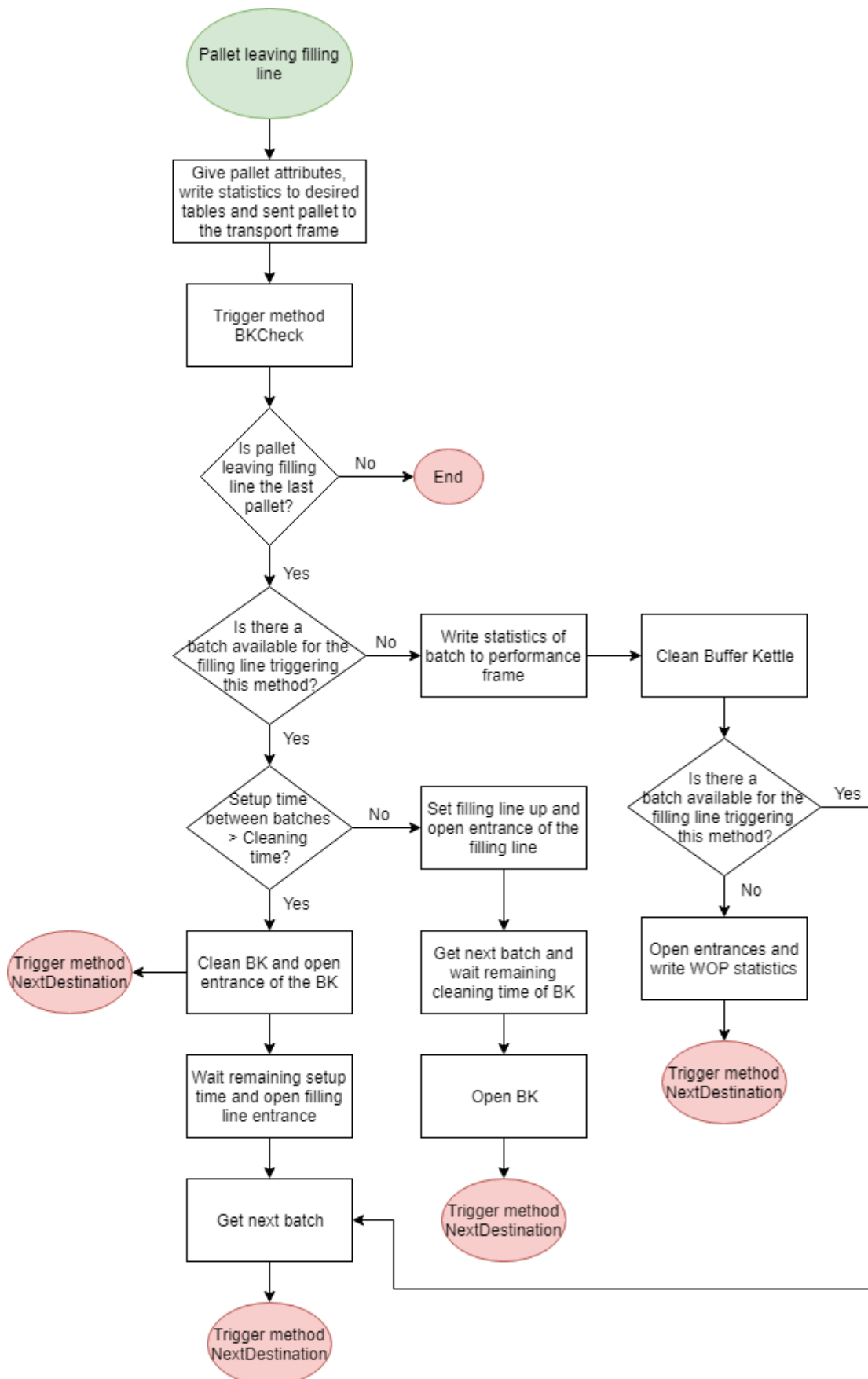
Figure 4-5 Method: Check Exit Filling Line

Transport

Arrival of Pallet. Figure 4-6 displays the flowchart of this method on the left. This method is triggered when a pallet enters the buffer of a specific filling line in the transport frame. This method makes sure that the AGV knows that the pallet is arrived at a buffer.

Sensor Trigger. Figure 4-6 also displays the flowchart of this method on the right. This method is triggered when the AGV has contact with a sensor. The sensor is located on the track on which the AGV moves. When the location of the sensor is the destination of the AGV, the AGV either loads or unloads a pallet to or from a buffer. If the pallet is unloaded at the destination location it looks in the content list to verify if there is a pallet that needs transportation.
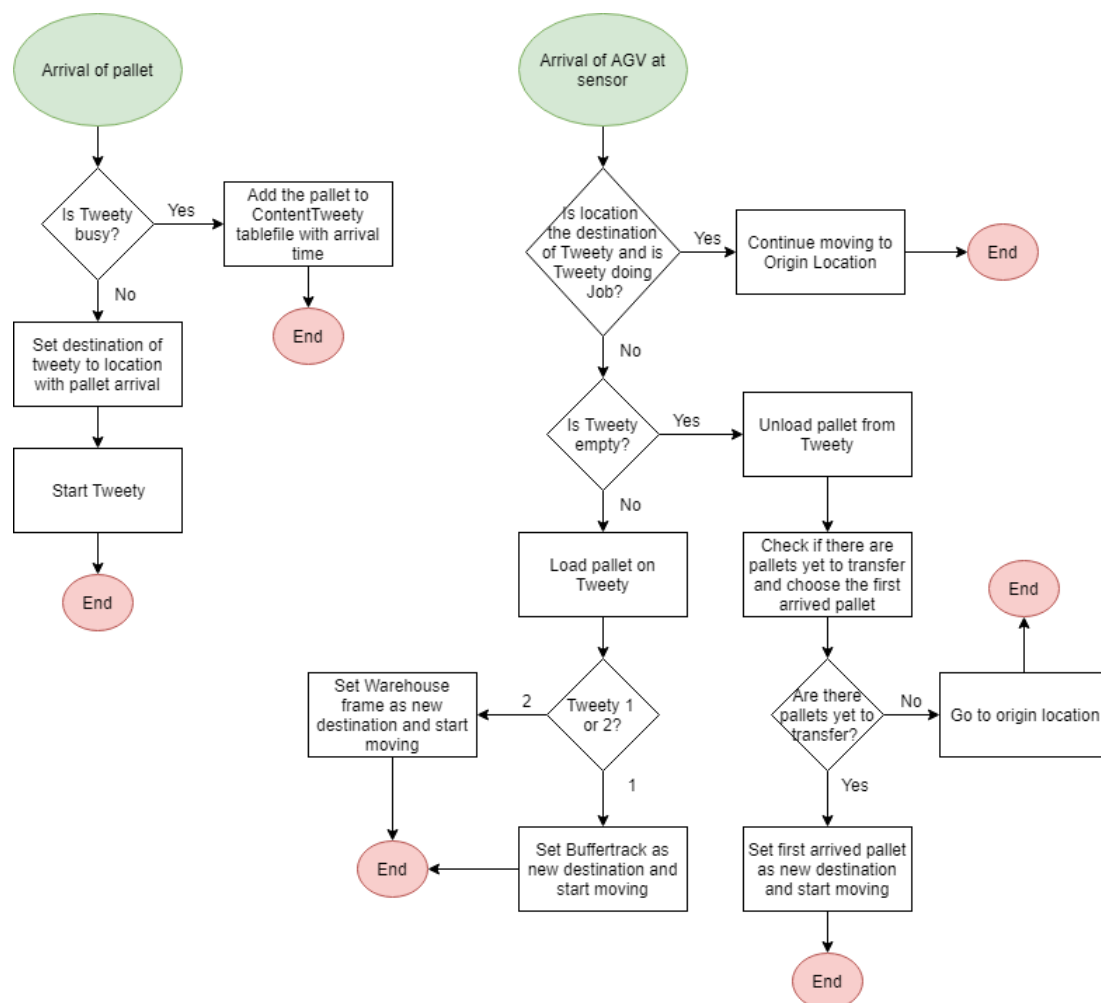
Figure 4-6 Methods at Transport Frame

Finished Goods Warehouse

Generating Transport. Figure 4-7 displays the flowchart of this method. This method is called by a generator every half an hour. It checks if there is a transport scheduled on basis of the fixed transport schedule. If this is the case and the FGW contains more than 80 pallets, the transport is executed and a random number between 31 and 33 is taken via a uniform distribution to transport several pallets to an EDC. If the FGW contains less than 80 pallets, we cancel a truck transport, since no truck can be fully loaded. In this situation there are multiple pallets divided over multiple loading bays and we cannot fully load a truck. If there are

more than 330 pallets in the warehouse and no truck transport is scheduled, we schedule an extra truck transport.
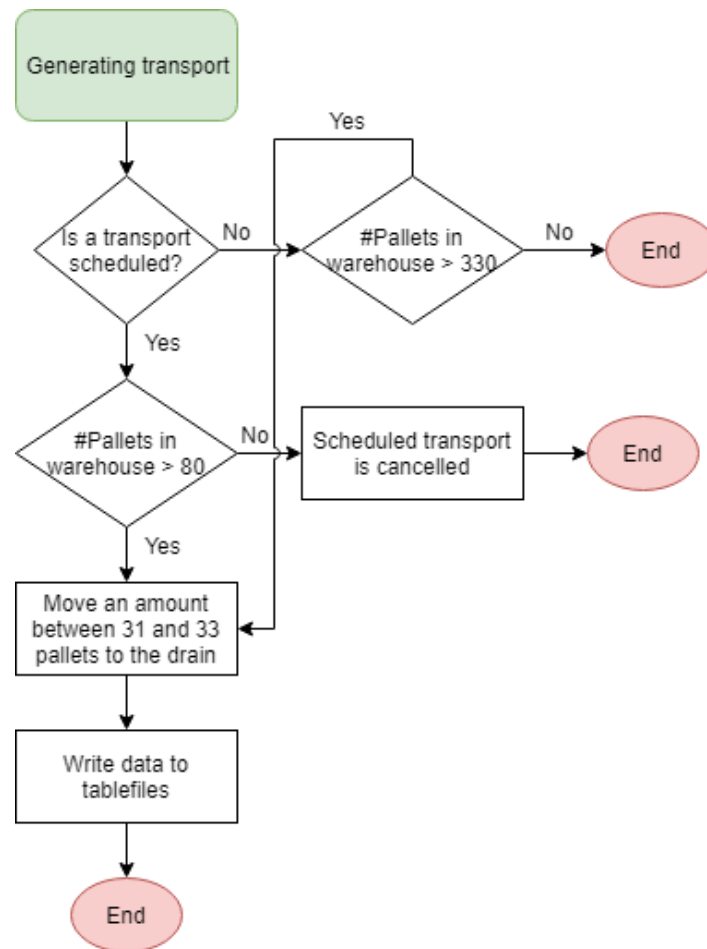
Figure 4-7 Method: Generating Transport

4.2 Experimental Design

By using simulation, we evaluate the effect of changes made to the production processes of Company X. With the simulation model we want to answer, at first, the research question: "*What is the impact of the new filling line on the internal supply chain and how can Company X optimally use this new filling line, considering the available resources?*". Second, we want to answer the research question: "*How can we identify and elevate the bottleneck that arise, after growth in tonnage production on the new filling line, considering the internal supply chain?*". In this section we address the second question of research question 3: "*What is the experimental design used in this simulation study?*".

Table 4-4 displays our experimental design. We make a distinction between fixed factors, growth scenarios, and interventions. Now, we describe these concepts in more detail. First, the fixed factors. In the simulation model, we use the same list of orders for a replication. The list of orders in replication x in experiment y are the same as the orders in replication x in experiment y + 1. The list of orders in replication x differ from the list of orders in replication x + 1. Also, the shift distributions for all filling lines are constantly the same, with exception for the SFVision filling line. Finally, the OEE Rate, or the availability percentage, is fixed for all filling lines over all replications and experiments. These fixed factors make sure that we continuously compare the same system.

Second, for the growth scenarios we run and evaluate multiple future states to determine the consequences of the new filling line and to make sure that Company X could eventually reach the growth scenario. First, we want to analyse how Company X can reach the 700 tons. Second, we analyse how Company X can reach multiple growth scenario. We describe the growth scenarios that Company X would like to reach later in more detail.

Finally, before running future states, we discuss the interventions that we use to reach the growth scenario. Table 4-4 displays the interventions that we use. We create these interventions with the Manager Planning and Logistics. To reach a growth scenario, we use the what-if analysis as approach by analysing multiple interesting future states in which we exploit the bottleneck. We use one or more interventions in a future state. We determine the specific future states after we know the impact of the new filling line and thus when we find the bottleneck. First, we determine the impact of the new filling line to find out if the new filling line can produce, with the current resources, the amount of tonnages for which it is bought. If this is not the case, then we would like to know what department dictates the throughput.

We determine the impact of the new filling line by analysing multiple shift distributions. By analysing multiple shift distributions, we give FS recommendations on the way in which they should schedule a week, such that they can make sure that the internal supply chain is aligned, and flow is realized. We analyse one shift distribution for 5 different weeks of production, such that we make sure that we give recommendations that are applicable for multiple weeks of production. For this research we decide to make use of predefined shift distributions for the new filling line. It is infeasible to analyse all combinations of shifts distributions. So, we determine these distributions by hand. Appendix H displays all shift distributions for different number of shifts for the new filling line. We would like to know the impact of the new filling line on the production process of Company X, so the optimal shift distribution is not interesting to answer the research question. We create the shift distributions in collaboration with the Manager Planning and Logistics and these are created in such a way that we analyse multiple interesting situations that are also feasible in real life. The situations that we analyse are for example an even spread over the week or an extreme situation in which 8 shifts are active in the beginning or at the end of the week to find out if there are differences between shift distributions. In addition to the shift distributions, we use the following interventions:

- *Alwid20L Shift Distribution.* We vary the shift distributions for the Alwid20L. FS and the Manager Planning and Logistics presume that it is not optimal to schedule this filling line and the new filling line simultaneously for every shift. The reason for this presumption is the high production speed that can be realized on both lines.
- *Broken shifts.* The Manager Planning and Logistics is interested to find out if it is desired to break shifts in half. For this situation, we only use the new filling line and the Alwid20L, due to the fast production speed. Using broken shifts means that an operator processes the first four hours on the SFVision and the last four hours on the Alwid20L.
- *Extra RK.* In consultation with the Specialist Processing, we determined that there is the possibility at Company X to add a maximum of 2 10 m^3 RKs at Jupiter.
- *Extra BK.* In consultation with the Specialist Processing, we determined that there is the possibility at Company X to add a maximum of two BKs for the new filling line by sharing the BKs of the GVP filling with the new filling line.
- *Starting a new batch.* The logic for when a new batch starts at mixing can be altered. Chapter 2 displays the way in which the mixing department currently start batches.

Experimental Design	
Fixed Factors	**Short Description**
1. Orders	1. The orders, with their characteristics, used in the simulation is for every experiment in all future states the same. The list of orders used differ per replication.
2. Shift distribution	2. The shift distribution for the other filling lines are fixed and are in tune with the shift distributions of 2018.
3. OEE Rate	3. The calculated OEE Rate over data from 2018 remains the same as explained before.
Growth Scenario	**Short Description**
1. Current situation	1. We evaluate the current situation, where the number of tonnages for the new filling line is 700 tons a week.
2. Future situation	2. We evaluate the future situation, where the number of tonnages required for the new filling line increases.
Intervention	**Short Description**
1. Shift distribution	1. We evaluate multiple shift distributions for the new filling line where we also vary the number of shifts between 8 and 15.
2. Alwid20L shift distribution	2. We evaluate the impact of changing the shift distribution of the SFVision to the Alwid20L shift distribution.
3. Broken shifts	3. We evaluate the system by using broken shifts for the new filling line and the Alwid20L filling line.
4. Extra BKs	4. We evaluate the possibility to add a maximum of 2 BKs for the new filling line.
5. Extra RKs	5. We evaluate the possibility to add a maximum of 2 10 m^3 RKs at Jupiter.
6. Starting a new batch	6. We evaluate multiple ways in which batches are started at mixing.

Table 4-4 Experimental Design

4.3 Model Validation and Verification

In this section we address the third question of research question 3: *"Is the DES model credible?".* This means that we should make sure that the simulation model coincides with reality and the conceptual model on paper. This is important in our research, since we want a model that presents reality well enough. Figure 4-8 visualizes this logic. The goal is to construct a credible model. This means that the stakeholders of this research believe that the model displays reality well enough to achieve the goals stated in Chapter 1.
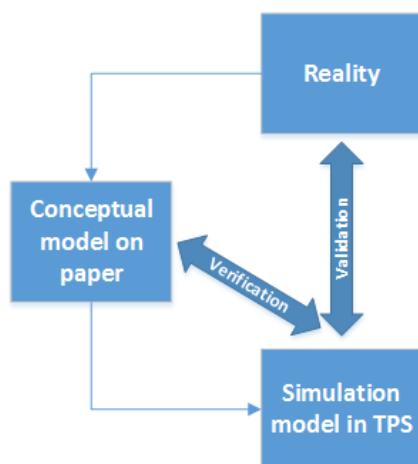
Figure 4-8 Model Verification and Validation (Mes, 2018)

4.3.1 Verification

Verification is a concept that has multiple techniques that can be used to debug the computer program of a simulation model. Law (2015) gives eight techniques that are useful. We executed multiple techniques while simulating. First, we write and debug the computer program in modules, such that errors can easily be found. Debugging is the process of identifying and removing errors from computer hardware or software. We stepped through the code line by line to verify if the code does what it is supposed to do. Second, we use the structured walk-through of the program technique. This means that we use various persons who review the simulation model, since we can get, according to Law (2015) into a mental rut and, thus, may not be a good critic. Third, we use animation. We observe the system as it evolves over time by looking at the animations of the model. Finally, we perform preliminary runs to check whether the output is plausible. Using these methods, we remove the errors from the model, and we were able to conclude that the model is correct.

4.3.2 Validation

Since we verified the model, we validate the output of the simulation model with data out of 2018. We simulate 6 weeks of production. After simulating these 6 weeks, we gather the output of some KPIs and validate these numbers with the data that we expect. There are multiple KPIs that we validate. If these numbers coincide with the production history, we assume that we have a valid simulation model of the production system. We discuss the results briefly.

Figure 4-9 displays the progress of the number of pallets in store over a six-week period. After consulting the relevant operators, we conclude that this kind of trend is accurate. We also validate the simulation model by analysing the number of trucks that it cancels. In 2018, over the six weeks of which we used the shift distribution, 26 trucks are cancelled. Our simulation model cancels 28 trucks over a six-week period. Therefore, we conclude that the output of the model meets the real output accurately enough for the FGW.

Number In Store
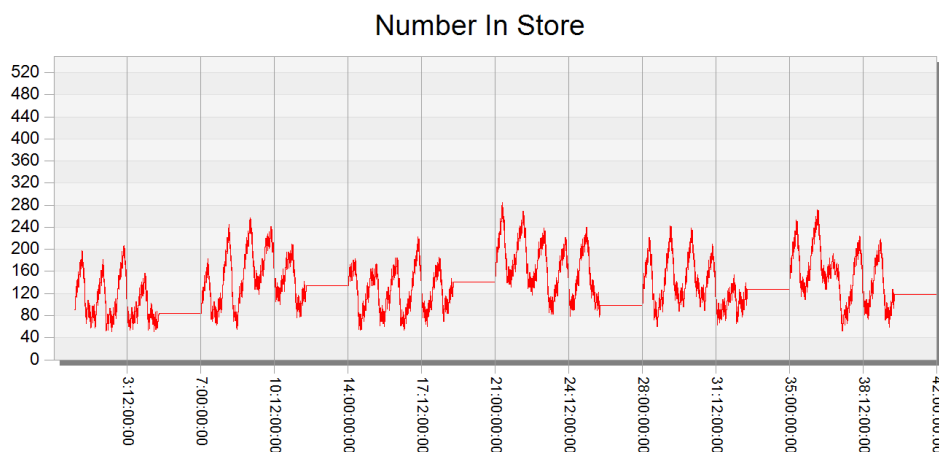
Figure 4-9 Inventory Trend in FGW over 6 Weeks

Table 4-5 displays the number of tonnages over six weeks per filling line. We see some variation between the filling lines. For example, the SFVision5L has produced more tonnage than expected, although when we look at the percentage, this is only 2.6%. In total, we expect 10,361,313 kg of production over six weeks. Our model has a total output of 10,368,134 kg. The difference of our model in comparison with the total output is in total 6,821 kg or 0.0007%. Therefore, we conclude that the production output of the model meets the real production output accurately enough.

Filling Line	SFVision5L	R'berg10L	GVP	Safepack	Kugler	Breitner	Multivuller	ABL	Pouch	Flexlijn	Alwid20L
Simulation model	1,981,659	1,498,684	1,357,792	566,422	876,589	892,681	169,488	735,676	184,844	2,104,299
Output 2018	1,931,532	1,530,528	1,382,418	607,244	836,361	889,819	179,723	740,684	190,170	2,072,834
Difference	50,127	-31,844	-24,626	-40,822	40,228	2,862	-10,235	-5,008	-5,326	31,465
Percentage of total	2.60%	-2.08%	-1.78%	-6.72%	4.81%	0.32%	-5.69%	-0.68%	-2.80%	1.52%

Table 4-5 Validation of Tonnage over 6 Weeks per Filling Line

Table 4-6 displays the average number of orders per week of the simulation model, after three replications, minus the number of orders per week that we would expect after analysing the data from 2018. We see little variation between the both situations. We take these results as our starting point, since the WOP is on average 16 hours over six weeks over all filling lines and thereby not much growth can be realized. So, the results that we get after analysing the impact of the new filling line should coincide with these values. When looking at KPIs such as Average Orders Mixed Per Week in Table 4-7, we also see little variation between the output of the simulation model and the output of 2018. Therefore, we conclude that the production output of the model meets the real production output accurately enough.

Difference	SFVision5L	Rauenberg10L	GVP	Safepack	Kugler	Breitner	Multivuller	ABL	Pouch	Flexlijn	Alwid20L
Week1	1.67	0.00	-0.67	-0.33	0.00	0.00	0.33	-0.67	0.00	1.67
Week2	-0.33	3.33	-0.33	0.33	0.67	-0.33	0.00	-1.33	-0.33	-1.33
Week3	-0.33	0.00	0.00	-1.67	2.00	-1.67	0.00	0.00	0.33	-0.33
Week4	0.33	1.33	0.00	-1.33	-2.00	-1.00	-0.33	0.33	-0.33	0.33
Week5	0.33	-2.67	-0.67	-0.67	-0.33	-0.33	0.67	-0.33	1.00	0.00
Week6	-1.33	-2.67	-0.67	0.33	0.33	-0.67	0.33	0.33	-1.33	-0.67
Total	0.33	-0.67	-2.33	-3.33	0.67	-4.00	1.00	-1.67	-0.67	-0.33

Table 4-6 Validation of Orders per Filling Line per Week

KPI	Output Simulation Model[1]	Output 2018[1]	Difference
Average orders per week	185	187	-2
Total orders	1110	1121	-10
Average orders mixed per day	36.97	37.4	-0.43
Average orders mixed per shift	12.3	12.5	-0.2
Maximum orders mixed per day	45	43[2]	2
Maximum orders mixed per shift	17	17[2]	0

Table 4-7 Validation of Orders on Basis of KPIs

Table 4-8 displays the number of pallets over six weeks per filling line. We see some variation between the filling lines. For example, the SFVision5L and the Alwid20L have produced more pallets than expected, although when we look at the percentage, this is only 1.7% and 1.1%. In total, we expect 17,199 pallets over six weeks. Our model has an output of 17,243 pallets. The difference of our model in comparison with the expected output is in total 44 pallets or 0.003%. Therefore, we conclude that the pallet output of the model meets the real pallet output accurately enough.

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[1] Without the production of cGMP orders
[2] According to multiple operators at the mixing department

Filling Line	SFVision5L	R'berg	Safepack	Kugler	Breitner	M'vuller	ABL	Pouch	F'lijn	20L	cGMP
Simulation model	2,451	2,110	2,037	867	1,200	2,189	292	1,511	534	3,802	245
Output 2018	2,409	2,146	2,074	877	1,167	2,186	302	1,478	555	3,760	245
Difference	42	-36	-37	-10	33	3	-10	33	-21	42	0
Percentage of total	1.7%	-1.7%	-1.8%	-1.1%	2.8%	0.1%	-3.3%	2.2%	-3.8%	1.1%	0%

Table 4-8 Validation of Pallets over 6 Weeks per Filling Line

4.3.3 Warmup Period, Replications, and Run Length

As explained in Chapter 3, there are various types of simulations regarding output analysis. A distinction can be made between a system where the performance depends on initial conditions and a system where the performance does not depend on initial conditions. The performance of our simulation model does not depend on the initial conditions, since we want to get the performance of the stead state behaviour. Another distinction can be made between terminating and non-terminating simulations. If a natural event specifies the end of a simulation run, we speak of a terminating simulation (Law, 2015, pp. 493-497). There is no natural event that specifies the end of a simulation run. So, we are dealing with a non-terminating simulation. Since we are dealing with a non-terminating simulation, we need to determine the run length.

Concluding, the type of our simulation output is non-terminating and steady state. With such a simulation model, a warmup, number of replications, and a run length needs to be determined. This means that initial output should be deleted, because observations from beginning of simulations depend on initial conditions and they are not representative for steady state behaviour. To determine the warmup period, we use the Welch's graphical method approach as described in Law (2015, pp. 511-520). Appendix F shows that the system is after 180 batches in steady state. Since, one week of production consists on average of 180 batches, we exclude the first of week of the simulation model.

We determine the number of replications by using the method described in Law (2015, pp. 503-506). We conclude that we need three replications. Appendix F describes the method and the conclusions in more detail. As run length, we take 6 weeks. Within this run length, we incorporate the warmup. We determined in consultation with the Manager Planning and Logistics this six-week period, since we want to analyse the impact for multiple weeks of production.

4.4 Conclusion

In this chapter we answered the following research question: *"What is the conceptual model of the production facility of Company X?".* We first determined the conceptual model by describing the general outline of the model, the input parameters used in the simulation model, the output parameters collected after running an experiment, the scope and level of detail of the simulation model, and finally, the process and logic flowcharts. These concepts determine our conceptual model. Second, we determined the experimental design by determining growth scenarios and interventions. The specific experimental design that we use is reliant on the specific growth scenario and the conclusions out of the previous future states. Third, we verified our simulation model by using four different techniques and we validated our simulation model by looking at the output of 2018 and our simulation model. Finally, we determined a warmup period of one week, three replications are needed per experiments, and we use a run length of six weeks. Now, we completed the simulation model design, and in the following chapter we present the results of the experimental design.

5 Results

This chapter provides an answer to the research questions: *"What are the results of the experiments conducted with the simulation model?"* and *"What should Company X do when considering growth in the number of tonnages produced per week on the new filling line?".* In Section 5.1 we address the impact of the new filling line on the internal supply chain. In Section 5.2 we explain the way in which the new filling line can be used optimally to reach 700 tons of production per week, considering the available resources. In Section 5.3 we analyse and explain the way in which Company X can reach multiple growth scenarios by analysing multiple future states. We conclude this chapter in Section 5.4.

5.1 Impact of the New Filling Line

First, we are interested in the consequences of the new filling line on the internal supply chain. We use the DES model that we validated and verified, while using the new filling line with its characteristics. The way in which we start up batches, as explained in Chapter 2, is not altered. We create the shift distribution for the new filling line on basis of the results of Chapter 2. We calculated that we need, in the most ideal case, 8 shifts a week to produce 700 tons. The distribution of these shifts over the week is varied such that we also get a good impact of multiple shift distributions and we analyse if the shift distribution of the new filling line has any impact at all on the total output. Table 5-1 displays the 10 experiments.

