Master Thesis

Optimizing a perishable storage system, under increased throughput, using multi-scenario simulation

Alexander Jongerius
s1384481
September, 2020

MSc Industrial Engineering & Management, Production & Logistic Management
University of Twente, The Netherlands.

UNIVERSITY OF TWENTE.

Internal Supervisor:
DR. IR. M.R.K. Mes
DR. IR. E.A. Lalla

Preface

I am delighted to present my thesis to you the reader. Writing this thesis during the COVID-19 pandemic has been an additional challenge, yet I am very pleased with the result. Furthermore I would like to take this opportunity to thank both my internal as external supervisors for their flexibility and help in, what essentially was, a strange period. I would further like to note that this report is optimized for digital reading. Therefore references to figures are interactive and figures are presented in high resolution (for zooming in).

Management Summary

The stage for this research is set at a production facility of company X in the Netherlands that focuses on producing consumer-oriented food products. Plans have been made to start the production of a new product referred to as product X. All product created at the facility share the same liquid base ingredient referred to as ingredient A. To start production of product X an increase of about 30% in ingredient A supplied to the plant is to be expected. Bottlenecks are identified in the current facility with respect to ingredient A reception and storage. The main objective of this research is to provide insights in the effectiveness of different interventions on facilitating the increased storage throughput generated by the new product X line in a robust and future-proof way.

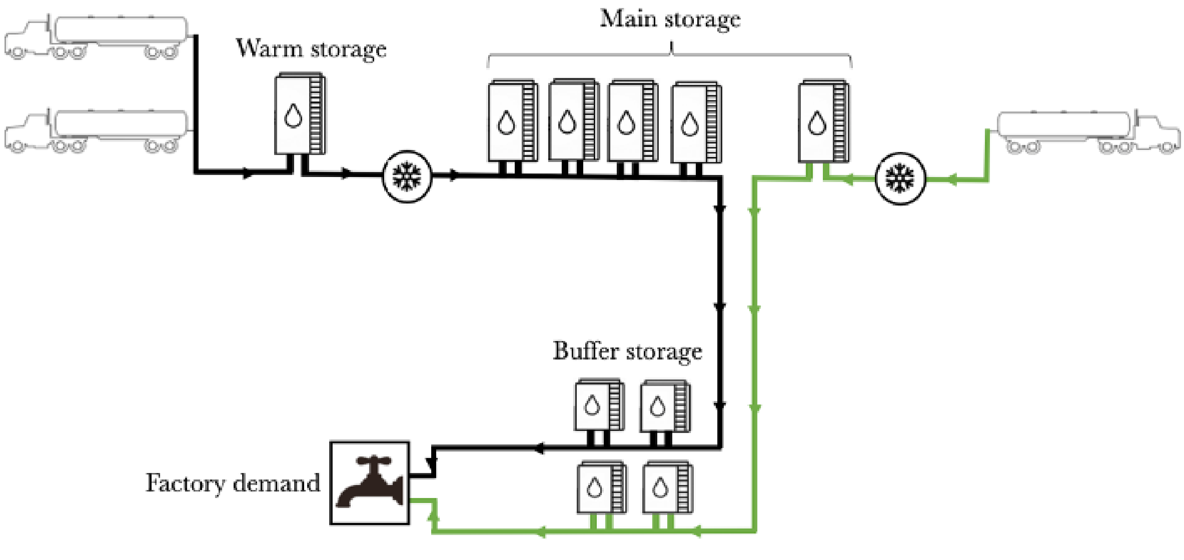


Figure 1: Current ingredient A reception facilities of the production facility

Currently the storage system for non-organic ingredient A, sketched as the black system in Figure 1.2, consists of a 185KL warm reception tank, four 185KL main storage tanks and two 95KL buffer storage tanks. Within the current storage system, two possible areas of improvement are found: physical and organizational. Solutions within the physical layer focus on rearranging the buffer and regular storage layout. Whereas solutions within the

organizational layer focus on a more efficient use of the physical layer to accommodate the growth in ingredient A supply and usage.

A simulation model is created to weigh and test the different solution domains on key performance criteria such as dwell time (time in a tank) and factory demand stockout hours (weekly number of hours in the week demand is not fulfilled). Future scenarios focus on different factory demand levels, or in other words, factory or system throughput. Within factory demand we differentiate between conventional ingredient A demand (over the existing pasteurizers) and product X based ingredient A demand (over the new product X pasteurizer). To ensure a robust and future-proof solution, an increase in conventional demand is also to be expected.

It is found that the current system, when optimizing the organizational layer accordingly, is able to facilitate an increased throughput over the existing pasteurizers of 105 million liters annually (+84%). Yet, due to the fact that flowrates will also increase when the new product X pasteurizer is in operation, throughput problems occur with the current layout. To facilitate the new product X production, one of two proposed layouts needs to be implemented. Of the two proposed new layouts, the one that focuses on removal of the buffer storage is found to be optimal. This layout is able to facilitate the simulated maximum throughput both for product X and conventional demand well within boundary conditions. It furthermore greatly improves performance for all scenarios and throughput levels.

Optimizing the organizational layer improved performance and throughput for almost all scenarios. Nevertheless, it must be concluded that, as is often within the process industry, to facilitate radical change, most attention should be given to the physical layer, i.e. the equipment.

Table of Contents

Abbreviations

CIP	Cleaning in place
JIT	Just in time
KPI	Key performance indicator
FT	Flow transmitter
LT	Level transmitter

List of Figures

List of Tables

Chapter 1

Introduction

This chapter aims to provide the background necessary to understand the problem setting. First, we will provide an introduction to the company that is under consideration. Second, we will elaborate upon the research motivation and description of the problem at hand and discuss the objective of this research. Third, we will discuss how to approach the problem and describe the research. Finally, we will explain the methods that are to be used to resolve the problem.

The stage for this research is set at a production facility of company X in the Netherlands that focuses on producing consumer-oriented food products. All product created at the facility share the same liquid base ingredient referred to as ingredient A. The processes within the plant can be divided into three main steps: ingredient A reception, processing and filling. In Figure 1.1, an overview of the processes within the production plant of company X is given.

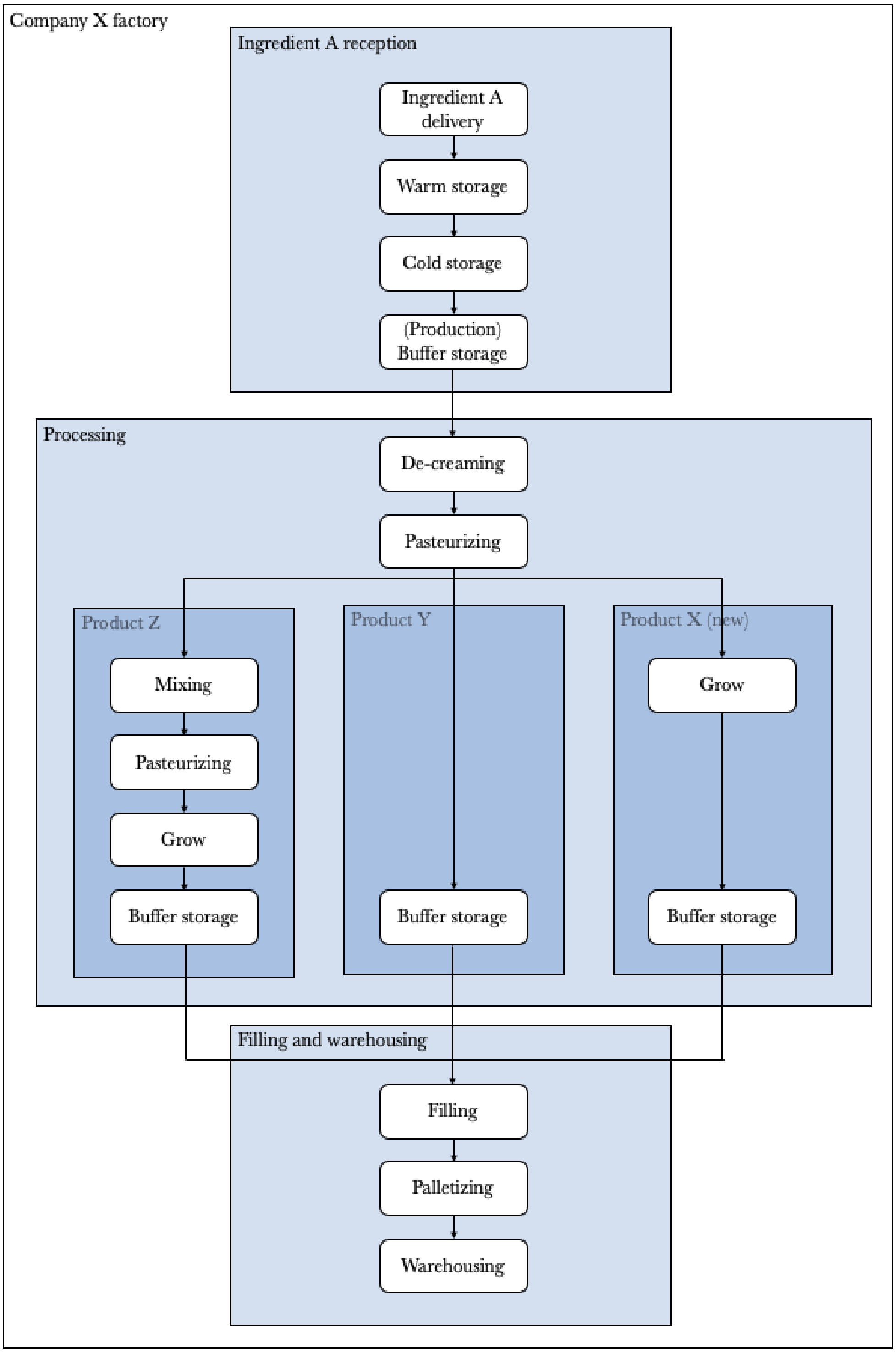


Figure 1.1: Global overview of processes; the main focus of the factory is on the processing, where also the new product X line is sketched. This research shall focus on ingredient A reception, the stage that lies before processing.

1.1 Research motivation

Plans have been made to start producing a new product X in the plant. As ingredient A is also the main raw ingredient of this new product, an increase of about 30% of ingredient A supplied to the plant is required to start production. The team tasked with the realization of this project is currently in the dark about how to accommodate this increase most efficiently.

1.2 Problem description

To accommodate the growth in ingredient A supply, some bottlenecks are identified in the current facility with respect to ingredient A reception and storage. While these bottlenecks are identified, finding a future proof solution requires a much deeper insight into ingredient A supply planning, weekly and daily production patterns, and optimization of ingredient A throughput. Additionally, insights in the effects of possible modifications to the existing system in terms of layout, capacities and/or process operation are also believed to be essential.

The ingredient A reception system currently in place is described in Figure 1.2 and consists of a direct warm reception tank to ensure maximum unloading capacity as there is cooling capacity for 60KL/h. Next, several cooled storage tanks are in place, these tanks are the main storage of ingredient A for plant usage, each tank has a design capacity of 185KL. From the main storage, ingredient A gets pumped to an intermediate cold storage where processing lines are connected to de-creaming and pasteurization. In addition, there is a second ingredient A stream, organic ingredient A (green in Figure 1.2), which has to be separated from the "normal" ingredient A, which increases the complexity of the situation.

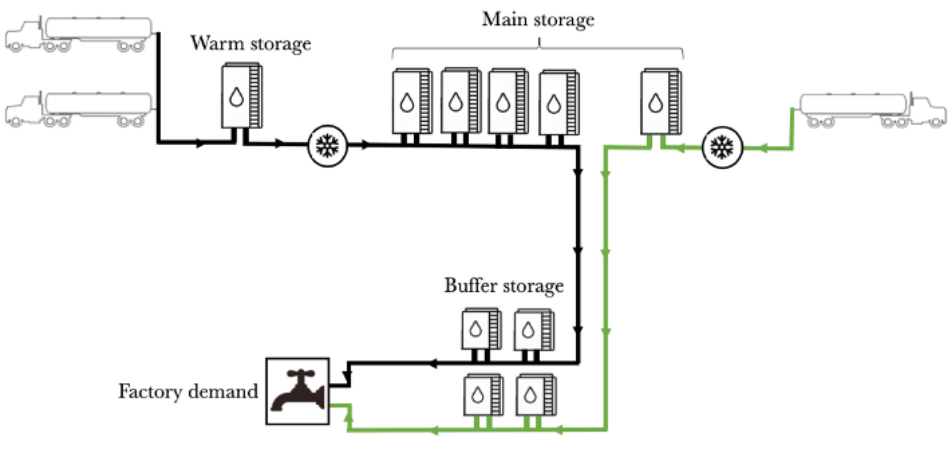


Figure 1.2: Current ingredient A reception facilities

In this research this part of ingredient A reception is described as the physical layer of the system. In addition to the physical layer, we define an organizational layer that encompasses all operational and planning actions and decisions that influence the system.

Ingredient A has a maximum storage time and tanks need to be cleaned between batches for quality reasons. For the same reasons, ingredient A coming from different tanks cannot be mixed, a strict track and tracing system combined with several restrictive parameters are used to guarantee quality. The full requirements in regard to the storage and buffering of ingredient A are stated in subsection 4.1.

Besides comprehensive storage requirements, ingredient A is supplied asynchronously with the demand from the factory. This increases the uncertainty within the system and consecutively could increase the storage capacity necessary to buffer against this uncertainty.

1.3 Research objective

The main objective of this research is to provide insights in the effectiveness of different interventions on facilitating the storage throughput of the new product X line in a robust and future-proof way. This while assuring that different aspects of system performance regarding throughput, quality and food safety are taken into account.

1.4 Problem approach

In this section we describe the problem and the way we aim to tackle it. This starts with the problem statement and concludes with research design and methods.

1.4.1 Problem statement

The core problem that comes forward from the problem description provided by company X in combination with interviews conducted with different stakeholders is identified as:

> *'Company X is currently in the dark about an adequate adaption to the raw material reception to accommodate a 30% increase in ingredient A supplied, generated by a new production line.'*

From the core problem the main research question is derived, answering this question is the main goal of this research. The question is phrased as:

'In which way do the current ingredient A reception facilities need to be adapted to accommodate the growth in supply and still be able to deal with variation in supply and factory demand?'

1.4.2 Research design

The broad outline of this research is to first gather more information on the current system and support this using literature. The information gathered is used to predict or approximate ingredient A reception system operation when the new production line is in use. This needs to be done in a structured way, where the model is correctly built and validated. The next step is to design the different experiments for testing solutions and future scenarios. Some solutions defined by the project team focus on an increase in the storage capacity (physical layer), while others are focused on a more efficient use of the existing infrastructure (organizational layer). This consideration forms the backbone of this research.

To be able to solve the core problem in a structured way, the main research question is divided into sub-questions to create a structured project buildup. The first stage of the research is to provide a clear technical description of the current system. This consists of a technical physical description (1a) of the system followed by an analysis of the organizational layer of the system (1b). To feed an eventual model that can approach the system's future state, it is key to identify data sources in the current system (1c). Next it is important to map the requirements that are associated with these types of systems to ensure these requirements are taken into account in the model creation (1d). Finally, the performance of the current system is analyzed (1e).

1. How is the current system being operated?
   (a) What are the technical details related to the physical layer?
   (b) How is the organizational layer operated and what are the relations with the physical layer?
   (c) What data is available from this system?
   (d) What are requirements related to this system?
   (e) What is the performance of this system?

The second sub-question focuses on a comprehensive literature review on similar systems, their performance and modeling methods. The first step is to find similar systems in literature and investigate what are common areas of focus for improving these systems (2a). Next it is vital to learn more about different ways of evaluating future scenarios (2b), this knowledge will support conceptual model building. Sub-question 2c focuses on steps that need to be taken to execute a sound simulation study. The final part of the literature study is to focus on validation and verification to ensure correctness of the results (2d).

2. What is known in literature about optimization in the process industry?
   (a) What are areas of improvement?
   (b) What is a fitting way to approximate future scenarios in this industry?
   (c) What is a fitting way to approximate future scenarios in this industry?
   (d) How can we verify and validate a model that approximates future scenarios?

The third sub-question focuses on how to build a model that can provide accurate performance metrics of new process layouts to determine the best process layout for ingredient A reception that optimizes cost and performance, while guaranteeing ingredient A availability and product quality.

3. Using the input from the literature review and system analysis, how to structure and develop a model to determine the best way to estimate the impact of future scenarios?
   (a) In what way can factory demand and deliveries be modeled?
   (b) How can internal operations be described by a model?
   (c) What are possible interventions in both the organizational and physical domain?
   (d) What future scenarios are to be expected?
   (e) What combination of scenarios and interventions should be investigated?

The final sub-question focuses on the results and the interpretation. First, we will focus on the performance that is to be expected from the different physical and organizational interventions. Second, conclusions are drawn on the effectivity of the different interventions.

4. What results are derived from the simulation model?
   (a) What performance can be expected from the different physical and organizational interventions?
   (b) What effects can be found of different physical and organizational interventions?

1.5 Methodology

The first set of sub-questions of the research is answered using information obtained from company X in the form of internal documents, interviews with stakeholders and use of the production management systems. The second set of sub-questions is answered using scientific literature research and analysis. Using the available historical data sources mapped in the first stage, supplemented with findings from literature, a conceptual model is created that can approach the system state. Related to this model are the interventions and scenarios. The interventions describe the actions that are undertaken to facilitate the different scenarios. These scenarios consist of different future system throughput levels to ensure the different interventions are robust and future-proof. Using the simulation model conclusions are drawn regarding the performance of the different interventions for the tested scenarios.

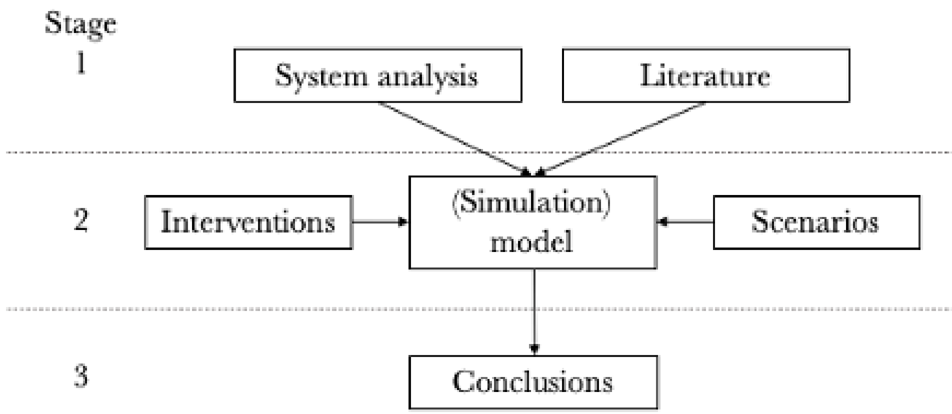


Figure 1.3: Research method build-up of this thesis.

Chapter 2

Current State of System

To be able to structurally analyze the function of and the relations within the current system, we will start with a low complexity system description. This description is then supplemented with new additional relations and functions found within this chapter. To decrease the level of complexity, the ingredient A reception facilities as described in Figure 1.2 are simply defined using an organizational layer and a physical layer. These layers are defined as:

1. **Physical**
   The physical layer defines the 'hard' ingredient A storage facilities on location. These consist of different types of ingredient A storage and buffer tanks, transport lines and unloading facilities. Solutions within this direction focus on rearranging the buffer and regular storage layout to accommodate the growth in ingredient A throughput.

2. **Organizational**
   The organizational layer defines the efficiency of the infrastructure available. The organizational layer also defines the 'storage strategy' or: which ingredient A to store in which tank at which time. Solutions within this layer focus on a more efficient use of the physical layer.

Furthermore, one input and one output are respectively defined as ingredient A deliveries and factory demand. This simplified system description can be found in Figure 2.1.

Using this simplified model, the physical layer is analyzed first as this serves as the operational basis of the system. The second part of this chapter focuses on the organizational layer and its place in the relational diagram. The chapter will conclude with a more detailed relational diagram that will function as the base for the simulation model.