	Shift Number															
Exp	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Sum
1	X	X	X	X	X	X	X	X								8
2								X	X	X	X	X	X	X	X	8
3	X	X				X	X	X	X	X	X					8
4	X			X	X		X			X	X			X	X	8
5	X		X		X		X		X		X		X		X	8
6	X	X	X	X					X	X	X	X				8
7	X				X	X	X	X	X	X	X					8
8	X	X		X	X		X	X				X	X			8
9	X	X	X			X	X	X			X	X				8
10	X	X				X	X	X				X	X	X		8

Table 5-1 Experiments where we use 8 shifts out of 15 shifts in total

When running the simulation model, after incorporating the new filling line, we find some interesting results. Now, we present per department the results of the experiments to find the best shift distribution and the impact of the new filling line on the internal supply chain.

Mixing

Figure 5-1 displays the results of the 10 experiments. The variance in experiment 5 is the lowest over all experiments, which shows that the workload for the mixing employees is most levelled over the shifts. Previously, we had a Total WOP of 16 hours over all filling lines over 5 weeks. Now, we have a Total WOP of 4 days for experiment 5. Around 75% of this WOP comes from the new filling line, as can be seen in Figure 5-1. The WOP on the other filling line increases with only a small portion, since mixing is busy meeting demand of the new filling line. The average utilization over the most important RKs, RK101, RK102, RK103, RK104, RK110, and RK111, for experiment 5 is 92%. This utilization is already high. However, the model is always trying to start a batch after completion of another batch, so it still happens that batches are not started. According to the mix operators, the RKs are never down and can

always be used, if there are raw materials and mix operators available. We assumed in Chapter 4 that the raw materials and mix operators are available. So, the mixing department should be able to produce more orders with the current amount of resources. Besides, the utilization of RK107, the RK producing 5 m^3 batches, is 40%. The last RK who produces the Hypo batches, RK22, has an average utilization of 42%. We conclude that experiment 5 gives us the most levelled workload for the mixing department. Also, we see that the mixing department has a negative impact on the total output produced since not enough batches are available in time.
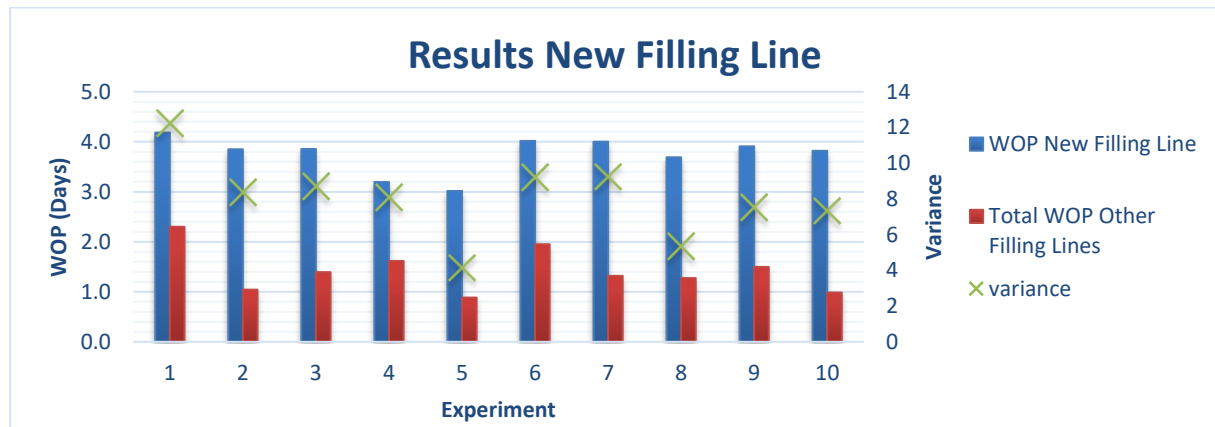
Figure 5-1 Results Mixing Department – over a five-week period

Filling

Table 5-2 displays the difference in orders between the simulation model and reality for all filling lines and the number of tonnage that the SFVision produces on average per week for the 10 experiments. Figure 5-2 displays the kilograms per hour and the revenues. We see that, with 8 shifts, we cannot process 700 tons of 5L and 10L batches, no matter what kind of shift distribution we use. For the other filling lines, when looking at the difference in orders over 5 weeks of production, we see a small impact, but these numbers correspond with the results out of our validation in Chapter 4. Experiment 5 results in the highest number of orders produced on the new filling line, the highest KG/Hour, and the highest revenues. Concluding, experiment 5, the experiment with the most even distribution gives us the best results, since mixing can prepare the BKs for the next active shift. By using this shift distribution, the total tonnage output per week has increased from 1,728.02 tons to 1,809.84 tons. As has been said, the production plant sells its products to the EPC for €233 per ton. The revenues per week increased from €402,628.66 to €421,693.54 by only incorporating the new filling line.

Experiment	SFVision	GVP	Safe-pack	Kugler	Breit-ner	Multi-vuller	ABL	Pouch	Flexlijn	Alwid 20L	Tonnage SFVision
1	-18.13	0.07	-0.27	-0.27	-0.20	-1.20	-0.13	-0.67	0.00	-0.07	503.71
2	-17.27	-0.07	-0.33	0.07	0.33	-0.80	0.07	-0.20	0.13	-0.33	512.56
3	-16.40	-0.33	-0.27	-0.20	0.13	-0.93	0.00	-0.27	0.33	-0.40	521.36
4	-14.60	-0.07	-0.33	-0.20	0.13	-0.93	0.20	-0.13	0.27	-0.27	539.07
5	-11.67	-0.47	-0.20	-0.13	0.27	-0.80	0.13	-0.13	0.07	-0.20	566.78
6	-17.20	-0.07	-0.40	-0.40	0.07	-1.00	0.07	-0.53	0.13	-0.07	513.41
7	-17.40	0.00	-0.13	-0.13	0.00	-0.93	0.00	0.00	0.33	-0.27	511.22
8	-14.93	-0.13	-0.27	0.27	0.13	-0.73	0.27	-0.20	0.33	-0.20	535.39
9	-16.20	0.07	-0.07	-0.07	-0.07	-0.73	0.20	-0.07	-0.07	-0.07	522.08
10	-15.93	-0.20	-0.20	-0.40	0.40	-0.67	0.00	-0.33	0.20	-0.07	525.81

Table 5-2 Results Filling – on average per week

Results KG/Hour and Revenues

Legend: KG/Hour SFVision; KG/Hour Remaining Filling Lines; Total Revenues

Bar labels (KG/Hour Remaining Filling Lines): 881, 890, 884, 888, 890, 887, 889, 895, 894, 891
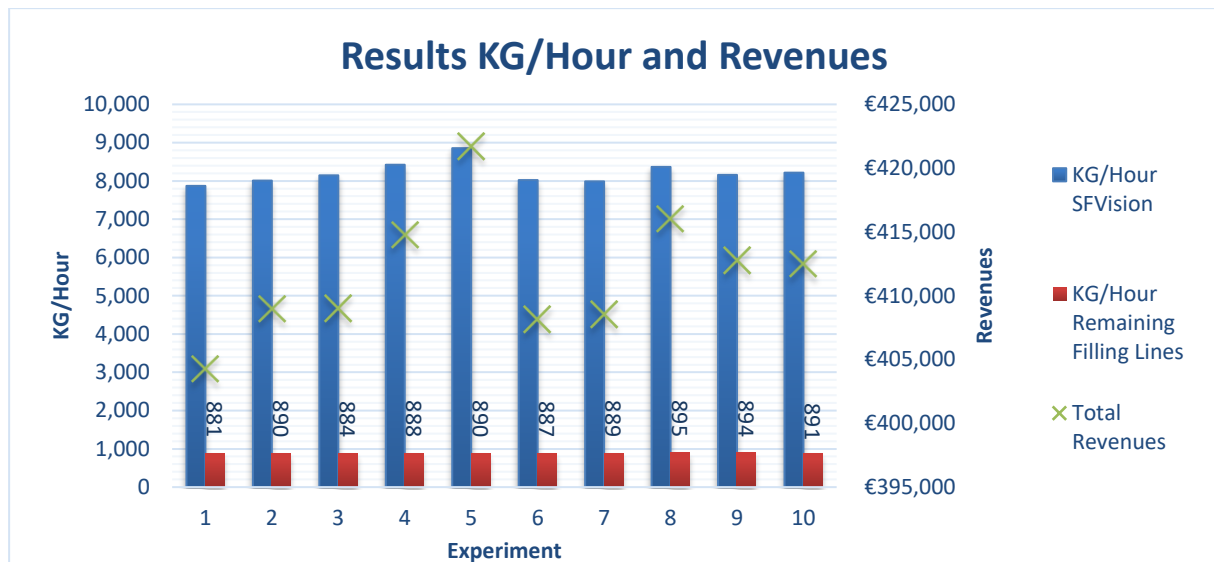
Figure 5-2 Results Filling Department – on average per week

Transport

As said before, after a pallet is fully stacked with the desired number of boxes, the AGV is called to bring the pallet to the warehouse. Since the pallet wrapper or the machine who puts the top foil on the pallet needs to be replenished after respectively 75 or 200 pallets, we see in Figure 5-3 that the filling lines are sometimes blocked. The figure displays the hours in which the filling lines are blocked over a five-week period. For the new filling line this is on average 2.2 hours, which is over a five-week period still low. However, no matter how small, the pallet wrapper and the top foil machine do dictate the overall system throughput. The number of hours in which the filling line is blocked increases when the KG/Hour increases. We conclude that Company X does not need any extra pallet wrappers or top foil machines, since the impact is low over a five-week period and there is still an improvement potential. We recommend Company X to faster replenish the top foil machine or the pallet wrapper, when the time in which the filling line is blocked increases.

Total Time during which Filling Line is Blocked

Legend: SFVision; Other Filling Lines
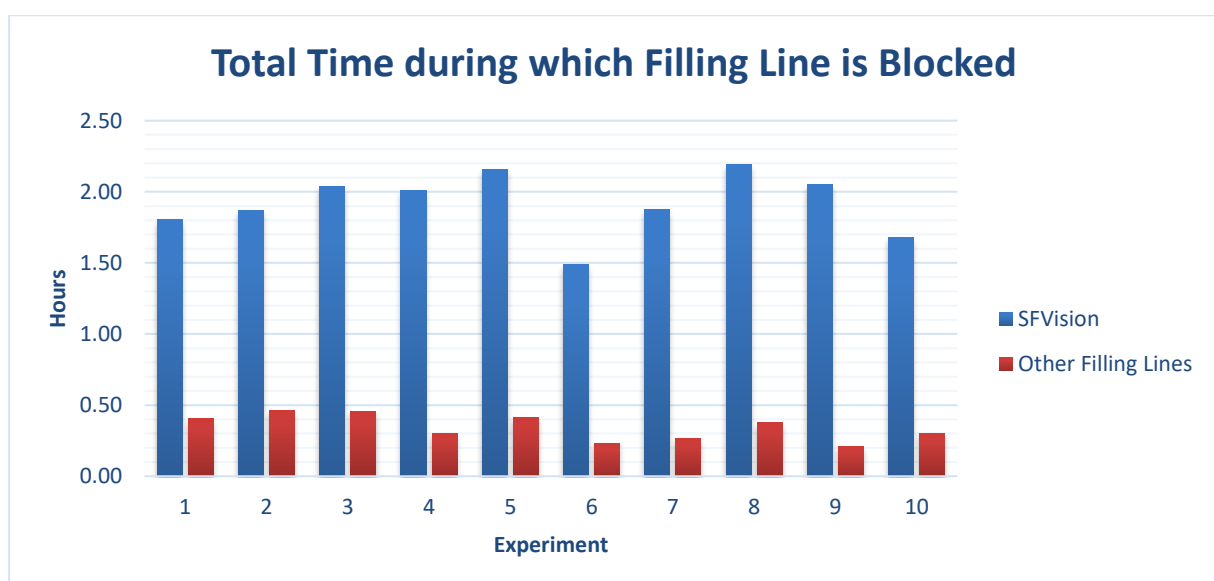
Figure 5-3 Results Transport Department – over a five-week period

Finished Goods Warehouse

As said before, in the FGW the pallets are temporarily stored until a truck transport is available to bring the pallets to the EDCs. Table 5-3 shows the results after simulating the 10 experiments for the FGW. We see that experiment 5 gives us the lowest number of cancelled trucks and the highest number of incoming pallets. The more trucks are cancelled and extra trucks are ordered, the higher the difference in workload per shift. Since no extra trucks are required and 16 trucks are cancelled, we conclude that experiment 5 gives us the most flow at the FGW. The number of shifts in which the FTEs at the FGW have a workload above the 7 hours varies between experiments. Table 16 in Appendix J displays the average number of FTEs and trucks necessary in a shift per experiment. Currently there are 4 trucks arranged for the night shift, 10 trucks for the morning shift, and 5 trucks for the afternoon shift. For every experiment we do not need extra FTEs or trucks in the morning or afternoon shift. When the SFVision is active in the night shift, the workload is almost always more than 7 hours. This is because in the night shift 2 FTEs are working instead of 3.

Experi-ment	Extra Trucks	Cancelled Trucks	Number of Shifts Above 7 Hours	Average Number of Incoming Pallets per Shift
1	6	36	18	189.17
2	6	35	14	191.43
3	3	26	19	191.43
4	0	22	26	193.31
5	0	16	19	196.84
6	1	28	17	190.56
7	3	25	19	191.83
8	0	21	13	193.77
9	0	22	14	193.11
10	0	24	18	192.47

Table 5-3 Results FGW – over a five-week period

Conclusion

After analysing 10 different shift distributions, each with their own characteristics, we see that Company X, with the current way of working, cannot reach the target of 700 tons a week on the new filling line. Also, we see that shift distribution 5, where the shifts are evenly distributed over the week, gives us the best results for all departments. So, in the remainder of this research we use an even distribution of shifts when analysing multiple future states and we recommend the FS department to schedule the new filling line as even as possible over the week. Next, the FGW needs extra capacity in terms of FTEs in the night shift when the new filling line is active to be able to process all pallets and trucks. Finally, we see spare capacity on the RKs, but it remains unsure if Company X can reach the goal of 700 tons or some growth scenarios with the current resources. Using these results, we conclude that the mixing department is the current bottleneck, since mixing dictates the overall system throughput. However, mixing still has spare capacity, since the average utilization is 92%. As explained in Chapter 3, there are two kind of bottlenecks, a Bottleneck Resource and a CCR. We conclude that we are dealing with a CCR, since all RKs have spare capacity and the WOP on the other filling lines is not increased. According to King (2009), we should make sure that the scheduling process are coordinated and synchronized to eliminate that portion of the limitation. In the next section we analyse multiple future states with one or more interventions to analyse when Company X can reach the target of 700 tons a week on the new filling line.

5.2   Using the New Filling Line Optimally

We want to create a production process in which the goal of 700 tons can be reached on the new filling line with 60 hours of production. This means that, at least, 70 orders should be mixed and filled at the new filling line in a week. In the previous section we concluded that this 700 tons with 60 hours of production per week is not feasible, with the current way in which orders are started at mixing. The internal supply chain is not aligned in such a way that the goal can be reached. In other words, we are dealing with a bottleneck at the mixing department. In this section we explain what Company X should do to reach the 700 tons of production per week by exploiting the bottleneck, considering the available resources. We refer to this scenario as Growth Scenario 1. After we find the most desired future state, we show the consequences of the future state for the FGW. So, we do not consider the FGW when determining the most desired future state, since the FGW can adapt to the other departments.

To reach the required output, we analyse multiple future states. We create these future states with the Manager Planning and Logistics. We know that we should unburden the mixing department, since mixing is not able to mix enough 5L and 10L batches with the current way in which orders are started and the current number of resources. For this growth scenario, we do not incorporate the use of extra RKs or extra shifts, since the filling line is bought for the current resources. Using the DES model, we want to answer the following what if questions:

1. What happens when we use broken shifts for the new filling line and the Alwid20L?
2. What happens when we adjust the Alwid20L shift distribution to the shift distribution of the new filling line?
3. What happens when we give the new filling line more priority at mixing?
4. What happens when we add the two BKs of the GVP filling line to the new filling line?

After the impact of these future states are known, we combine multiple approaches to find a positive interrelation. We generate an answer, by using the DES model, to the following what if questions:

5. What happens when we combine the broken shifts and the new routing approach?
6. What happens when we combine the two extra BKs with the new routing approach?
7. What happens when we combine the broken shifts and the two extra BKs?
8. What happens when we combine the broken shifts, the new routing, and the two extra BKs?

First, we give a description of the eight future states and the consequences of the future states for Company X. Second, we display the results of the future states. Finally, we describe the conclusions.

5.2.1   Future States
Future State 1

In the first future state, we use broken shifts. We would like to know if the new filling line can produce 700 tons a week when we combine the shifts of the new filling line with the shifts of the Alwid20L filling line. Table 3 in Appendix H displays the shift distributions used for this future state. We only use one shift distribution for the Alwid20L and one shift distribution for the new filling line, since we adjusted these shift distributions to each other. It is not interesting to analyse multiple different experiments for the same number of shifts, since we see that an even distribution over the week results in the highest output. The costs of this intervention are

estimated at €25,200 by multiplying the costs of one FTE per hour by the number of FTEs that need retraining by the number of retraining hours. The Production Manager estimates these values respectively at €35, 9 FTEs, and 80 hours of retraining. The operators need retraining, because the operators cannot operate all filling lines.

Future State 2

In the second future state, we adjust the Alwid20L shift distribution to the shift distribution of the new filling line. We run the best configuration out of the previous section where we alter the distribution each week, such that the overlap with the Alwid20L is as small as possible. The costs of this intervention are negligible, since only the GPL needs to be informed.

Future State 3

In the third future state, we change the way in which we start orders at mixing. Table 2-4, Table 2-5, and Table 2-6, in Chapter 2 explain how mixing starts orders right now. We change this way, by starting batches for the new filling line earlier by lowering the limit at which a batch can start. Since mixing has spare capacity, we want to create a larger buffer for the new filling line, such that we get less WOP for the SFVision. The costs of implementing this intervention are estimated at €2,000. These costs come from instructing all mixing personnel on the way in which they should start batches for the new filling line in combination with the other filling lines. Qlikview does not need any changes, since Qlikview already visualizes the filling and mixing times and the characteristics of a batch.

Table 5-4 displays the new way in how we start orders for the new filling line. In the table we show when mixing should start the batch for all possible combinations of the number of batches in the BKs and RKs. As explained in the flow charts, this check is only performed when the SFVision has priority over the other filling lines. We use the table in the simulation model to make sure that a batch is only started when we are certain that the batch can also be moved to a BK. This future state considers the Time Till Close (TTC) for those situations in which it is not sure that the batch can directly be moved from a RK to a BK. If there are still two batches to be filled before we move the batch to the BK, we consider the Total Processing Time in the RKs (TPTRK) or the Total Processing Time in the BKs (TPTBK) for the new filling line. When the mixing time and the TTC is larger than the RPT of the batch that is being processed plus the filling time of the next batch, we start the batch. These constraints make sure that we only start a batch when we are certain that the batch can also be moved directly into a BK. The advantage of using this reasoning is that we do not keep a RK unnecessary occupied.

	Situation 1		Situation 2		Situation 3	
BK	1. RK	1. Starting batch?	2. RK	2. Starting batch?	3. RK	3. Starting batch?
0/1	< 3	Always	3	TTC > RPT	4	Mix Time > RPT + (TPTRK/4) & TTC > RPT + (TPTRK/4)
2	< 2	Always	2	TTC > RPT	3	Mix Time > RPT + TPTBK & TTC > RPT + TPTBK
3	0	Always	1	TTC > RPT	2	Mix Time > RPT + (TPTBK/2) & TTC > RPT + (TPTBK/2)
4	N.A.		0	TTC > RPT	1	Mix Time > RPT + (TPTBK/3) & TTC > RPT + (TPTBK/3)

Table 5-4 New Routing for the SFVision Filling Line

Future State 4

In the fourth future state, we analyse the impact of adding the two BKs of the GVP filling line to the new filling line. So, in this new situation, the GVP filling line shares its BKs with the SFVision. We would like to know if the new filling line can produce 700 tons a week with more BKs. Installing and buying the equipment, including a change station, costs €75,000. Company X has a spare change station, so the costs for installing and buying the other equipment is estimated at €50,000 by the Maintenance Manager. For this future state, two options are interesting. First, option A, we analyse what happens when both filling lines share the same BKs and second, option B, we analyse what happens when we make one BK dedicated for the new filling line and one BK dedicated to the GVP filling line. For this future state we use the routing that mixing currently uses, with the alteration that now the limit for starting an order for the new filling line is higher since we can fill more BKs. We make sure that we only start batches that can directly be moved to a BK. The total costs increase by €2,000 for instructing all mixing personnel on the way in which they should start batches for the new filling line in combination with the other filling lines. The total costs of this intervention are therefore €52,000.

Future State 5 *(Combination of Future State 1 and Future State 3)*

In the fifth future state, we use the combination of broken shifts and the new routing. We estimate the costs of this intervention at €27,200 since we need to instruct the mixing personnel and 9 operators at the filling department need retraining.

Future State 6 *(Combination of Future State 3 and Future State 4A)*

In the sixth future state, we use the combination of extra BKs and the new routing. We estimate the costs at €52,000 since we need to adjoin the BKs of the GVP filling line to the SFVision and the mixing personnel need to be informed on the new way in which batches are started.

Future State 7 *(Combination of Future State 1 and Future State 4A)*

In the seventh future state, we use the combination of broken shifts and two extra BKs with the current routing as explained in Chapter 2. We estimate the costs of this intervention at €77,200 since we need to adjoin the BKs of the GVP filling line to the SFVision, the mixing personnel need to be informed on the new way in which batches are started, and 9 operators at the filling department need retraining.

Future State 8 *(Combination of Future State 1, Future State 3, and Future State 4A)*

In the eighth future state, we use the combination of broken shifts, two extra BKs, and the new routing. We estimate the costs of this intervention at €77,200 since we need to adjoin the BKs of the GVP filling line to the SFVision, the mixing personnel need to be informed on the new way in which batches are started, and 9 operators at the filling department need retraining.

5.2.2   Conclusion

Now that the future states and the consequences are clear, we describe our main findings. Table 4 and Table 5 in Appendix I display per future state the results on the KPIs that were explained in Chapter 4. Figure 5-4, Figure 5-5, and Figure 5-6 visualize the results on the KPIs such that we get a clear understanding of the impact of different future states. In these figures, Future State 0 is the best experiment, experiment 5, out of the previous section with an even distribution and no alterations. The conclusions of the future states follow below these figures.

Figure 5-4 Results Growth Scenario 1 – WOP and Utilization – over a five-week period

Figure 5-5 Results Growth Scenario 1 – Output and Revenues – on average per week

Figure 5-6 Results Growth Scenario 1 – KG/Hour – on average per week

General

We see in Figure 5-5 that, apart from Future State 2, all future states increase the volume per week on the new filling line in relation to Future State 1. Future State 2 does not increase the volume of the SFVision; therefore, we exclude the intervention of altering the shift distributions of the Alwid20L and SFVision to each other from now on. When we use broken shifts in Future State 1, the WOP decreases for all filling lines, which automatically results in an increase in output and a higher kilogram per hour. When we change the routing or add extra BKs, the WOP at the new filling line is decreasing, while the WOP at the other filling lines increases. When using extra BKs, we recommend to not use dedicated BKs for the filling lines since we see, in relation to sharing the BKs with the GVP filling line, an increase in WOP over all filling lines and a decrease in kilogram per hour for the other filling lines. For the first five future states, we do see an increase in tonnage, but Company X cannot produce 700 tons per week on the SFVision with these future states due to the high WOP. So, we conclude that if Company X wants to use 8 shifts, a combination of the previous explained interventions is necessary.

If Company X wants to reach the goal using the current resources, investments are required. Using broken shifts and extra BKs makes sure that Company X can process 700 tons a week, while still producing the required number of batches for the other filling lines. As said, we estimate the total investment costs of this intervention at €77,200. When mixing also alters the way in which batches are started, Company X can even produce, on average, 737 tons a week. With this extra intervention, the investment costs remain the same, since the costs for instructing the mixing operators is not changing. With all three interventions combined, we see an increase in WOP of 24 hours and therefore a decrease of 7 orders produced over the other filling lines in relation to future state 7. The total revenues per week increases with €4,153.38. So, we recommend using the three interventions combined, if Company X is willing to let the WOP over the other filling lines increase. Otherwise, we recommend using Future State 7.

Naturally, the costs are also increasing since we need, among others, more raw materials, more FTEs, and more truck transports. The costs per ton for Company X is €219. This number is the target that the Site Manager has set for the production plant. Included in this amount are among others labour, utilities, maintenance, supplies, and outside services. The Supply Chain Finance Analyst assumes that this amount decreases when the total tonnage is increasing. Since we do not know with how much the costs per ton is decreasing, we use the €219. Considering these costs per ton, the profit per week increases with €2,151.80 per week. The payback period while using Future State 8 is 36 weeks, as can be seen in Table 6 in Appendix I. This table also displays the revenues, the costs, the profit, and the payback period for the other future states.

With the last future state, we see in Figure 5-4 that the utilization of the most important RKs is almost near the 100%, which shows us that we cannot grow any higher in tonnage with the current resources. Mixing now remains the bottleneck, but where it previous was a Capacity Constraint Resource it is now a Bottleneck Resource. So, the capacity of the mixing department is just not enough to realize growth. For the next section, where we want to realize growth, we incorporate the use of extra RKs.

Transport and Finished Goods Warehouse

Using all three interventions, the time in which the new filling line is blocked increases, because the kilograms per hour increases. Over a five-week period, this number increases by 57% to

3 hours and 23 minutes. So, the same conclusion as in the previous section stands, we do not need extra pallet wrappers or an extra machine who puts the top foil on the pallets. However, since the time blocked is increasing, we analyse what Company X should do to reduce this. When the setup time of the top foil machine is reduced from 10 to 5 minutes and the AGV is moved closer to the new filling line, the time in which the filling line is blocked can be reduced to 59 minutes on average over a five-week period. So, we recommend Company X to setup a team that has the goal of reducing the setup time from 10 to 5 minutes and by moving the AGV closer to the new filling line. For the remainder of this research we use these improvements.

Table 5-5 shows that we do not cancel trucks during a five-week period for the future state with all three interventions. During this period, we need 15 trucks extra to be able to transport all pallets to the EDCs. After analysing the model, we conclude that we, for all interventions, need the extra trucks always in the night shift as can be seen in Table 17 in Appendix J and Figure 5-7. This increases the work pressure for the FTEs in the night shift, therefore we also need one extra FTE in the night shift when the new filling line is active as can be seen in Table 17 in Appendix J and Figure 5-8. We conclude that we need 3 trucks a week extra in the night shift, while using Future State 8. Arrangements with carriers should be made such that there are 22 truck transports per week.

Future State	Extra Trucks	Cancelled Trucks	Number of Shifts Above 7 Hours	Average Number of Incoming Pallets per Shift
0	0	16	19	196.84
1	2	2	16	202.56
2	0	15	21	196.16
3	2	8	23	200.70
4A	2	6	23	201.84
4B	2	5	21	202.41
5	8	1	18	205.45
6	7	2	23	205.41
7	13	1	21	208.15
8	15	0	22	209.54

Table 5-5 Results Growth Scenario 1 – FGW – over a five-week period

Figure 5-7 Results Growth Scenario 1 – Number of Truck Transports – on average per shift

Figure 5-8 Results Growth Scenario 1 – Number of FTEs – on average per shift

5.3 Growth Scenarios

Now that we know that and how Company X can optimally use the new filling line in combination with the other filling lines and the internal supply chain to reach the goal, we go to the second phase of this research. We see that the utilization, by using Future State 8, is around the 98%. We also see that the interventions have a positive impact on the total output for the SFVision. In the second phase we increase the available resources to answer research question 5: *"How should the internal supply chain be controlled, when considering growth in the number of tonnages produced per week on the new filling line?".* To answer this research question, we first determine the growth scenarios that are feasible to reach. Second, we use the DES model to give insight in how we can reach the growth scenario. In this step bottlenecks arise. Using the Theory of Constraints as explained in Chapter 3, we resolve these bottlenecks by following an iterative process of eliminating bottlenecks to improve the process during each cycle.