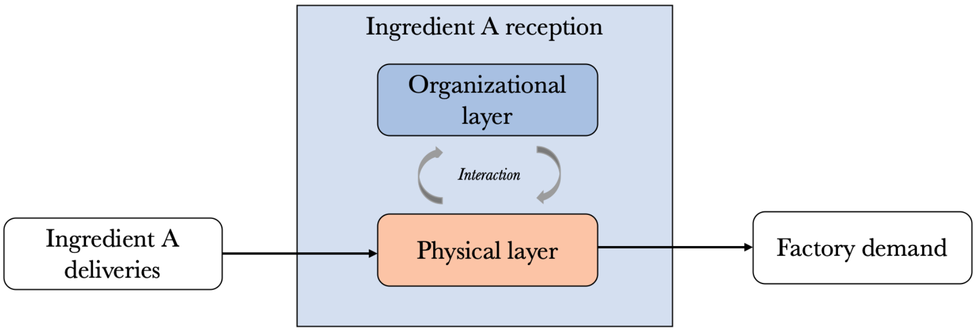


Figure 2.1: Initial overview system.

2.1 Physical layer

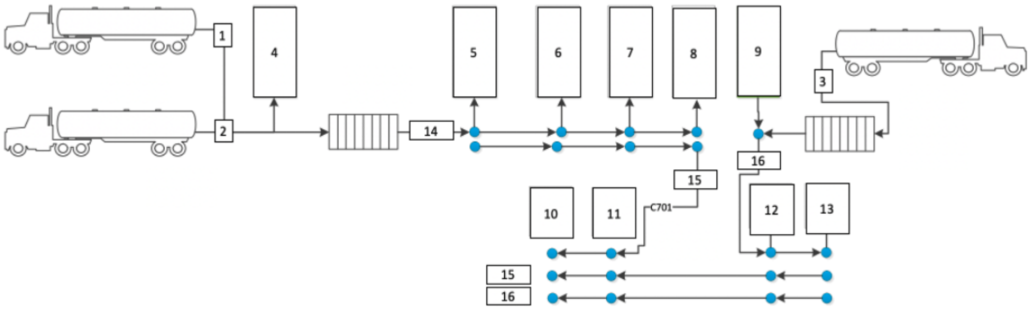
The physical layer has partially been discussed in the problem description, yet the full technical details have not been given. The complete details of the system are necessary to ensure correctness for conceptual model building. Therefore, the overview in Figure 2.2 is created with all technical details.

From the upper halve of Figure 2.2, it becomes clear that there are two separate systems, one for normal ingredient A (left) and one for organic ingredient A (right). For both systems the product flow is illustrated in the lower half of Figure 2.2. Besides the cleaning requirements mapped in the figure, there are two more requirements, one regarding batch traceability, the other regarding residence time:

1. Ingredient A inside the main storage tank is labeled as an individual batch, when ingredient A is drained from the tank to the buffer storage the batch is 'locked'. This individual batch (size can vary between 1-185KL) shall never mix with another batch within this system due to traceability requirements.

2. The time ingredient A spends in storage is to be kept below 30 hours to ensure optimal product quality.

In Appendix B photos of different parts of this system are provided. The performance of this system is described in section 2.3.



#	Description	Capacity	Cleaning	#	Description	Capacity	Cleaning
1	Unloading 1	120KL/h	CIP after use (also truck)	10	Buffer storage	95KL	CIP after cycle empty-full-empty
2	Unloading 2	120KL/h	CIP after use (also truck)	11	Buffer storage	95KL	CIP after cycle empty-full-empty
3	Unloading 3	90KL/h	CIP after use (also truck)	12	Buffer storage Bio	95KL	CIP after cycle empty-full-empty
4	Warm storage	185KL	CIP after cycle empty-full-empty	13	Buffer storage Bio	95KL	CIP after cycle empty-full-empty
5	Main storage	185KL	CIP after cycle empty-full-empty	14	Pipe cooler to cold Storage	90KL/h	CIP each day
6	Main storage	185KL	CIP after cycle empty-full-empty	15	Pipe Main storage to buffers	70KL/h	CIP each day
7	Main storage	185KL	CIP after cycle empty-full-empty	16	Pipe Main storage to buffers Bio	70KL/h	CIP each day
8	Main storage	185KL	CIP after cycle empty-full-empty	17	Line to pasteurizer 1	30KL/h	CIP with pasteurizer
9	Main storage Bio	185KL	CIP after cycle empty-full-empty	18	Line to pasteurizer 2	30KL/h	CIP with pasteurizer

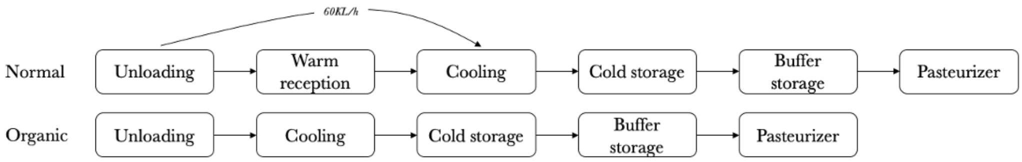


Figure 2.2: Physical layer description and product flow.

2.2 Organizational layer

From initial observations it is determined that the direct organizational layer consists of two main pillars: planning and operations. Where planning operates from a more top down level, operations runs the factory, making decisions with a daily planning as a basis. In this section the organizational layer is analyzed on function and relations with the simplified system, found in Figure 1.2, as a basis. This analysis starts with the planning, followed by an operational analysis and concludes with an organogram of the relations within the organizational layer.

2.2.1 Planning

The planning department at company X plays a vital role in the operation of the factory. They make sure enough ingredient A is in stock and is being delivered to keep production going. They furthermore plan the filling operations, that encompass which product is being filled at what filling line at what time. These are viewed as separate jobs for the planning department. An organogram can be found in Figure 2.3.

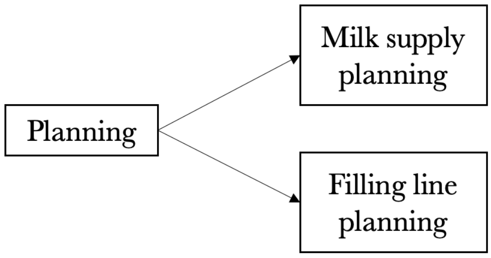


Figure 2.3: Planning department job overview.

Ingredient A delivery planning is a complex interplay between actual supply and forecasted factory demand. The goal is to maintain enough supply to feed the factory processes while maintaining a young stock. Additional complexity comes from the fact that deliveries are determined by a central national organ: Allocation. This department determines ingredient A distribution for all company X factories in the Netherlands, making the maximum planning horizon for scheduled deliveries about one and a half week. The actual timing and quantity of the deliveries are communicated by Allocation once a day with a horizon of 24 hours. In practice this means that not all scheduled become actual deliveries. Yet it must be noted that last minute reallocation of ingredient A between factories, even after the actual delivery communication 24 hours before reception, is also possible in rare occasions. This makes the planner's job even more complex.

The complete flowchart of ingredient A supply planning is found in Figure 2.4. The process starts with a daily morning update on actual supply and actual production of the last 12 hours. At the same moment, planning also receives the actual deliveries from Allocation for the next 24 hours. Following this announcement, it could be the case that an update in deliveries or production planning is necessary. Once a week, on Wednesdays, the factory's ingredient A demand forecast for next week is made and sent to Allocation, which results in a concept planning of ingredient A deliveries for next week. In most cases the concept planning becomes the actual deliveries planning for the corresponding days, yet it may still be subjected to change.

Besides the ingredient A delivery planning, planning is also responsible for scheduling the product filling lines to fulfill final product demand. A simplified snapshot of a planning look-a-like can be found in Figure 2.5. Here we find the schedule for a single filling line in the bottom of the figure where two different products are scheduled to be filled, the different products are visualized by yellow and blue colors. Working our way backwards through the process, we can find that the second to last step is to store and possibly grow the half-finished products before filling. In this case the yellow product is stored in tank number one and the blue product in tank number two. We find that the blue product has a minimum growing time, which is visualized with a green color and a maximum storage time, visualized by the red color. The yellow product does not have any of these restrictions. Consequently, from this store and grow schedule we can plan the pasteurizer and subsequently ingredient A demand from the buffer storage.

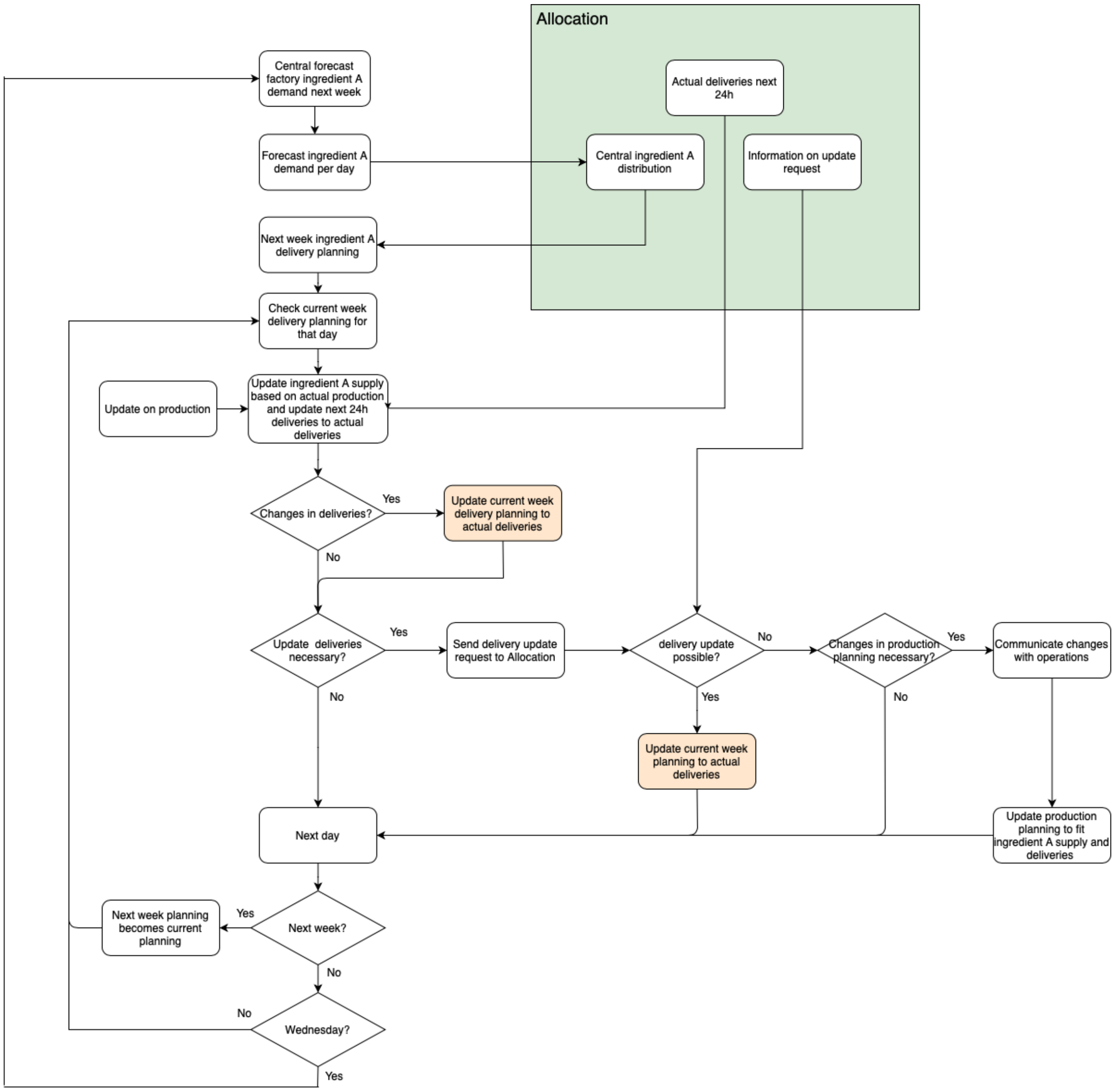


Figure 2.4: Flowchart of ingredient A supply planning.

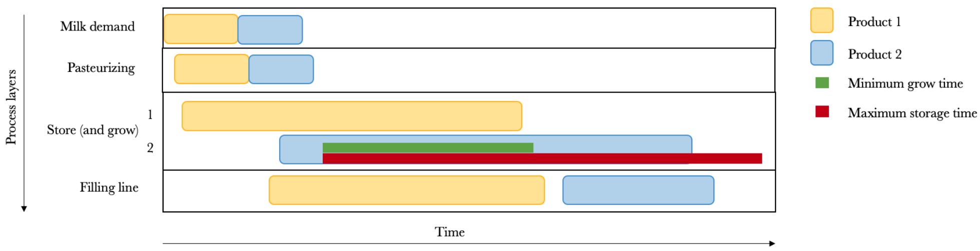


Figure 2.5: Simplified scheduling overview.

2.2.2 Operations

The operations department is responsible for all ingredient A related operations within the factory, they make sure the semi-finished products are ready to be filled at the designated filling line at the right time. Operations receive a time at which the semi-finished products should be ready to be filled, these times have a small margin of error for when the actual filling starts. The sequence at which they fulfill the orders is the choice of operations themselves: the complete planning from Figure 2.5 is not shared with operations. This complete planning is just for the planning department to get an overview whether the schedule is viable for operations. Besides operating the pasteurization and prefill storage, operations is also responsible for any additional semi-finished products that need to be added to products to create a ready to fill product, the so-called "process ingredient A".

Operations also makes sure enough ingredient A is present in the buffer tanks (10 to 13 in Figure 2.2) to sustain production. This is ensured by filling one of the buffer tanks while draining ingredient A, for production, from the other. The modus operandi is to keep ingredient A as forward as possible, thus keeping the buffer tanks filled when possible. This process is not automated but operated by manual actions of the operators. When this process goes out of sync by an operator acting too late, long waiting times can easily occur. A supplement on the position of operations department described in Figure 2.3, which can be found below in Figure 2.6.

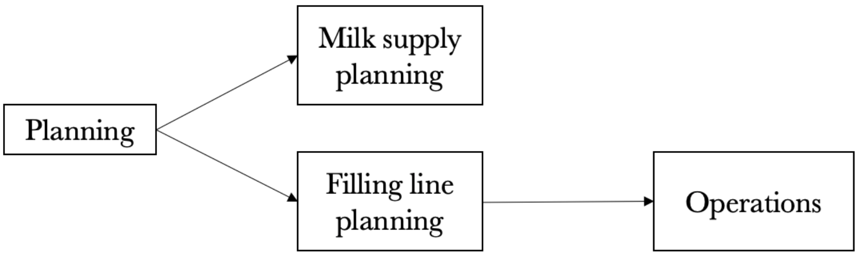


Figure 2.6: Relation Planning and Operation.

2.2.3 Organogram

With the information obtained on the planning and operations departments within the organizational layer we can supplement Figure 2.1. This results in a complete organogram of the organizational layer which can be found in Figure 2.7. The figure shows that the planning department uses external demand forecasting in combination with a Material Requirement Planning (MRP) to estimate the factory's ingredient A demand. This planning is then communicated with Allocation that consequently schedules the actual deliveries. The operations department is the one that determines the actual factory demand based on the filling line planning that is created. They furthermore determine which ingredient A is stored in which tank in the reception system.

In summary, from the system analysis it has become clear that the functioning of the system consists of a complex interplay between operations, planning and ingredient A supply. The relations within this system have been mapped to contribute to the understanding of the system and support conceptual model design in a later stage. In the next section the performance of the current system is analyzed to be able to compare model results and further deepen understanding of the system.

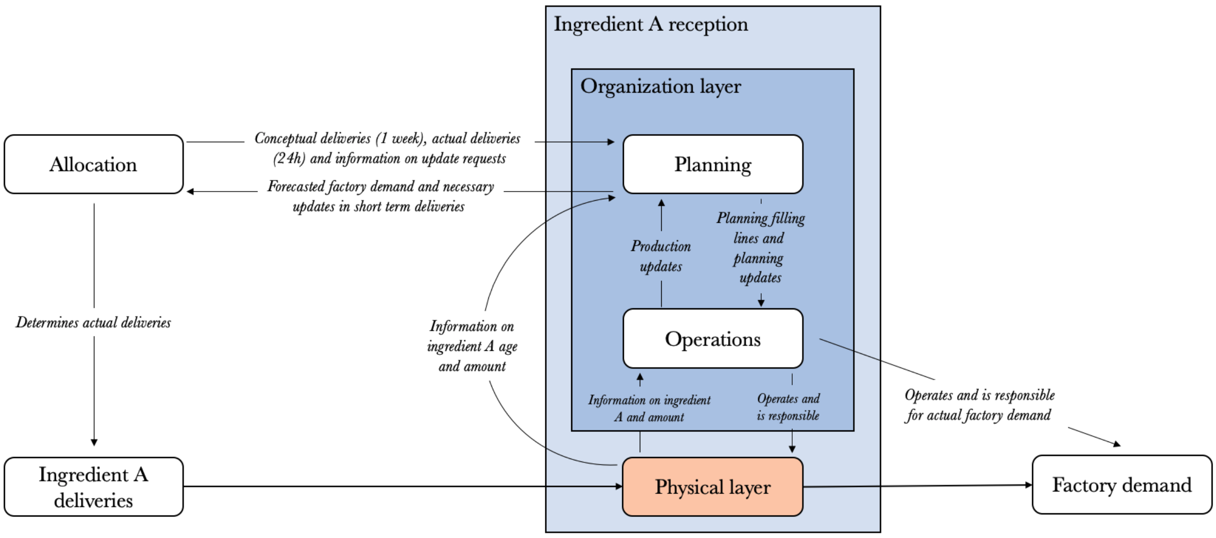


Figure 2.7: System organogram.

2.3 System performance

The primary goal of the historical data analyses is to better understand the working and performance of the current system in order to feed the simulation and interpret the results. Within this chapter a three-way division is made to structure the results, this division can be found in Figure 2.8. The first part focuses on ingredient A deliveries, the second on the storage and the third on the factory demand.

The data that is available comes from level transmitters in each of the tanks, these sensors log the tank levels when the system is changing. This data is cleaned so a datapoint is present for each minute and for each tank. In Figure 2.9 an example of the cleaned level data of a tank is illustrated. A comprehensive description of how this data is cleaned and mutated can be found in Appendix C.

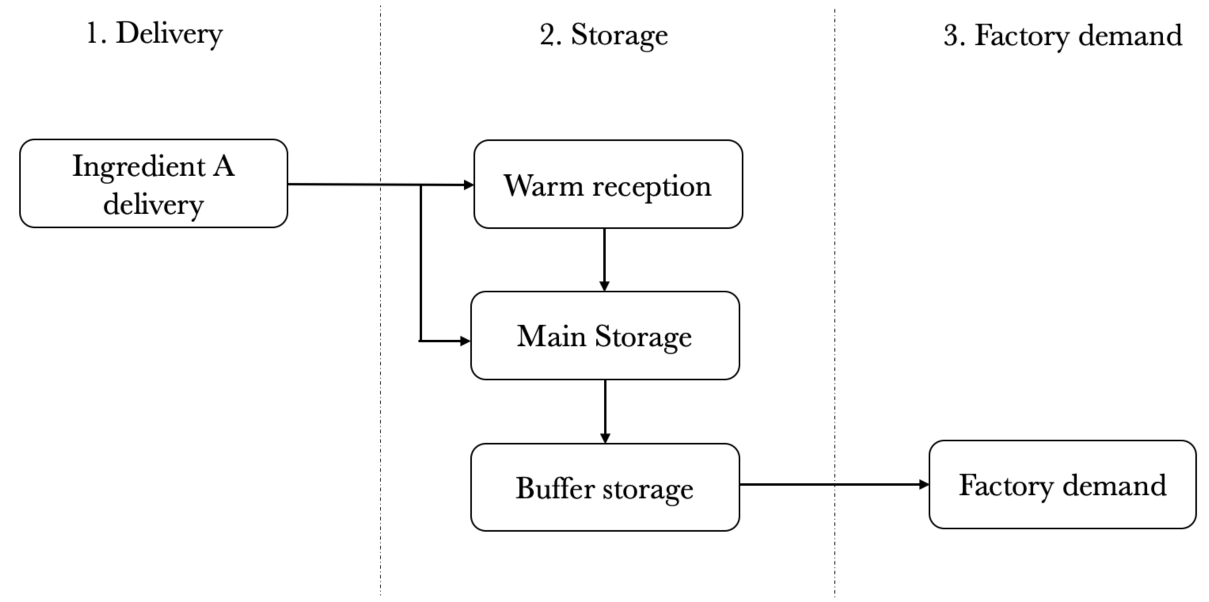


Figure 2.8: Components of system's performance.

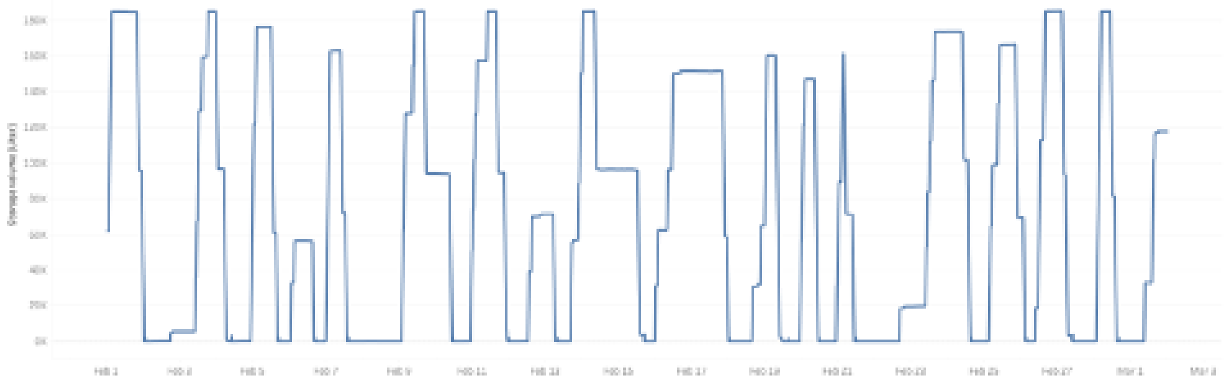


Figure 2.9: Tank level data.

2.3.1 Delivery

The delivery facilities are at the start of ingredient A reception system and consist of three stations where tank trucks can be unloaded and cleaned. Of these three unloading stations two are used for regular ingredient A and one is used for organic ingredient A. The data that is used is of a flow transmitter on each of the stations. This transmitter logs ingredient A flow when the flow is changing, the data is cleaned as to ensure a datapoint is present at each minute; a comprehensive description can be found in Appendix C.

From the available flow data, truck arrival hours are calculated for both regular and organic ingredient A. In the analyzed timespan the number of truck arrivals is found to be 585, where 452 trucks carried regular ingredient A and 133 trucks carried organic ingredient A. More information on daily and hourly truck arrival can be found in Appendix C.

2.3.2 Main storage

Next the dwell time, the time a batch of ingredient A spends in a tank, is analyzed for the main storage tanks over 2019, to depict on average how long ingredient A stays in the storage. For both the regular and the organic ingredient A time bins of 2 hours are used, which can be found on the x-axis of Figure 2.10. On the y-axis the percentage of total ingredient A volume that fits the bin is displayed. For example, about 7% of all regular ingredient A in the main storage in 2019 has a dwell time of 14-16 hours.

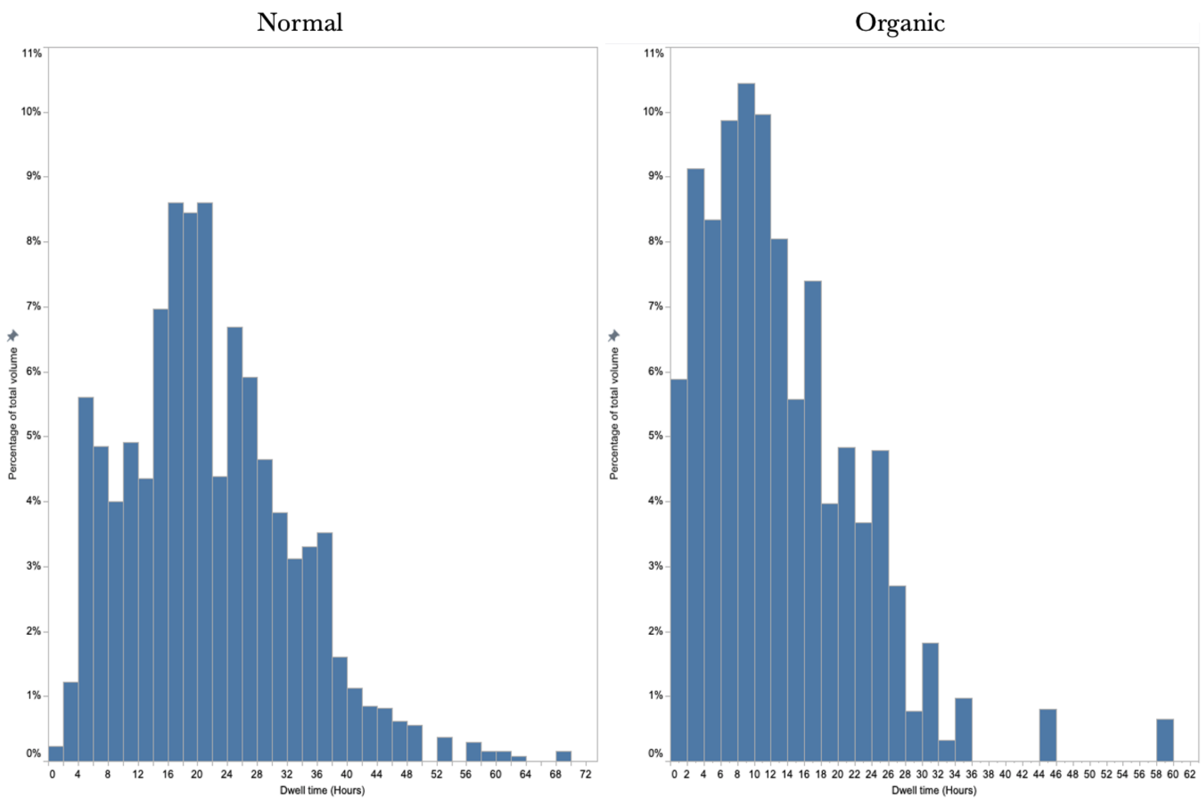


Figure 2.10: Dwell times of regular and organic ingredient A in main storage.

Table 2.1: Main storage performance conclusions

Normal ingredient A	Organic ingredient A
1. 935 storage cycles have been observed. Meaning an average of 233 cycles per tank, or about 0,64 tank cycles per day.	1. 370 storage cycles have been observed. Meaning an average of 185 cycles per tank, or about 0,51 tank cycles per day.
2. Average cycle time is 18.74 hour.	2. Average cycle time is 10.48 hour.
3. Average dwell time is 21.32 hour.	3. Average dwell time is 13.16 hour.
4. Average cycle volume per cycle is found to be 134,762 liter.	4. Average cycle volume per cycle is found to be 56,811 Liter.
5. For more than a fifth of ingredient A (20.57%) the dwell time in main storage is more than 30 hours.	5. For almost three-quarters (74.68%) of ingredient A, the dwell time is below 18 hours.
6. All cycles account for 126,002,425 liters of ingredient A.	6. All cycles account for 21,019,892 liters of ingredient A.
7. Normal ingredient A main storage utilization is determined at 52.0%	7. Organic ingredient A main storage utilization is determined at 47.4%

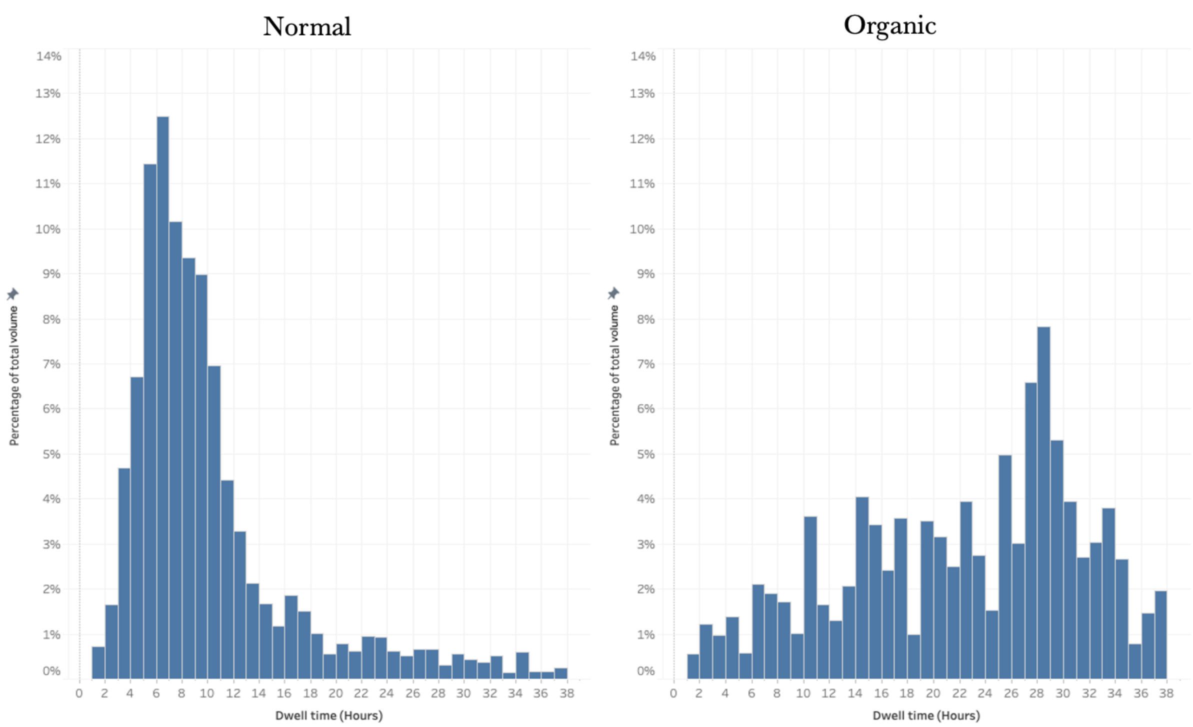


Figure 2.11: Dwell times of regular and organic ingredient A in buffer storage.

2.3.3 Buffer storage

Next the dwell time for ingredient A in the buffer storage is analyzed. For both the regular and the organic ingredient A time bins of 2 hours are used, which can be found on the x-axis of Figure 2.11. The percentage of total ingredient A volume that fits the bin can be found on the y-axis.

Table 2.2: Buffer storage performance conclusions

Normal ingredient A	Organic ingredient A
1. 1391 buffer storage cycles have been observed. Meaning an average of 696 cycles per tank, or about 1.90 tank cycles per day. One cycle was removed due to a cycle volume that is larger than tank capacity. Another is removed due to a high volume and very low cycle time (0.03h). 2. Average cycle time is 9.67 hour. 3. Average dwell time is 10.13 hour. 4. Average cycle volume per cycle is found to be 80,477 Liter. 5. All cycles account for 112,340,153 liters This is a difference of 13,662,272 liter (10.08%) with the amount observed in main storage. This difference could be due to a number of factors, namely: product loss, filling a tank while at the same time draining to pasteurizers (as cycle volume is the maximum tank level between start and end), incomplete cycles that are not taken into account. 6. Normal buffer utilization is determined at 82.7%.	1. 373 buffer storage cycles have been observed. Meaning an average of 187 cycles per tank, or about 0.51 tank cycles per day. 2. Average cycle time is 26.68 hour. 3. Average ingredient A dwell time is 27.66 hour. 4. Average cycle volume per cycle is found to be 53,722 Liter. 5. Over half of ingredient A(52,33%) 6. has a dwell time larger than 23 hours. All cycles account for 19,984,758 liters. This is a difference of 1,035,134 liter (4.92%) with the amount observed in main storage. This difference could be due to a number of factors, namely: product loss, filling a tank while at the same time draining to pasteurizers (as cycle volume is the maximumtank level between start and end), incomplete cycles that are not taken into account. 7. Organic buffer utilization is at 58.4%.

2.4 Conclusion

It can be concluded that the operation of the current system is a complex interplay between Operations, Planning and Allocation. The relational structure mapped in Figure 2.7 should be Incorporated in the model's design for it to be an accurate representation of the current system. In general, it is found that the performance of the organic system is far beneath maximum capacity and is not seen as a possible future bottleneck. Therefore this part of the system is excluded for the rest of this research. In terms of performance the 'normal' ingredient A system is found to be lacking somewhat as dwell times have found to be long. Possible adaptations to the system, to decrease the dwell time, should be Incorporated in this research.

Chapter 3

Theoretical Background

A study of literature is conducted to position this work and provide new insights for effective execution of this study. The first part of this chapter focuses on literature concerning optimization of manufacturing and chemical systems. The second part of this chapter focuses on literature regarding different simulation methods and valid simulation model building.

3.1 Optimization in process manufacturing

All manufacturing can be broadly divided into two different categories: discrete parts assembly manufacturing and process industry manufacturing. Discrete parts assembly manufacturing encompasses finished products that are composed of individual components that are combined. Examples include but are not limited to cellphones, laptops and furniture. This process typically starts with an abundant number of raw materials and once completed delivers few finished stock keeping units. On the contrary, the process manufacturing industry is characterized by few raw materials being used as input to create many differentiated SKU's through processes such as baking and/or mixing. (King et al., 2008) In Figure 3.1 a schematic for a 'v-type process' typical for process manufacturing is given. For the following sections we will solely focus on process manufacturing, as the basis of this research is characterized by this type of manufacturing.

Within process manufacturing the focus for improvement is mainly on equipment instead of labor. Where in many assembly processes bottlenecks can be eliminated by adding extra people, this is rarely the case for process manufacturing (King, 2019). This is in line with Ashayeri et al. (1996), who characterizes the process industry by costly specialized equipment and a high degree of automation. In addition, process industries frequently have high stock levels within their supply chain with large cycle times of which only 0.3%-5% account for value adding operations (Shah, 2005).

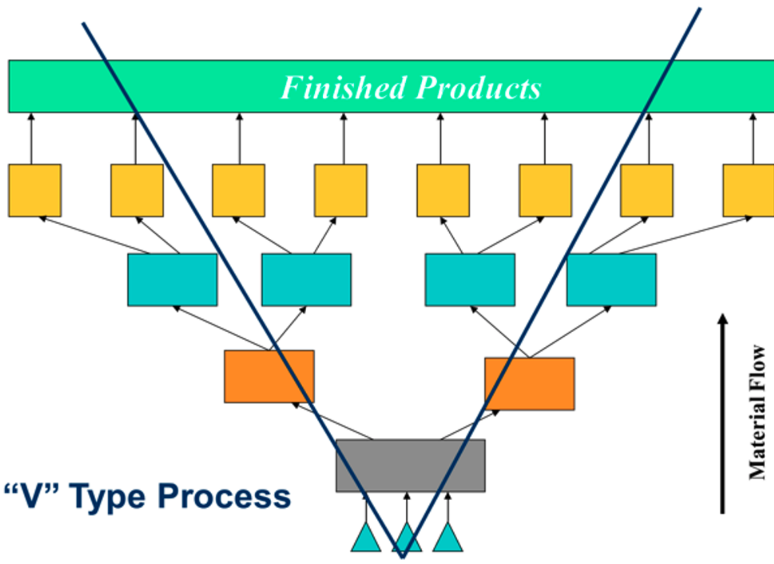


Figure 3.1: V-type process (King et al., 2008).

When applying different lean principles to the process industry by the use of simulation, Abdulmalek and Rajgopal (2007) found that some principles from lean management such as value stream mapping can be universally applied. When these lean principles are applied it was concluded that non-value adding time could be reduced from 8.6 to just two times the value adding time. Work-in-process and lead time can also be reduced with 90% and 70% respectively. Furthermore, by performing surveys in the food, chemical and textile industry, Koumanakos (2008), determined that firms with high levels of inventory had lower rates of return compared to firms that had lean type inventory management. A lean approach to inventory control can therefore be highly effective in process type industries (Panwar, Nepal, Jain & Rathore, 2015).

One of the lean principles that is frequently mentioned when it comes to reducing inventory is Just in time (JIT) inventory management. JIT is a system where the customer initiates demand and this transmits backwards from final assembly all the way to raw material inventory, in a way 'pulling' the required materials out of the process when they are required (Abdulmalek & Rajgopal, 2007). When applying JIT principles at Dow Chemical, Cook & Rogowski (1996) were able to reduce lead time by 25% and lead time variety by 50%, while decreasing inventory by 62.5%. The value adding time within the ingredient A reception is 0%, as it only involves raw material storage. As time spent in storage is no-value adding time, by reducing dwell time, the non-value adding time over the whole chain is reduced.

It becomes clear that the process industry has a lot to gain concerning inventory management. Yet optimizing inventory management involves a delicate balance between customer satisfaction and unnecessary holding costs. The stock that a company has on hand to buffer against uncertainty is defined as 'safety stock'. Customer satisfaction or service level, important indicators of business success, would increase as the amount of safety stock increases (Jung, Blau, Pekny, Reklaitis & Eversdyk, 2004). Within the ingredient A reception system this service level can be viewed as the system's ability to fulfill factory demand. An extra complexity arises in the form of the perishable nature of the stored goods, which would make large amounts of safety stock subjected to an increased risk of spoilage.

Jahangirian et al. (2010), states that simulation is the second most widely used technique concerning operations management for processes in manufacturing and business. When implementing for example the new product X production line, anticipated problems can be addressed before real-world production is affected (Mehra, Inman & Tuite, 2006). Cachon & Fisher (1997), used simulation to optimize the supply chain for Campbell soup and was able to reduce inventory levels with 66% while maintaining or increasing fill rates. Mehra et al. (2006), used simulation to investigate lot size reduction in the continuous process industry and found that typical improvements can be found for lead time, throughput, operating expense, inventory costs, net profit, and return on investments.

In the next subsection literature on simulation is reviewed, as one of the benefits of simulation is that it allows for an estimation of a system's performance under a projected set of operating conditions (Law, 2015).

3.2 Simulation

According to Cassandras & Lafortune (2008), the definition of a system is twofold: first a system consists of components and second a system is associated with a function. Law ((2015)), defined different ways of studying a system using the flow chart depicted in Figure 3.2. Simulation can be defined as obtaining a numerical solution by experimenting with a mathematical model of a system.

Simulation is a powerful tool for analyzing complex stochastic systems and is used in a wide variety of fields such as: marketing, supply chain, military and healthcare (Negahban & Smith, 2014). Studies can be conducted using different types of simulation models. The steps in which to conduct a simulation study are described in the following section.

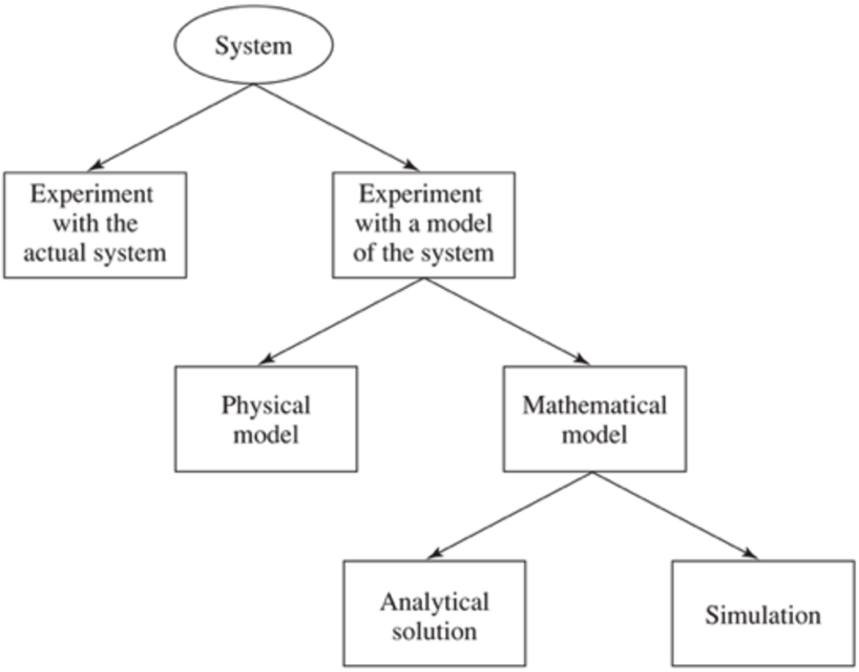


Figure 3.2: Ways of studying a system (Law, 2015).

3.2.1 Simulation study build-up

Building a simulation model is just a step in a bigger effort to design or analyze a system using simulation. There is a variety of components that require attention such as model randomness, validation and output analysis (Law, 2015). As a basis Banks et al. (2005), define four different phases of a simulation study:

1. Problem formulation, definition of objectives and project plan.
2. Collecting data and constructing a model.
3. Experiment design and execution.
4. Documentation and reporting (and possible implementation).