5.3.1 The Growth Scenarios

We first describe the possible growth scenarios that are feasible and which we analyse. In combination with the Site Manager, Manager Planning & Logistics, the Production Manager, and the Make Planner, we determine the growth scenarios in a brainstorm session. Since the plant in Location X is one of many, Company X can move production from one plant to another when this is profitable. The plant in Location X is attractive to Company X, since the plant has an ideal location in which all warehouses can be supplied against low cost. Also, when the new filling line is up and running, the kilograms per hour become higher, which increases the margin. Taken these reasons into consideration, we conclude that there are two growth scenarios that are interesting and feasible to reach. The growth scenarios we want and which Company X eventually can reach, provided that the plant is ready, are the following:

Growth Scenario 2: We want to analyse the way in which Company X can produce 800 tons a week on the new filling line, with the number of orders for the other filling lines remaining the same.

Growth Scenario 3: We want to analyse the way in which Company X can produce 1,000 tons a week on the new filling line, with the number of orders for the other filling lines remaining the same.

5.3.2 Reaching the Growth Scenarios

Now that we know the growth scenarios that Company X would like to reach in the future, we analyse multiple future states to find out how Company X can reach the amount of tonnages on the new filling line plus the implications on the supporting departments.

5.3.2.1 Growth Scenario 2

In the second growth scenario we want to produce 800 tons a week on the new filling line. We see in Figure 5-5 that we cannot reach this amount by having 8 shifts, since Future State 8 has no WOP. Also, we see little spare capacity on the RKs. In this section we do not initially use extra RKs, since we would also like to know what the consequences are of increasing the number of shifts with the current amount of resources. It is a possibility for Company X to produce less on other filling lines, if the total revenues increase. For this growth scenario we increase the number of shifts for the new filling line until a maximum of 12, since a higher number of shifts results in a decrease in orders over the other filling lines and is therefore not recommended. In this section we run the shift distributions as displayed in Appendix H, since the number of shifts increases. We use the shift distributions out of Table 2 when we do not use broken shifts or Table 3 when we use broken shifts. We create all shift distributions such that the SFVision has an even distribution over the week, since we see that this results in the highest output over all filling lines. Figure 5-5 shows that having a combination of interventions results in an increased output, therefore we analyse these interventions with more shifts. So, using the DES model, we want to answer the following what if questions:

1. What happens when we use extra shifts, broken shifts, and the new routing approach?
2. What happens when we use extra shifts, two extra BKs, and the new routing approach?
3. What happens when we use extra shifts, broken shifts, and two extra BKs?
4. What happens when we use extra shifts, broken shifts, the new routing approach, and two extra BKs?

Now, we describe the results of these four future states. Table 7 and Table 8 in Appendix I display per future state the results on the KPIs that were explained in Chapter 4. Figure 5-9, Figure 5-10, and Figure 5-11 visualize the results of the future states, such that we get a clear understanding of the impact of different future states. The conclusions of the future states follow below these figures. After the conclusions we analyse the impact of one extra RK.
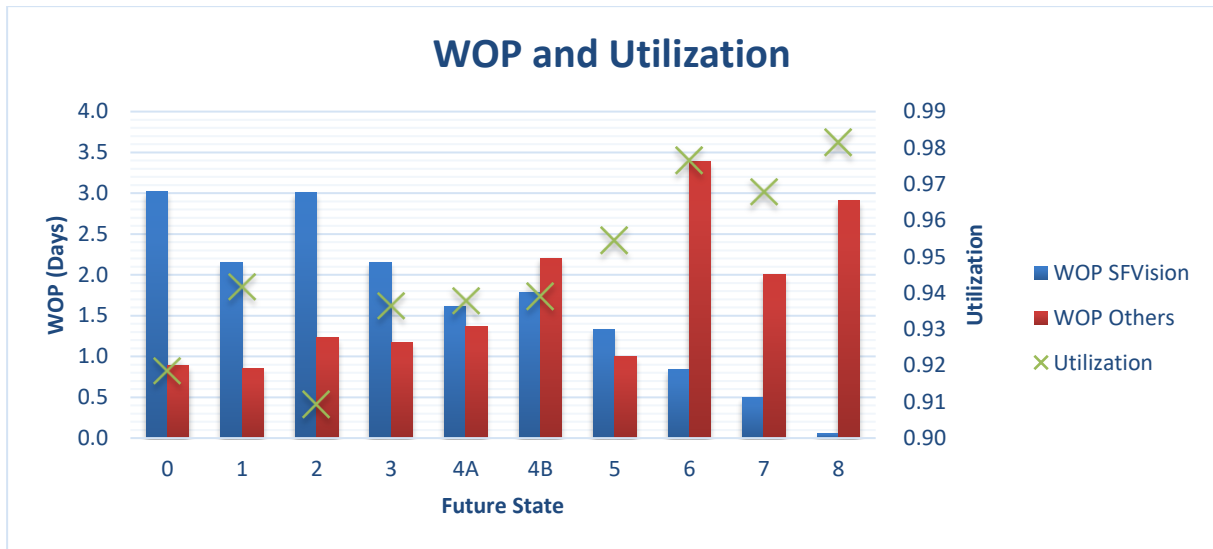

Figure 5-9 Results Growth Scenario 2 – WOP and Utilization – over a five-week period
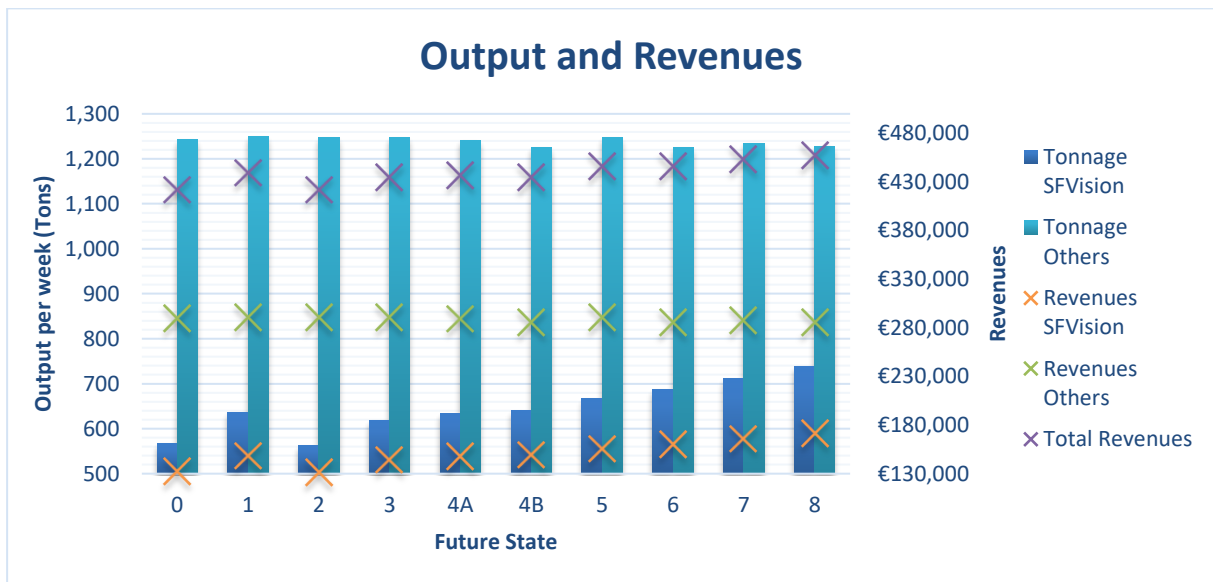
Figure 5-10 Results Growth Scenario 2 – Output and Revenues – on average per week
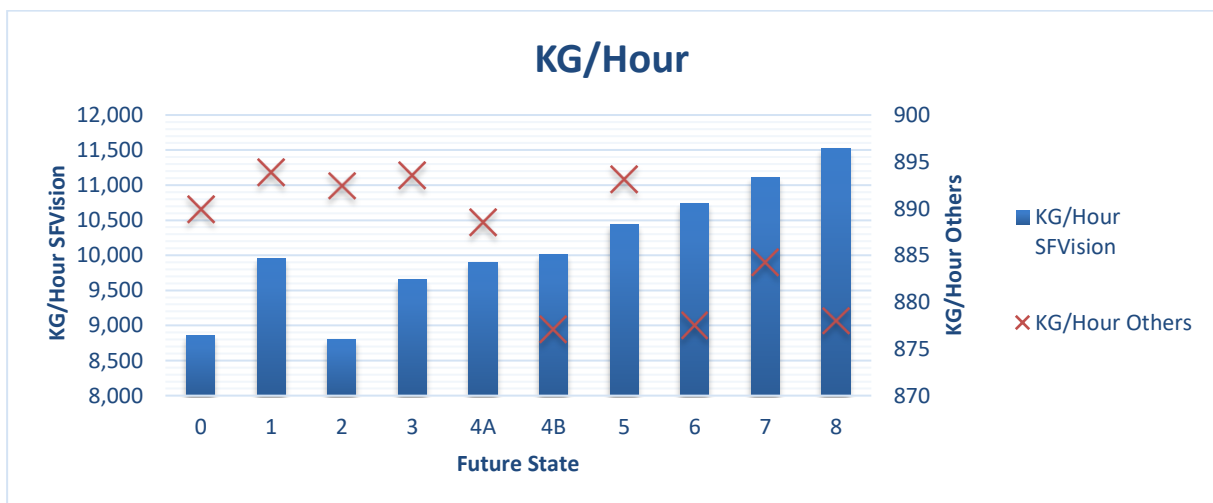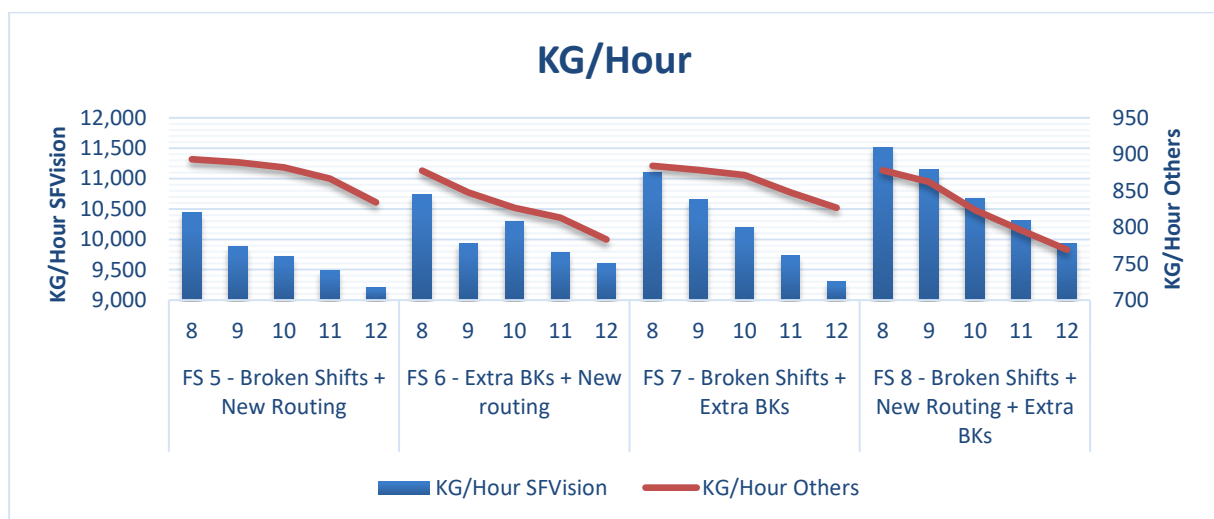

Figure 5-11 Results Growth Scenario 2 – KG/Hour – on average per week

With all future states Company X can reach the goal of 800 tons, but the WOP for the new filling line and the other filling lines increases when the number of shifts increases. The WOP increases for all filling lines, because the utilization of the most important RKs is almost 100%. One future state has a higher impact than another on the number of orders produced over the other filling lines. This is a trend which we see for every future state. When the WOP over the other filling lines increases, the output of these filling lines decreases. This decreases the kilograms per hours and hereby also the revenues that Company X receives for the output of those filling lines. Since the growth in output over the new filling line is greater than the decrease in orders over the other filling lines, the total revenues and the total tonnage produced per week increases for all future states. So, the SFVision can produce, without much investments, a high number of orders, but the other filling lines are negatively affected. Now we analyse each future state in more detail.

Future State 5

In Future State 5 we analyse the intervention of using the new routing in combination with broken shifts. After analysing this future state, we see in Figure 5-10 that Company X needs

at least 11 shifts to produce 800 tons on the new filling line. The impact of this future state on the other filling lines is not as huge as in the previous future state. Now, we produce on average per week 4.8 orders less than required. This future state results in the smallest WOP over all filling lines for every number of shifts. With this future state the highest revenue can be generated in comparison with the other future states, but we need more shifts. So, in comparison, the WOP is higher than with another future state where we need less shifts to reach the 800 tons.

Future State 6

In Future State 6 we analyse the intervention of using the new routing in combination with extra BKs and extra shifts. After analysing this future state, we see in Figure 5-10 that Company X needs at least 10 shifts to produce 800 tons on the new filling line. This future state has a significant impact on the other filling lines, since we produce on average per week 11 orders less.

Future State 7

In Future State 7 we analyse the intervention of using extra BKs in combination with broken shifts. After analysing this future state, we see in Figure 5-10 that Company X needs at least 10 shifts to produce 800 tons on the new filling line. Just as with the previous future state, we see a small impact on the other filling lines. In this future state, we produce on average 4.3 orders less than required.

Future State 8

In Future State 8 we analyse the intervention of using the new routing in combination with broken shifts and extra BKs. After analysing this future state, we see in Figure 5-10 that Company X needs at least 9 shifts to produce 800 tons on the new filling line. Just as with the previous future state, we see a small impact on the other filling lines. In this future state, we produce on average 6 orders less than required. This future state results in the highest number of orders produced on the new filling line for all number of shifts, but the decrease in orders over the other filling lines is also the highest. Therefore, this future state does not result in the highest revenue for the higher number of shifts. However, this future state is the most efficient future state, due to the largest KG/Hour.

Transport and Finished Goods Warehouse

After we reduced the setup time for the top foil machine from 10 to 5 minutes and moved the AGV 4 meters closer to the new filling line, we analyse the blocked time for the four future states. The blocked time did not increase in relation to Growth Scenario 1, because the KG/Hour for the SFVision did not increase. When analysing the results of the FGW, we see the same phenomenon as before. We need extra truck transports in a week. Table 5-6 displays how many extra truck transports we need over a five-week period. When analysing the number of truck transports and FTEs required, as displayed in Table 18 in Appendix J, Figure 5-12, and Figure 5-13, we see that we almost always need an extra truck transport and an extra FTE in the night. The 10 and 5 truck transports in the morning and afternoon respectively, are almost always enough to transport the pallets to the EDCs.

Future State	Shifts	Extra Trucks	Cancelled Trucks	Number of Shifts Above 7 Hours	Average Number of Incoming Pallets per Shift
Future State 5 Extra BKs + New Routing	9	16	0	22	205.54
	10	23	0	23	209.24
	11	30	0	27	211.51
	12	30	0	27	212.42
Future State 6 Broken Shifts + New Routing	9	8	4	18	209.76
	10	15	0	39	213.31
	11	21	0	36	216.65
	12	20	0	28	217.03
Future State 7 Broken Shifts + Extra BKs	9	23	0	23	213.24
	10	27	0	27	214.94
	11	28	0	25	215.87
	12	29	1	28	216.10
Future State 8 Broken Shifts + New Routing + Extra BKs	9	21	0	24	212.67
	10	21	0	23	212.97
	11	20	0	24	213.76
	12	22	1	28	213.85

Table 5-6 Results Growth Scenario 2 – FGW – over a five-week period
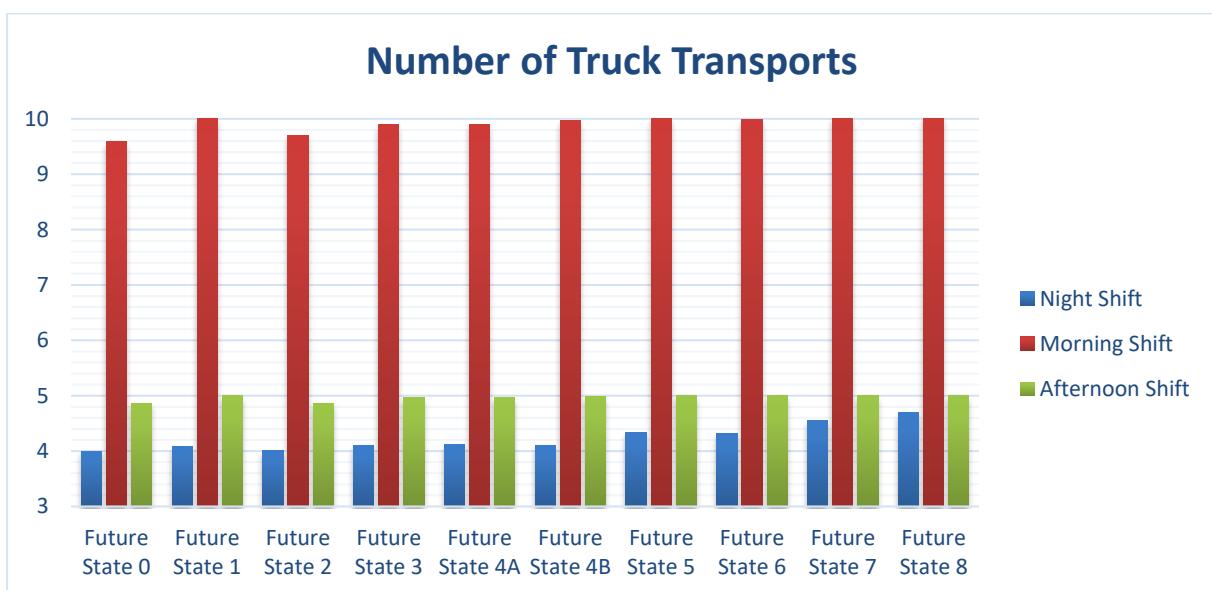

Figure 5-12 Results Growth Scenario 2 – Number of Truck Transports – on average per shift
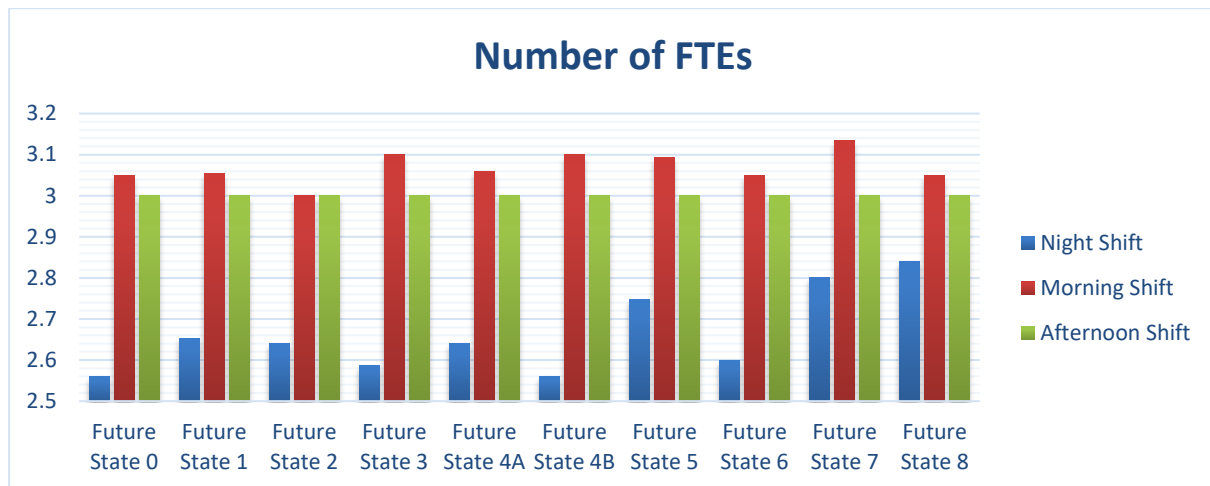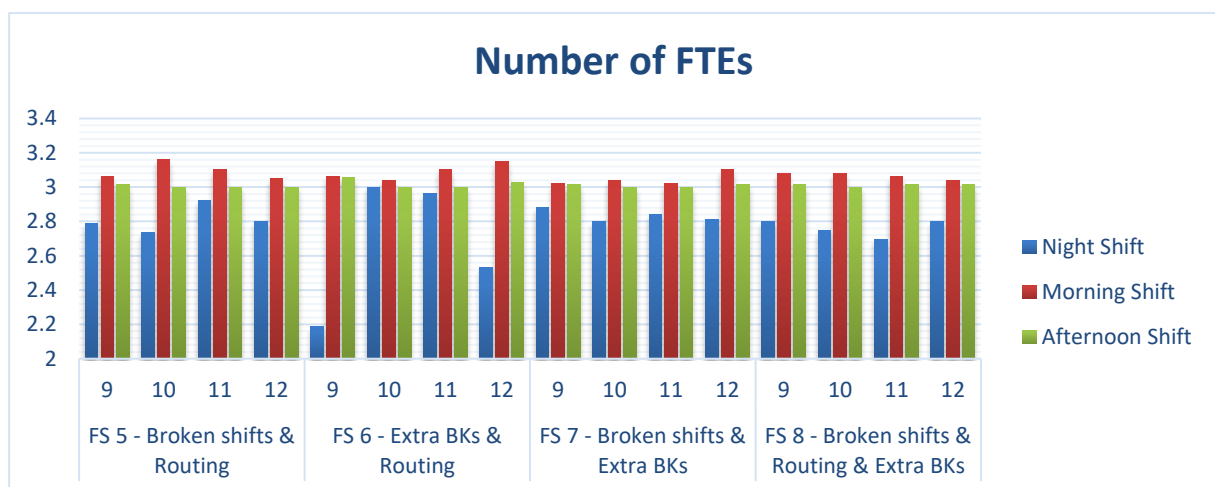

Figure 5-13 Results Growth Scenario 2 – Number of FTEs – on average per shift

Conclusion

We conclude that Company X can produce 800 tons on the new filling line. On the other hand, the orders for the other filling line are, as expected, decreasing. It is up to the management team if they want to produce less orders on the other filling lines against the same number of resources, while increasing the total revenues. If Company X is willing to do so, then we recommend using Future State 8, since this results in the largest profit and the largest KG/Hour. The payback period while using all three interventions combined is 27 weeks with 9 shifts, as can be seen in Table 9 in Appendix I. This table also displays the revenues, the costs, the profit, and the payback period for the other future states. However, if Company X is not willing to let the output decrease over the other filling lines, we require an extra RK. In the next section, we also show when Company X can produce 800 tons on the new filling line with 1 extra RK, while keeping the orders for the other filling lines at an acceptable level.

5.3.2.2 Growth Scenario 2 with 1 Extra RK

Now, we describe the results of adding 1 extra RK. According to the Specialist Processing, we determined that there is the possibility to add a maximum of 2 10 m^3 RKs at Jupiter. This RK needs to have the same characteristics as RK103 according to the Specialist Processing, because RK103 has, in reality, the highest utilization. Adding one RK costs €633,000, according to the Specialist Processing and the Maintenance Manager. For this scenario we are interested in the results of multiple interventions. Figure 5-5 shows that having a combination of interventions results in a more efficient production process, therefore we analyse these interventions with more shifts. Now, we describe the results of the interventions. Table 10 and Table 11, in Appendix I, display per future state the results on the KPIs that were explained in Chapter 4 for all future states. Figure 5-14, Figure 5-15, and Figure 5-16 visualize the results of the lowest amount of shifts required in order to produce 800 tons for the future states where we use a combination of interventions. The conclusions follow below these figures.
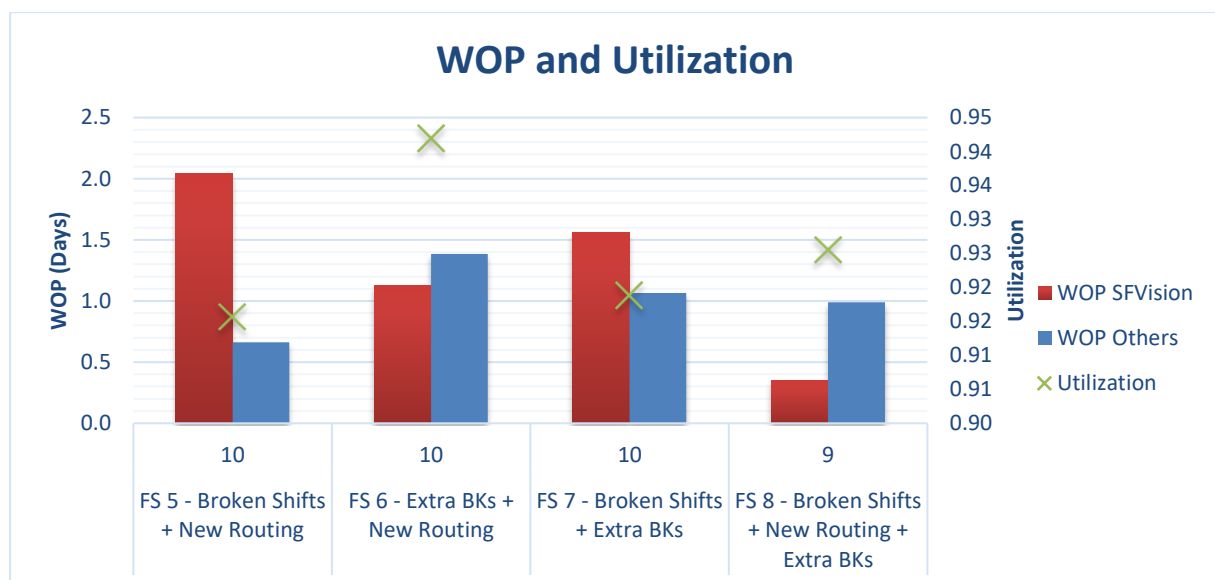
Figure 5-14 Results Growth Scenario 2 – 1 RK – WOP and Utilization – over a five-week period
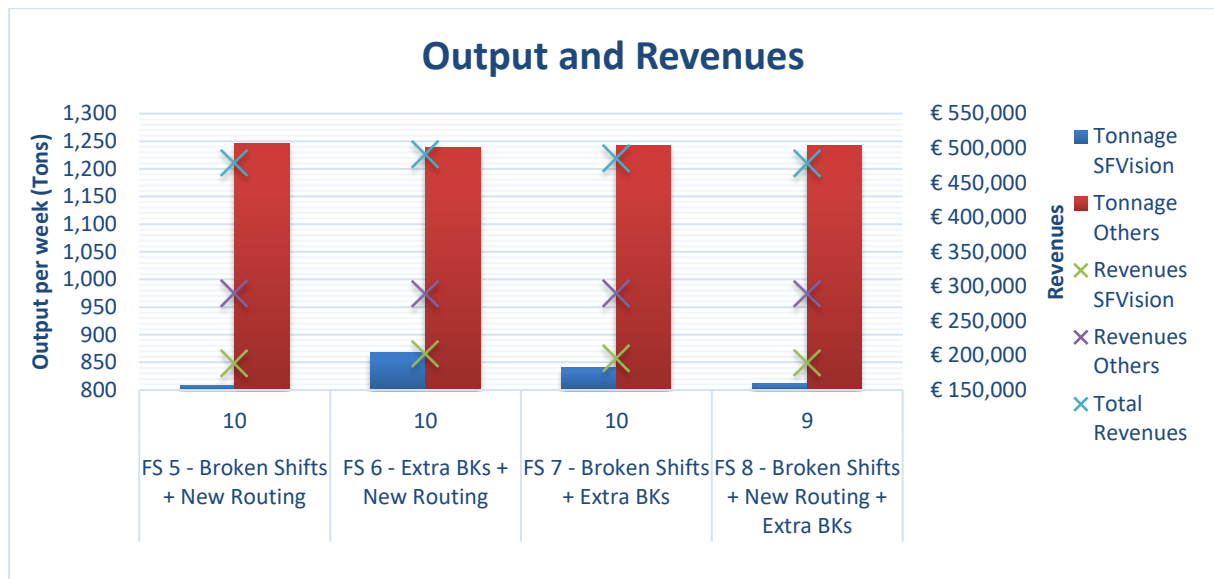
Figure 5-15 Results Growth Scenario 2 – 1 RK – Output and Revenues – on average per week
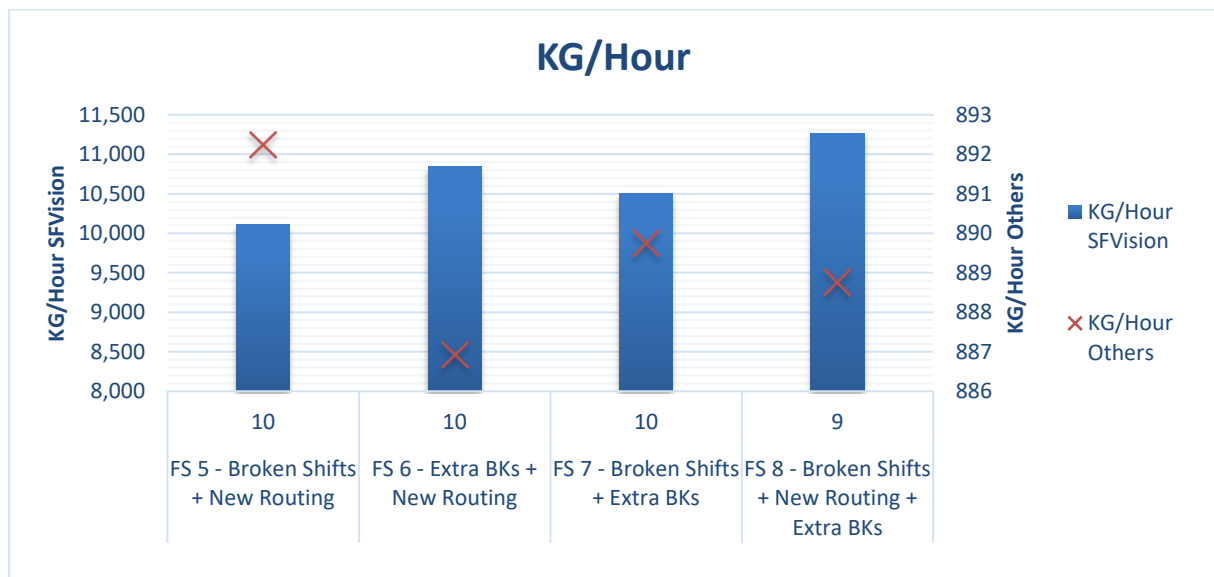
Figure 5-16 Results Growth Scenario 2 – 1 RK – KG/Hour – on average per week

Conclusion

We see in Figure 5-15 that Company X can reach the 800 tons with all future states. For Future State 5 until 7 we need 10 shifts, while we need 9 shifts for Future State 8. By building an extra RK, all future states have, in contrast to the previous scenario, no impact on the output of the other filling lines as can be seen in Figure 5-10 and Figure 5-15. We conclude that Future State 8 is more attractive than the others, since this future state requires less shifts to produce the 800 tons and is therefore more efficient. This results in the highest KG/Hour and the lowest WOP over all filling lines. On a negative, the payback period while producing 800 tons with Future State 8 is 204 weeks as can be seen in Table 12 in Appendix I. This table also displays the revenues, the costs, the profit, and the payback period for the other future states. So, we recommend that Company X only uses extra RKs when they find this payback period acceptable and is willing to keep the number of orders for the other filling lines the same.

Transport and Finished Goods Warehouse

Just as with Growth Scenario 2 without an extra RK, the blocked time did not increase in relation to Growth Scenario 1, because the KG/Hour for the SFVision did not increase. When analysing the results of the FGW, we see the same phenomenon as before. We need extra truck transports in a week. Table 5-7 displays how many extra truck transports we need over a five-week period. When analysing the number of truck transports and FTEs required, as displayed in Table 19 in Appendix J, Figure 5-17, and Figure 5-18, we see that we almost always need two extra truck transports in the night. Also, we need an extra FTE in the night and in the morning. The 5 truck transports and 3 FTEs in the afternoon, are almost always enough to transport the pallets to the EDCs.

Future State	Shifts	Extra Trucks	Cancelled Trucks	Number of Shifts Above 7 Hours	Average Number of Incoming Pallets per Shift
FS 5	10	38	0	29	182.89
FS 6	10	43	0	44	184.83
FS 7	10	41	0	32	184.29
FS 8	9	33	0	25	181.42

Table 5-7 Results Growth Scenario 2 – 1 RK – FGW – over a five-week period
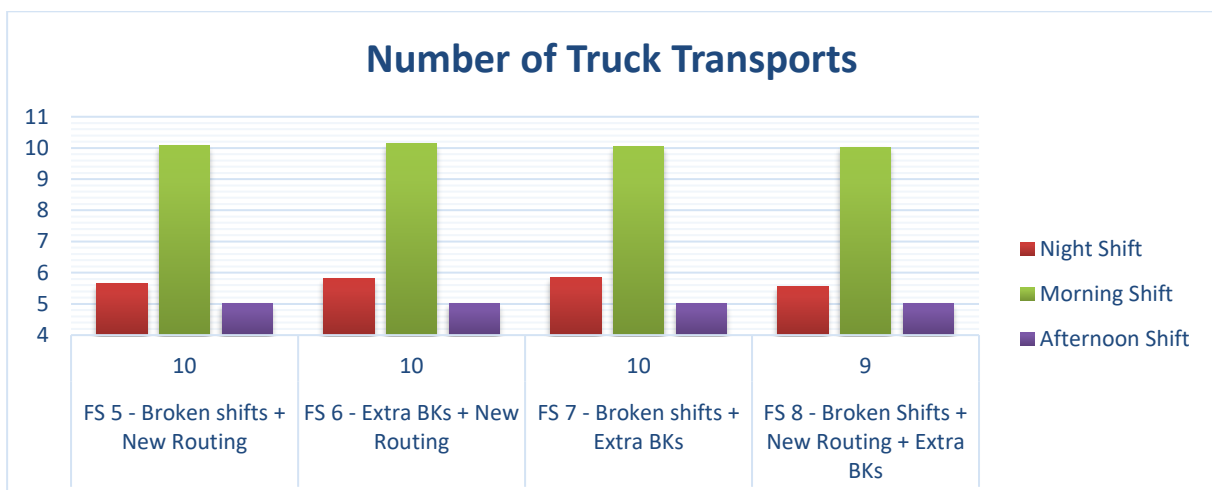
Figure 5-17 Results Growth Scenario 2 – 1 RK – Number of Truck Transports – on average per shift
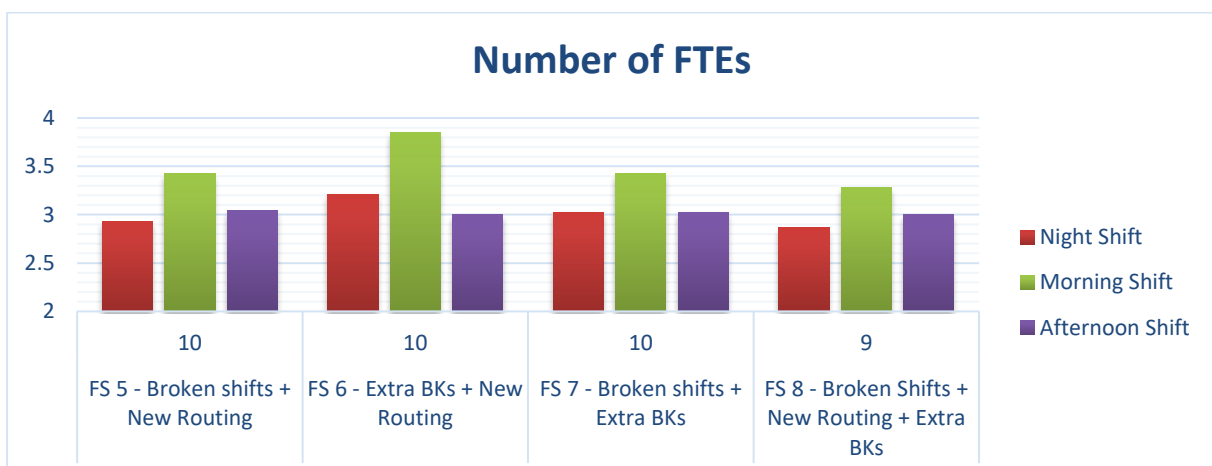
Figure 5-18 Results Growth Scenario 2 – 1 RK – Number of FTEs – on average per shift

5.3.2.3 Growth Scenario 3

For the third growth scenario we want to produce 1,000 tons a week on the new filling line. By using the previous analysed future states, we see that we cannot reach this target without a decrease in orders over the other filling lines. Even with extra BKs, a new routing, and using broken shifts, we cannot reach this target since the utilization of the RKs is 100%. So, mixing is still the bottleneck. The only thing that remains is adding extra RKs at the mixing department. According to the Specialist Processing, we determined that there is the possibility to add a maximum of 2 10 m^3 RKs at Jupiter. In this section, we analyse the impact of adding one and two RKs, since we know that 1 RK is enough to produce 800 tons. However, producing 1,000 tons is an increase of 25% and therefore we do not know if 1 RK is sufficient. Adding one RK costs €633,000, while adding two RKs costs €1,139,400 according to the Specialist Processing and the Maintenance Manager. Using the DES model, we want to answer the following 2 what if questions:

1. What happens when we add one RK at the mixing department?
2. What happens when we add two RKs at the mixing department?

1. Scenario 1

In the first scenario we add one extra RK to our simulation model. This RK needs to have the same characteristics as the one out of the previous section. For this scenario we are interested in the results of multiple interventions. Figure 5-5 shows that having a combination of interventions results in a more efficient production process, therefore we analyse these interventions for the number of shifts from 8 to 15. Now, we describe the results of the interventions. Table 10 and Table 11, in Appendix I, display for all future states the results on the KPIs that were explained in Chapter 4. Figure 5-19, Figure 5-20, and Figure 5-21 visualize the results of the future states that results in an output higher than 1,000 tons, such that we get a clear understanding of the impact of the different future states with extra shifts. The conclusions follow below these figures.
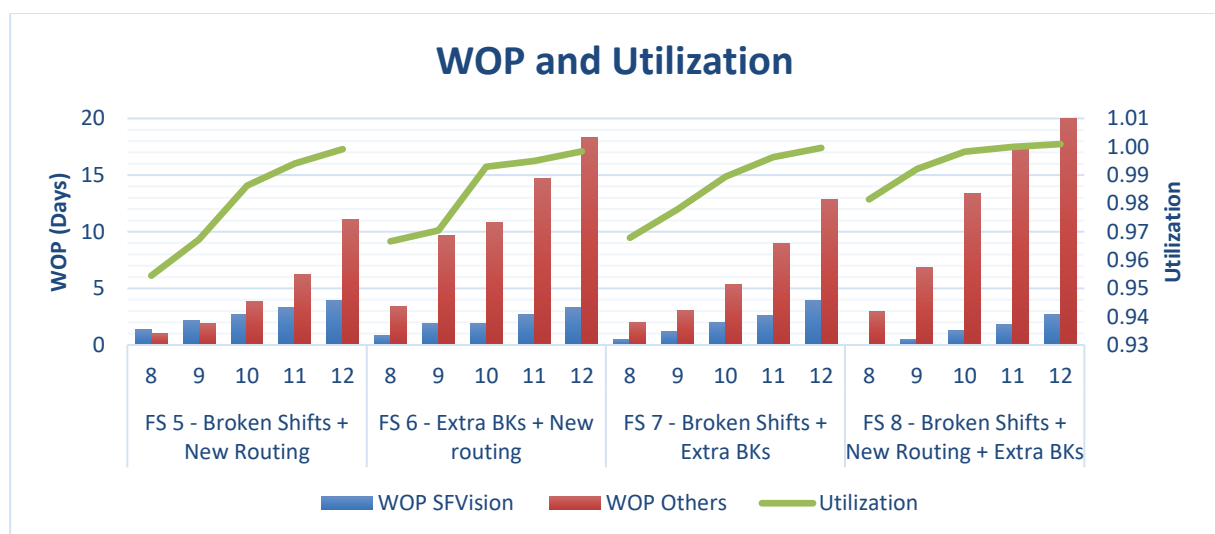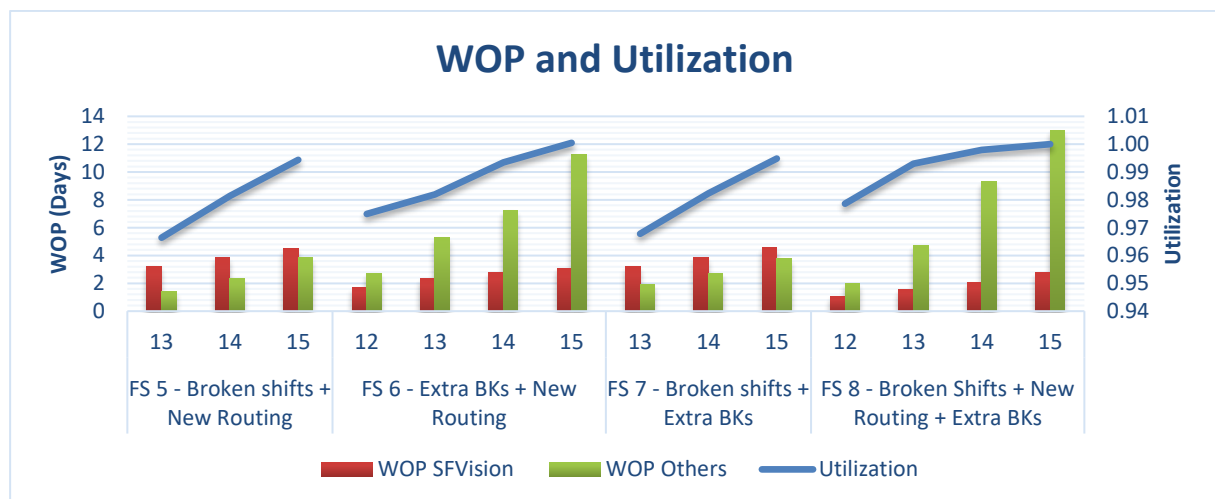

Figure 5-19 Results Growth Scenario 3 – 1 RK – WOP and Utilization – over a five-week period
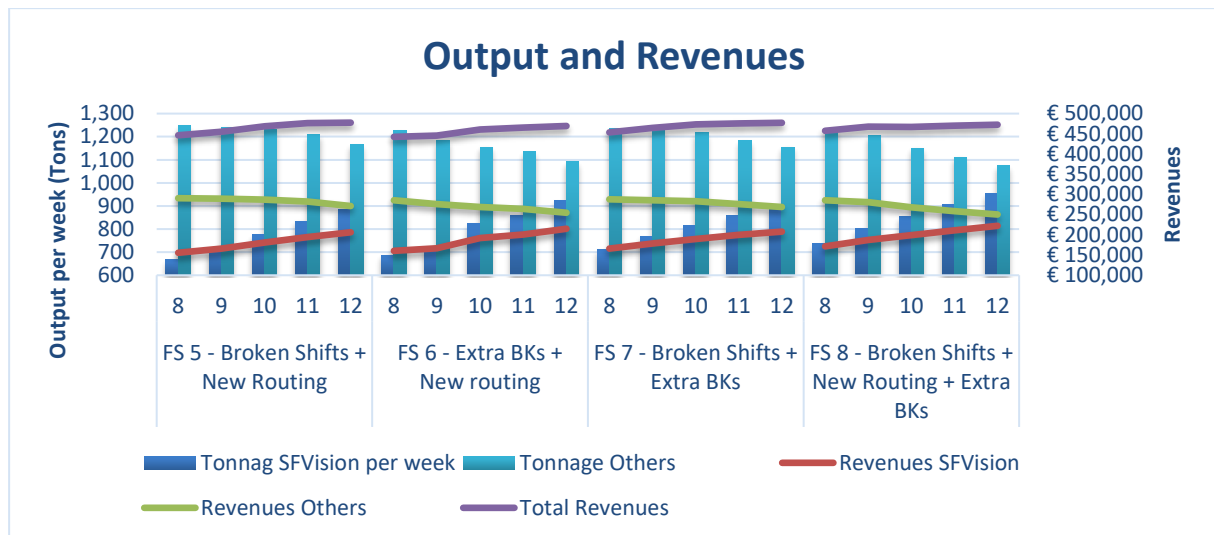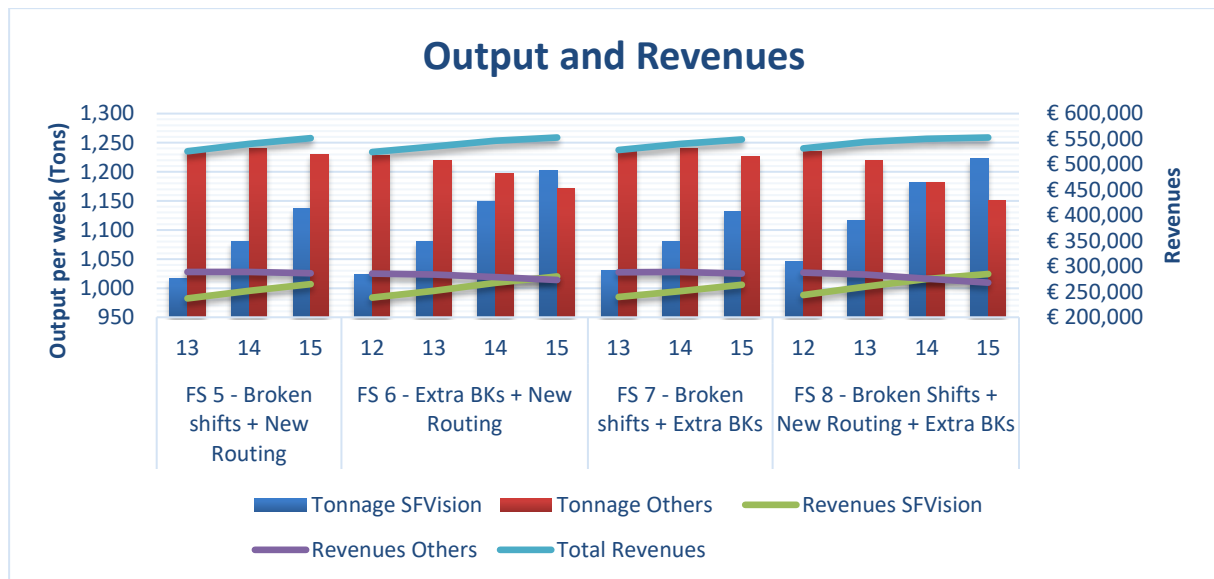
**Figure 5-20 Results Growth Scenario 3 – 1 RK – Output and Revenues – on average per week**
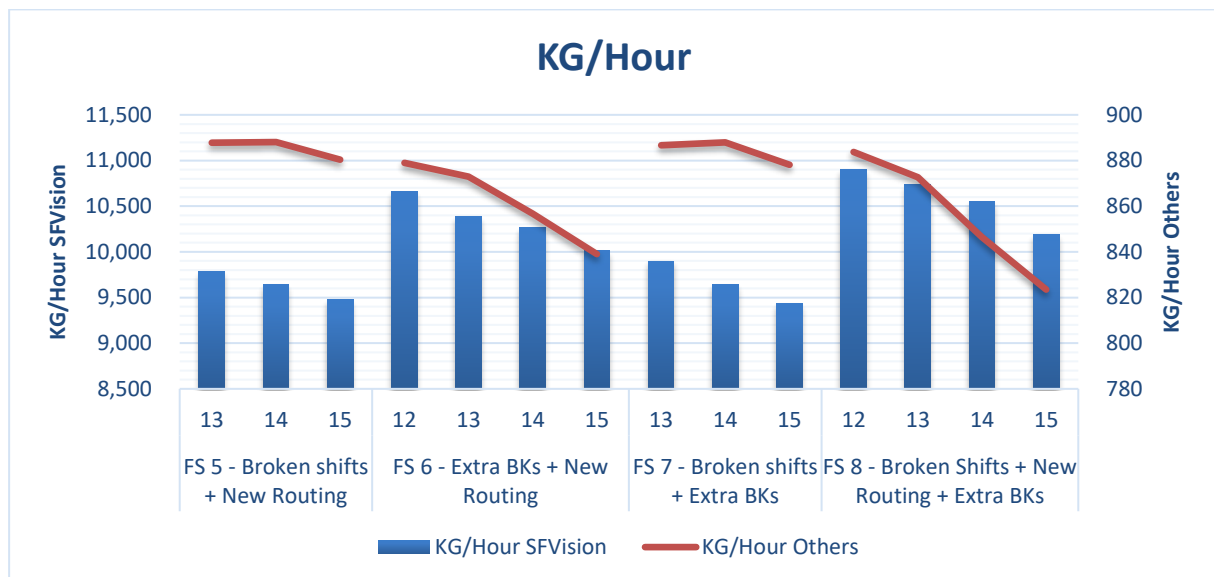
Figure 5-21 Results Growth Scenario 3 – 1 RK – KG/Hour – on average per week

General

We see in Figure 5-20 that Company X can reach the 1,000 tons with all future states. One future state is more attractive than another, since some future states have no impact on the other filling lines. Especially when the number of shifts is increasing for some future states, the kilograms per hours for the other filling lines and the new filling line decreases. We conclude that by using Future State 8 Company X can produce 1,000 tons with 12 shifts. This results in the highest KG/Hour and the lowest WOP over all filling lines and is therefore the most efficient future state. The impact of this future state on the other filling lines is almost negligible, since the kilograms per hour for the other filling lines coincides with the kilograms per hour out of Section 5.1. In the future state with the three interventions we see an increase in profit per week of €6,670 while using 12 shifts. The payback period for this future state is 106 weeks, as can be seen in Table 12 in Appendix I. This table also displays the revenues, the costs, the profit, and the payback period for the other future states.

When we use 14 or 15 shifts with the future state in which we use all three interventions, we see that we reach the utilization of 100%. This automatically result in a lower output for the other filling lines, since the WOP increases. So, we do not recommend using more than 14 shifts. Next, we see that the results of the future states with the broken shifts do not alter much in relation to the future states without those broken shifts. The higher the number of shifts, the lower the number of shifts that are broken. Therefore, we do not recommend using broken shifts when Company X is planning to use more than 12 shifts.

Transport and Finished Goods Warehouse

Just as with Growth Scenario 2, the blocked time did not increase in relation to Growth Scenario 1, because the KG/Hour for the SFVision did not increase. When analysing the results of the FGW, we see the same phenomenon as before. We need extra truck transports per week. Table 5-8 displays how many extra truck transports we need over a five-week period. Using Future State 8, we see that we need 15 extra truck transports per week. When analysing the number of truck transports and FTEs required, as displayed in Table 19 in Appendix J, Figure 5-22, and Figure 5-23, we see that we almost always need at least 7 truck transports and almost 2 extra FTEs in the night. Now, we also need one extra FTE in the morning when the new filling line is up. The 10 and 5 truck transports in the morning and afternoon respectively, are almost always enough to transport the pallets to the EDCs.

Future State	Shifts	Extra Trucks	Cancelled Trucks	Number of Shifts Above 7 Hours	Average Number of Incoming Pallets per Shift
Future State 5	13	73	0	40	196.54
Extra BKs +	14	86	0	39	200.88
New Routing	15	97	0	40	204.50
Future State 6	12	73	0	41	196.09
Broken Shifts +	13	82	0	38	199.43
New Routing	14	91	0	40	202.70
	15	98	0	43	204.88
Future State 7	13	75	0	39	196.92
Broken Shifts +	14	85	0	37	200.60
Extra BKs	15	96	0	38	204.16
Future State 8	12	73	0	38	197.86
Broken Shifts +	13	83	0	43	202.27
New Routing +	14	83	0	41	203.50
Extra BKs	15	86	0	40	204.92

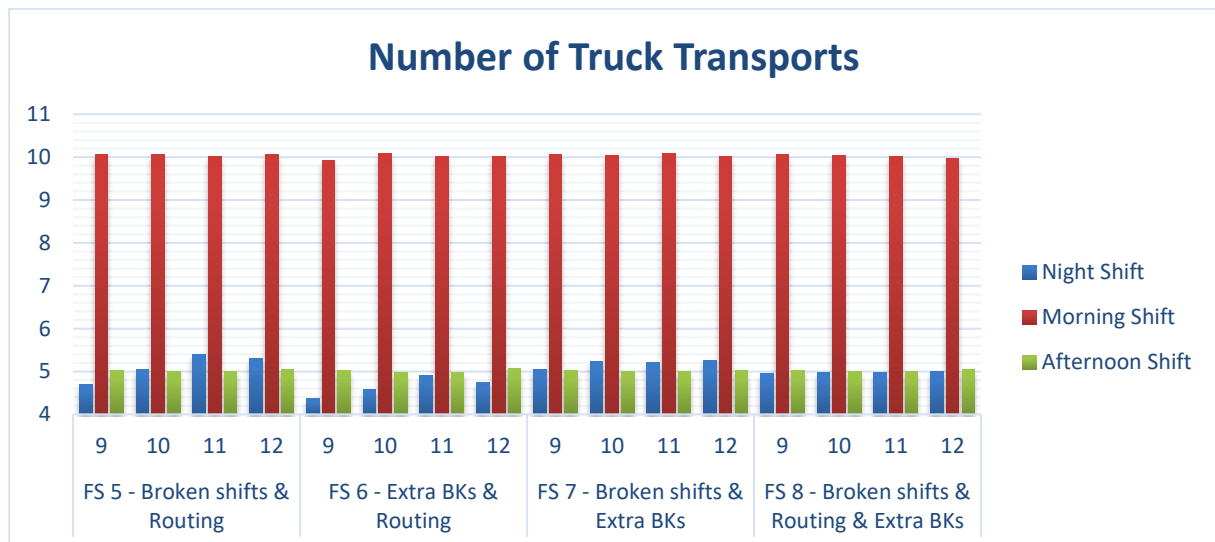Table 5-8 Results Growth Scenario 3 – 1 RK – FGW – over a five-week period
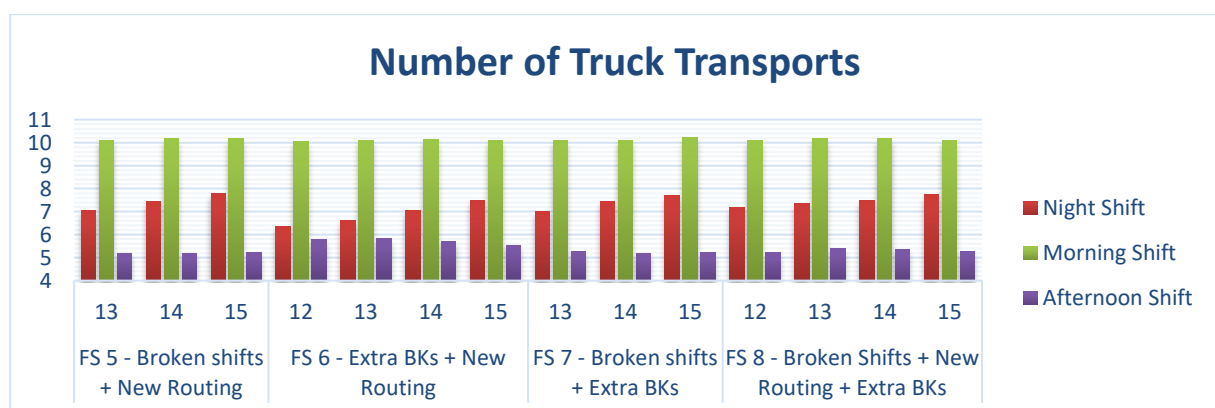
Figure 5-22 Results Growth Scenario 3 – 1 RK – Number of Truck Transports – on average per shift
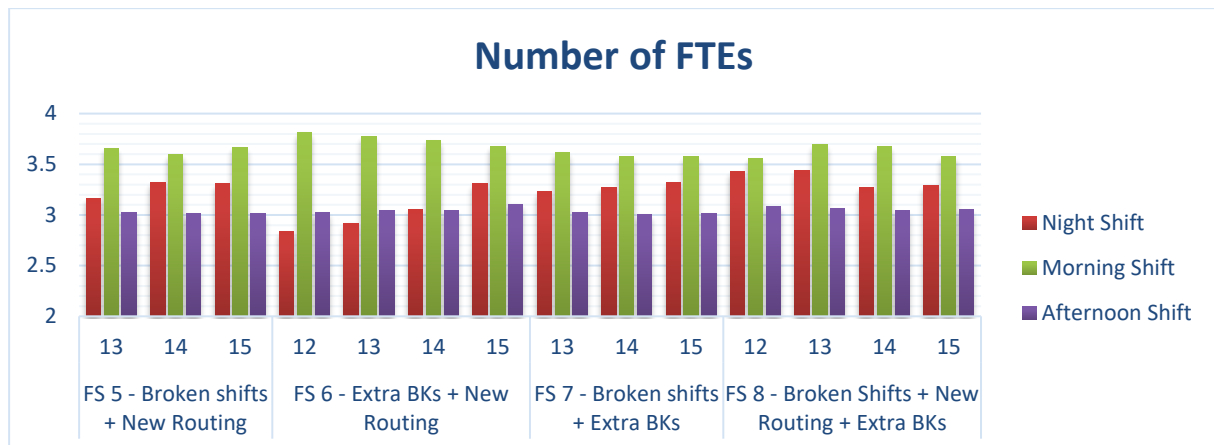
Figure 5-23 Results Growth Scenario 3 – 1 RK – Number of FTEs – on average per shift

Concluding, Company X can produce 1,000 tons a week while adding 1 RK at the mixing department. However, when Company X wants to produce more than this target, the other filling lines get negatively affected.