These four phases can also be distinguished in the ten steps for a sound simulation study as defined by Law (2015), and visualized in Figure 3.3. Important within the 10-stage plan are the two feedback loops, after step 3 and 6, that prevent entering a next stage without first positively validating the previous work.

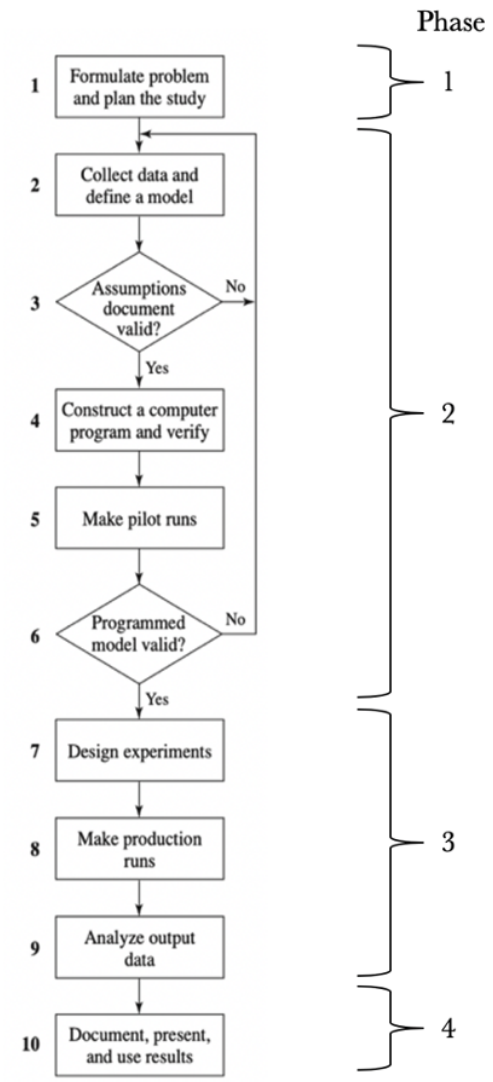


Figure 3.3: Steps to a sound simulation study (Law, 2015).

3.2.2 Simulation model

Within simulation models a differentiation is made between static and dynamic models. Static models describe the status of a system at a specific time, whereas dynamic models describe a system's status over time. Next a differentiation is made between deterministic and stochastic models. Deterministic models operate without any random components whereas stochastic models use probabilistic components. The final differentiation is between continuous and discrete models. From initial system description and previous experiences, a dynamic stochastic discrete event model seems fitting for the system, therefore this option is investigated.

Discrete event simulation

Discrete event simulation (DES) is one of the most common types of simulation models (Negahban & Smith, 2014). In a literature review of simulation studies conducted concerning operations management for processes in manufacturing and business Jahangirian et al. (2010) found that over 44% of the studies used DES. Vieira et al. (2018), goes as far as stating one of the important areas in the fourth industrial revolution, industry 4.0, is DES. DES is modelling a system as its state changes instantly on different points in time. It is a step-by-step description of the system, where the system is in a steady state between these time steps and instantly moves from step to step; an example of this type of modeling can be found in Figure 3.4. On the other hand, continuous simulation fits systems in which the variables can change continuously (Özgün & Barlas, 2009).

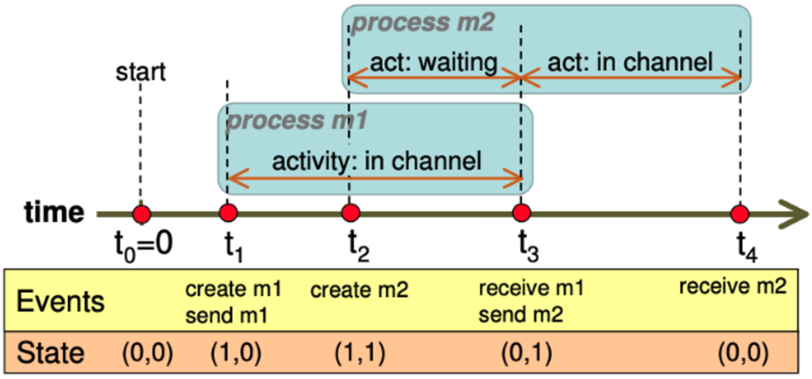


Figure 3.4: Example of discrete event (t) timeline of two processes (de Lara et al., 2014)

The fact that ingredient A reception is a semi-continuous process does not mean that continuous simulation is the most suitable simulation technique. On the contrary, in this case a DES model would suit the current situation, as ingredient A reception is a steady state with a state change at certain events: tanker arrival, buffer switching, start and stop of certain ingredient A transfer flow. There are also different ways to build up a DES model, namely stochastic and deterministic. Most queueing and inventory systems are modeled stochastically. This means the simulation model will contain probabilistic components instead of fixed deterministic problems, this causes each of the simulation runs to be different. Yet this also means that the results of the simulation are an estimate of the true characteristics of the modeled system (Law, 2015).

3.2.3 Verification and validation

Verification and validation of a model is important for the credibility of the results. Different techniques are used in different stages of the simulation study process. Law (2015), defines five classes of techniques for improving validity and credibility:

1. Collect high-quality information and data on the system
2. Interact with managers on a regular basis
3. Maintain a written assumptions document and perform a structured walk-through
4. Validate components of the model by using quantitative techniques
5. Validate the output from the overall simulation model

Where techniques described in class two and three can be easily and directly implemented, the techniques described in classes one and four are determined based on the situation at hand. For class four this is due to the fact that validation techniques are strongly dependent on the type of model components (e.g. probabilistic components). Validation of the output from the simulation model is crucial to the validity and credibility. Within these classes we again differentiate between the different techniques based on (Law, 2015).

1. *Comparison with an existing system* or described by Sargent (2010) as historical data validation. Here historical data is used to test wether the model behaves as the systems does. The accuracy within this comparision depends on the model usage and the utility function of the manger (Law, 2015). Another form of this comparison that is both described by, Law (2015),as well as Sargent (2010) is a Turing test where individuals who are knowledgeable about the system are asked to diferentiate between model data and real world data.

2. *Comparison with expert opinion* or described by Sargent (2010) as face validity. This technique encompasses the validation of a model by reviewing the model's output and behavior by expert opinion. It should be taken into account that simulation is only used when there is no consensus on exactly what output to expect (Law, 2015).

3. *Comparison with expert opinion* or described by Sargent (2010) as face validity. This technique encompasses the validation of a model by reviewing the model's output and behavior by expert opinion. It should be taken into account that simulation is only used when there is no consensus on exactly what output to expect (Law, 2015).

Another output validation technique that is mentioned by Sargent (2010) that is applicable for all models is internal validation. Here results from serval replications are compared, when these results have a large inconsistent variability it could make the models results questionable.

3.3 Conclusion

From the literature study we have identified different possible areas of improvement that could be applicable in this study. Both JIT and buffering against uncertainty are related to further optimizing inventory levels by decreasing dwell time (JIT) and tailoring the uncertainty buffer volume also called safety stock. Increasing capacity while decreasing the dwell time in this study could also be achieved by rearranging inventory. Where most studies focus on these forms of optimization separately, this study contributes to literature by combining these forms of optimization to achieve a future-proof solution for optimizing process capacity.

It furthermore is determined that simulation, with a special focus on discrete event simulation, forms an effective tool in analyzing complex stochastic systems which most likely represent ingredient A reception. The steps necessary to execute such a study have been mapped. Finally, different model validation techniques have been mapped that are used later in this research.

Chapter 4

Simulation Model Design

For this model we distinguish between two fundamentally different parts, namely: the innerworkings and the factory demand & ingredient A deliveries. The first part of this model formulation focuses on the factory demand & ingredient A deliveries. Here the innerworkings of the system are treated as a black box. The second part focuses on filling in the black box of innerworkings. It is furthermore determined that modeling the organic ingredient A system is unnecessary as the normal ingredient A system is clearly depicted as the bottleneck through interviews with stakeholders. The systems also operate with a certain level of independence which would make modeling these systems side-by-side unnecessarily complex.

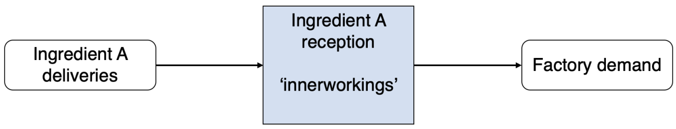


Figure 4.1: Simplified model.

4.1 Ingredient A deliveries and factory demand

When modeling the ingredient A reception facilities, the balance between supply (deliveries) and demand (factory usage) is of utmost importance as this has a direct effect on the performance of the system. Hence, if ingredient A was delivered just before it is used in the factory almost no storage is necessary. Therefore, modeling this balance is key to creating a viable model. This model should be able to grasp the complex relations established in subsection 2.2 and visualized in Figure 2.4. To be able to do this, we want to find a periodic relation between factory demand and deliveries made to the system. If such a relation could be found, this would replace the complex relational charts and form the foundation for the conceptual model.

For the actual system, deliveries are made in a binary manner, tank trucks are unloading or not. It is determined that the model complexity can be greatly be reduced by modeling delivery flow continuously and update flow on an hourly manner based on historic data. In consultation with experts on the system it is determined that this simplification should minimally affect aggregated results and a similar real-world effect is noticeable due to limited cooling capacity.

Similarities are present for the factory demand, where pasteurizers are operational or not. For the actual system pasteurizers are operational mostly throughout the day, yet scheduling these is difficult and dataset information is limited on binary operation. Therefore it is again chosen to model factory demand continuously and update demand on an hourly manner based on historic data.

4.1.1 Historic patterns

When it comes to a daily relation between demand and deliveries, we can distinguish between the three different system statuses found in Table 4.1. A daily situation where more ingredient A is delivered than is asked for as factory demand is described as 'increasing', as this results in a stock increase. When factory usage outweighs deliveries on a daily level the system is described as 'decreasing' as stock levels decrease. Finally, when the deliveries are equal to the factory demand the system is described as 'neutral'.

Table 4.1: System statuses

System status	Deliveries	Factory usage
Increasing	++	-
Decreasing	+	- -
Neutral	+	-

Using normalized stock level data over 2019, Figure 4.2 is created, each line represents the normalized stock level for a given week. This figure clearly shows a weekly pattern where ingredient A stock is at its maximum level at the beginning of the week, decreasing to a minimum on Thursdays and Fridays, after which stock levels increase on Saturdays and Sundays. These drastic changes may be attributed to different factors such as: demand, labor requirements, delivery requirements etc. The changes in ingredient A stock consequently results in an increasing system status on Fridays and Saturdays and in a decreasing system status on Wednesdays and Thursdays.

Combining Figure 4.2 and the classification found in Table 4.1 results in Figure 4.3. Here the average stock mutation per weekday is given, in liters, together with the appropriate classification.

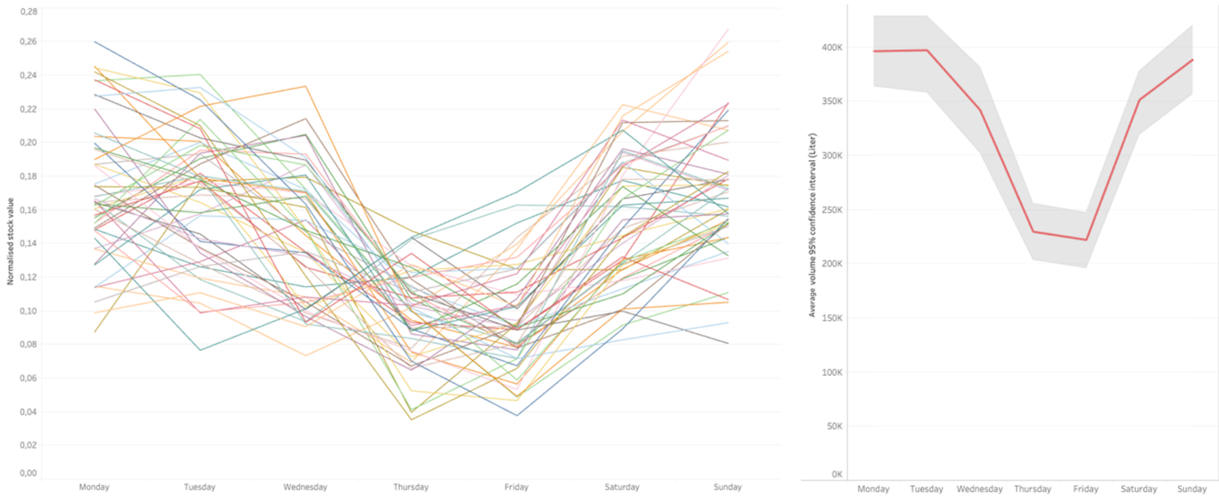
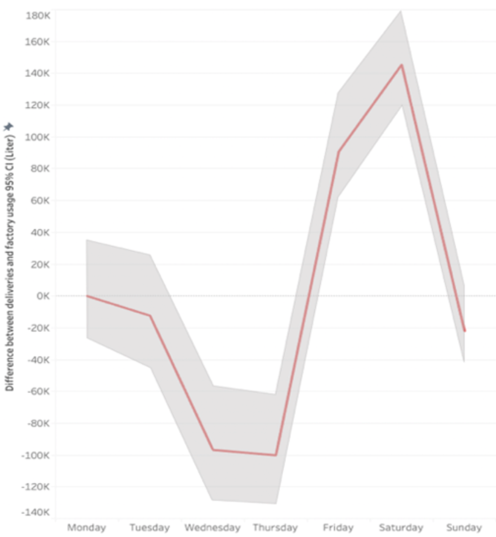


Figure 4.2: Normalized storage volume per weekday and average stock level using a 95% confidence interval.



Weekday	System status
Monday	Neutral
Tuesday	Decreasing
Wednessday	Decreasing
Thursday	Decreasing
Friday	Increasing
Saturday	Increasing
Sunday	Decreasing

Figure 4.3: Average daily mutation with 95% confidence interval.

Besides a daily status we also examine the possibility of weekly status according to the classification of Table 4.1. Using the historic dataset, the distribution in Figure 4.4 is created, here the distribution of weekly statuses is shown together with the corresponding volume. The weekly status shows whether within a week there is more factory demand than ingredient A deliveries (decreasing system status) or whether there is more ingredient A delivered than factory demanded (increasing system status). The data shows that the variation in liters of ingredient A in stock on a weekly basis is much smaller than the variation in liters of ingredient A in stock on a daily basis.

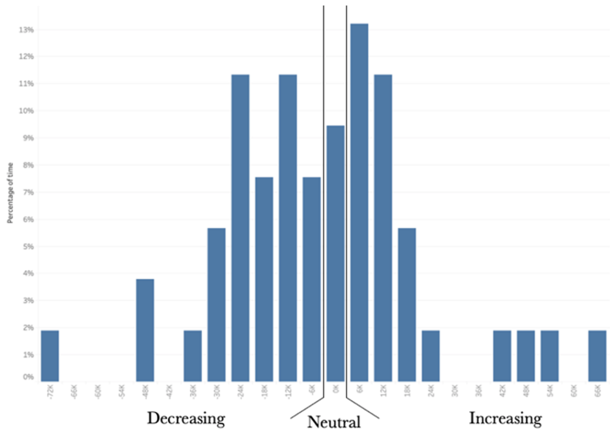


Figure 4.4: Stock mutation on week level.

For the model it is key to follow these daily and weekly patterns to achieve a strong representation of the real system. From Figure 4.4 it becomes evident that the weekly changes in total stock amount are minimal and the daily surpluses on Fridays and Saturdays and shortages on Wednesdays and Thursdays are strongly related. Hence, when there is a large surplus in ingredient A stock level on one day, this is followed by a large decrease in ingredient A storage as to ensure the weekly stock level is near neutral. This is due to the fact that the planning department updates new ingredient A deliveries in adjustment to the current level of ingredient A in stock.

4.1.2 Mathematical model

Using the weekly related surplus and shortage patterns, a model can be created that generalizes the complex delivery planning and operational relations. For the model we chose to determine demand and deliveries per week, as this fits with the weekly cycles. It furthermore is determined to start a week on Friday, as this day on average has the lowest stock level of ingredient A within the weekly cycle. An aggregated factory usage (X) based on a normal distribution (fitted in Appendix F) is picked at the beginning of the week. This (X) is then distributed to X_{ij}, which is the factory usage for each day (i) of the week and per hour (j) again according to historical data. This factory demand forms the basis for the calculation of the deliveries.

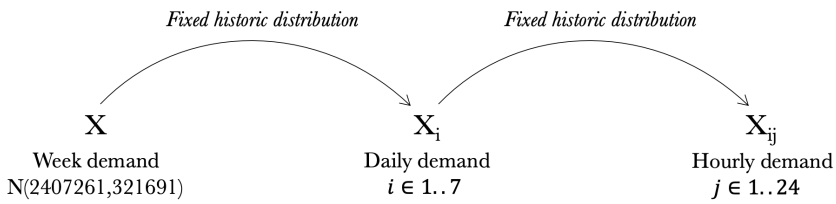


Figure 4.5: Determining week and hourly demand.

Next the weekly under or overshoot (S) is determined, this is the difference between the weekly factory demand and the aggregated deliveries. Or in other words: the shortage or surplus at the end of the week which starts on Friday morning and ends Thursday night. This is done using a Normal distribution, based on historical data. Next the demand/delivery misalignment is determined using a Normal distribution, based on historical data. This demand/delivery misalignment is the misalignment, on a daily level, between factory demand and deliveries. The comprehensive fitting of this distribution can be found in Appendix F. The demand/delivery misalignment (IC) is distributed over the days of the week using historical fractions. In the current situation this results in a surplus on Fridays and Saturdays, a neutral situation on Mondays and a decrease for the other days of the week.

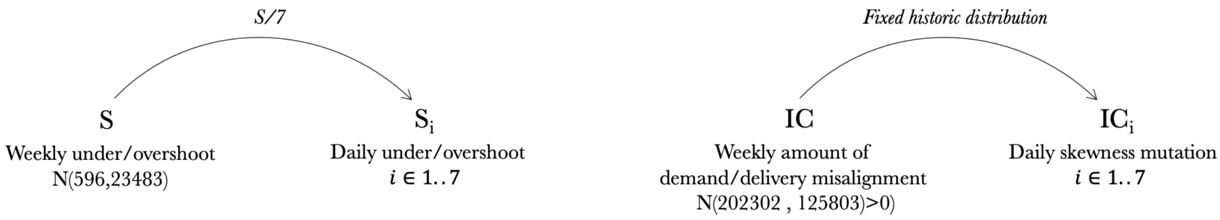


Figure 4.6: Determining daily overshoot and demand/delivery misalignment.

The daily deliveries are determined using: the daily demand (X), the daily under/overshoot (S) and the daily misalignment (IC). The daily deliveries (D_i) are determined using: $D_i = X_i + S_i$. For the first simulation weekday deliveries (D_i) within this calculation we compensate for the overshoot of the previous week (S_{n-1}).

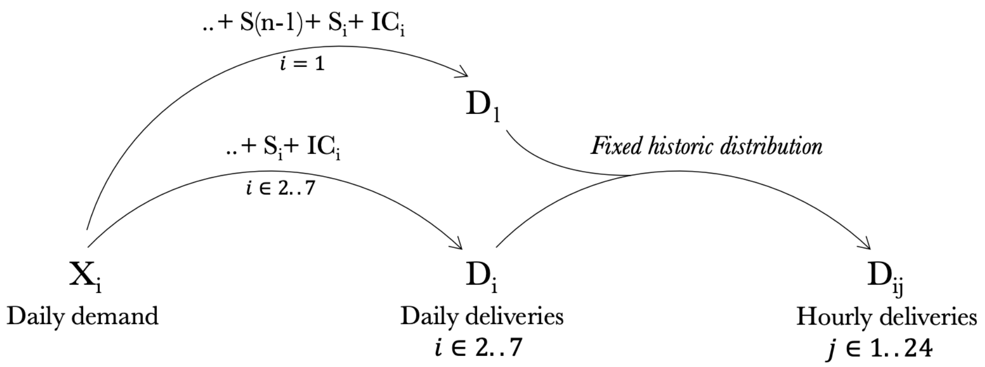


Figure 4.7: Determining hourly deliveries from daily demand.

The complete overview of model variables is displayed in Table 4.2. An overview of the weekly factory usage and deliveries can be found in Table 16. In Appendix G a step-by-step calculation of the deliveries and factory usage can be found.