2. Scenario 2

In the second scenario we use two extra RKs. One RK needs to have the same characteristics as RK103 according to the Specialist Processing. In reality, RK103 is the RK with the highest utilization and therefore it is most desired to have another RK103. The second RK should have the same characteristics as RK104, so this new RK is also equipped with a stronger stirring mechanism. We analyse the same interventions as in scenario 1. Now, we describe the results of the interventions. In Appendix I, Table 13 and Table 14 displays for all future states the results on the KPIs that were explained in Chapter 4. Figure 5-24, Figure 5-25, and Figure 5-26 visualize the results of the interventions, such that we get a clear understanding of the impact of the different future states with extra shifts. The conclusions of the future states follow below these figures.
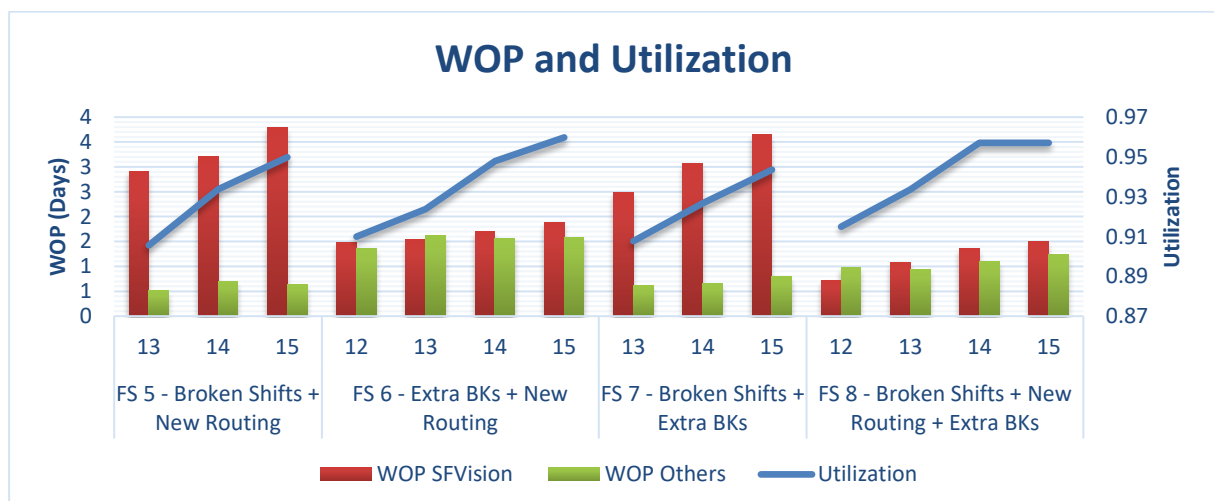
Figure 5-24 Results Growth Scenario 3 – 2 RKs – WOP and Utilization – over a five-week period
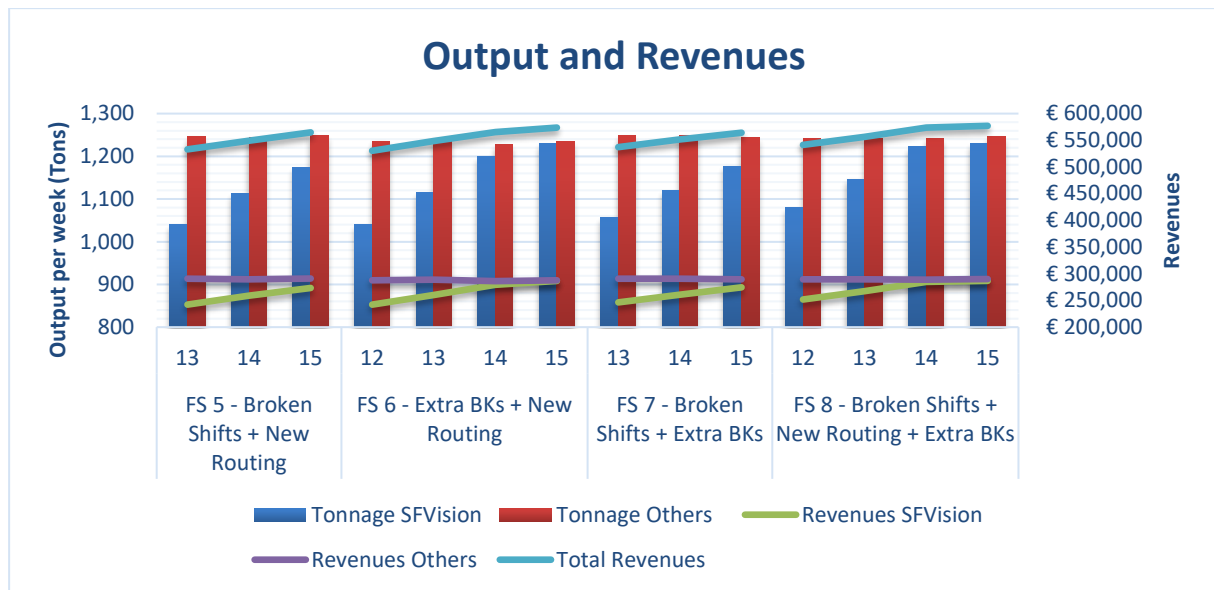
Figure 5-25 Results Growth Scenario 3 – 2 RKs – Output and Revenues – on average per week
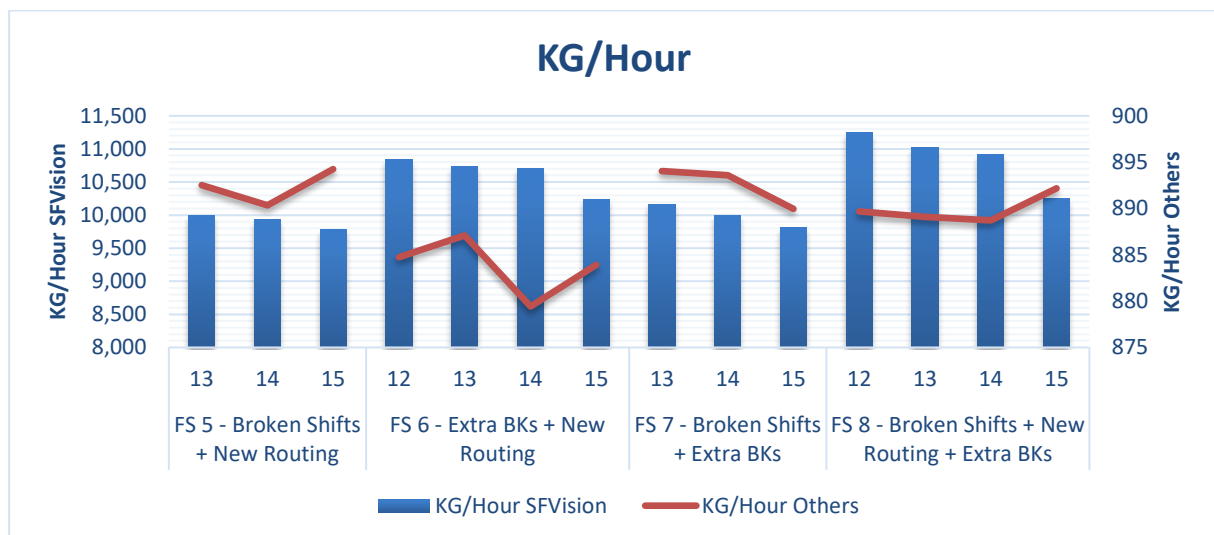
Figure 5-26 Results Growth Scenario 3 – 2 RKs – KG/Hour

General

We see in Figure 5-25 that Company X can reach the 1,000 tons with all future states. One future state is more attractive than another, since some future states have no impact al all on the other filling lines. Especially when the number of shifts is increasing for some future states, the KG/Hour for the SFVision decreases while the KG/Hour for the other filling lines remains almost equal. We conclude that using broken shifts, using the new routing, and sharing the BKs of the GVP filling line Company X can produce 1,000 tons with 12 shifts. This results in the highest KG/Hour and the lowest WOP over all filling lines and is therefore the most efficient future state. The impact of this future state on the other filling lines is almost negligible, since the kilograms per hour for these lines coincides with the kilograms per hour out of our validation. With Future State 8, we see an increase in profit of €7,260 while using 12 shifts. The payback period for this future state is 167 weeks, as can be seen in Table 15 in Appendix I. This table also displays the revenues, the costs, the profit, and the payback period for the other future states.

When we increase the number of shifts, we see that the WOP for the SFVision is increasing, but the WOP for the other filling lines is hardly increasing. So, we see that with 2 extra RKs Company X can even produce around 1,250 tons a week on the new filling line without any impact on the other filling lines. With 15 shifts, we increase the profit by €9,416 a week in relation to the future state with no alterations. This results in a payback period of 129 weeks. Next, we see, just as with the previous scenario, that the results of the future states with the broken shifts do not alter much in relation to the future states without those broken shifts. The higher the number of shifts, the lower the number of shifts that are broken. Therefore, we do not recommend using broken shifts when Company X is planning to use more than 12 shifts.

Concluding, Company X can produce more than 1,000 tons a week while adding 2 RKs at the mixing department without an impact for the other filling lines with the same number of shifts. So, this is the same conclusion as with 1 extra RK, therefore we recommend that Company X only builds 1 RK when they want to produce 1,000 tons on the new filling line. At a maximum, Company X can produce around the 1,250 tons a week on the new filling line when Company X uses the future state with all three interventions and 15 shifts.

Transport and Finished Goods Warehouse

Just as with Growth Scenario 2 and scenario 1, the blocked time did not increase in relation to Growth Scenario 1, because the KG/Hour for the SFVision did not increase. So, no alterations are required at the AGVs, the pallet wrapper, or the top foil machine.

When analysing the results of the FGW, we see that we need extra truck transports per week. Table 5-9 displays how many extra truck transports we need over a five-week period. When analysing the number of truck transports and FTEs required, as displayed in Table 20 in Appendix J, Figure 5-27, and Figure 5-28, we see that we always need at least 7 truck transports and still 1 extra FTE in the night. For the afternoon shift we do not need extra FTEs, but we do need one extra truck transport. The 10 truck transports in the morning are enough to transport the pallets to the EDCs, but we do need a fourth FTE in the morning to be able to process all pallets.

Intervention	Shifts	Extra Trucks	Cancelled Trucks	Number of Shifts Above 7 Hours	Average Number of Incoming Pallets per Shift
Broken shifts + New Routing	13	83	0	40	239.85
	14	95	0	42	245.05
	15	110	0	42	251.20
Extra BKs + New Routing	12	79	0	42	238.20
	13	97	0	43	245.64
	14	113	0	46	252.41
	15	125	0	50	255.64
Broken shifts + Extra BKs	13	85	0	40	240.90
	14	97	0	43	245.90
	15	109	0	41	250.77
Broken Shifts + New Routing + Extra BKs	12	80	0	38	241.28
	13	93	0	44	247.40
	14	104	0	47	254.08
	15	113	0	44	256.36

Table 5-9 Results Growth Scenario 3 – 2 RKs – FGW – over a five-week period

Number of Truck Transports
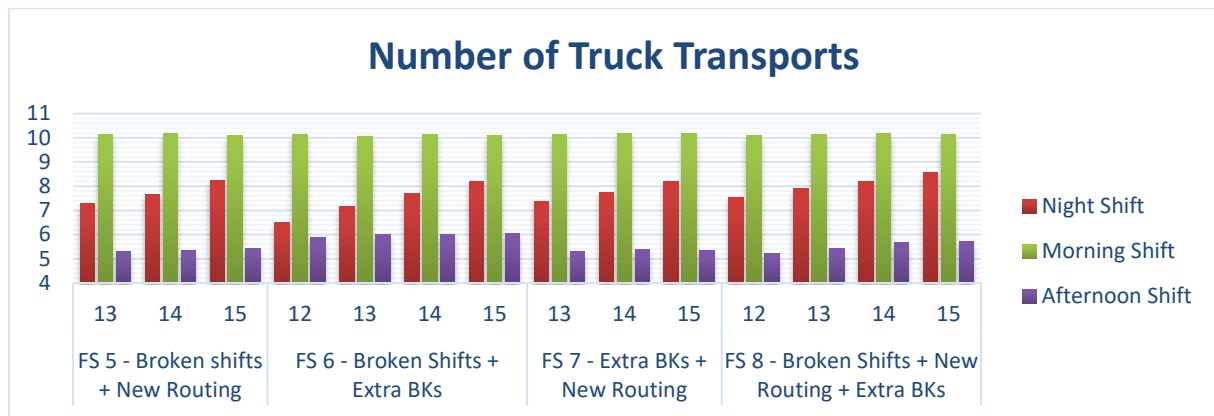
Figure 5-27 Results Growth Scenario 3 – 2 RKs – Number of Truck Transports – on average per shift
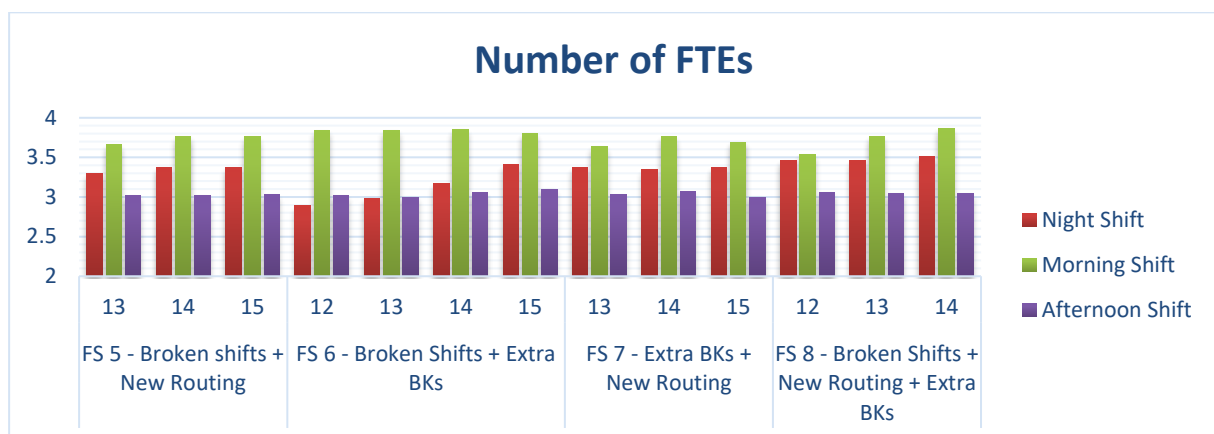
Number of FTEs

Figure 5-28 Results Growth Scenario 3 – 2 RKs – Number of FTEs – on average per shift

5.4   Conclusion

In this chapter we use the DES model to analyse multiple future states in order to answer the research questions: *"What are the results of the experiments conducted with the simulation model?"* and *"What should Company X do when considering growth in the number of tonnages produced per week on the new filling line?"*. Before analysing multiple future states, we analyse the impact of the new filling line on the production process of Company X by analysing multiple shift distributions. We conclude that a distribution of shifts where there is a maximum of one consecutive shift, results in the highest output and the most even workload for the supporting departments. Also, we conclude that by just swapping the new filling line for the 5L and 10L filling line, Company X cannot produce 700 tons a week on the new filling line. Mixing dictates the overall system throughput and is therefore the bottleneck.

To reach the 700 tons of production we exploit the bottleneck. We create multiple future states with one or more interventions that we analyse by using the DES model. We conclude that using broken shifts and extra BKs makes sure that Company X can process 700 tons a week, while still producing the required number of batches for the other filling lines. We estimate the total investment costs of this intervention at €77,200. When mixing also alters the way in which batches are started via the new routing, Company X can produce, on average, 737 tons a week. Using this future state, the profit per week increases with €2,151.80 per week. The payback period while using all three interventions combined is 36 weeks. By using this future state, we conclude that we need 3 trucks a week extra in the night shift. Arrangements with carriers should be made such that there are 22 truck transports per week. This increases the

work pressure for the FTEs in the night shift, therefore we also need one extra FTE in the night shift. With this future state, we see that the utilization of the most important RKs is almost near the 100%, which shows us that we cannot grow much higher in tonnage with the current resources. Mixing now stays the bottleneck, but where it previous was a CCR it is now a Bottleneck Resource.

Now that we know that Company X can optimally use the new filling line in combination with the other filling lines and the internal supply chain to reach the goal, we answer our second research problem. The growth scenarios we want and which Company X eventually can reach, provided that the plant is ready, are reaching 800 and 1,000 tons on the new filling line in a week. We conclude that Company X can produce 800 tons on the new filling line after analysing the future states. On the other hand, the orders for the other filling line are, as expected, decreasing, due to the high utilization of the most important RKs. It is up to the management team if they want to produce less orders on the other filling lines against the same number of resources, while increasing the total revenues. If Company X is willing to do so, then we recommend using Future State 8, since this results in the largest profit and the largest KG/Hour. The payback period while using all three interventions combined is 27 weeks with 9 shifts. However, if Company X is not willing to let the output decrease over the other filling lines, we require an extra RK.

After analysing the impact of an extra RK, we conclude that by using broken shifts, using the new routing, and sharing the BKs of the GVP filling line, Company X can produce 800 tons with 9 shifts. This results in the highest KG/Hour and the lowest WOP over all filling lines and is therefore the most efficient future state. This has no impact at all on the other filling lines, but on a negative, the payback period while producing 800 tons with Future State 8 is 204 weeks. With this future state, we see that we almost always need at least 7 truck transports and almost 2 extra FTEs in the night. We also need one extra FTE in the morning when the new filling line is up.

For the third growth scenario we want to produce 1,000 tons a week on the new filling line. Even with extra BKs, a new routing, and using broken shifts, we cannot reach this target since the utilization of the RKs is almost 100%. So, mixing is still the bottleneck. The only thing that remains is adding extra RKs at the mixing department. We conclude that Company X can produce 1,000 a week while adding 1 RK at the mixing department. The future state with all three interventions is most efficient and the payback period is 106 weeks. For this future state we always need at least 3 extra truck transports on a day, 2 extra FTEs in the night, and 1 extra FTE in the morning. When Company X wants to produce more than this target, the other filling lines get negatively affected. So, we need a second RK, when Company X wants to produce more than 1,000 tons a week without an impact for the other filling lines. The payback period for the most efficient future state to produce 1,000 tons with 2 extra RKs is 167 weeks. Company X can produce a maximum of the 1,247 tons a week on the new filling line when Company X uses the future state with all three interventions and 15 shifts. The payback period for this future state is 129 weeks.

6 Conclusions and Recommendations

This chapter provides a conclusion to the research problems. Section 6.1 provides the conclusions of the research. Section 6.2 addresses research and additional recommendations. Section 6.3 addresses the limitations of this research and Section 6.4 describes subjects for further research. We conclude this chapter in Section 6.5 with some final words.

6.1 Conclusions

Company X currently does not know what the impact of the new filling line is on the organization and the planning department. The new filling line asked for an enormous investment and Company X wants to optimally use this filling line for multiple growth scenarios in combination with the existing lines. First, we answer the following research question:

What is the impact of the new filling line on the internal supply chain and how can Company X optimally use the new filling line, considering the available resources?

Subsequently, we answer the second research question:

How can we identify and elevate the bottleneck that arise, after growth in tonnage production on the new 5L and 10L filling line, considering the internal supply chain?

6.1.1 Research Question 1

By just incorporating the new filling line in the simulation model, Company X cannot produce 700 tons a week for multiple shift distributions. We conclude that a distribution of shifts where there is at most consecutive shift results in the highest output and the most even workload for the supporting departments. So, we do not have to order any extra truck transports and the filling line is influenced by the transport department in acceptable way. Since the WOP is high for the new filling line, we conclude that the mixing department is the current bottleneck, since mixing dictates the overall system throughput. However, mixing still has spare capacity, since the average utilization of the RKs is 92%. To be able to optimally use the new filling line we analyse multiple future states with one or more interventions. For the first six future states, we do see an increase in tonnage, but Company X cannot produce 700 tons per week on the SFVision with these future states due to the high WOP. So, we conclude that if Company X wants to use 8 shifts, a combination of interventions is necessary. Two future states result in producing at least 700 tons on the new filling line. The future state with extra BKs, a new way in which orders are started at mixing, and using broken shifts results in the highest output for the SFVision and the highest revenue. For this future state we need 3 trucks a week extra in the night shift. This increases the work pressure for the FTEs in the night shift, therefore we also need one extra FTE in the night shift. In this way we can optimally use the new filling line, considering the available resources. For the transport department we need to reduce the setup time for the top foil machine from 10 to 5 minutes and move the AGV 4 meters closer to the new filling line to reduce the time in which the new filling line is blocked.

6.1.2 Research Question 2

To answer the second research question, we first determine the growth scenarios that Company X would like to reach. Second, we use the DES model to give insight in how we can reach the growth scenarios. The growth scenarios Company X wants to reach, provided that the plant is ready, are reaching 800 and 1,000 tons on the new filling line in a week. For the first growth scenario we use extra shifts in combination with extra BKs, having a new routing, and/or using broken shifts, since these future states result in a highly increased output. We

conclude that Company X can produce 800 tons on the new filling line while using all combinations of the interventions. However, the WOP for the new filling line and the other filling lines increases when the shifts increases, because the utilization of the most important RKs is almost 100%. One future state has a higher impact than another on the number of orders produced over the other filling lines. While using this future state, we almost always need an extra truck transport and an extra FTE in the night. The 10 and 5 truck transports in the morning and afternoon respectively, are almost always enough to transport the pallets to the EDCs. So, to reach the 800 tons of production we need to use all interventions combined, having 4 extra truck transports, and having 3 FTEs in the night shift. However, if Company X is not willing to let the output decrease over the other filling lines, we require an extra RK. After analysing the impact of an extra RK, we conclude that by using broken shifts, using the new routing, and sharing the BKs of the GVP filling line, Company X can produce 800 tons with 9 shifts. This results in the highest KG/Hour and the lowest WOP over all filling lines and is therefore the most efficient future state. This has no impact at all on the other filling lines, but on a negative, the payback period while producing 800 tons with Future State 8 is 204 weeks. With this future state, we see that we almost always need at least 7 truck transports and almost 2 extra FTEs in the night. We also need one extra FTE in the morning when the new filling line is up.

Next, we conclude that Company X can produce 1,000 tons a week while adding 1 RK at the mixing department. However, when Company X wants to produce more than this target, the other filling lines get negatively affected. We conclude that Company X need to use broken shifts, the new routing, and sharing the BKs with 12 shifts. This results in an output higher than 1,000 tons and the same output for the other filling lines. In this future state we need 15 extra truck transports per week and 2 extra FTE for all night shifts. Now we also need 1 extra FTE in the morning shift

When Company X builds 2 extra RKs, Company X can produce more than 1,000 tons a week without an impact for the other filling lines. The payback period for the most efficient future state, the future state with all three interventions, is 167 weeks. Also, Company X can produce a maximum of the 1,247 tons a week on the new filling line when Company X uses the future state with all 3 interventions and 15 shifts. The payback period for this future state is 129 weeks.

Concluding, Company X can reach all growth scenarios when the interventions are implemented. The transport department is not a bottleneck, since the AGVs, the pallet wrapper, and the top foil machine do not have an impact on the output of the filling lines. The FGW is a bottleneck, since we need to make sure that we have an extra FTE in the night shift and extra truck transports. If the FGW is not proper handled, the warehouse gets overfull and thereby the filling lines cannot deliver their stacked pallets. This results in standstills at filling lines.

6.2 Recommendations

Now we give the recommendations to Company X. We recommend on how Company X should alter its currents practices to be able to use the new filling line optimally for a given number of tonnages per week. Next, we give additional recommendations.

6.2.1 Research Recommendations

Since we want to know how Company X can optimally use the new filling line to reach 700 tons, considering the available resources, we recommend Company X to share the BKs of the

GVP filling line with the SFVision, use broken shifts, and use the new routing since this results in the highest output for the SFVision and the highest revenue. We recommend to arrange 3 trucks a week extra in the night shift, while using this future state. Arrangements with carriers should be made such that there are 22 truck transports per week. This increases the work pressure for the FTEs in the night shift, therefore we also need 1 extra FTE in the night shift.

When Company X is ready to grow in the amount of tonnage on the SFVision to 800 tons, we recommend using the new routing and broken shifts, since this results in the largest profit. The downside of this future state is that we need 11 shifts to produce 800 tons, thus this results in a large amount of WOP on the new filling line. However, in this way, the number of tonnages on the other filling lines remains equal. The payback period for the combination of broken shifts and the new routing is 8 weeks with 11 shifts. If Company X does not want to have any WOP on the SFVision, we recommend using the future state with all 3 interventions. With this future state we only need to use 9 shifts. This future state results, with 9 shifts, in the same amount of tonnage per week for the other filling lines but in somewhat less tonnage on the SFVision. When analysing the results of the FGW, we see the same phenomenon as before. Now we need 4 extra truck transports in a week and 1 extra FTE in the night shift. The payback period while using all three interventions combined is 27 weeks with 9 shifts. However, if Company X is not willing to let the output decrease over the other filling lines, we recommend building an extra RK. By using the new routing and sharing the BKs of the GVP filling line Company X can produce 800 tons with 9 shifts. This results in the highest KG/Hour and the lowest WOP over all filling lines and is therefore the most efficient future state. This future state has no impact at all on the output of the other filling lines.

When Company X is ready to grow in the amount of tonnage on the SFVision to 1,000 tons, we recommend Company X to build 1 extra RK at the mixing department. This RK should have the same characteristics as RK103. Next, Company X needs to use the broken shifts, the new routing, and sharing the BKs with 12 shifts. This results in an output higher than 1,000 tons and the same output for the other filling lines. In this future state we need 15 extra truck transports per week and one extra FTE for all night shifts. If Company X only wants to produce 1,000 tons on the new filling line, we do not recommend building 2 extra RKs. We only recommend building 2 extra RKs when Company X wants to produce more on the new filling line than 1,000 tons, because with 1 RK the tonnages on the other filling lines decreases. With 2 RKs, all 3 interventions, and 15 shifts, Company X can produce the required output on the other filling lines while also producing 1,250 tons on the new filling line.

6.2.2 Additional Recommendations

Data in SAP and reality does not always correspond. So, sometimes the data in SAP says that there is more or less liquid in a raw material tank than in reality. This leads to rescheduling a truck delivery by the planning department, while this was not necessary. Rescheduling a truck delivery costs money and time. Eventually, this could lead to rescheduling the planning of orders at the filling department. Every Sunday night, the team leader revises the data in SAP. To make sure that data corresponds with reality, we recommend for the short term to revise the data in SAP on a more regular basis or to make an online platform in which Call Off can see the volume of a tank in real time. We recommend for the long term to make the data more accurate in SAP, such that the data in SAP corresponds with reality.

Company X is currently busy to unroll a new software system. This software system is called the ODCE toolkit and collects data from the filling lines. Momentarily, this data is not representative, since the operators do not fill in the data as required. More focus is required

on this toolkit, so that this toolkit ultimately provides the planning department with better parameters.