Table 4.2: Model variables

Variable	Description	Calculation
X	Actual factory usage (week)	Normal distribution: $\mu = 2407261$ $\sigma^2 = 321691$
S	Weekly under or overshoot	Normal distribution: $\mu = 596$ $\sigma^2 = 23483$
S(n-1)	Over/undershoot of previous week	Known
D	Total delivery amount week	D = X + S - S(n-1)
IC	Demand/delivery misalignment	Normal distribution (>=0): $\mu = 232302$ $\sigma^2 = 125803$

Table 4.3: Weekly factory usage and deliveries

Day	Factory usage	Deliveries
1	X_1	$X_1 + IC_1 + S/7 - S(n\text{-}1)$
2	X_2	$X_2 + IC_2 + S/7$
3	X_3	$X_3 + IC_3 + S/7$
4	X_4	$X_4 + IC_4 + S/7$
5	X_5	$X_5 + IC_5 + S/7$
6	X_6	$X_6 + IC_6 + S/7$
7	X_7	$X_7 + IC_7 + S/7$
Weekly total	X	D = X + S - S(n-1)

4.2 Ingredient A reception innerworkings

Now that a mathematical model is created for the inflow (deliveries of ingredient A) and the expected outflow (factory demand), the next step is to create a conceptual discrete event model that is able to model the system described in Figure 4.8. Within this conceptual model, we differentiate between three event types:

1. Time dependent events

2. Main storage events

3. Buffer storage events

Besides these three different event types, we defined the following five tank statuses:

1. Filling: the tank is being filled
2. Draining: the tank is being drained
3. Product waiting: the tank is filled with product and not being filled or drained
4. Empty: the tank is empty and ready to be filled.
5. Cleaning in Place (CIP): the tank is being cleaned

Next the different events and model actions are discussed for each of the event types concluding with the model assumptions.

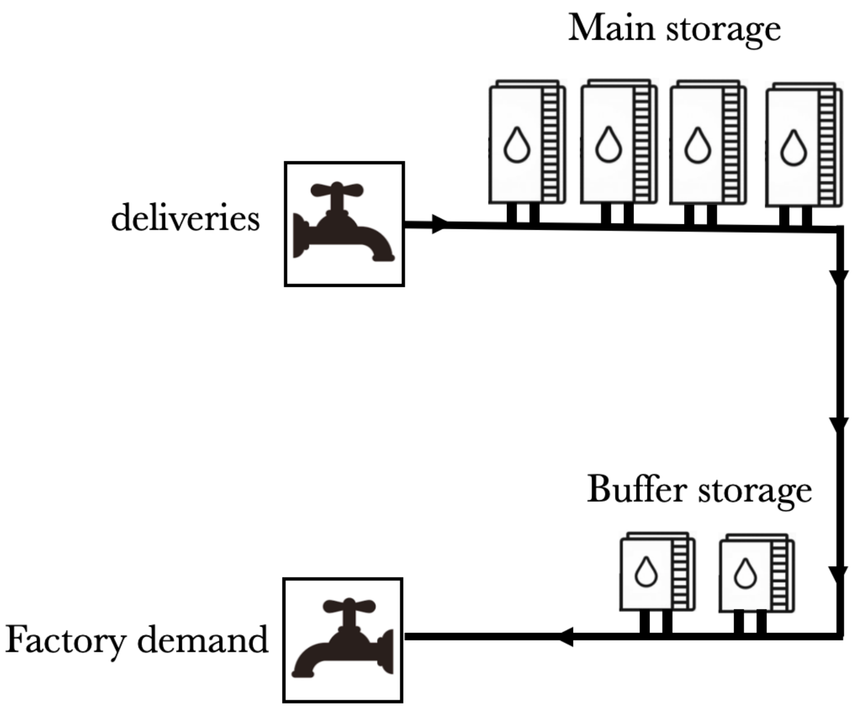


Figure 4.8: Conceptual model structure with four main storage tank and two buffer storage tanks.

4.2.1 Time dependent events

Within the conceptual model we have two time dependent events. The first time dependent event is the weekly logic that defines ingredient A deliveries and factory demand, defined in subsection 4.1. The second time dependent event is the hourly logic that checks if factory demand has been fulfilled, if not remaining factory demand is added to the next production hour. When factory demand is fulfilled within the hour, the product flow is reduced to zero for the remaining of that hour.

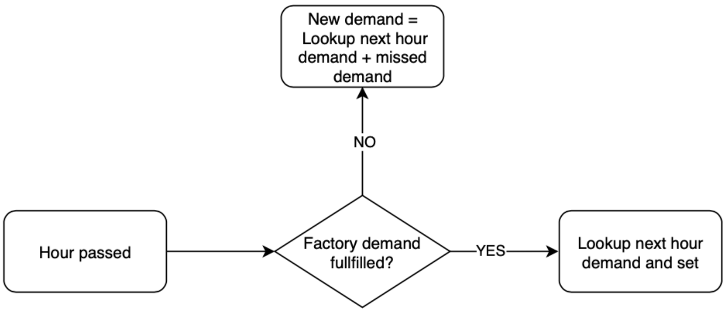


Figure 4.9: Logic behind 'hour passed' event.

4.2.2 Main storage events

Main storage events are events that take place within the main storage tanks. The following events and model actions are defined:

1. When a main storage tank reaches its maximum level, this tank needs to be disconnected from the inflow. If a new empty tank is available this tank is connected to the inflow, else the drain is connected.

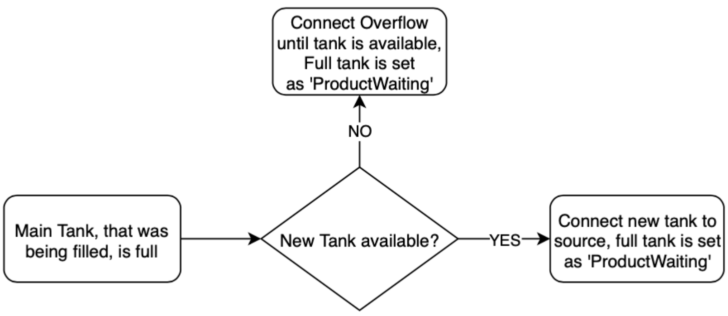


Figure 4.10: Logic behind 'full main tank' event.

2. When a main storage tank becomes empty it can only be the case that this tank was filling one of the buffer tanks. The empty main storage tank is placed in a 30-minute cleaning program and a check is done if the buffer tank has a storage volume that is larger than 700L. If this is not the case the buffer tank is considered empty and filled from another tank. If the storage volume is larger than 700L, the buffer tank is set as ready to fulfill factory demand when necessary.

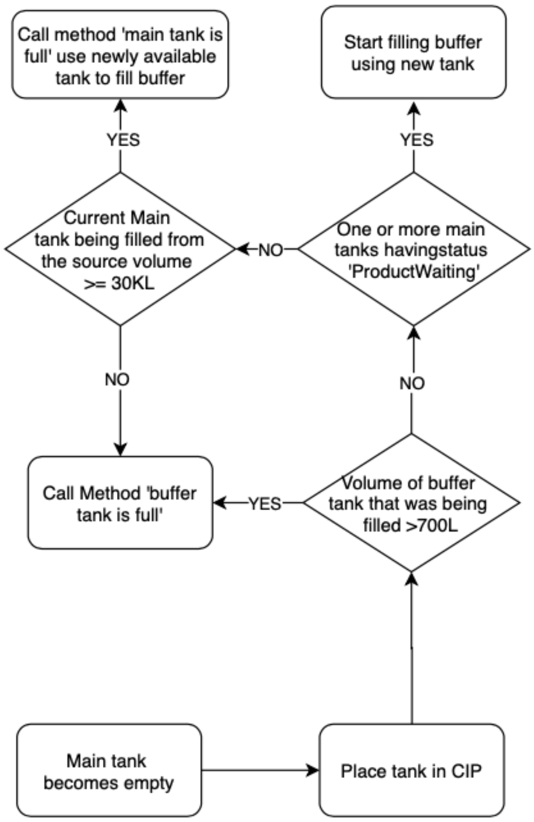


Figure 4.11: Logic behind 'empty main tank' event.

3. When a main storage tank comes out of the cleaning program, there are two options: if the overflow at that time is connected to the inflow, the overflow is disconnected and this newly cleaned tank is connected to the inflow to store ingredient A and therefore receives the status 'filling'. When the overflow is not connected the tank received the status 'empty' and is placed in the waiting line of available tanks.

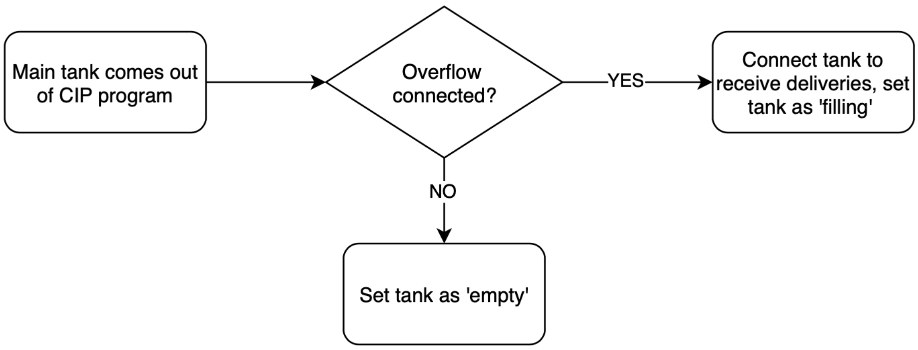


Figure 4.12: Logic behind 'main tank coming out of CIP' event.

4. The main storage tanks have fill level sensors that are triggered when one of three intermediate levels is reached. If a certain amount of 'empty' storage tank is available, it switches the tank that is being filled, which triggered the sensor, to a new empty tank. By doing this, dwell times are reduced, and the model shows more similarities with the real word systems operation.

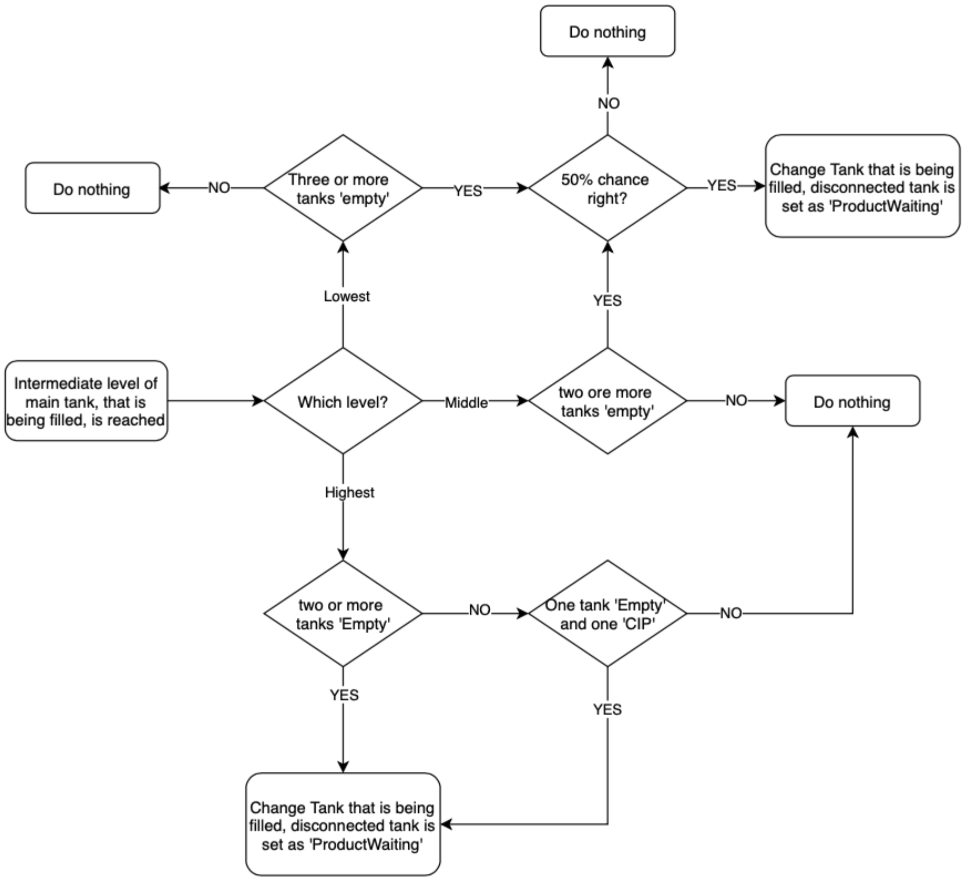


Figure 4.13: Logic behind 'intermediate fill level' event.

4.2.3 Buffer storage events

Buffer storage events are events that occur in the two buffer storage tanks. The following events and model actions are defined:

1. When a buffer becomes full, this is due to a transfer from the main storage. The first action is to disconnect the storage and set the tank as ready. If factory demand is being fulfilled from the other buffer, no other action is necessary. When this is not the case, the newly filled buffer is connected, and the other buffer is filled when possible.

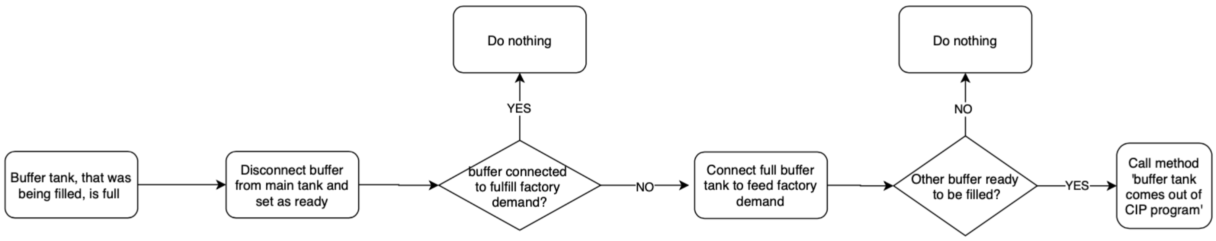


Figure 4.14: Logic behind 'full buffer' event.

2. When one of the buffers becomes empty this is always due to the fact that this buffer was fulfilling factory demand. In this case the new buffer needs to be connected when possible. When the status of the other buffer is 'productwaiting' the tank can be switched easily. When the other tank status is 'empty' or 'CIP' no switch can be made. Finally, if the other tank is being filled and the volume is larger than 30KL (to prevent switching to an almost empty tank), and by switching between tanks the remaining volume in the main storage tank does not require extra buffer CIP, the filling switch is made.

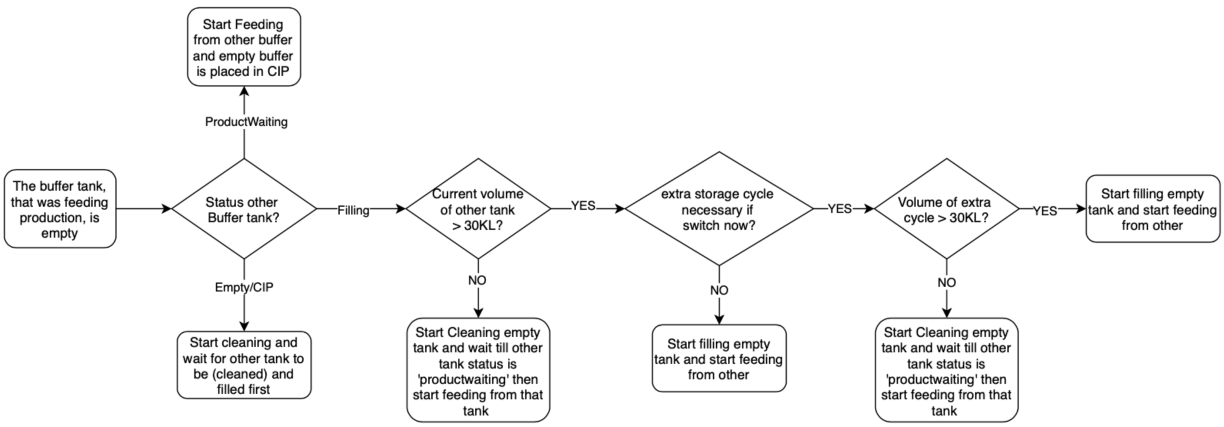


Figure 4.15: Logic behind 'empty buffer' event.

3. When one of the buffer tanks comes from CIP, the next actions depend on the status of the other buffer tank. When the other tank is being filled or empty, no actions are undertaken (besides placing in a queue). If the other status is draining or CIP, the possibilities are explored to start filling the buffer.

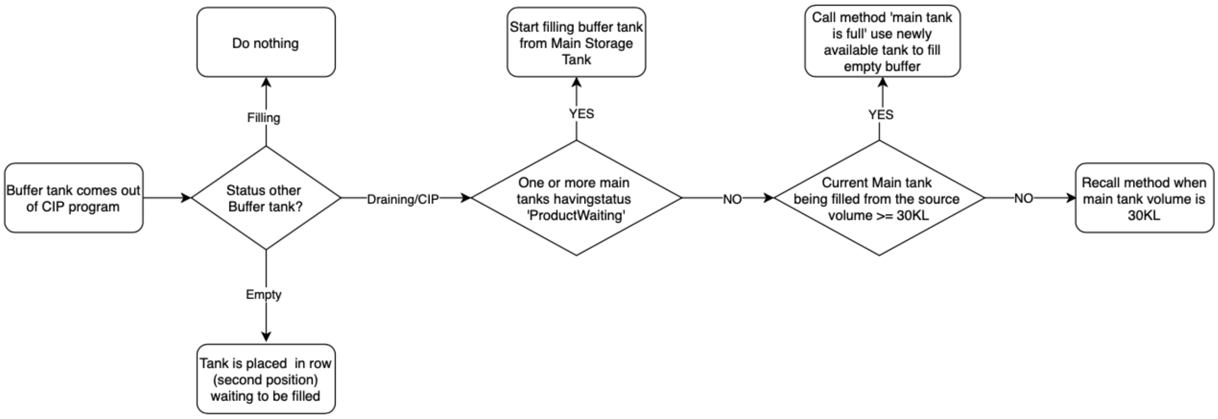


Figure 4.16: Logic behind 'buffer coming out of CIP' event.

4.2.4 Model assumptions

As it impossible to exactly replicate the real system; certain assumptions have to be made to simplify the system. Within the model design phase, the following assumptions are made based on previous analysis and expert opinion:

1. The preferred position for ingredient A is in one of the two buffer tanks. Hence, when these tanks are empty, they get filled immediately if certain conditions apply.
2. Only the normal ingredient A system is simulated as this is identified as the bottleneck, and this greatly simplifies the simulation model.
3. Deliveries are a constant flow, that is changed every hour according to historical distributions.
4. If factory demand is not met, the missed amount is added to the demand of the next hour.
5. Cleaning happens directly after a tank has been emptied and has a fixed time of 45 minutes.
6. Only tanks need cleaning.
7. Flow between tanks is constant and instant at max flowrate.
8. Buffer flow is at a maximum rate until demand is met or buffers are empty.
9. When hourly demand is met, flow from the buffer becomes 0 until next hour begins.
10. The model operates with a fixed amount of safety stock to buffer against the uncertainties

11. The model uses a distribution to pick a random weekly demand, in reality there would be a seasonal relation between different weeks, i.e. resulting in multiple weeks with larger demand.

12. Flow from main storage to buffer storage is almost instant.

13. Safety stock is at 160.000 Liter, according to historical data.

14. Overflow spillage is added to the next day deliveries to maintain balance in the system.

4.3 Model output

To be able to analyze the model's output, different KPI's are used, some are previously used for the historic data analysis, others are model specific. For both the buffers as well as for the main storage, the dwell and cycle time are logged. The dwell time is the average time ingredient A spends in storage (from the point of the oldest ingredient A in the tank). The cycle time is the average cycle duration. The dwell time is one of the most important KPI's whereas the cycle time is mainly used to calculate the dwell time and other KPI's. Utilization is an important indicator for the usage level of the system. The utilization for both the main storage and the buffer are calculated using formulas 4.1 & 4.2.

$$BufferUtilisation\ \% = \frac{Number\ of\ cycles * average\ cycle\ time}{Total\ sim\ time} * 100 \tag{4.1}$$

$$MainUtilization\ \% = \frac{Number\ of\ cycles * average\ cycle\ time}{Total\ sim\ time} * 100 \tag{4.2}$$

Measuring when the system storage capacity is zero is done by measuring the overflow amount. The statistic is calculated using formula 4.3.

$$Overflow\ \% = \frac{Overflow\ amount}{Total\ amount\ created(source)} * 100 \tag{4.3}$$

Another KPI is the weekly number of hours that demand is not fulfilled, especially when increasing throughput and demand. This KPI will provide information on boundary conditions of the system. One drawback is that this KPI does not exist in the current system or historical dataset. Interpretation can only be done on expert opinion and comparison is only possible between simulations.

$$Stockouthours\ per\ week = \frac{Number\ of\ stockouts}{Total\ sim\ weeks} \tag{4.4}$$

For the calculation of the number of replications and warm-up time, a combined KPI is defined as this diminishes the need to calculate the replications and warm-up for each KPI individually. This KPI can also be used for easy comparison between different simulation settings. The calculation of the combined KPI is done using formula 4.5.

$$Combined\,score \ = \ Dwelltime\,main + Dwelltime\,buffer + Stockout\,hours + Overflow\,\% \tag{4.5}$$

4.4 Model implementation

The DES model is created using the Siemens plantsimulation® software according to the logic defined earlier in this chapter. A screenshot of the model can be found in Figure 4.17, a description of the models components is found below.