Momentarily, the planning department uses an Excel sheet with all orders that are ideally produced in the week. Scheduling is hard, since it is not visualized when orders are produced. This leads to mistakes and thus rescheduling. We recommend planning on basis of a Gantt Chart, in which all orders with their specific characteristics are displayed. Now, planning can happen by dragging and dropping orders in a specific order.

As explained in Chapter 2, Company X uses an attic where some filling lines are supplied with containers and caps. The employee supplying those products does not know how many containers or cans he or she should supply through the dosing bunkers (containers) and cap hoppers (caps). Often, the FTE supplies more than necessary. Eventually, the filling line operator needs to clean the surplus containers and caps before he or she can start a new batch. This takes much time in which no products are produced. Our recommendation is to set some computers next to the dosing bunkers and cap hoppers, such that the FTE can register how many containers or caps he or she supplied. On this computer also the maximum number of containers or cans should be displayed, such that the FTE can compare the maximum with his own supply. This would result in less surplus containers and caps and this decreases the line clearance time.

6.3 Research Limitations
In this section, we critically discuss our research. There are some limitations that might have influenced the accuracy of our simulation model. First, there was little data available on mixing, filling, and setup times. We cannot say with certainty that the data used is accurate and representative. As there was little data available, the corresponding statistical distributions might therefore not represent the real world adequately. Second, as the production line is built but not producing at the designed speed, due to start-up problems, we are not able to validate the simulation model after including the new filling line. Third, Company X does not store failure data, therefore we could not include failure data. Therefore, we use an OEE Rate to enlarge the filling time. More data should be collected to improve the accuracy of the simulation model. Fourth, the Supply Chain Finance Analyst assumes that the costs per ton decreases when the total tonnage is increasing. Since we do not know with how much the costs per ton is decreasing, we use the €219 which is the current target. This can result in a skewed payback period. Fifth, we assume that the RKs have a maximum utilization of 100%, which is also feasible to reach. It is unknown if this is the case. Finally, as said before, not all RKs can mix all batches due to several reasons. We included specific remarks and the connections between RKs and BKs in the simulation model. The matter that we did not consider, is the connections of a RK to the raw material kettles. So, in the DES model we could start a batch at a RK where the connection between the RK and the raw material kettle does not exist for all ingredients.

6.4 Further Research
Further research needs to be done in analysing the impact of the Support Team on the new filling line, since we left this department outside our scope. It remains unsure if the Support Team department is capable to deliver the raw materials JIT to mixing or the filling lines. If the Support Team is not capable to do this, this could result in standstills at the new filling line. The delivery of the raw materials from the warehouses to the filling line should not be a problem, but the delivery of goods to the warehouses could be a potential bottleneck. Nowadays, the on-time delivery of multiple goods does not go according to plan, therefore this results in a great deal of rescheduling. This could result in the fact that Company X is not reaching the

targets on the new filling line. When the volume increases, Company X needs more deliveries per day. With the current number of resources, it is unsure if Company X is capable to unload all trucks in a week.

We recommend that the impact of the new filling line on the Canhal is analysed. In the Canhal the 5L, 10L, and 20L cans are delivered to the filling lines. The 5L cans are delivered via a depalletizer. The canhal employee only has to put pallets with the 5L containers on a conveyor belt via a forklift truck, when the SFVision is active and producing 5L cans. When the SFVision produces 10L containers, the canhal employee has to put the containers, by hand, on a conveyor belt. The canhal employee needs to do the same for the Alwid20L as for the 10L cans, when the line is active. When the SFVision is producing 10L cans, the canhal employee needs to put 1,000 cans in 22 minutes on the buffer track. It remains unsure if the canhal employee can combine the activities of supplying the 10L cans and the 20L cans at the same time. We recommend that Company X analyses this potential bottleneck. Next, we see that when the SFVision produces 5L cans, a maximum of 15,520 cans can be reached in a shift. The supplier of the 5L cans has some restrictions. First, no more than 10 trailers may be retrieved per week. Second, no more than 2 trailers may be retrieved per day. Finally, one trailer cannot contain more than 9,504 cans. So, this means that we use 1.6 trailers per shift. On average we use 80,000 5L cans and 30,000 10L cans per week, when we want to produce 700 tons. This means that Company X will retrieve the 9 trailers per week, but the supplier needs to be informed that the moment of pickup, by the carrier, is changing since no more than 2 trailers can be retrieved per day and in the worst case, where Company X is only producing 5L cans, we need 4.8 trailers per day. New arrangements are not particularly necessary for this future scenario. The same goes for the delivery of 10L cans and 20L cans, since only the volume of 5L cans increases. When Company X wants to produce 800 or 1000 tons, then we need respectively 11 and 15 truck transports of 5L cans in a week. Arrangements with the supplier and the carrier are needed for these growth scenarios. We recommend that Company X explores the possibility if the current supplier and the carrier can deliver such an amount per week.

6.5 Final Words
Removed due to confidentiality.

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Appendix

Appendix A – Supply Plan Adherence
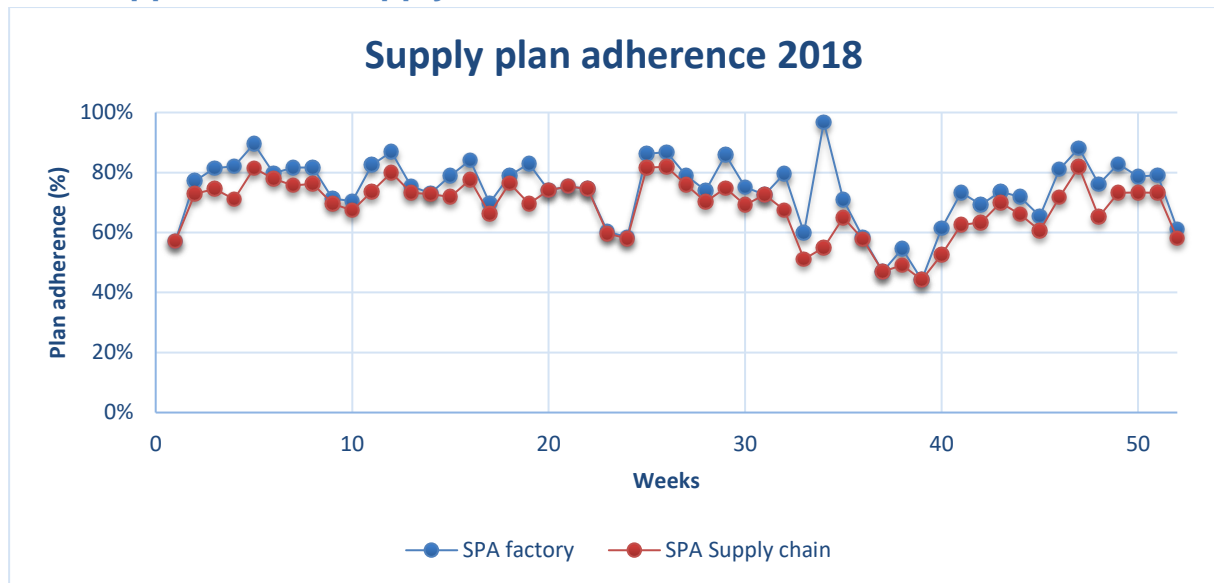
Figure 1 Supply Plan Adherence 2018

Appendix B – Flow of Materials

Figure 2 Layout of the Production Plant of Company X Enschede

Appendix C – Current Layout
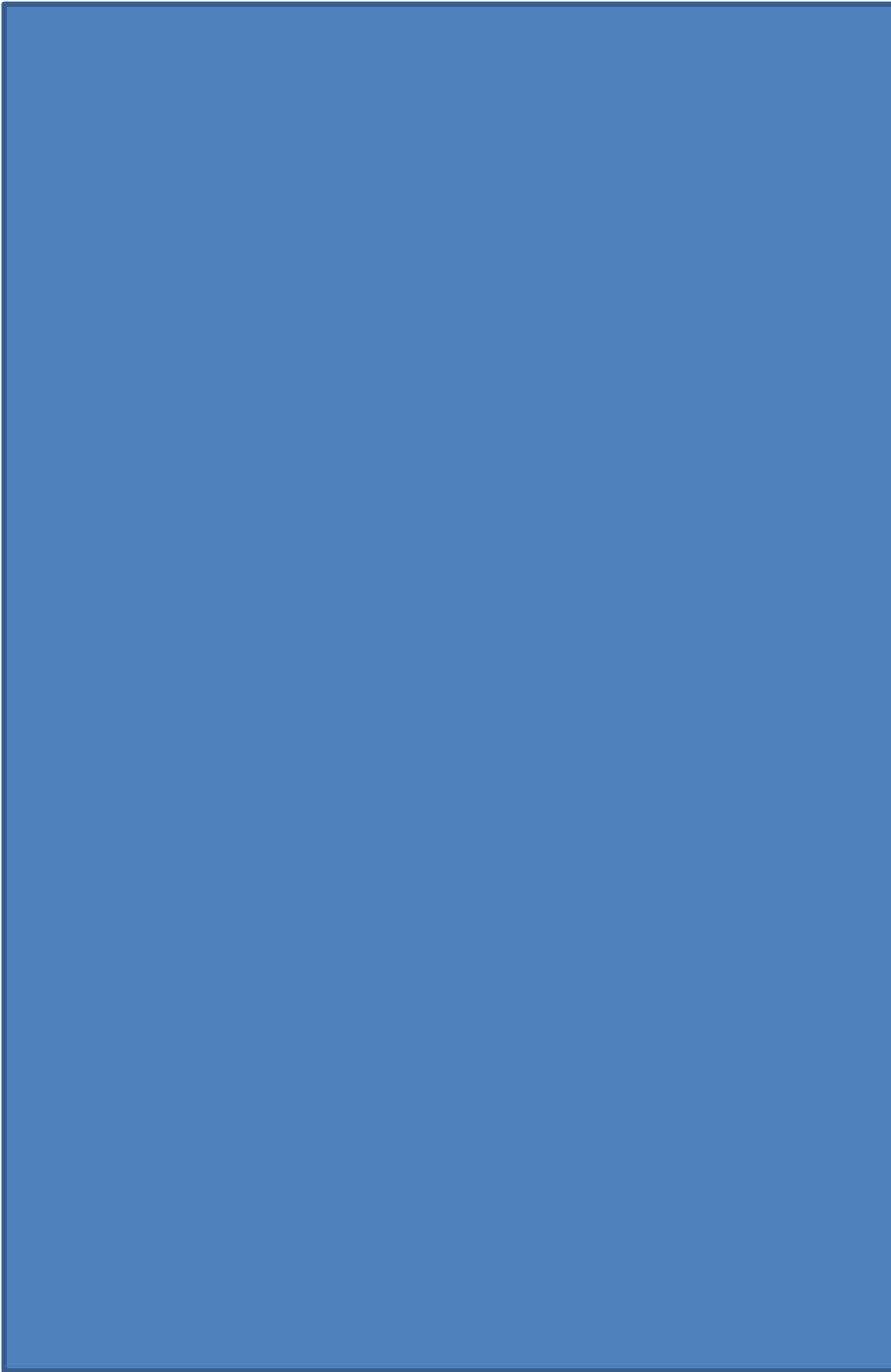
Figure 3 Layout Filling Department Current Situation

Appendix D – Future Layout
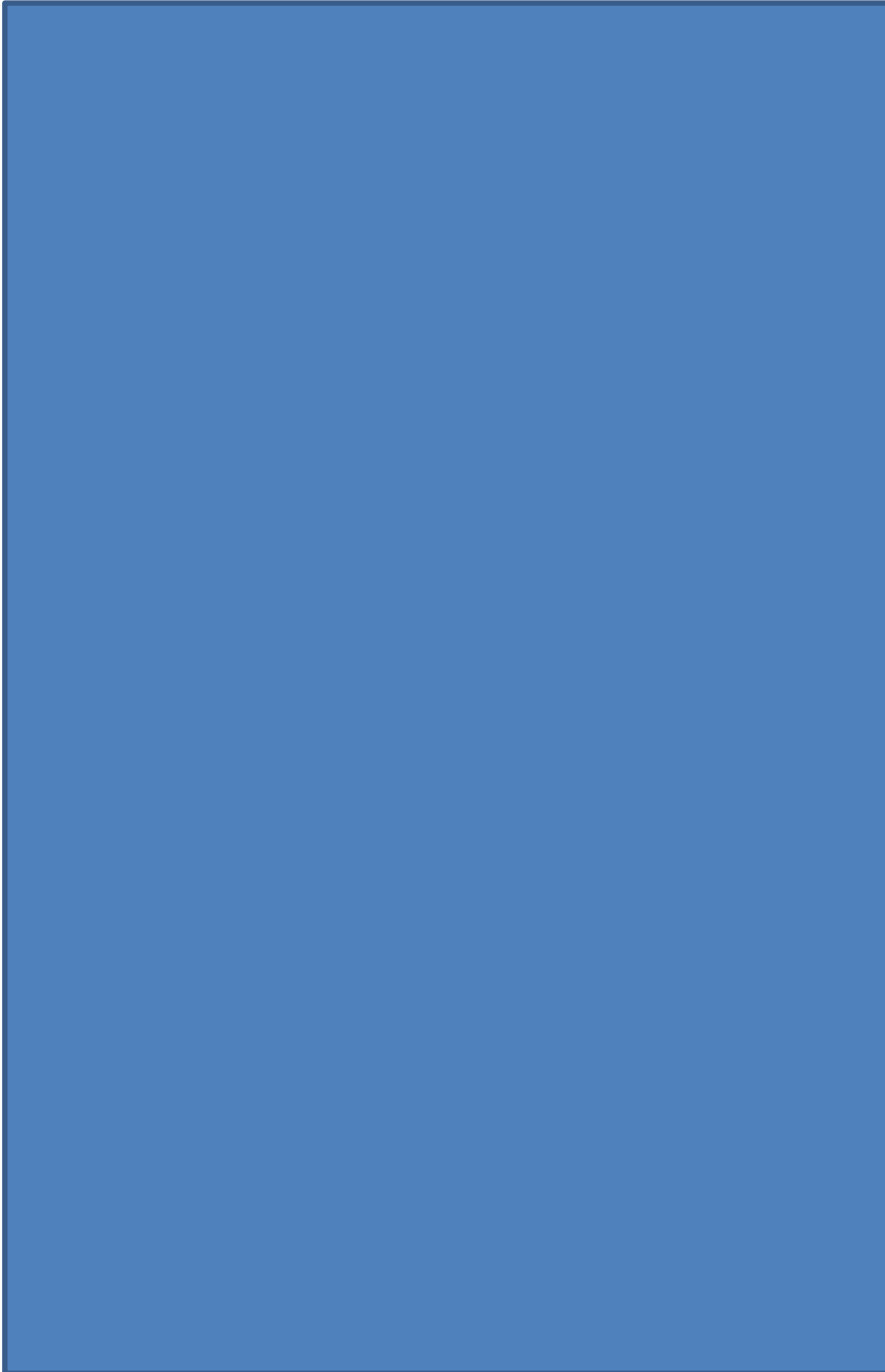
Figure 4 Layout Filling Department Future Situation

Appendix E – Setup Matrix

Figure 5 Setup Matrix

Appendix F – Warmup and Number of Replications

To determine the warmup period, we use Welch's graphical approach. The idea is to take the mean of a batch over n runs, such that the mean smooths variability in individual observations. It provides more insight in dependency on initial state. Then, the moving average over a predefined window *w* is taken to smooth out high-frequency fluctuations. These moving averages are plotted, and we choose the observation beyond which the output is stable is taken as the warmup period. Figure 6 displays the plot with a window of 100 and 10 replications. Concluding, we exclude the first week of the simulation model, since, on average, one week consists of 180 batches. This means, that we start gathering data from this point onwards. Obviously, this method is not completely correct, since weeks of production differ among each other due to different shift distributions. Therefore, we choose a high predefined window to smooth out these high-frequency fluctuations.
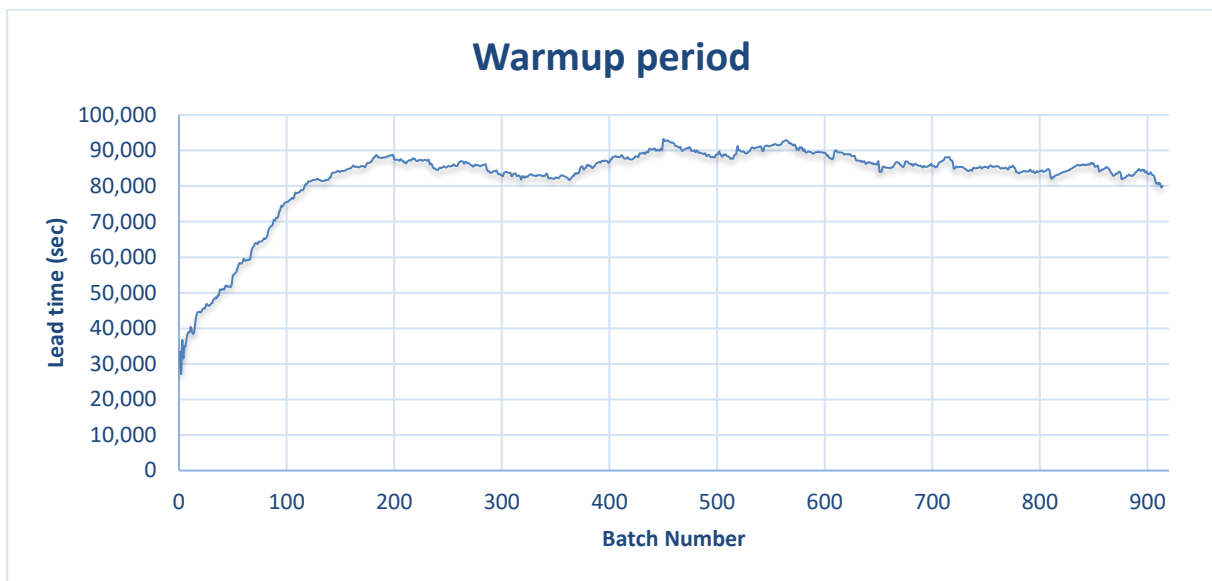
Figure 6 Determining the Warmup Period

For the number of replications necessary in our simulation model, we perform some preliminary runs. The approach to determine the number of replications is as follows. First, we make n independent replications with the same initial condition, same terminating event, and different seed values for the random number generator. We perform replications until the width of the confidence interval, relative to the average is sufficiently small. Equation 1 displays the formula used.

$$\frac{t_{n-1,1-\alpha/2}\sqrt{S^2/n}}{\overline{X}} < \gamma'$$

Equation 1 Number of Replications

In the formula, $\overline{X}$ is the average over the number of replications *n*, while S^2 is the variance of the number of replications. We take a significance level of 95% and use the Student's t-distribution for n-1 degrees of freedom. Also, we use a relative error of 5%. This 5% is the relative error, in our case, we want the corrected target value. These numbers are commonly used in simulation studies (Law, 2015). Equation 2 displays the formula used to calculate the corrected target value.

$$\gamma' = \frac{\gamma}{(1+\gamma)}$$

Equation 2 Corrected Target Value

We take the total lead time as the indication used, since the lead time is a good indication of which the average can be taken. In addition to this practical reason, the lead time also says a lot of the results of one replication. By using this formula and when looking at the total lead time, we see that after two replications the error is below the relative error. Therefore, we conclude that three replications are sufficient.

n	Average lead time per run	Average lead time n replications	Variance	t-inv	CI half-width	Error	OK/NOTOK
1	87,080.84						
2	83,998.76	85,539.80	4,749,630.87	12.71	19,580.82	0.229	NOTOK
3	85,307.00	85,462.20	2,392,880.85	4.30	3,842.70	0.045	OK
4	80,954.05	84,335.16	6,676,117.78	3.18	4,111.43	0.044	OK

Table 1 Determination of the Number of Replications

Appendix G – Shift Distributions Filling Lines

Week 1	Shifts															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Kugler				1			1	1			1	1	1	1	1	8
Breitner	1		1	1	1	1	1		1	1	1		1	1		11
Multivuller	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
ABL		1		1		1	1				1		1			6
cGMP		1	1	1	1		1	1		1				1	1	9
Pouch	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Alwid20L	1	1		1	1		1		1	1		1		1		9
SFVision5L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Safepack	1	1		1		1	1	1	1	1	1	1	1	1		12
Rauenberg10LGVP	1	1	1		1	1		1		1	1		1		1	10
Flexlijn		1	1		1	1		1	1		1	1		1	1	10
Total	7	9	7	9	8	8	9	8	7	8	9	7	8	9	7	120

Week 2	Shifts															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Kugler	1		1	1	1	1		1	1		1	1			1	10
Breitner	1	1	1	1		1	1		1	1		1	1	1		11
Multivuller	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
ABL		1	1		1			1	1		1	1				7
cGMP		1		1	1		1	1		1	1		1	1	1	10
Pouch	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Alwid20L	1		1	1		1	1	1	1		1	1		1	1	11
SFVision5L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Safepack	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Rauenberg10LGVP		1		1	1	1	1	1		1	1		1	1	1	11
Flexlijn	1	1	1		1	1	1	1	1	1	1	1	1	1	1	14
Total	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	134

Week 3	Shifts															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Kugler	1		1	1		1	1		1	1		1	1		1	10
Breitner							1			1	1	1	1	1	1	7
Multivuller	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
ABL		1			1		1	1			1			1		6
cGMP		1	1	1	1	1		1	1	1	1	1	1	1	1	13
Pouch	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Alwid20L		1	1		1	1		1	1	1	1	1		1	1	11
SFVision5L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Safepack	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Rauenberg10LGVP	1	1	1	1	1		1	1		1	1		1	1		11
Flexlijn	1		1	1		1	1	1	1			1	1		1	10
Total	7	8	9	8	8	8	9	9	8	9	9	9	9	9	9	128

Week 4	Shifts															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Kugler	1		1	1		1	1		1	1		1	1		1	**10**
Breitner	1		1	1			1		1	1	1	1	1	1	1	**11**
Multivuller	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
ABL		1	1		1	1		1			1			1	1	**8**
cGMP		1		1	1		1	1		1	1		1		1	**9**
Pouch	1	1		1	1	1	1	1	1	1		1	1	1	1	**13**
Alwid20L	1	1	1		1	1		1	1		1	1		1		**10**
SFVision5L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
Safepack	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
Rauenberg10LGVP	1	1	1	1	1	1	1	1	1	1	1	1	1	1		**14**
Flexlijn	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
Total	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	**135**

Week 5	Shifts															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Kugler	1		1	1		1	1	1	1	1	1	1		1	1	**12**
Breitner	1	1		1	1		1	1		1	1		1	1		**10**
Multivuller	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
ABL		1		1			1							1		**4**
cGMP	1		1		1	1			1	1	1	1	1	1	1	**11**
Pouch	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
Alwid20L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
SFVision5L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
Safepack	1	1	1	1	1	1	1	1	1	1	1	1	1	1		**14**
Rauenberg10LGVP	1	1	1	1	1	1	1	1	1		1	1	1	1	1	**14**
Flexlijn		1	1		1	1		1	1	1		1	1		1	**10**
Total	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	**135**

Week 6	Shifts															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Kugler	1	1			1	1		1	1		1	1	1	1	1	**11**
Breitner	1		1	1		1	1	1	1		1	1	1	1	1	**12**
Multivuller	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
ABL		1		1	1		1	1			1		1	1		**8**
cGMP			1	1		1	1		1	1					1	**7**
Pouch	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
Alwid20L	1	1	1	1	1	1			1	1	1	1		1	1	**12**
SFVision5L	1	1	1	1	1	1		1	1	1	1	1	1	1	1	**14**
Safepack	1	1	1	1	1			1	1	1	1	1	1	1		**12**
Rauenberg10LGVP	1	1	1		1	1			1	1		1	1		1	**10**
Flexlijn	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
Total	9	9	9	9	9	9	7	8	9	8	9	9	9	9	9	**131**

Appendix H – Shift Distributions New Filling Line

#shifts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Sum	M	D	W	D	V
8	1	1	1	1	1	1	1	1								8	3	3	2	0	0
8								1	1	1	1	1	1	1	1	8	0	0	2	3	3
8	1	1				1	1	1	1	1	1					8	2	1	3	2	0
8	1			1	1		1			1	1			1	1	8	1	2	1	2	2
8	1		1		1		1		1		1		1		1	8	2	1	2	1	2
8	1	1	1	1					1	1	1	1				8	3	1	1	3	0
8	1				1	1	1	1	1	1	1					8	1	2	3	2	0
8	1	1			1	1		1	1			1	1			8	2	2	2	1	1
8	1	1	1	1		1	1	1			1	1				8	3	1	2	2	0
8	1	1				1	1	1				1	1	1		8	2	1	2	1	2
9	1	1			1	1		1	1		1			1	1	9	2	2	2	1	2
10	1	1		1	1		1	1		1	1		1	1		10	2	2	2	2	2
11	1	1		1	1	1		1	1		1	1		1	1	11	2	3	2	2	2
12	1	1		1	1	1		1	1		1	1	1	1	1	12	2	3	2	2	3
13	1	1	1	1	1	1		1	1	1	1	1		1	1	13	3	3	2	3	2
14	1	1	1	1	1	1		1	1	1	1	1	1	1	1	14	3	3	2	3	3
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	3	3	3	3	3

Table 2 Shift Distribution per Number of Shifts

#Shifts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Sum
8	1		1		1		1		1		1		1	1	1		1		1		1		1		1		1		1		16
9	1		1	1	1		1		1		1	1	1		1		1		1		1	1	1		1		1		1		18
10	1		1	1	1		1		1	1	1		1	1	1		1	1	1		1	1	1		1		1		1		20
11	1		1	1	1		1		1	1	1		1	1	1		1	1	1	1	1		1	1	1		1		1	1	22
12	1	1	1	1	1		1		1	1	1		1	1	1		1	1	1	1	1		1	1	1		1	1	1	1	24
13	1	1	1	1	1		1	1	1	1	1		1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	26
14	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	28
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	30

Table 3 Shift Distribution per Number of Shifts for Broken Shifts intervention

Appendix I – Filling and Mixing Results

Growth Scenario 1

Scenario	WOP SFVision	WOP Others	Utilization	Orders SFVision	Orders Others
No changes	3.017	0.885	0.919	-58.33	-7.33
Future State 1	2.151	0.851	0.942	-20.33	-4.67
Future State 2	3.014	1.228	0.909	-59.67	-5.67
Future State 3	2.149	1.165	0.936	-31.33	-2.00
Future State 4A	1.617	1.367	0.938	-21.67	-9.00
Future State 4B	1.778	2.203	0.939	-17.33	-21.33
Future State 5	1.329	0.994	0.954	-2.33	-5.67
Future State 6	0.846	3.388	0.977	8.00	-16.00
Future State 7	0.493	1.999	0.968	20.33	-11.67
Future State 8	0.061	2.915	0.981	34.67	-18.33

Table 4 Growth Scenario 1 – Results Table 1 – over a five-week period

Future State	Tonnage SFVision	KG/Hour SFVision	KG/Hour Others	Revenues SFVision	Revenues Others	Total Revenues	Total Tonnage per week
No changes	566.78	8,855.95	889.94	132,060	289,634	421,694	1,809,844
Future State 1	636.77	9,949.58	893.85	148,368	290,909	439,277	1,885,308
Future State 2	563.36	8,802.51	892.45	131,263	290,450	421,713	1,809,928
Future State 3	618.02	9,656.59	893.53	143,999	290,803	434,802	1,866,102
Future State 4A	633.67	9,901.10	888.54	147,645	289,180	436,825	1,874,788
Future State 4B	640.38	10,005.94	877.10	149,209	285,455	434,664	1,865,511
Future State 5	668.00	10,437.44	893.16	155,643	290,682	446,325	1,915,559
Future State 6	687.19	10,737.30	877.48	160,115	285,578	445,693	1,912,846
Future State 7	710.65	11,103.83	884.22	165,580	287,772	453,352	1,945,718
Future State 8	737.18	11,518.46	877.98	171,763	285,742	457,506	1,963,543