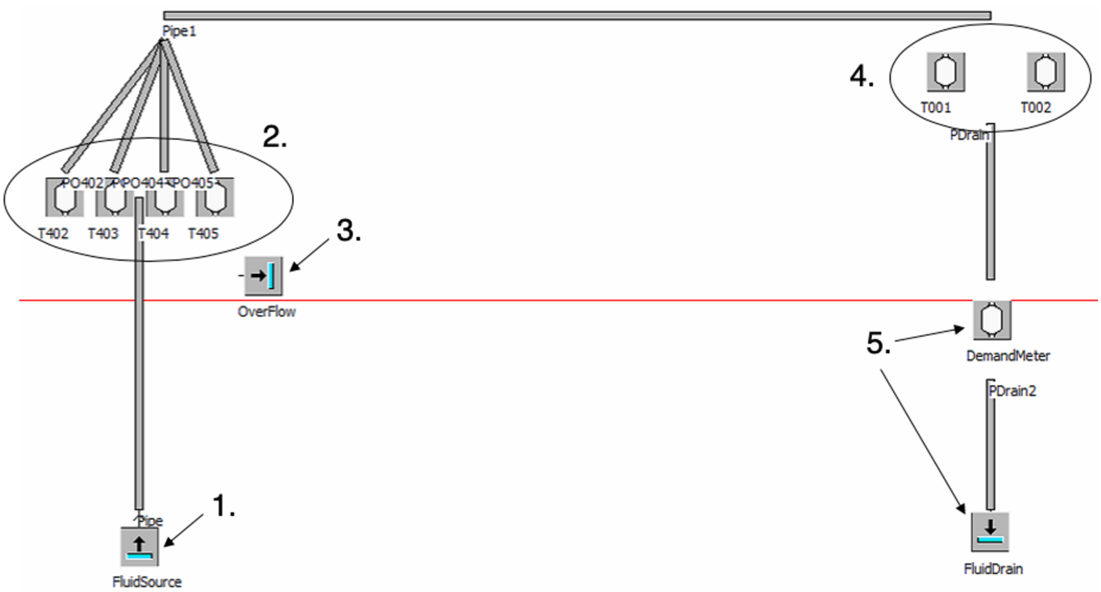


Figure 4.17: Model screenshot.

1. The Fluidsource, this object creates ingredient A at a constant flowrate, the flowrate is updated hourly according to the week delivery planning made previous to a modeling week.

2. Ingredient A that is generated is stored in one of the four 185KL main storage tanks.

3. The overflow object is used when all 4 tanks are unavailable.

4. Ingredient A is pumped from the main storage to one of two 95KL buffer tanks, one of these tanks is connected to pasteurizers which fulfill factory demand. Preferably ingredient A is stored in these tanks, as stockout occasions would result in the factory not receiving any ingredient A.

5. Ingredient A that is drained via the fluid drain is used in the factory. Using an intermediate tank (DemandMeter) demand fulfillment is checked every hour. If demand is not met, the remaining demand is added to the next hour.

4.5 Warm-up time

The model warm-up time is determined according to Welch's method using 10 independent replications. The combined KPI score is calculated for each simulation week and visualized in Figure 4.18 together with a 6- and 10-week moving average. From the figure it is determined that a warm-up time of 10 weeks is sufficient to provide accurate results.

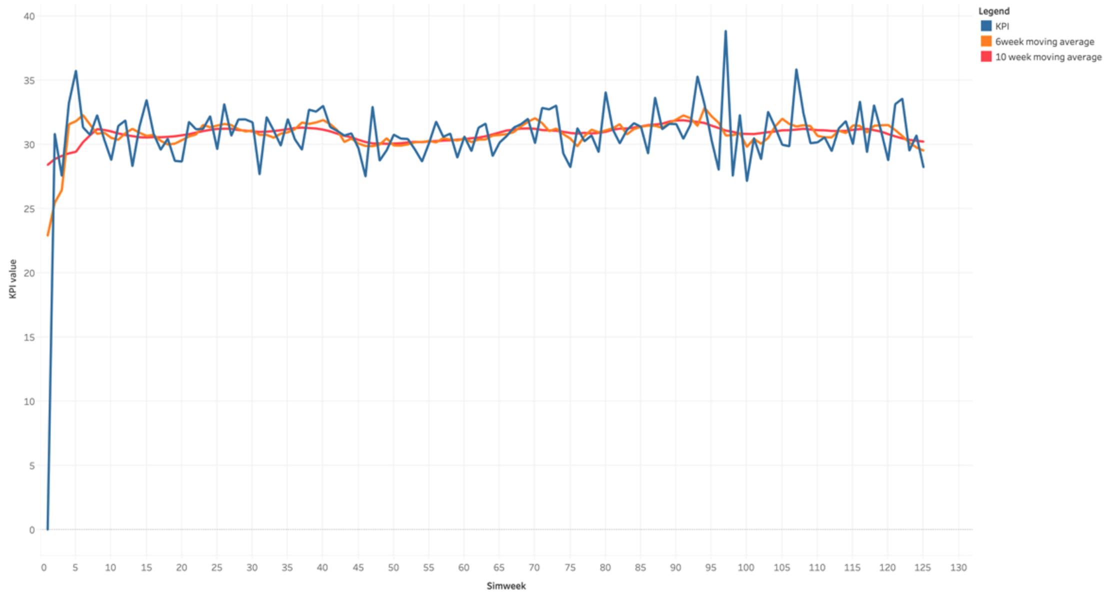


Figure 4.18: Combined KPI over time.

4.6 Number of replications

The number of replications is determined using the sequential approach for the combined score KPI. The relative error that is aimed for is: $\gamma = 0.025$ or in other words: the halfwidth of the 95% confidence interval has a relative error of $\gamma = 0.025$. When γ is used for the estimation of the relative error, a corrected target value must be used, this value is determined using formula 6. Now $n_0 \geq 2$ replications are made, and the 95% confidence half-width is determined using the sample variance (S_{n^2}) and formula 7. If the condition of formula 8 is met, the right number of replications is reached. If not, we increment n with one and redetermine and re-test δ (n,a) against the sample average .

$$\gamma' = \frac{\gamma}{1\ +\ \gamma} = \frac{0.025}{1.025} = 0.02439 \tag{4.6}$$

$$\delta\,(n,a) = t_{\mathrm{n\text{-}1,1\text{-}a/2}} * \sqrt{\frac{S^{2_{\mathrm{n}}}}{n}} \tag{4.7}$$

$$\frac{\delta\,(n,a)}{X} = 0.02439 \tag{4.8}$$

The number of replications is determined to be n=25 with the 95% confidence interval of the combined KPI of (33.02, 34.64).

4.7 Verification & validation

First to be verified is the yearly throughput. In Figure 4.19 the throughput of one year is visualized for 25 runs together with a 95% confidence interval of the average. We find that the historic throughput of 126 million liters falls within this confidence interval. The fact that the average is slightly higher could be due to the fact that in the historic throughput for week 52 & 1 is significantly lower.

Figure 4.19: Annual troughput.

4.7.1 Storage patterns

When comparing the storage patterns of the simulation (orange) to the historic data (blue) lots of similarities can be found in terms of size, length and buildup. It may become clear that the model has a somewhat smoothened buildup and decrease due to the constant demand and supply. Yet the assumption that supply and demand can be modeled continuously seems to have little effect on the storage patterns. When consulting expert opinion on the model's storage logic, it is also confirmed that the patterns are very similar to real-world data and the assumptions are correct. It is important to note here that the patterns can only be compared on similarities on shape, and not on size and position as the model output is completely independent.

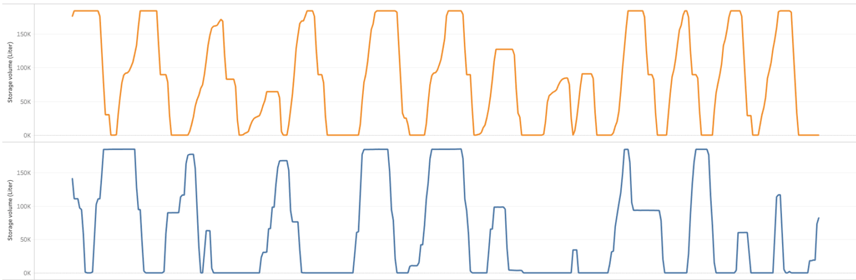


Figure 4.20: Storage patterns model (orange) vs historic (blue).

4.7.2 Storage cycles

One year of storage cycles is visualized for one model run and overlaid with the history cycles. It becomes clear that the spread in cycle time of the model cycles is somewhat less for the model cycles in comparison to the historic dataset. In Figure 4.21 the cycles are visualised for the main storage (left) and buffer storage (right).

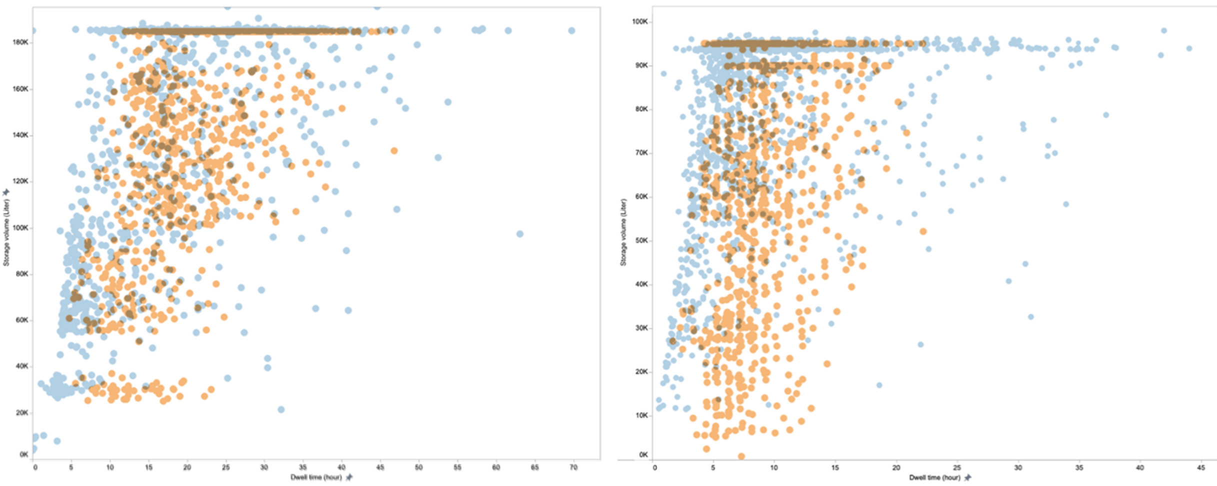


Figure 4.21: Storage cycles dwell time (x-axis) vs storage volume (y-axis), model (orange) vs historic (blue).

This difference can be explained by the fact that in reality we observe variations in the amount of stock left on the lowest point of the week (Friday morning); within the simulation this is fixed and only affected by (small) weekly variations. The difference can be found in Figure 4.22 where the stock on Friday 00:01 is visualized for the whole year. Modeling the seasonality found in the historic data is difficult as bringing the actual variation to the model would drastically influence results in a random way, diminishing usability of the data. It may also be noted that the historic data is a snapshot of Friday 00:01 whereas this is the actual start of the week for the model. In future scenarios where the throughput will go to a maximum modeling seasonality is not necessary, as this is not present. In the current way the model is set up it uses weekly changes that are observed, yet it compensates weekly for previous week, so the model does not spiral out of control.

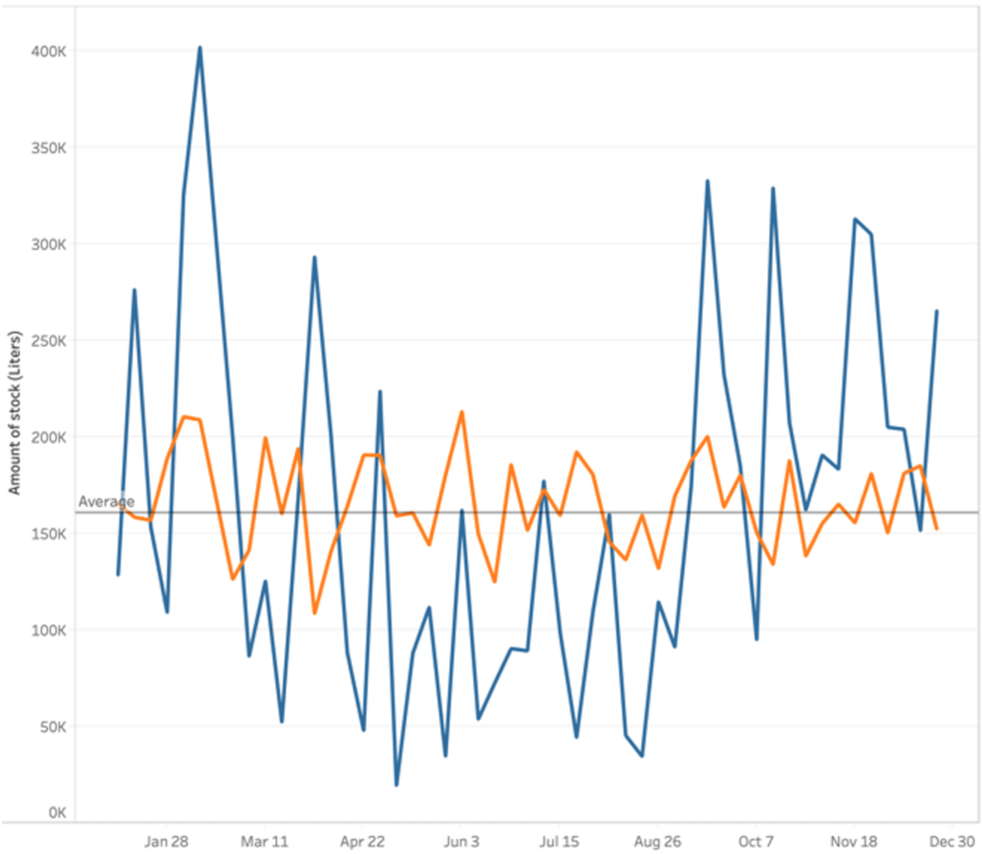


Figure 4.22: Stock at Friday 00:00 model (orange) vs historic (blue).

4.7.3 Key performance indicators

As final part of the validation, the KPIs are compared from 25 model replications to results from historical data analysis, this comparison can be found in Table 4. After discussion with experts on the system, the results have been found to be very similar. The larger difference in buffer utilization is due to the fact that the model focuses on keeping the buffers stocked, resulting in immediate filling after CIP is completed. In the real world operation this could take some time, resulting in a lower buffer utilization.

Table 4.4: Comparison KPI's model vs historic

Indicator	Unit	Historic	Model	Difference
Dwell Time Main	Hour	21,32	21,14	-1%
Dwell Time Buffer	Hour	10,13	10,24	1%
Cycle Time Main	Hour	18,74	19,05	2%
Cycle Time Buffer	Hour	9,67	9,85	2%
Main tank utilization	%	52%	53%	2%
Buffer Utilization	%	77%	99%	28%
Main cycle Volume	Liter	134762	131801	-2%
Buffer cycle volume	Liter	80477	75303	-6%

4.8 Conclusion

It can be concluded that the model proposed in subsection 4.1 in combination with the internal operation proposed in subsection 4.2 represent a valid representation of the actual system for this research. The model proposed is not supposed to be interpreted at an individual run level and only produces results on an aggregated basis. Therefore, the averaging of the (slight) seasonality found in Figure 4.22 is not a problem. In the next chapter, the multiple future scenarios and different iterations of layouts are discussed.

Chapter 5

Experiments

This chapter will discuss the future scenarios, the interventions to deal with these scenarios and the experimental design. The goal of the chapter is to provide a clear overview of the experiments that are conducted. The experiments will consist of two different phases: the first one consisting of experiments on the current situation and the second on experiments with the new product X line and two different physical interventions. The experiments on the current situation will provide additional grounds to compare results with each other.

5.1 Scenarios

The scenarios are the future environments that the to be defined interventions are tested in. In this case the scenarios focus on different (factory) demand levels, or in other words, factory or system throughput. Within this demand we differentiate between conventional demand and product X demand.

5.1.1 Conventional demand

The conventional demand is the factory demand that is generated by the two existing pasteurizers. These two pasteurizers account for the demand of all sorts of products that the factory produces. In future scenarios an increase in conventional throughput is to be expected aside from product X demand. Therefore, it is chosen to model different levels of conventional demand to test the robustness of different interventions under these circumstances.

1. Current demand is at 126 million liters using the historical distribution.
2. Extra demand is given by sequentially increasing the (yearly) throughput by 13 million liters.

When factory throughput increases, it is to be expected that the spread in week demand will remain similar to the current situation as demand becomes easier to predict. In other words, the distributions that generate conventional week demand under increased throughput have the same standard deviation as the current one (fitted in Appendix F). An overview of the distributions that give conventional throughput can be found in Figure 5.1, the current distribution is sketched in non-dotted blue.

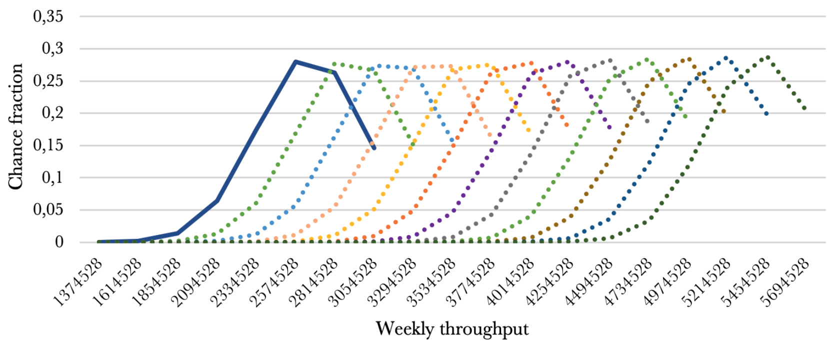


Figure 5.1: New (conventional) weekly demand scenarios (weekly throughput in liters on x-axis).

5.1.2 Product X demand

Product X demand is generated by the new third pasteurizer, which will solely process product X. Together with experts on the system, two different scenarios for (future) yearly throughput are determined at:

1. Product X normal, 55 million liters
2. Product X high, 105 million liters

As the new pasteurizer only processes product X at a fixed yearly demand, it is determined to model product X demand binary. In other words: demand for the product X pasteurizer is 25000L/h or 0 L/h according to a fixed schedule for each scenario. This results in shorter periods of increased demand, which more accurately represent reality. Both schedules for product X demand, that can be found in Appendix H, are determined in dialogue with experts on the system to have the most accurate representation.

5.2 Interventions

The interventions are defined in order to further optimize or facilitate ingredient A demand for the different scenarios defined in the subsection 7.1. Following the structure in the report, interventions are categorized in two different domains: organizational and physical. The physical interventions, discussed first, focus on changes in the storage layout. The organizational interventions focus on changes in the modus operandi.

5.2.1 Physical interventions

The common denominator for the two solutions within this subchapter is that they involve a different use of the available infrastructure. Both solutions are provided by the team tasked with the design and implementation of the new product X line. The (layout) effect of both solutions is sketched for the normal ingredient A system as well as the bio ingredient A. Again, of these two systems only the normal ingredient A system is seen as a potential bottleneck and therefore simulated.

Direct connect

In the current system ingredient A is first stored in one of the main storage tanks, then pumped to one of the buffer tanks before it can be pasteurized. The ‘Direct connect’ layout eliminates the need to pump to the buffer first for the new product X pasteurizer as it is directly connected to the main storage. This setup, which can be found in Figure 5.2, is thought to increase throughput and reduce dwell times. It furthermore drastically reduces complexity and it is thought this also greatly increases capacity. Due to the on-site location of the tank park this solution requires a long new (expensive) connection from the main tanks to the pasteurizer. One possible drawback to this solution is the fact that it increases the number of places that need to have ingredient A stock, as having empty main storage tanks in combination with product X demand results in a stockout situation, even when there are two full buffer tanks of ingredient A (190KL) available.

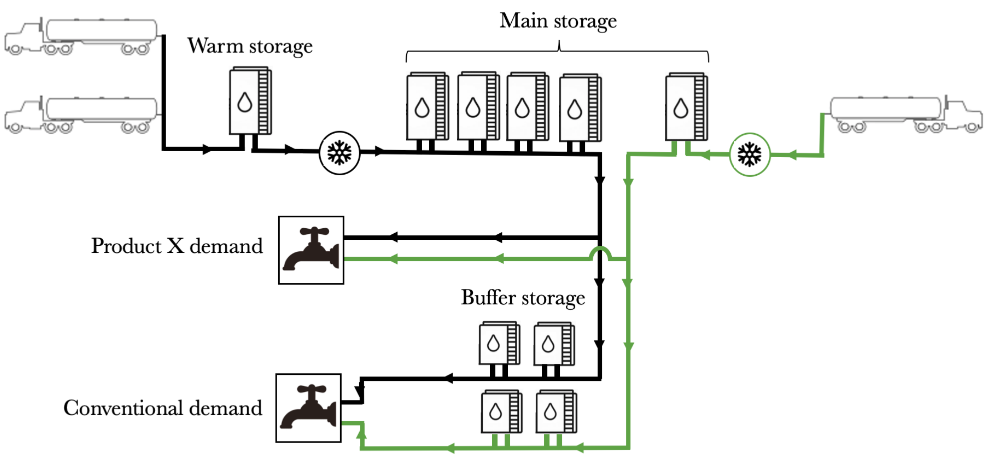


Figure 5.2: New product X line layout ’direct connect’.

The only differentiation with the validated model is the additional product X line directly linked to the main storage. To make this layout function, small changes are made to some of the models' logic, these are also described in Appendix I.

Tank park split

The second solution, found in Figure 5.3, takes the first idea to the next level. Here the entire need of the buffer tanks is removed by splitting the tank park. Where in the first setup only the new pasteurizer was connected directly to the main storage tanks, this is now the case for all tanks. Hence, the need for buffer tanks is eliminated for all pasteurizers that are directly fed from main storage tanks. The four tanks that were previously dubbed 'buffer storage' will become the bio ingredient A main storage. The advantage of this solution is that again the complexity is greatly reduced, but now for all pasteurizers. It furthermore eliminates the potential bottleneck of pumping ingredient A from main storage to buffer storage.

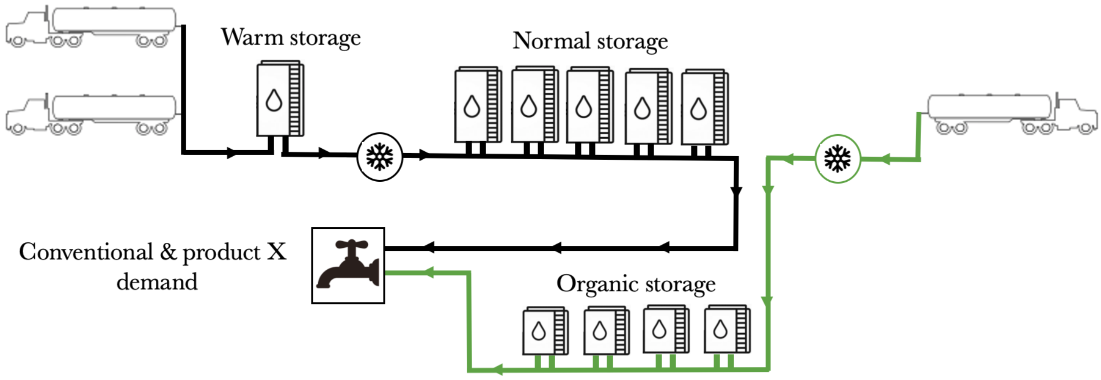


Figure 5.3: New product X line lay-out 'tank park split'.

The simulation model is again updated to fit the new layout, this updated model can be found in Appendix I. Due to the simplicity of this layout, the internal logic is also simplified as described in Appendix I.

5.2.2 Organizational interventions

Within the organizational interventions, we differentiate between two interventions: changes in demand/delivery misalignment and variations in the amount of safety stock. Besides these interventions, updated delivery fractions are presented to accommodate the deliveries that come with the larger throughput scenarios that are proposed.

Demand/delivery misalignment

In general, it is a fact that when ingredient A is delivered closer to the factory demand more throughput can be realized while improving throughput time. Within the model the misalignment between demand and deliveries is given by a normal distribution that simulates the complex planning operations. This intervention encompasses a further optimization of the planning department and is given by defining two new demand/delivery distributions. These distributions are used to determine the demand/delivery misalignment (IC) in the model. Both distributions are defined in concurrence with experts on the system.

	Average	Std dev
Current	202302	125803
Improved	180000	97478
Optimized	100000	54154

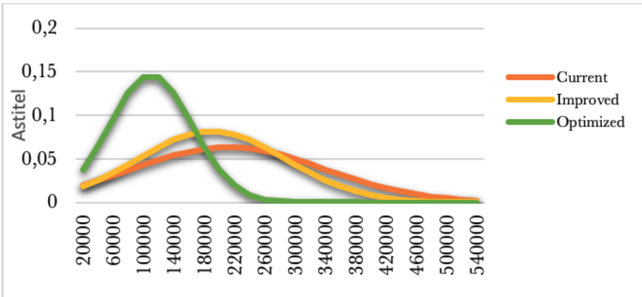


Figure 5.4: Improved demand/delivery misalignment (demand/delivery misalignment amount in liters on x-axis).

Safety stock

The amount of stock on the first hour of the first (model) day of the week is defined as safety stock. The goal of the safety stock is to buffer against external and internal uncertainties within the week. When throughput increases, the safety stocks function shifts to buffering again demand and delivery misalignment within a day. Yet high safety stock levels have a negative effect on dwell time, especially at lower throughput levels. To explore the effects of changes in safety stock, the following three levels are proposed:

1. Current level, 160KL
2. Mid-level, 220KL
3. High level, 280KL

5.2.3 Updated delivery fractions

The model caps the incoming deliveries at 60.000L/h, as this is the cooling capacity, and shifts remaining deliveries to the next hour. In future scenarios where throughput rises, the current delivery distribution is insufficient in spreading the large amount of deliveries over the day, as it is based on annual throughput of 125 million liters. This results in deliveries moving to the next day, mostly due to the fact that current deliveries are not spread out equally throughout the day. This is devastating for the model effectivity as this could result in a large temporary shortage of ingredient A as it is delivered a day later.

To combat this, deliveries should be scheduled more evenly over the day for the busiest days. Therefore, in Appendix J we introduce updated delivery fractions, for high throughput scenarios, that spread out deliveries more evenly over the day. These new fractions ensure that deliveries scheduled on a day can take place on that day, thus these are not shifted to the next, preventing problems with insufficient stock. In reality the planning department would also schedule deliveries in such a way that the deliveries are spread out more over the day to accommodate extra deliveries.

5.3 Experiment design

Due to the large number of scenarios and non-linear physical interventions it is determined that experiments will consist of (almost) all possible combinations. These combinations are sketched in Figure 5.5. One exception is the conventional physical intervention where only experiments are conducted for the 'no product X' and 'normal product X' scenario as the 'high product X' scenario is deemed not possible for this layout. The other exception is the 'direct connect' intervention where the 'no product X' scenario is not included as this is equal to the conventional 'no product X' combination.

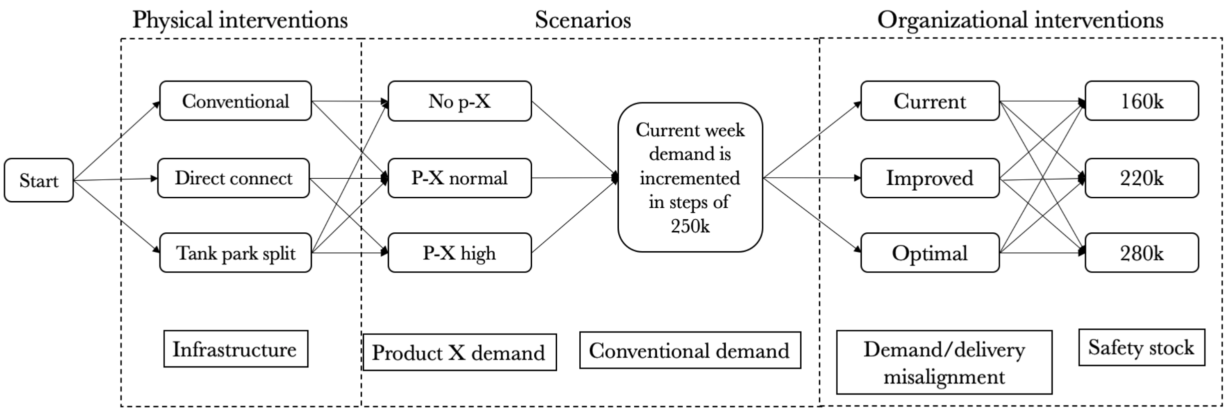


Figure 5.5: Experiment combinations.

Chapter 6

Results

Within this chapter the results of the simulation study are presented. This is done for each of the scenarios separately. We start each scenario's results by providing a table with an overview of the maximum throughput for each of the layouts. Secondly an optimal pathway is sketched, this pathway provides insights on which organizational interventions are optimal, for each of the layouts, at different simulated throughput levels that fall within boundary conditions defined in Table 6.1. Next, a table is provided that show the effects of different organizational interventions on KPI performance for each of the layouts. Each scenario section is concluded with a comparison of different averaged KPI values for the tested layouts.

Table 6.1: Boundary conditions

Conventional	Stockout hours per week <20 hours Dwell time main + Dwell time buffer <30 hours Overflow percentage <1%
Direct connect	Product X stockout hours + conventional stockout hours <21 hours Dwell time main + Dwell time buffer <30 hours Overflow percentage <1%
Tank park split	Stockout hours per week <20 hours Dwell time main <28 hours Overflow percentage <1%

Together with experts on the system, limiting constraints are determined, which are described in Table 6.1. The limiting constraints regarding dwell time will affect the lower levels of throughput, where stockout constraints limit higher levels. The complete results can be found in Appendix K, the results outside these boundary conditions are in red.

6.1 No product X

For the scenario where no product X is being produced, the maximum throughputs within the parameters are presented in Table 8. For the split tank park layout, the simulated maximum is reached.

Table 6.2: Throughput results 'no product X' scenario

Layout	Conventional (liter)	Product X (liter)	Total (liter)
Conventional (crnt.)	204M	-	204M
Conventional (opt.)	230M	-	230M
Split tank park	254M (simulated maximum)	-	254M

6.1.1 Optimal pathway

For both the conventional and split tank park layout the optimal pathway is sketched in Figure 6.1. For the conventional layout (optimized interventions), when lower throughput is present (between 115 and 151 million) the optimal organizational intervention consists of low safety stock and optimal demand/delivery misalignment which reduces dwell times. When increasing throughput to values between 151 and 176 million it is better to use the historical demand/delivery misalignment instead of increasing safety stock as this results in lower dwell times within the system. When reaching the maximum amount of throughput at 229 million liter a year, the improved demand/delivery misalignment in combination with the largest amount of safety stock becomes necessary. The improved demand/delivery misalignment is used as this yields a better result in terms of dwell time and overflow percentage compared to the current demand/delivery misalignment. The tank park split layout has reached the simulated maximum without increasing the safety stock.

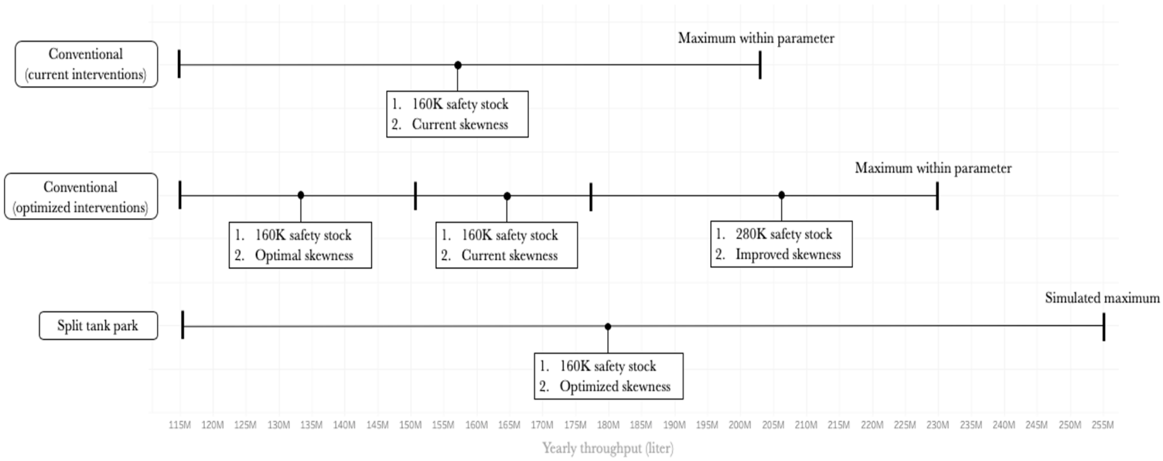


Figure 6.1: Optimal pathways 'no product X' scenario

6.1.2 Organizational intervention performance

For both the conventional system and the split tank park the effects of the different KPI settings for this scenario are given in Figure 6.2, where the effects on the KPI's have been averaged over the effective range determined in Figure 6.1. Differences are given in percentages compared to values of the previous level.

		Demand/delivery misalignment						Safety stock					
		Conventional		Improved		Optimized		160K		220K		280K	
Layout	KPI	abs	%	abs	%	abs	%	abs	%	abs	%	abs	%
Conventional	Stockout occasions /week	3,58	-	3,9	9%	4,94	27%	5,02	-	4,19	-17%	3,22	-23%
	Stockout Hours	9,73	-	10,71	10%	13,91	30%	14,05	-	11,56	-18%	8,74	-24%
	Dwelltime Main (hour)	19,28	-	18,42	-4%	15,56	-16%	14,23	-	17,85	25%	21,17	19%
	Dwelltime Buffer (hour)	7,63	-	7,55	-1%	7,28	-4%	7,07	-	7,53	7%	7,87	5%
	OverFlow Percentage	0,07	-	0,02	-71%	0	-100%	0,01	-	0,02	-	0,06	200%
	Main Utilization	60%	-	59%	-2%	53%	-10%	52%	-	57%	10%	63%	11%
Split tank park	Stockout occasions /week	0,02	-	0,02	0%	0,02	0%	0,06	-	0	-100%	0	-
	Stockout Hours	0,05	-	0,05	0%	0,06	20%	0,16	-	0	-100%	0	-
	Dwelltime Main (hour)	23,86	-	22,9	-4%	20,02	-13%	18,7	-	22,36	20%	25,71	15%
	OverFlow Percentage	0,03	-	0,01	-67%	0	-100%	0	-	0,01	-	0,03	200%
	Main Utilization	81%	-	79%	-2%	75%	-5%	74%	-	78%	5%	83%	6%

Figure 6.2: Organizational intervention effects on KPI for 'no product X' scenario

Improved demand/delivery misalignment results, for both scenarios, in a small reduction (-4%) of the dwell time and only for the conventional layout in an increase of stockout occasions and hours of about 10%. For both layouts the optimization is accompanied with a 70% decrease for the, already low, overflow percentage. The optimized demand/delivery misalignment level reduces dwell times with another 16% and 13% respectively and brings down the overflow to 0 for both layouts. The increase in stockout occasions and hours is about 30% for the conventional layout, whereas for the 'split tank park' layout only a 20% increase in stockout hours is observed.

Increasing the safety stock for 160K to 220K results in an average increase in main dwell time of 25% for the conventional system and a slightly lower increase of 20% for the 'split tank park layout' stockout hours are reduced with 18% and 100% respectively. Increasing safety stock to the highest tier results in a slightly higher reduction (-24%) of stockout occasions and hours for the conventional layout. For both layouts this is accompanied with an increase in dwell times and rather drastic increase of the overflow percentage (200%).

6.1.3 Layout performance

Averaging differences on KPI's for the 'no product X' scenario results in Figure 6.3. It becomes clear that the 'tank park split' performs considerably better on all KPI's. There is almost a 100% reduction in stockout occasions and hours. The dwell time is reduced by 8% although there are some considerations in the calculation of the conventional dwell time, which result in this being slightly higher. The increase in utilization is to be expected as the conventional system uses buffer storage which is not included in this utilization. The differences in KPI's when reviewing different throughput levels can be found in Appendix L.

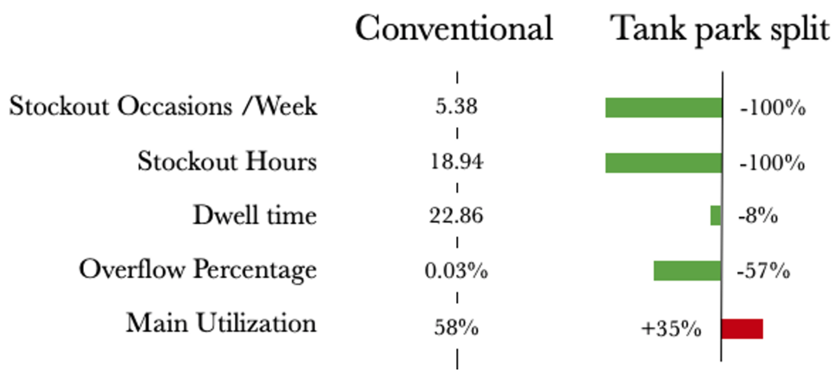


Figure 6.3: Layout effect on KPI's for the 'no product X' scenario

6.2 Medium product X

For the medium product X scenario, the maximum throughputs within the parameters are presented in Table 6.3.

Table 6.3: Throughput results 'medium product X' scenario

Layout	Conventional (liter)	Product X (liter)	Total (liter)
Conventional	-	-	-
Direct connect	190M	54M	244M
Split tank park	255M (simulated maximum)	54M	309M

6.2.1 Optimal pathway

For both the conventional, the split tank park and the direct connect layout the optimal pathway is sketched in Figure 6.4. For the conventional system no throughput window within constraints is found. This is most likely due to the fact that when combining normal factory demand with product X demand, the strain on the two buffer tanks becomes too much. The limited capacity of the buffers in combination with the limited pumping capacity between the main and buffer tanks makes that the stockout hour constraint of 20 hours is reached rapidly. With the highest tier of safety stock (280K) the stockout hours still surpass the 20-hour limit with a value of 22.53.