Table 5 Growth Scenario 1 – Results Table 2 – on average per week

Future State	Tonnage	Revenues	Costs	Profit	Increase in profit	Invest-ments	Payback Period
No changes	1,809,844	421,694	396,356	25,338	-	0	-
Future State 1	1,885,308	439,277	412,883	26,394	1,057	25,200	24
Future State 2	1,809,928	421,713	396,374	25,339	1	0	-
Future State 3	1,866,102	434,802	408,676	26,125	788	2,000	3
Future State 4A	1,874,788	436,825	410,578	26,247	909	52,000	57
Future State 4B	1,865,511	434,664	408,547	26,117	779	52,000	67
Future State 5	1,915,559	446,325	419,507	26,818	1,480	27,200	18
Future State 6	1,912,846	445,693	418,913	26,780	1,442	52,000	36
Future State 7	1,945,718	453,352	426,112	27,240	1,902	77,200	41
Future State 8	1,963,543	457,506	430,016	27,490	2,152	77,200	36

Table 6 Growth Scenario 1 – Payback Period – on average per week

Growth Scenario 2

Future State	Shifts	WOP SFVision	WOP Others	Utilization	Orders SFVision	Orders Others
Future State 5	9	2.158	1.865	0.967	-30.00	-10.00
Broken shifts &	10	2.675	3.879	0.986	6.33	-13.67
New Routing	11	3.320	6.214	0.994	36.67	-24.00
	12	3.934	11.090	0.999	63.67	-48.67

Future State						
Future State 6	9	1.909	9.647	0.970	-27.67	-39.00
Extra BKs &	10	1.888	10.857	0.993	31.00	-55.33
New Routing	11	2.671	14.694	0.995	50.67	-64.33
	12	3.299	18.288	0.998	81.67	-84.67
Future State 7	9	1.152	3.057	0.978	0.67	-19.00
Broken shifts &	10	2.005	5.359	0.989	26.00	-21.67
Extra BKs	11	2.619	8.980	0.996	49.67	-40.33
	12	3.939	12.872	1.000	67.33	-54.67
Future State 8	9	0.516	6.803	0.992	19.67	-30.00
Broken shifts &	10	1.237	13.342	0.998	47.33	-55.33
New Routing &	11	1.793	17.601	1.000	74.00	-75.67
Extra BKs	12	2.677	21.326	1.000	98.67	-95.00

Table 7 Growth Scenario 2 – Results Table 1 – over a five-week period

Future State	Tonnage SFVision	KG/Hour SFVision	KG/Hour Others	Revenues SFVision	Revenues Other filling lines	Total Revenues	Total Tonnage per week
Future State 5	711.19	9,877.63	888.99	165,707	289,326	455,033	1,952,932
Broken shifts &	777.51	9,718.88	881.97	181,160	287,042	468,202	2,009,451
New Routing	834.46	9,482.51	866.67	194,429	282,061	476,490	2,045,022
	884.66	9,215.25	834.10	206,127	271,460	477,587	2,049,729
Future State 6	714.57	9,924.53	847.85	166,494	275,936	442,430	1,898,842
Extra BKs &	823.62	10,295.21	826.74	191,903	269,065	460,968	1,978,404
New Routing	860.57	9,779.16	812.89	200,512	264,559	465,071	1,996,012
	921.70	9,601.08	783.14	214,757	254,876	469,633	2,015,590
Future State 7	766.73	10,648.97	878.32	178,647	285,854	464,501	1,993,567
Broken shifts &	815.15	10,189.42	871.23	189,931	283,547	473,478	2,032,093
Extra BKs	856.95	9,738.12	847.72	199,670	275,894	475,564	2,041,048
	892.94	9,301.49	826.42	208,056	268,961	477,017	2,047,284
Future State 8	802.78	11,149.74	861.98	187,048	280,534	467,582	2,006,791
Broken shifts &	854.13	10,676.63	823.67	199,012	268,066	467,079	2,004,630
New Routing &	907.00	10,306.84	795.72	211,331	258,971	470,302	2,018,464
Extra BKs	954.18	9,939.40	769.09	222,324	250,305	472,629	2,028,452

Table 8 Growth Scenario 2 – Results Table 2 – on average per week

Future State	Tonnage	Revenues	Costs	Profit	Increase in profit	Invest-ments	Payback Period
Future State 5	1,952,932	455,033	427,692	27,341	2,084	27,200	13
Broken shifts &	2,009,451	468,202	440,070	28,132	2,875	27,200	9
New Routing	2,045,022	476,490	447,860	28,630	3,373	27,200	8
	2,049,729	477,587	448,891	28,696	3,439	27,200	8
Future State 6	1,898,842	442,430	415,846	26,584	1,327	52,000	39
Extra BKs &	1,978,404	460,968	433,270	27,698	2,441	52,000	21
New Routing	1,996,012	465,071	437,127	27,944	2,687	52,000	19
	2,015,590	469,633	441,414	28,218	2,961	52,000	18
Future State 7	1,993,567	464,501	436,591	27,910	2,653	77,200	29
Broken shifts &	2,032,093	473,478	445,028	28,449	3,192	77,200	24
Extra BKs	2,041,048	475,564	446,990	28,575	3,318	77,200	23
	2,047,284	477,017	448,355	28,662	3,405	77,200	23
Future State 8	2,006,791	467,582	439,487	28,095	2,838	77,200	27
Broken shifts &	2,004,630	467,079	439,014	28,065	2,808	77,200	27
New Routing &	2,018,464	470,302	442,044	28,258	3,001	77,200	26
Extra BKs	2,028,452	472,629	444,231	28,398	3,141	77,200	25

Table 9 Growth Scenario 2 – Payback Period – on average per week

Growth Scenario 3 – 1 RK

Future State	Shifts	WOP SFVision	WOP Others	Utilization	Orders SFVision	Orders Others
Future State 1 Current situation	8	2.843	0.421	0.836	-149.00	-2.00
	9	3.665	0.611	0.844	-128.33	2.00
	10	4.042	0.367	0.876	-85.00	-1.33
	11	4.739	0.506	0.899	-58.00	-1.00
	12	5.191	0.511	0.910	-30.33	-3.00
	13	6.094	0.612	0.921	0.00	-1.00
	14	6.383	0.728	0.950	27.33	-3.33
	15	7.363	0.888	0.962	57.00	-6.33
Future State 2 New Routing	8	1.587	0.570	0.854	-114.33	-6.33
	9	2.178	0.862	0.877	-83.00	-6.00
	10	2.429	0.694	0.906	-39.67	-8.00
	11	2.824	0.671	0.927	-1.33	-6.00
	12	3.234	1.382	0.949	35.00	-4.67
	13	3.428	2.029	0.954	70.00	-10.00
	14	3.986	2.579	0.976	106.33	-12.67
	15	4.429	3.129	0.995	143.67	-14.33
Future State 3 Broken shifts	8	1.892	0.457	0.862	-114.67	-3.33
	9	2.558	0.382	0.876	-85.67	-5.67
	10	3.486	0.413	0.888	-64.67	-4.33
	11	3.929	0.470	0.903	-35.33	-4.67
	12	4.911	0.496	0.915	-12.67	-9.00
	13	5.774	0.648	0.938	13.00	-11.67
	14	6.384	0.690	0.951	38.33	-9.33
	15	7.176	0.911	0.965	64.33	-7.67
Future State 4 Extra BKs	8	1.418	0.999	0.857	-107.67	-8.33
	9	2.304	1.203	0.867	-87.33	-11.33
	10	2.283	1.158	0.896	-36.67	-12.67
	11	3.016	1.368	0.921	-5.00	-8.67
	12	3.611	1.478	0.936	19.33	-14.00
	13	3.653	2.736	0.952	64.33	-13.00
	14	4.681	2.830	0.972	90.00	-15.67
	15	4.999	3.687	0.989	130.67	-23.00
Future State 5 Broken Shifts + New Routing	8	0.979	0.715	0.874	-95.33	-3.00
	9	1.377	0.691	0.894	-56.33	-3.67
	10	2.043	0.664	0.916	-27.00	-5.33
	11	2.601	0.550	0.936	9.33	-2.67
	12	2.963	0.843	0.949	43.33	-4.67
	13	3.240	1.419	0.966	82.33	-13.67
	14	3.884	2.365	0.981	116.33	-11.00
	15	4.481	3.830	0.994	149.33	-18.00
Future State 6 Extra BKs + New Routing	8	0.461	1.285	0.891	-79.67	-10.67
	9	1.085	5.159	0.916	-49.33	-17.33
	10	1.126	1.384	0.942	4.33	-10.67
	11	1.563	2.097	0.949	36.67	-15.67
	12	1.686	2.715	0.975	85.67	-19.33
	13	2.323	5.292	0.982	116.33	-22.00
	14	2.782	7.246	0.993	156.00	-35.00
	15	3.093	11.254	1.000	183.33	-49.00
Future State 7	8	0.346	0.833	0.882	-76.00	-5.33

Broken Shifts + Extra BKs	9	0.876	0.727	0.903	-43.00	-6.67
	10	1.563	1.066	0.919	-10.33	-8.67
	11	2.062	0.859	0.942	21.33	-7.00
	12	2.635	1.235	0.956	56.00	-12.00
	13	3.200	1.932	0.968	89.00	-12.67
	14	3.863	2.731	0.982	116.00	-11.00
	15	4.578	3.758	0.995	146.00	-18.33
Future State 8 Broken Shifts + New Routing + Extra BKs	8	1.078	1.976	0.903	-66.33	0.00
	9	1.576	4.741	0.926	-26.33	-11.33
	10	2.070	9.306	0.945	14.67	-8.00
	11	2.782	12.980	0.968	61.67	-11.33
	12	1.078	1.976	0.979	98.00	-13.33
	13	1.576	4.741	0.993	138.00	-19.67
	14	2.070	9.306	0.998	171.67	-41.33
	15	2.782	12.980	1.000	194.67	-58.33

Table 10 Growth Scenario 3 – 1RK – Results Table 1 – over a five-week period

Future State	Tonnage SFVision	KG/Hour SFVision	KG/Hour Others	Revenues SFVision	Revenues Other filling lines	Total Revenues	Total Tonnage per week
Future State 1 Current situation	584.76	9,136.88	893.86	136,249	290,911	427,160	1,833,307
	622.62	8,647.50	899.97	145,071	292,901	437,971	1,879,705
	701.04	8,763.06	895.92	163,343	291,580	454,923	1,952,460
	751.46	8,539.28	895.70	175,089	291,509	466,599	2,002,569
	802.61	8,360.53	893.18	187,008	290,689	477,697	2,050,203
	857.86	8,248.62	894.24	199,881	291,034	490,915	2,106,930
	912.59	8,148.10	892.08	212,633	290,332	502,965	2,158,648
	968.46	8,070.48	893.03	225,651	290,639	516,290	2,215,836
Future State 2 New Routing	647.61	10,118.97	891.12	150,894	290,019	440,913	1,892,329
	705.04	9,792.20	892.10	164,274	290,339	454,613	1,951,127
	784.12	9,801.55	888.87	182,701	289,288	471,989	2,025,704
	858.29	9,753.32	889.79	199,982	289,588	489,570	2,101,157
	928.41	9,670.96	890.62	216,320	289,856	506,176	2,172,429
	993.92	9,556.92	885.61	231,583	288,225	519,808	2,230,935
	1,059.88	9,463.18	882.49	246,951	287,209	534,161	2,292,535
	1,127.48	9,395.67	882.22	262,703	287,124	549,827	2,359,772
Future State 3 Broken shifts	646.86	10,107.21	889.85	150,719	289,605	440,324	1,889,803
	700.04	9,722.76	890.80	163,109	289,915	453,024	1,944,311
	738.72	9,233.94	892.73	172,121	290,544	462,665	1,985,686
	792.10	9,001.10	894.05	184,559	290,973	475,531	2,040,907
	835.17	8,699.64	890.85	194,594	289,932	484,525	2,079,508
	882.99	8,490.29	886.22	205,737	288,425	494,161	2,120,864
	935.02	8,348.35	888.90	217,859	289,295	507,154	2,176,627
	983.09	8,192.40	892.67	229,060	290,523	519,583	2,229,970
Future State 4 Extra BKs	658.20	10,284.45	891.85	153,362	290,258	443,620	1,903,948
	695.51	9,659.85	888.21	162,054	289,071	451,125	1,936,158
	789.76	9,872.01	886.20	184,014	288,417	472,431	2,027,602
	849.94	9,658.35	887.04	198,035	288,691	486,726	2,088,952
	897.61	9,350.12	883.52	209,144	287,545	496,689	2,131,711
	983.97	9,461.21	885.11	229,264	288,063	517,327	2,220,287
	1,030.05	9,196.88	882.05	240,002	287,069	527,070	2,262,104
	1,103.95	9,199.55	874.39	257,219	284,574	541,793	2,325,294
	681.59	10,649.87	895.06	158,811	291,301	450,112	1,931,812

Future State 5 Broken Shifts + New Routing	754.48	10,478.94	895.58	175,795	291,471	467,266	2,005,431
	809.08	10,113.45	892.24	188,515	290,382	478,897	2,055,351
	876.30	9,957.92	898.97	204,177	292,572	496,750	2,131,972
	944.95	9,843.20	896.83	220,173	291,877	512,050	2,197,639
	1,017.47	9,783.34	887.81	237,070	288,941	526,011	2,257,558
	1,079.80	9,641.11	888.07	251,594	289,025	540,619	2,320,253
	1,137.56	9,479.70	880.36	265,052	286,517	551,569	2,367,249
Future State 6 Extra BKs + New Routing	710.97	11,108.85	888.19	165,655	289,065	454,720	1,951,589
	767.72	10,662.84	879.68	178,880	286,297	465,177	1,996,469
	867.45	10,843.18	886.92	202,117	288,651	490,768	2,106,301
	931.92	10,590.04	881.96	217,138	287,036	504,175	2,163,839
	1,023.36	10,660.02	878.90	238,443	286,043	524,486	2,251,013
	1,079.89	10,383.53	872.93	251,614	284,098	535,712	2,299,192
	1,149.71	10,265.25	856.70	267,882	278,815	546,697	2,346,340
	1,201.50	10,012.54	839.04	279,951	273,070	553,021	2,373,479
Future State 7 Broken Shifts + Extra BKs	717.97	11,218.34	891.18	167,288	290,038	457,326	1,962,771
	777.94	10,804.69	892.64	181,260	290,513	471,773	2,024,775
	840.74	10,509.29	889.74	195,893	289,570	485,464	2,083,534
	900.36	10,231.34	891.31	209,783	290,081	499,865	2,145,342
	966.05	10,063.00	887.08	225,089	288,703	513,792	2,205,115
	1,029.53	9,899.36	886.72	239,881	288,588	528,469	2,268,109
	1,079.66	9,639.86	887.99	251,562	289,000	540,562	2,320,008
	1,131.92	9,432.64	878.11	263,736	285,784	549,521	2,358,457
Future State 8 Broken Shifts + New Routing + Extra BKs	735.00	11,484.44	897.62	171,256	292,134	463,390	1,988,797
	811.27	11,267.59	888.76	189,025	289,252	478,277	2,052,692
	886.60	11,082.52	892.90	206,578	290,599	497,177	2,133,807
	980.07	11,137.15	887.23	228,356	288,752	517,108	2,219,346
	1,046.14	10,897.28	883.72	243,750	287,610	531,360	2,280,516
	1,117.04	10,740.80	872.65	260,271	284,007	544,278	2,335,956
	1,181.26	10,547.00	846.44	275,235	275,477	550,712	2,363,569
	1,223.09	10,192.43	823.49	284,980	268,007	552,987	2,373,337

Table 11 Growth Scenario 3 – 1 RK – Results Table 2 – on average per week

Future State	Tonnage	Revenues	Costs	Profit	Increase in profit	Investments	Payback Period
Future State 1 Current situation	1,833,307	427,160	401,494	25,666	409	633,000	1,547
	1,879,705	437,971	411,655	26,316	1,059	633,000	598
	1,952,460	454,923	427,589	27,334	2,077	633,000	305
	2,002,569	466,599	438,563	28,036	2,779	633,000	228
	2,050,203	477,697	448,995	28,703	3,446	633,000	184
	2,106,930	490,915	461,418	29,497	4,240	633,000	149
	2,158,648	502,965	472,744	30,221	4,964	633,000	128
	2,215,836	516,290	485,268	31,022	5,765	633,000	110
Future State 2 New Routing	1,892,329	440,913	414,420	26,493	1,236	635,000	514
	1,951,127	454,613	427,297	27,316	2,059	635,000	308
	2,025,704	471,989	443,629	28,360	3,103	635,000	205
	2,101,157	489,570	460,153	29,416	4,159	635,000	153
	2,172,429	506,176	475,762	30,414	5,157	635,000	123
	2,230,935	519,808	488,575	31,233	5,976	635,000	106
	2,292,535	534,161	502,065	32,095	6,838	635,000	93
	2,359,772	549,827	516,790	33,037	7,780	635,000	82
Future State 3 Broken shifts	1,889,803	440,324	413,867	26,457	1,200	658,200	548
	1,944,311	453,024	425,804	27,220	1,963	658,200	335

	1,985,686	462,665	434,865	27,800	2,543	658,200	259
	2,040,907	475,531	446,959	28,573	3,316	658,200	199
	2,079,508	484,525	455,412	29,113	3,856	658,200	171
	2,120,864	494,161	464,469	29,692	4,435	658,200	148
	2,176,627	507,154	476,681	30,473	5,216	658,200	126
	2,229,970	519,583	488,363	31,220	5,963	658,200	110
Future State 4 Extra BKs	1,903,948	443,620	416,965	26,655	1,398	683,000	488
	1,936,158	451,125	424,019	27,106	1,849	683,000	369
	2,027,602	472,431	444,045	28,386	3,129	683,000	218
	2,088,952	486,726	457,480	29,245	3,988	683,000	171
	2,131,711	496,689	466,845	29,844	4,587	683,000	149
	2,220,287	517,327	486,243	31,084	5,827	683,000	117
	2,262,104	527,070	495,401	31,669	6,412	683,000	107
	2,325,294	541,793	509,239	32,554	7,297	683,000	94
Future State 5 Broken Shifts + New Routing	1,931,812	450,112	423,067	27,045	1,788	660,200	369
	2,005,431	467,266	439,189	28,076	2,819	660,200	234
	2,055,351	478,897	450,122	28,775	3,518	660,200	188
	2,131,972	496,750	466,902	29,848	4,591	660,200	144
	2,197,639	512,050	481,283	30,767	5,510	660,200	120
	2,257,558	526,011	494,405	31,606	6,349	660,200	104
	2,320,253	540,619	508,135	32,484	7,227	660,200	91
	2,367,249	551,569	518,427	33,141	7,884	660,200	84
Future State 6 Extra BKs + New Routing	1,951,589	454,720	427,398	27,322	2,065	685,000	332
	1,996,469	465,177	437,227	27,951	2,694	685,000	254
	2,106,301	490,768	461,280	29,488	4,231	685,000	162
	2,163,839	504,175	473,881	30,294	5,037	685,000	136
	2,251,013	524,486	492,972	31,514	6,257	685,000	109
	2,299,192	535,712	503,523	32,189	6,932	685,000	99
	2,346,340	546,697	513,849	32,849	7,592	685,000	90
	2,373,479	553,021	519,792	33,229	7,972	685,000	86
Future State 7 Broken Shifts + Extra BKs	1,962,771	457,326	429,847	27,479	2,222	710,200	320
	2,024,775	471,773	443,426	28,347	3,090	710,200	230
	2,083,534	485,464	456,294	29,169	3,912	710,200	182
	2,145,342	499,865	469,830	30,035	4,778	710,200	149
	2,205,115	513,792	482,920	30,872	5,615	710,200	126
	2,268,109	528,469	496,716	31,754	6,497	710,200	109
	2,320,008	540,562	508,082	32,480	7,223	710,200	98
	2,358,457	549,521	516,502	33,018	7,761	710,200	92
Future State 8 Broken Shifts + New Routing + Extra BKs	1,988,797	463,390	435,547	27,843	2,586	710,200	275
	2,052,692	478,277	449,539	28,738	3,481	710,200	204
	2,133,807	497,177	467,304	29,873	4,616	710,200	154
	2,219,346	517,108	486,037	31,071	5,814	710,200	122
	2,280,516	531,360	499,433	31,927	6,670	710,200	106
	2,335,956	544,278	511,574	32,703	7,446	710,200	95
	2,363,569	550,712	517,622	33,090	7,833	710,200	90
	2,373,337	552,987	519,761	33,227	7,970	710,200	89

Table 12 Growth Scenario 3 – 1 RK – Payback Period – on average per week

Growth Scenario 3 – 2 RKs

Future State	Shifts	WOP SFVision	WOP Others	Utilization	Orders SFVision	Orders Others
Future State 1 Current situation	8	2.369	0.542	0.764	-144.00	-4.67
	9	3.482	0.399	0.779	-119.33	-2.67
	10	3.820	0.514	0.818	-80.00	-4.33
	11	4.345	0.655	0.835	-49.67	-0.67
	12	4.874	0.626	0.851	-15.67	-5.00
	13	5.437	0.511	0.866	18.00	-1.67
	14	6.106	0.477	0.886	46.00	-3.67
	15	6.530	0.621	0.906	78.67	-4.00
Future State 2 New Routing	8	1.530	0.651	0.792	-110.33	-8.00
	9	1.742	0.704	0.810	-73.33	-1.33
	10	2.072	0.532	0.841	-30.00	-3.33
	11	2.403	0.489	0.870	12.33	-3.33
	12	2.666	0.702	0.888	50.33	-4.00
	13	3.070	0.511	0.896	89.67	-4.00
	14	3.313	0.623	0.925	134.33	-2.67
	15	3.755	0.512	0.945	169.00	-3.67
Future State 3 Broken shifts	8	1.921	0.563	0.788	-114.33	-7.67
	9	2.512	0.626	0.810	-84.33	-11.00
	10	3.218	0.489	0.826	-55.33	-7.33
	11	3.696	0.612	0.841	-28.67	-10.67
	12	4.563	0.505	0.856	-1.00	-6.67
	13	5.582	0.542	0.870	22.33	-8.67
	14	5.977	0.384	0.891	50.67	-6.00
	15	6.594	0.682	0.900	84.33	-8.67
Future State 4 Extra BKs	8	1.466	0.682	0.784	-107.00	-5.00
	9	1.900	0.758	0.801	-77.00	-3.00
	10	2.071	0.948	0.827	-29.67	-9.67
	11	2.621	0.792	0.843	6.00	-7.33
	12	2.912	1.119	0.874	40.00	-8.00
	13	3.359	1.086	0.888	83.33	-10.00
	14	3.753	0.984	0.915	113.67	-10.33
	15	4.426	1.041	0.933	148.33	-8.67
Future State 5 Broken Shifts + New Routing	8	0.720	0.516	0.808	-87.67	-4.00
	9	1.160	0.766	0.826	-52.33	-9.67
	10	1.718	0.536	0.851	-14.00	-7.00
	11	2.117	0.527	0.872	21.33	-6.00
	12	2.507	0.574	0.887	55.00	-6.67
	13	2.912	0.508	0.906	95.00	-6.67
	14	3.207	0.693	0.934	134.67	-6.67
	15	3.783	0.645	0.950	167.67	-4.67
Future State 6 Extra BKs + New Routing	8	0.406	1.505	0.819	-73.67	-12.67
	9	0.694	3.310	0.839	-40.33	-10.67
	10	0.893	1.056	0.869	7.33	-11.00
	11	1.144	1.356	0.881	50.67	-16.00
	12	1.482	1.366	0.910	94.33	-14.33
	13	1.550	1.624	0.924	137.00	-11.67
	14	1.692	1.560	0.948	181.33	-18.33
	15	1.891	1.575	0.960	198.33	-14.00
Future State 7	8	0.290	0.641	0.811	-74.33	-1.67

Broken Shifts + Extra BKs	9	0.822	0.691	0.832	-39.67	-11.00
	10	1.293	0.473	0.857	-3.00	-2.67
	11	1.858	0.809	0.869	28.33	-8.67
	12	2.164	0.727	0.891	67.00	-4.00
	13	2.477	0.612	0.908	104.33	-7.00
	14	3.070	0.650	0.927	138.33	-8.67
	15	3.657	0.789	0.944	169.00	-8.33
Future State 8 Broken Shifts + New Routing + Extra BKs	8	0.020	0.860	0.827	-65.00	-6.33
	9	0.215	1.255	0.853	-21.67	-4.00
	10	0.452	0.923	0.872	19.67	-9.00
	11	0.657	0.917	0.891	66.33	-10.00
	12	0.710	0.981	0.915	115.00	-8.33
	13	1.069	0.943	0.934	153.67	-9.67
	14	1.355	1.097	0.957	194.67	-10.33
	15	1.500	1.247	0.957	198.33	-8.00

Table 13 Growth Scenario 3 – 2 RKs – Results Table 1

Future State	Tonnage SFVision	KG/Hour SFVision	KG/Hour Others	Revenues SFVision	Revenues Other filling lines	Total Revenues	Total Tonnage per week
Future State 1 Current situation	593.97	9,280.86	888.91	138,396	289,298	427,694	1,835,598
	639.49	8,881.86	894.74	149,002	291,197	440,199	1,889,267
	710.72	8,883.96	892.48	165,597	290,462	456,059	1,957,333
	768.32	8,730.89	895.81	179,018	291,547	470,565	2,019,591
	829.99	8,645.68	890.63	193,387	289,859	483,246	2,074,016
	892.68	8,583.51	896.13	207,996	291,650	499,646	2,144,404
	947.23	8,457.41	891.78	220,705	290,234	510,938	2,192,868
	1,010.70	8,422.54	891.55	235,494	290,158	525,652	2,256,017
Future State 2 New Routing	654.86	10,232.21	888.85	152,583	289,279	441,861	1,896,401
	723.32	10,046.17	893.52	168,535	290,802	459,336	1,971,400
	803.41	10,042.56	889.59	187,193	289,520	476,713	2,045,979
	883.02	10,034.29	893.02	205,743	290,636	496,379	2,130,383
	958.86	9,988.14	892.56	223,415	290,488	513,903	2,205,592
	1,031.69	9,920.14	891.93	240,385	290,283	530,668	2,277,544
	1,112.57	9,933.66	893.98	259,229	290,949	550,177	2,361,276
	1,177.40	9,811.67	893.52	274,334	290,798	565,133	2,425,462
Future State 3 Broken shifts	648.40	10,131.26	891.81	151,077	290,245	441,322	1,894,087
	702.54	9,757.54	888.84	163,692	289,278	452,971	1,944,079
	756.15	9,451.83	888.40	176,182	289,135	465,317	1,997,069
	806.07	9,159.91	882.45	187,815	287,196	475,011	2,038,673
	857.09	8,927.99	891.49	199,701	290,139	489,840	2,102,317
	902.98	8,682.50	888.49	210,394	289,162	499,557	2,144,019
	956.98	8,544.47	890.29	222,976	289,750	512,726	2,200,541
	1,022.24	8,518.66	890.61	238,182	289,853	528,035	2,266,244
Future State 4 Extra BKs	660.79	10,324.78	892.34	153,963	290,417	444,380	1,907,210
	715.28	9,934.50	895.16	166,661	291,332	457,993	1,965,637
	803.69	10,046.15	890.28	187,260	289,745	477,006	2,047,234
	870.05	9,886.97	891.71	202,722	290,209	492,932	2,115,587
	938.11	9,771.98	891.15	218,580	290,028	508,608	2,182,866
	1,018.33	9,791.62	888.36	237,270	289,121	526,392	2,259,192
	1,075.42	9,601.95	886.95	250,572	288,663	539,235	2,314,315
	1,135.89	9,465.79	890.24	264,663	289,734	554,397	2,379,387
	695.67	10,869.88	894.94	162,092	291,263	453,354	1,945,727

Future State 5 Broken Shifts + New Routing	762.96	10,596.65	890.67	177,769	289,873	467,643	2,007,050
	834.07	10,425.85	889.71	194,338	289,560	483,897	2,076,813
	900.62	10,234.31	894.75	209,844	291,201	501,045	2,150,409
	967.04	10,073.33	892.13	225,320	290,348	515,668	2,213,169
	1,039.74	9,997.51	892.51	242,260	290,470	532,730	2,286,395
	1,112.72	9,935.03	890.33	259,265	289,763	549,027	2,356,340
	1,174.39	9,786.62	894.25	273,634	291,037	564,670	2,423,479
Future State 6 Extra BKs + New Routing	723.32	11,301.83	887.48	168,533	288,834	457,367	1,962,948
	783.47	10,881.55	888.07	182,549	289,025	471,574	2,023,924
	872.77	10,909.67	886.36	203,356	288,470	491,826	2,110,843
	958.73	10,894.62	880.82	223,383	286,668	510,051	2,189,059
	1,040.38	10,837.29	884.73	287,939	287,939	575,877	2,276,168
	1,115.79	10,728.75	887.09	288,707	288,707	577,413	2,354,874
	1,198.43	10,700.28	879.43	286,213	286,213	572,426	2,426,814
	1,229.10	10,242.47	883.91	287,672	287,672	575,344	2,463,740
Future State 7 Broken Shifts + Extra BKs	721.21	11,268.91	896.26	168,042	291,691	459,733	1,973,102
	785.35	10,907.59	888.00	182,986	289,005	471,991	2,025,711
	854.33	10,679.16	894.00	199,059	290,955	490,015	2,103,067
	915.51	10,403.51	888.59	213,314	289,196	502,510	2,156,694
	990.32	10,315.87	894.42	230,745	291,094	521,839	2,239,652
	1,057.43	10,167.57	894.04	246,381	290,969	537,350	2,306,223
	1,119.86	9,998.71	893.59	260,926	290,822	551,748	2,368,016
	1,177.26	9,810.49	889.95	274,301	289,640	563,941	2,420,347
Future State 8 Broken Shifts + New Routing + Extra BKs	738.03	11,531.79	889.31	171,962	289,429	461,392	1,980,221
	819.37	11,380.07	894.63	190,912	291,163	482,075	2,068,991
	896.70	11,208.73	888.67	208,931	289,222	498,153	2,137,996
	988.64	11,234.59	888.85	230,354	289,280	519,634	2,230,188
	1,079.91	11,249.03	889.69	289,553	289,553	579,106	2,322,623
	1,146.37	11,022.78	889.10	289,362	289,362	578,724	2,388,267
	1,222.01	10,910.85	888.73	289,242	289,242	578,484	2,463,396
	1,230.49	10,254.06	892.16	290,359	290,359	580,717	2,476,661

Table 14 Growth Scenario 3 – 2 RKs – Results Table 2 – on average per week

Future State	Tonnage	Revenues	Costs	Profit	Increase in profit	Investments	Payback Period
Future State 1 Current situation	1,835,598	427,694	401,996	25,698	441	1,139,400	2,582
	1,889,267	440,199	413,749	26,450	1,193	1,139,400	955
	1,957,333	456,059	428,656	27,403	2,146	1,139,400	531
	2,019,591	470,565	442,290	28,274	3,017	1,139,400	378
	2,074,016	483,246	454,210	29,036	3,779	1,139,400	301
	2,144,404	499,646	469,624	30,022	4,765	1,139,400	239
	2,192,868	510,938	480,238	30,700	5,443	1,139,400	209
	2,256,017	525,652	494,068	31,584	6,327	1,139,400	180
Future State 2 New Routing	1,896,401	441,861	415,312	26,550	1,293	1,141,400	883
	1,971,400	459,336	431,737	27,600	2,343	1,141,400	487
	2,045,979	476,713	448,069	28,644	3,387	1,141,400	337
	2,130,383	496,379	466,554	29,825	4,568	1,141,400	250
	2,205,592	513,903	483,025	30,878	5,621	1,141,400	203
	2,277,544	530,668	498,782	31,886	6,629	1,141,400	172
	2,361,276	550,177	517,119	33,058	7,801	1,141,400	146
	2,425,462	565,133	531,176	33,956	8,699	1,141,400	131
Future State 3 Broken shifts	1,894,087	441,322	414,805	26,517	1,260	1,164,600	924
	1,944,079	452,971	425,753	27,217	1,960	1,164,600	594

	1,997,069	465,317	437,358	27,959	2,702	1,164,600	431
	2,038,673	475,011	446,469	28,541	3,284	1,164,600	355
	2,102,317	489,840	460,407	29,432	4,175	1,164,600	279
	2,144,019	499,557	469,540	30,016	4,759	1,164,600	245
	2,200,541	512,726	481,918	30,808	5,551	1,164,600	210
	2,266,244	528,035	496,307	31,727	6,470	1,164,600	180
Future State 4 Extra BKs	1,907,210	444,380	417,679	26,701	1,444	1,189,400	824
	1,965,637	457,993	430,474	27,519	2,262	1,189,400	526
	2,047,234	477,006	448,344	28,661	3,404	1,189,400	349
	2,115,587	492,932	463,314	29,618	4,361	1,189,400	273
	2,182,866	508,608	478,048	30,560	5,303	1,189,400	224
	2,259,192	526,392	494,763	31,629	6,372	1,189,400	187
	2,314,315	539,235	506,835	32,400	7,143	1,189,400	167
	2,379,387	554,397	521,086	33,311	8,054	1,189,400	148
Future State 5 Broken Shifts + New Routing	1,945,727	453,354	426,114	27,240	1,983	1,166,600	588
	2,007,050	467,643	439,544	28,099	2,842	1,166,600	411
	2,076,813	483,897	454,822	29,075	3,818	1,166,600	306
	2,150,409	501,045	470,939	30,106	4,849	1,166,600	241
	2,213,169	515,668	484,684	30,984	5,727	1,166,600	204
	2,286,395	532,730	500,720	32,010	6,753	1,166,600	173
	2,356,340	549,027	516,039	32,989	7,732	1,166,600	151
	2,423,479	564,670	530,742	33,929	8,672	1,166,600	135
Future State 6 Extra BKs + New Routing	1,962,948	457,367	429,886	27,481	2,224	1,191,400	536
	2,023,924	471,574	443,239	28,335	3,078	1,191,400	387
	2,110,843	491,826	462,275	29,552	4,295	1,191,400	277
	2,189,059	510,051	479,404	30,647	5,390	1,191,400	221
	2,276,168	530,347	498,481	31,866	6,609	1,191,400	180
	2,354,874	548,686	515,717	32,968	7,711	1,191,400	155
	2,426,814	565,448	531,472	33,975	8,718	1,191,400	137
	2,463,740	574,051	539,559	34,492	9,235	1,191,400	129
Future State 7 Broken Shifts + Extra BKs	1,973,102	459,733	432,109	27,623	2,366	1,216,600	514
	2,025,711	471,991	443,631	28,360	3,103	1,216,600	392
	2,103,067	490,015	460,572	29,443	4,186	1,216,600	291
	2,156,694	502,510	472,316	30,194	4,937	1,216,600	246
	2,239,652	521,839	490,484	31,355	6,098	1,216,600	200
	2,306,223	537,350	505,063	32,287	7,030	1,216,600	173
	2,368,016	551,748	518,596	33,152	7,895	1,216,600	154
	2,420,347	563,941	530,056	33,885	8,628	1,216,600	141
Future State 8 Broken Shifts + New Routing + Extra BKs	1,980,221	461,392	433,668	27,723	2,466	1,216,600	493
	2,068,991	482,075	453,109	28,966	3,709	1,216,600	328
	2,137,996	498,153	468,221	29,932	4,675	1,216,600	260
	2,230,188	519,634	488,411	31,223	5,966	1,216,600	204
	2,322,623	541,171	508,655	32,517	7,260	1,216,600	167
	2,388,267	556,466	523,030	33,436	8,179	1,216,600	149
	2,463,396	573,971	539,484	34,488	9,231	1,216,600	132
	2,476,661	577,062	542,389	34,673	9,416	1,216,600	129

Table 15 Growth Scenario 3 – 2 RKs – Payback Period – on average per week

Appendix J – Finished Goods Warehouse Results

Number of Truck Transports

Shifts	Experiment									
	1	2	3	4	5	6	7	8	9	10
1	4.0	4.2	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2	9.9	9.9	9.9	9.6	9.7	9.9	9.1	9.9	10.0	10.0
3	5.0	4.9	4.9	4.3	5.0	4.9	4.0	4.8	5.0	5.0
4	4.3	4.0	4.0	4.0	4.0	4.3	4.0	4.0	4.0	4.0
5	10.1	6.7	6.7	10.0	9.9	10.0	8.6	9.4	8.7	7.9
6	5.0	4.0	5.0	4.9	4.9	4.8	5.0	5.0	5.0	5.0
7	5.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
8	10.0	8.3	10.0	9.5	9.5	6.2	10.0	9.6	10.0	10.0
9	5.0	4.9	5.0	4.3	5.0	4.9	5.0	4.9	5.0	5.0
10	4.0	4.0	4.9	4.0	4.0	4.0	4.6	4.0	4.0	4.0
11	9.7	10.0	10.0	9.9	9.9	10.0	10.1	8.7	9.9	8.1
12	4.1	5.0	5.0	5.0	4.5	5.0	5.0	4.9	4.9	4.8
13	3.9	5.2	4.0	3.9	4.0	4.0	4.0	4.0	4.0	4.0
14	5.6	10.0	9.3	8.9	8.9	9.4	9.5	9.6	8.5	10.0
15	4.1	5.0	4.6	5.0	5.0	4.8	4.3	4.6	4.3	5.0

Number of FTEs

Shifts	Experiment									
	1	2	3	4	5	6	7	8	9	10
1	2.9	2.0	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
2	3.4	3.0	3.2	3.0	3.0	3.1	3.0	3.4	3.3	3.4
3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
4	3.0	2.0	2.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0
5	3.5	3.0	3.0	3.4	3.5	3.0	3.3	3.5	3.0	3.0
6	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
7	2.9	2.0	2.9	3.0	3.0	2.0	3.0	2.0	3.0	2.9
8	3.1	3.2	3.4	3.0	3.0	3.0	3.2	3.4	3.1	3.3
9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
10	2.0	3.0	3.0	2.9	2.0	2.9	2.9	2.0	2.0	2.0
11	3.0	3.7	3.6	3.6	3.6	3.6	3.7	3.0	3.8	3.0
12	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
13	2.0	2.7	2.0	2.0	2.9	2.0	2.0	2.6	2.0	2.5
14	3.0	3.5	3.0	3.5	3.0	3.0	3.0	3.0	3.0	3.7
15	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Table 16 Impact new filling line – FGW Results – on average per shift

Number of Truck Transports – Growth Scenario 1

Shifts	Scenario									
	0	1	2	3	4A	4B	5	6	7	8
1	4.0	4.0	4.1	4.3	4.5	4.4	4.4	5.0	4.5	4.4
2	9.7	10.0	10.0	10.0	9.8	9.9	10.0	10.0	10.1	10.0
3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4	4.0	4.1	4.0	4.0	4.0	4.0	4.1	4.0	4.1	4.2
5	9.9	10.0	9.9	10.0	10.0	10.0	10.1	10.0	10.0	10.1
6	4.9	5.0	4.9	4.9	4.9	5.0	5.0	5.0	5.0	5.0
7	4.0	4.3	4.0	4.1	4.1	4.1	5.1	4.3	5.5	5.5
8	9.5	10.1	9.8	9.9	9.9	9.9	10.1	9.9	10.1	10.1
9	5.0	5.0	5.0	5.0	4.9	4.9	5.0	5.0	5.0	5.0
10	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.2	4.7
11	9.9	10.0	9.9	10.0	10.0	10.0	10.0	10.0	10.0	10.0

Shifts	0	1	2	3	4A	4B	5	6	7	8
12	4.5	5.0	4.5	4.9	5.0	5.0	5.0	5.0	5.0	5.0
13	4.0	4.0	4.0	4.0	4.0	4.0	4.1	4.3	4.4	4.7
14	8.9	10.0	8.8	9.6	9.9	10.1	10.0	10.0	10.1	10.1
15	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Number of FTEs – Growth Scenario 1

	Scenario									
Shifts	**0**	**1**	**2**	**3**	**4A**	**4B**	**5**	**6**	**7**	**8**
1	2.9	2.7	3.0	3.0	2.9	2.9	2.7	3.0	2.9	2.7
2	3.0	3.2	3.0	3.0	3.0	3.0	3.1	3.0	3.3	3.2
3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
4	2.0	2.7	2.1	2.0	2.1	2.1	2.5	2.0	2.8	2.7
5	3.5	3.1	3.8	3.8	3.6	3.7	3.2	3.7	3.2	3.3
6	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
7	3.0	3.0	3.1	2.9	2.9	2.9	3.2	3.0	3.0	3.3
8	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
10	2.0	2.5	2.1	2.0	2.2	2.0	2.7	2.1	2.5	2.8
11	3.6	3.0	3.7	3.9	3.9	3.9	3.0	3.9	3.1	3.2
12	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
13	2.9	2.4	2.9	3.0	3.0	3.0	2.6	2.9	2.7	2.8
14	3.0	3.0	3.0	3.0	3.0	3.0	3.1	3.0	3.1	3.1
15	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Table 17 Growth Scenario 1 – FGW Results – on average per shift

Number of Truck Transports – Growth Scenario 2

	Broken shifts & Routing				Extra BKs & Routing				Broken shifts & Extra BKs				Broken shifts & Routing & Extra BKs			
Shifts	**9**	**10**	**11**	**12**	**9**	**10**	**11**	**12**	**9**	**10**	**11**	**12**	**9**	**10**	**11**	**12**
1	4.2	4.3	4.9	7.4	5.5	5.0	5.1	6.2	4.5	4.5	5.1	7.3	4.5	4.5	5.0	7.0
2	10.0	10.0	10.0	10.1	10.0	10.1	10.1	10.1	10.1	10.0	10.1	10.0	10.0	10.0	10.0	10.1
3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.0	5.0	5.0
4	4.6	4.5	4.8	4.1	4.2	4.5	5.9	4.3	4.7	5.1	4.5	4.0	5.1	4.5	4.3	4.0
5	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.1	10.1	10.1	10.0	10.2	10.0	10.0	10.0
6	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9	5.0	5.0	5.0	5.0
7	5.3	6.1	6.2	4.8	4.0	4.0	4.1	4.0	6.0	6.1	5.3	5.0	5.0	5.9	5.2	4.7
8	10.2	10.1	10.1	10.0	9.8	10.1	10.0	9.9	10.0	10.1	10.1	10.0	10.1	10.1	10.0	9.8
9	5.0	5.0	5.0	5.0	5.0	4.9	4.9	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
10	4.1	4.9	6.1	5.7	4.1	4.7	4.7	4.1	4.4	4.9	6.1	5.3	4.6	4.5	5.5	4.7
11	10.0	10.1	10.0	10.1	9.9	10.2	10.1	10.0	10.0	10.0	10.1	10.1	10.0	10.1	10.1	10.0
12	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0
13	5.3	5.5	4.9	4.5	4.0	4.8	4.7	5.1	5.7	5.5	5.1	4.7	5.5	5.5	4.9	4.5
14	10.1	10.1	10.0	10.1	9.9	10.1	10.0	10.1	10.1	10.0	10.0	10.0	10.1	10.0	10.0	10.0
15	5.0	5.0	5.0	5.2	5.1	5.0	5.0	5.1	5.0	5.0	5.0	5.1	5.0	5.0	5.0	5.3

Number of FTEs – Growth Scenario 2

	Broken shifts & Routing				Extra BKs & Routing				Broken shifts & Extra BKs				Broken shifts & Routing & Extra BKs			
Shifts	**9**	**10**	**11**	**12**	**9**	**10**	**11**	**12**	**9**	**10**	**11**	**12**	**9**	**10**	**11**	**12**
1	2.8	2.7	2.6	3.1	2.9	3.0	3.1	2.9	2.8	2.9	2.9	3.1	2.9	2.8	2.5	3.0
2	3.7	3.9	3.7	3.5	3.4	3.4	3.6	3.1	3.9	3.9	3.7	3.5	4.0	3.8	3.9	3.3
3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
4	2.7	2.7	2.7	2.3	2.1	3.1	2.8	3.1	2.9	2.8	2.5	2.4	2.7	2.7	2.3	2.5
5	3.1	3.8	4.0	3.8	3.7	3.3	3.0	3.2	3.1	3.9	3.8	3.9	3.2	3.9	3.7	3.6
6	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

7	3.1	3.1	3.4	3.1	2.0	2.8	2.9	2.0	3.2	3.0	3.1	3.1	3.0	3.3	3.1	3.1
8	3.0	3.0	3.0	3.0	3.7	3.7	3.5	3.7	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.1
10	2.5	2.6	3.1	3.1	2.0	3.1	3.1	2.0	2.7	2.7	3.1	3.0	2.7	2.4	3.1	3.0
11	3.0	3.0	3.0	3.0	3.0	3.9	3.8	3.9	3.1	3.0	3.0	3.0	3.0	3.1	3.0	3.0
12	3.1	3.0	3.0	3.0	3.1	3.0	3.0	3.1	3.1	3.0	3.0	3.1	3.1	3.0	3.1	3.0
13	2.9	2.6	2.7	2.4	2.0	3.0	2.9	2.7	2.9	2.7	2.7	2.5	2.7	2.6	2.5	2.3
14	3.1	3.1	3.1	3.6	4.0	4.0	4.0	3.8	3.1	3.1	3.0	3.7	3.1	3.0	3.0	3.9
15	3.0	3.0	3.0	3.0	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Table 18 Growth Scenario 2 – FGW Results – on average per shift

Number of Truck Transports – Growth Scenario 3 – 1 RK

Future State	Shifts	Night	Morning	Afternoon	Future State	Shifts	Night	Morning	Afternoon
Old Routing	8	4.0	9.7	4.9	Broken shifts + New Routing	8	4.5	10.0	5.0
	9	4.2	9.9	5.0		9	5.1	10.0	5.0
	10	4.6	10.0	5.0		10	5.7	10.1	5.0
	11	4.9	10.1	5.0		11	6.1	10.1	5.0
	12	5.4	10.0	5.1		12	6.6	10.1	5.1
	13	5.8	10.1	5.1		13	7.0	10.1	5.2
	14	6.4	10.1	5.1		14	7.4	10.2	5.2
	15	6.8	10.1	5.1		15	7.8	10.2	5.2
New Routing	8	4.2	10.0	5.0	Broken shifts + Extra BKs	8	4.7	10.1	5.0
	9	4.6	10.0	5.1		9	5.4	10.0	5.0
	10	5.2	10.1	5.0		10	5.8	10.1	5.0
	11	5.8	10.1	5.0		11	6.3	10.1	5.0
	12	6.1	10.1	5.5		12	6.6	10.1	5.1
	13	6.5	10.1	5.4		13	7.0	10.1	5.3
	14	7.1	10.1	5.5		14	7.5	10.1	5.2
	15	7.5	10.1	5.5		15	7.7	10.2	5.2
Broken shifts	8	4.3	10.0	5.0	Extra BKs + New Routing	8	4.7	10.0	5.0
	9	4.5	10.0	5.0		9	4.9	10.0	5.3
	10	5.0	10.0	5.0		10	5.8	10.1	5.0
	11	5.3	10.1	5.0		11	6.4	10.1	5.1
	12	5.7	10.1	5.0		12	6.3	10.1	5.8
	13	6.1	10.1	5.0		13	6.6	10.1	5.8
	14	6.6	10.0	5.1		14	7.1	10.1	5.7
	15	6.9	10.1	5.1		15	7.5	10.1	5.5
Extra BKs	8	4.3	10.0	5.0	Broken Shifts + New Routing + Extra BKs	8	5.0	10.0	5.0
	9	4.6	10.0	5.1		9	5.5	10.0	5.0
	10	5.2	10.1	5.0		10	6.2	10.0	5.0
	11	5.5	10.1	5.0		11	6.8	10.1	5.1
	12	5.9	10.1	5.5		12	7.2	10.1	5.2
	13	6.5	10.0	5.3		13	7.4	10.2	5.4
	14	6.8	10.1	5.5		14	7.5	10.2	5.3
	15	7.4	10.1	5.4		15	7.8	10.1	5.3

Number of FTEs – Growth Scenario 3 – 1 RK

Future State	Shifts	Night	Morning	Afternoon	Future State	Shifts	Night	Morning	Afternoon
Old Routing	8	2.6	3.3	3.0	Broken shifts + New Routing	8	2.8	3.1	3.0
	9	2.2	3.5	3.0		9	2.9	3.3	3.0
	10	2.9	3.6	3.0		10	2.9	3.4	3.0
	11	3.0	3.6	3.0		11	3.1	3.4	3.0
	12	2.6	3.7	3.0		12	3.1	3.5	3.0
	13	2.6	3.6	3.0		13	3.2	3.7	3.0

Future State	Shifts	Night	Morning	Afternoon	Future State	Shifts	Night	Morning	Afternoon
	14	2.9	3.6	3.0		14	3.3	3.6	3.0
	15	3.1	3.5	3.0		15	3.3	3.7	3.0
New Routing	8	2.6	3.3	3.0	Broken shifts + Extra BKs	8	2.8	3.2	3.0
	9	2.3	3.6	3.0		9	2.9	3.3	3.0
	10	3.0	3.9	3.0		10	3.0	3.4	3.0
	11	3.1	3.6	3.0		11	3.1	3.4	3.0
	12	2.7	3.8	3.1		12	3.2	3.5	3.0
	13	2.8	3.8	3.1		13	3.2	3.6	3.0
	14	3.1	3.7	3.1		14	3.3	3.6	3.0
	15	3.2	3.8	3.1		15	3.3	3.6	3.0
Broken shifts	8	2.8	3.1	3.0	Extra BKs + New Routing	8	2.7	3.3	3.0
	9	2.7	3.2	3.0		9	2.4	3.7	3.2
	10	2.7	3.3	3.0		10	3.2	3.9	3.0
	11	2.8	3.3	3.0		11	3.3	3.7	3.0
	12	2.9	3.4	3.0		12	2.8	3.8	3.2
	13	3.1	3.4	3.0		13	2.9	3.8	3.2
	14	3.1	3.5	3.0		14	3.1	3.7	3.1
	15	3.1	3.5	3.0		15	3.3	3.7	3.1
Extra BKs	8	2.6	3.3	3.0	Broken Shifts + New Routing + Extra BKs	8	2.9	3.1	3.0
	9	2.3	3.6	3.0		9	2.9	3.3	3.0
	10	3.0	3.7	3.0		10	3.2	3.4	3.0
	11	3.1	3.6	3.0		11	3.2	3.4	3.1
	12	2.8	3.8	3.0		12	3.4	3.6	3.1
	13	2.8	3.7	3.1		13	3.4	3.7	3.1
	14	3.0	3.7	3.1		14	3.3	3.7	3.0
	15	3.2	3.7	3.0		15	3.3	3.6	3.1

Table 19 Growth Scenario 3 – 1 RK – FGW Results – on average per shift

Number of Truck Transports – Growth Scenario 3 – 2 RKs									
Future State	Shifts	Night	Morning	Afternoon	Future State	Shifts	Night	Morning	Afternoon
Old Routing	8	4.1	9.9	4.9	Broken shifts + New Routing	8	4.5	10.0	5.0
	9	4.3	9.9	5.0		9	5.2	10.1	5.0
	10	4.7	10.1	5.0		10	5.8	10.1	5.0
	11	5.2	10.1	5.0		11	6.3	10.1	5.0
	12	5.6	10.0	5.2		12	6.8	10.1	5.1
	13	6.0	10.1	5.2		13	7.3	10.1	5.3
	14	6.5	10.1	5.2		14	7.7	10.2	5.3
	15	7.1	10.1	5.2		15	8.3	10.1	5.4
New Routing	8	4.3	10.0	5.0	Broken shifts + Extra BKs	8	4.8	10.1	5.0
	9	4.7	10.0	5.1		9	5.5	10.0	5.0
	10	5.6	10.1	5.0		10	5.9	10.1	5.1
	11	5.9	10.1	5.1		11	6.4	10.1	5.0
	12	6.2	10.1	5.6		12	6.9	10.1	5.2
	13	6.8	10.1	5.6		13	7.4	10.1	5.3
	14	7.3	10.2	5.7		14	7.7	10.2	5.4
	15	7.9	10.1	5.8		15	8.2	10.2	5.4
Broken shifts	8	4.2	10.0	5.0	Extra BKs + New Routing	8	4.8	10.0	5.0
	9	4.6	10.0	5.0		9	5.0	10.1	5.3
	10	5.1	10.1	5.0		10	6.0	10.2	5.0
	11	5.5	10.1	5.0		11	6.5	10.1	5.2
	12	6.0	10.1	5.0		12	6.5	10.1	5.9
	13	6.3	10.1	5.0		13	7.1	10.0	6.0
	14	6.7	10.1	5.1		14	7.7	10.1	6.0

Future State	Shifts	Night	Morning	Afternoon	Future State	Shifts	Night	Morning	Afternoon
	15	7.2	10.0	5.1		15	8.2	10.1	6.0
Extra BKs	8	4.5	10.0	5.0	Broken Shifts + New Routing + Extra BKs	8	4.9	10.0	5.0
	9	4.6	10.0	5.1		9	5.6	10.1	5.0
	10	5.4	10.1	5.0		10	6.3	10.1	5.0
	11	5.9	10.1	5.0		11	6.9	10.1	5.1
	12	6.1	10.1	5.5		12	7.5	10.1	5.2
	13	6.5	10.1	5.5		13	7.9	10.1	5.4
	14	7.0	10.1	5.6		14	8.2	10.2	5.7
	15	7.7	10.1	5.5		15	8.6	10.1	5.7

Number of FTEs – Growth Scenario 3 – 2 RKs

Future State	Shifts	Night	Morning	Afternoon	Future State	Shifts	Night	Morning	Afternoon
Old Routing	8	2.6	3.3	3.0	Broken shifts + New Routing	8	2.8	3.1	3.0
	9	2.2	3.5	3.0		9	2.9	3.2	3.0
	10	3.0	3.7	3.0		10	3.1	3.4	3.0
	11	3.0	3.6	3.0		11	3.1	3.4	3.0
	12	2.7	3.6	3.0		12	3.1	3.6	3.0
	13	2.7	3.7	3.0		13	3.3	3.7	3.0
	14	2.9	3.6	3.0		14	3.4	3.8	3.0
	15	3.1	3.7	3.0		15	3.4	3.8	3.0
New Routing	8	2.6	3.4	3.0	Broken shifts + Extra BKs	8	2.9	3.1	3.0
	9	2.3	3.7	3.0		9	2.9	3.3	3.0
	10	3.1	3.9	3.0		10	3.1	3.4	3.0
	11	3.1	3.7	3.0		11	3.1	3.4	3.0
	12	2.7	3.8	3.1		12	3.3	3.5	3.0
	13	2.9	3.9	3.1		13	3.4	3.6	3.0
	14	3.1	3.9	3.1		14	3.3	3.8	3.1
	15	3.3	3.8	3.2		15	3.4	3.7	3.0
Broken shifts	8	2.7	3.1	3.0	Extra BKs + New Routing	8	2.7	3.4	3.0
	9	2.7	3.3	3.0		9	2.4	3.7	3.1
	10	2.8	3.3	3.0		10	3.3	3.8	3.0
	11	2.9	3.4	3.0		11	3.3	3.7	3.1
	12	3.0	3.4	3.0		12	2.9	3.8	3.2
	13	3.1	3.5	3.0		13	3.0	3.8	3.3
	14	3.1	3.5	3.0		14	3.2	3.9	3.3
	15	3.2	3.5	3.0		15	3.4	3.8	3.3
Extra BKs	8	2.7	3.4	3.0	Broken Shifts + New Routing + Extra BKs	8	2.9	3.1	3.0
	9	2.3	3.6	3.0		9	3.0	3.3	3.0
	10	3.1	3.7	3.0		10	3.2	3.5	3.0
	11	3.2	3.7	3.0		11	3.3	3.4	3.1
	12	2.8	3.8	3.1		12	3.5	3.5	3.1
	13	2.8	3.8	3.1		13	3.5	3.8	3.1
	14	3.1	3.8	3.1		14	3.5	3.9	3.1
	15	3.3	3.7	3.1		15	3.6	3.8	3.1

Table 20 Growth Scenario 3 – 2 RKs – FGW Results – on average per shift