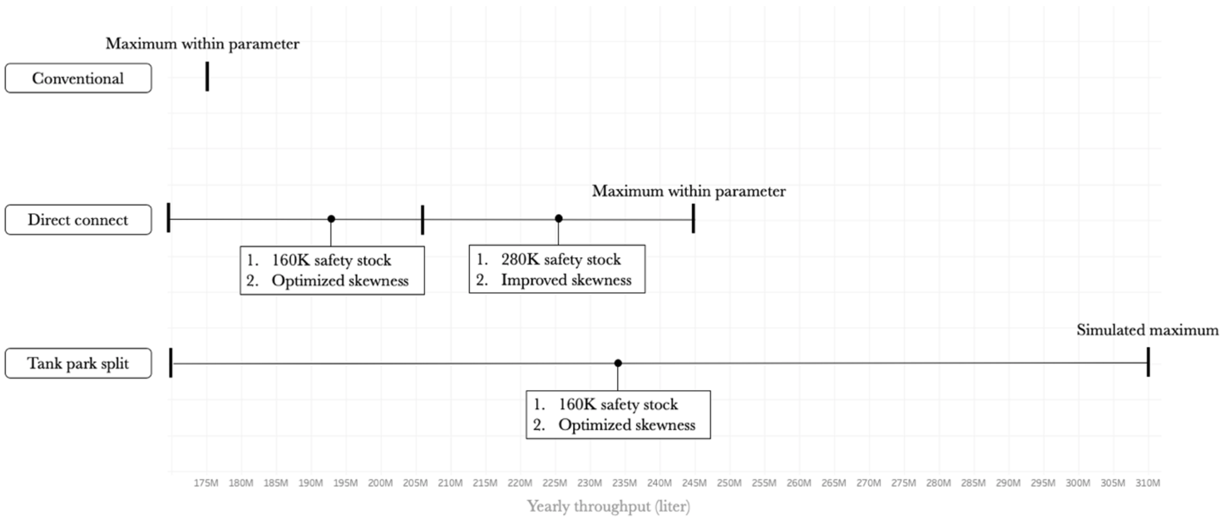


Figure 6.4: Optimal pathways 'medium product X' scenario

For the direct connect a maximum throughput of 244 million liters is reached until boundary conditions apply. This is due to the fact both the product X line and the buffers draw ingredient A from the same main tank, resulting in partially full buffer cycles, increasing stockouts. Boundary condition cycle volume of the conventional system (no product X) is at an average of 82,000 vs 72,000 liters for the 'direct connect' normal product X scenario. When the lower half of the throughput is present the system performs best with a low amount of safety stock together with an optimized demand/delivery misalignment. From 206 million liters to the maximum, the optimal combination of organizational intervention is changed to 280K safety stock together with the improved demand/delivery misalignment.

The tank park split layout facilitates a yearly throughput of 309 million liters while maintaining the current safety stock level. At this throughput level it is even possible to use the optimal demand/delivery misalignment level to improve dwell times from just over 12 hours to just over 9 hours. Related to this improvement is an increase in weekly stockout occasions from 0.35 to 1.10. When increasing safety stock to 220k, stockout occasions are 0.

6.2.2 Organizational intervention performance

For both the 'direct connect' and the 'tank park split' layout, the effects of the different KPI settings for this scenario are given in Figure 6.5. The conventional layout is excluded from the table as it did not meet boundary conditions and has no effective throughput range. The effects on the KPI's have been averaged over the effective range determined in in Figure 6.4. Differences are given in percentages compared to values of the previous level.

		Demand/delivery misalignment						Safety stock					
		Conventional		Improved		Optimized		160K		220K		280K	
Layout	KPI	abs	%	abs	%	abs	%	abs	%	abs	%	abs	%
Direct connect	Stockout occasions /week	5,14	-	5,22	2%	5,82	11%	6,1	-	5,29	-13%	4,79	-9%
	Product X stockout occasions /	0,04	-	0,03	-25%	0,16	433%	0,24	-	0	-100%	0	-
	Stockout Hours	12,74	-	12,85	1%	14,07	9%	14,69	-	12,98	-12%	11,99	-8%
	Dwelltime Main (hour)	15,89	-	15,32	-4%	12,74	-17%	11,7	-	14,73	26%	17,52	19%
	Dwelltime Buffer (hour)	7,72	-	7,7	0%	7,47	-3%	7,21	-	7,7	7%	7,98	4%
	OverFlow Percentage	0,13	-	0,04	-69%	0	-100%	0,01	-	0,04	-	0,12	200%
	Main Utilization	62%	-	61%	-2%	56%	-8%	55%	-	59%	7%	65%	10%
Split tank park	Stockout occasions /week	0,03	-	0,03	0%	0,04	33%	0,1	-	0	-100%	0	-
	Stockout Hours	0,08	-	0,08	0%	0,13	63%	0,29	-	0	-100%	0	-
	Dwelltime Main (hour)	17,92	-	17,23	-4%	14,9	-14%	13,94	-	16,76	20%	19,34	15%
	OverFlow Percentage	0,03	-	0,01	-67%	0	-100%	0	-	0,01	-	0,03	200%
	Main Utilization	82%	-	80%	-2%	75%	-6%	75%	-	79%	5%	84%	6%

Figure 6.5: Organizational intervention interaction on KPI for 'medium product X' scenario

Where demand/delivery misalignment improvement results in an expected increase in stockout hours, it is found that this is only slightly the case for the 'direct connect' layout (+1%). For the 'split tank park' layout the stockout hours and occasions remain the same as for the lower tier of demand/delivery misalignment optimization. Although it must be noted that the stockout hours and occasions for the 'split tank park' layout is already at a very low level. The improved demand/delivery misalignment level results, for both layouts, in a reduction of 4% in main dwell time and a 70% reduction in overflow percentage. Optimizing demand/delivery misalignment to the highest tier results in the expected in stockout occasions and hours. The observed 433% increase in product X stockout occasions for the 'direct connect' seems more drastic than it is, as product X stockout occasions are at low level. The positive benefits of the highest tier demand/delivery misalignment optimization are a 100% reduction in overflow for both layouts and a 17% and 14% reduction in dwell times for 'direct connect' and 'split tank park' layout respectively.

Increasing the safety stock one tier from 160K to 220K reduces the product X stockout occasions with 100% and the stockout hours with 12% for the 'direct connect' layout. The accompanied increase in dwell time is notable with 26% and 7% for the main storage and the buffer respectively. For the 'split tank park' layout the increase in safety stock results in a 100% reduction in stockout occasions and hours, the increase in dwell time is 20%. Moving to the highest tier of safety stock results in an 8% reduction in stock out hours and a 19% increase in stockout hours. As the stockout occasions and hours for 'split tank park' layout are already reduced to 0, only an increase in dwell time (15%) and overflow (200%) are observed.

6.2.3 Layout performance

For the direct connect layout we find an increase in stockout occasions combined with a decrease in stockout hours, meaning the average stockout length is strongly decreased. We also observe an increase in dwell time, this is the result of the new line drawing ingredient A from the main tanks directly which increases buffer dwell time. We furthermore find that the ‘tank park split’ solution perform better on all KPI’s, main storage utilization is increased due to the fact that no buffers are present.

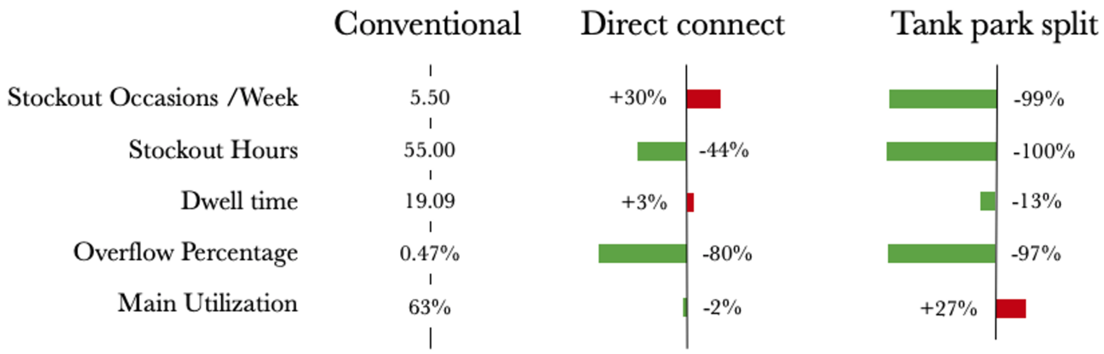


Figure 6.6: Layout effect on KPI’s for the ’medium product X’ scenario

6.3 High product X

For the high product X scenario, the maximum throughputs within the parameters are presented in Table 6.4.

Table 6.4: Throughput results ’high product X’ scenario

Layout	Conventional (liter)	Product X (liter)	Total (liter)
Direct connect	164M	105M	269M
Split tank park	255M (simulated maximum)	105M	360M

6.3.1 Optimal pathway

For both the ‘direct connect’ and the ‘split tank park’ layout the optimal pathway is sketched in Figure 6.7. For the ‘direct connect’ layout, a maximum throughput is reached of 269 million liters. This is due to the same reasons as mentioned for the normal product X scenario, yet now the cycle volume is even lower at around 66,000 liters. Between 220-256 million liters of throughput the optimal combination is at 220k safety stock in combination with the improved demand/delivery misalignment. From 256 to 269 million liters the optimal combination exists of 280k safety stock together with the optimized demand/delivery misalignment. It is important to note that a combination of 160k safety stock with the current demand/delivery misalignment is also able to reach this maximum, with slightly lower performance.

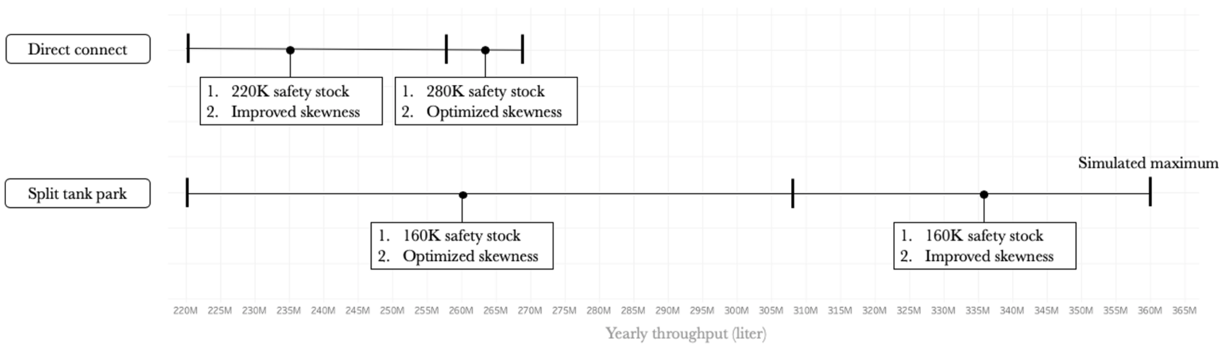


Figure 6.7: Optimal pathways 'high product X' scenario

For the split tank park layout, the simulated maximum throughput is reached, this time at 360 million liters a year. Same as for the 'normal product X' this is done using the conventional amount of safety stock of 160k liter. Yet now instead of the optimal demand/delivery misalignment the improved one is used as this decreases weekly stockout hours from 6.8 to 2.37. The optimal demand/delivery misalignment is used for lower throughput levels between 230-308 million liters.

6.3.2 Organizational intervention performance

For both the 'direct connect' and the 'tank park split' layout, the effects of the different KPI settings for this scenario are given in Figure 6.8 the effects on the KPI's have been averaged over the effective range determined in in Figure 6.7. Differences are given in percentages compared to values of the previous tier.

		Demand/delivery misalignment						Safety stock					
		Conventional		Improved		Optimized		160K		220K		280K	
Layout	KPI	abs	%	abs	%	abs	%	abs	%	abs	%	abs	%
Direct connect	Stockout occasions /week	5,69	-	5,71	*0%*	6,28	*10%*	6,62	-	5,76	*-13%*	5,3	*-8%*
	Product X stockout occasions / week	0,40	-	0,43	*8%*	1,03	*140%*	1,49	-	0,36	*-76%*	0,01	*-97%*
	Stockout Hours	12,13	-	12,16	*0%*	13,26	*9%*	13,87	-	12,25	*-12%*	11,44	*-7%*
	Dwelltime Main (hour)	13,62	-	13,31	*-2%*	11,39	*-14%*	10,46	-	12,87	*23%*	14,99	*16%*
	Dwelltime Buffer (hour)	7,73	-	7,74	*0%*	7,54	*-3%*	7,24	-	7,75	*7%*	8,01	*3%*
	OverFlow Percentage	0,22	-	0,11	*-50%*	0	*-100%*	0,02	-	0,09	-	0,22	*144%*
	Main Utilization	64%	-	63%	*-2%*	59%	*-6%*	58%	-	62%	*7%*	66%	*6%*
Split tank park	Stockout occasions /week	0,12	-	0,12	0%	0,29	142%	0,45	-	0,07	-84%	0	-100%
	Stockout Hours	0,44	-	0,42	-5%	1,07	155%	1,7	-	0,22	-87%	0,01	-95%
	Dwelltime Main (hour)	14,47	-	13,93	-4%	11,99	-14%	11,23	-	13,54	21%	15,61	15%
	OverFlow Percentage	0,04	-	0,01	-75%	0	-100%	0	-	0,01	-	0,04	300%
	Main Utilization	82%	-	80%	-2%	76%	-5%	75%	-	79%	5%	84%	6%

Figure 6.8: Organizational intervention interaction on KPI for 'high product X' scenario

Improving the demand/delivery misalignment for this scenario seems to have no effect on stockout hours for the direct connect layout, for the 'split tank park' layout there even is a positive effect with a 5% reduction. The reduction of the dwell time is minimal for both layouts with -2% and -4%, the decrease in overflow is with 50% and 75% more notable. When optimizing to the highest tier of demand/delivery misalignment, the expected effect on stockout occasions and hours become visible. A 9% and 155% increase in stockout hours is observed for the 'direct connect' and 'split tank park' layout respectively.

Increasing safety stock to the second tier reduces stockout hours with 12% and 87% for the 'direct connect' and 'split tank park' layout respectively. For both layouts the increase in dwell time is just over 20% for the main storage, the increase in buffer dwell time is 7% for the 'direct connect layout'. When moving to the highest tier of safety stock another stockout hour reduction of 7% and 95% is realized, bringing the amount of 'tank park split' stockout hours nearly to zero. For the 'direct connect' layout product X stockout occasions are also reduced by 97% to 0.01. The accompanied increase in dwell time is around 15% for both scenarios. Furthermore, a large increase (in percentage) in overflow is observed for both layouts.

6.3.3 Layout performance

Averaging differences on KPI's for the 'high product X' scenario results in Figure 6.9. From the figure it can become clear that the 'tank park split' layout strongly outperforms the direct connect on all KPI's. Stockout hours and occasions are greatly reduced by 98% and a reduction of 22% concerning dwell time is realized. Again, it is important to note that there are some considerations in the calculation of the 'direct connect' dwell time which result in this being slightly higher. The differences in KPI's when reviewing different throughput levels can be found in Appendix L.

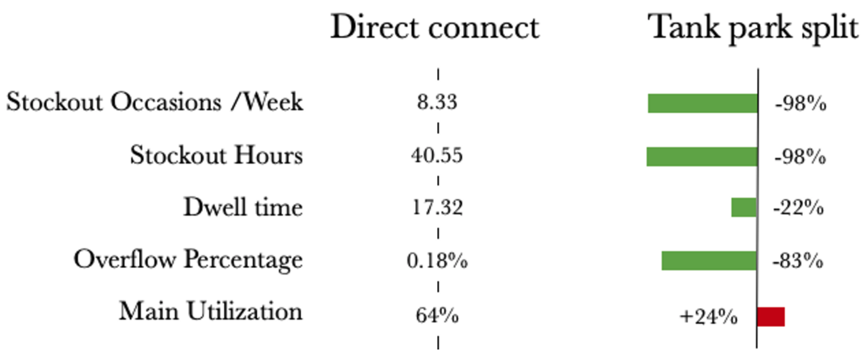


Figure 6.9: Layout effect on KPI's for the high product X' scenario

Chapter 7

Conclusions and implementation

Within this chapter, first the general conclusions of the research are presented. Next, a section is dedicated to translating the main findings to a workable implementation advice.

7.1 conclusions

The purpose of this research was to answer the following question:

> *'In which way do the current ingredient A reception facilities need to be adapted to accommodate the growth in supply and still be able to deal with variation in supply and factory demand?'*

From the results it became clear that the current layout and modus operandi should be able to facilitate an approximate annual conventional throughput increase of around 80 million liters, until boundary conditions are met. When optimizing organizational interventions, the annual throughput could be stretched another 26 million liters to 230 million liters annually. Although a possible throughput increase of 106 million is seemingly enough to facilitate the production of product X, this is not the case. As product X requires an additional pasteurizer, flowrates will increase (when three pasteurizers are in use). This increase in flowrate is the limiting factor for the current layout as a bottleneck situation will occur at the transfer between main storage and buffer storage.

The direct connect layout is able to facilitate both the normal and high product X scenarios until boundary conditions are reached at a yearly throughput of 245 million and 269 million liters respectively, considerably outperforming the conventional layout. The maximum of conventional annual throughput over the existing pasteurizers is 190 million liters for the 'low product X' and 159 million liters for the 'high product X' scenario.

When an even larger increase in conventional production is to be facilitated or an improvement of KPI performance needs to be realized, the to-go-to layout is the split tank park. The layout is able to facilitate the simulated maximum throughput for both product X scenarios well within boundary conditions. It furthermore greatly improves KPI performance for all scenarios and throughput levels.

The proposed organizational interventions both operate best at different levels of throughput. Optimizing demand/delivery misalignment levels is very effective in reducing dwell time, which is important at lower throughput levels. As an increase in stockout hours is generally less of a problem for this operating window, the proposed levels can be used at lower throughput levels. Reductions of main storage dwell times between 14-20% are observed, thus decreasing the amount of non-value adding time. It furthermore decreases storage occupancy, or system utilization with about 10%. Of the proposed demand/delivery misalignment tiers the improved level seems to reduce dwell times while minimizing the increase in stockout hours, which increases usability for operating windows with higher stockout hour values.

Increasing safety stock is optimally used at higher throughput levels, where dwell time increase has limited consequences. Beneficial effects of the safety stock are a reduction in the amount of stockout hours, which can increase the maximum throughput by up to 26 million liters.

7.2 Advice on implementation

As mentioned, the current layout is unable to handle the production of product X and therefore should be upgraded to either the direct connect layout or the split tank park. Connecting the pasteurizer directly to the main storage is part of both solutions, therefore we propose the following sequence of events:

1. *Optimizing the current demand/delivery alignment* will improve dwell times for the current system and decrease the amount of stock that spends over 30 hours in the storage system.

2. *Connecting the product X pasteurizer directly to the main storage* creates the direct connect layout described in Figure 5.2. Due to limited overhaul, compared to the split tank park, of the current infrastructure this layout is considerably cheaper. This layout is also able to deal with a large amounts of conventional throughput (190 million and 164 million) for both the medium and high product X scenario. With efficient use, the real-world could outperform the throughput levels reached in simulation.

3. *Splitting the tank park* is only necessary if performance issues come to light regarding throughput or KPI values of the direct connect layout. It is expected that the

financial impact of this layout is substantially larger Implementing this layout will increase throughput to far beyond maximum simulated values in this research. It is furthermore expected that KPI values will improve considerably compared to the direct connect layout.

Chapter 8

Discussion

When simulating a system there are always limitations in terms of assumption and simplification. The main assumptions for the simulation model used in this research can be found in subsection 6.2.4. The simulation model also generalizes the complex relational diagram in Figure 2.4 to a fixed weekly pattern (having variation in weekly demand and absolute weekly demand/delivery misalignment). Within this weekly pattern there are a lot of static fractions that remain the same throughout modeling time, further simplifying the system from the real-world. Another area that is greatly simplified and affects results is the simplification to continuous flow instead of binary as is in the real word the case for demand and deliveries. Especially for the factory demand this results in lower flow rates, which are crucial for the performance of this system, therefore influencing results in a positive manner.

It must furthermore be noted that the conventional and 'direct connect' layouts operate with less freedom as tanks cannot be filled and drained at the same time. This results in more waiting situations for the buffer tanks. For the 'split tank park' layout this is less of a problem as there is only one location to store ingredient A (only main tanks) instead of two for the other layouts.

It is assumed that transportation between tanks is instant, this again favors the 'tank park split' layout as the connections lines to the pasteurization are much longer than for the other layouts. A corner that has been cut in this research is remaining with a five-day workweek.

Finally, the storage strategy used is based on historical data, yet it will always operate reactively, so based on the situation at hand. In reality it is possible to base the storage strategy on the weekly planning, this would have beneficial effects on the dwell time and also somewhat on the stockout hours/occasions. This especially (negatively) effects the 'direct connect' layout, as a reduction in cycle volume is observed. This is due to a not optimal storage strategy where only one main storage tank is used to both transfer to the buffer storage and feed product X pasteurization, resulting in smaller buffer batches and increasing stockout hours.

References

Abdulmalek, F. A. & Rajgopal, J. (2007). Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. *International Journal of Production Economics*, *107*(1), 223–236. doi: 10.1016/j.ijpe.2006.09.009 21

Ashayeri, J., Teelen, A. & Selens, W. (1996). A production and maintenance planning model for the process industry. *International Journal of Production Research*, *34*(12), 3311–3326. doi: 10.1080/00207549608905092 20

Banks, J., Carson, J., Nelson, B. L. & Nicol, D. (2005). Discrete-event system simulation (Fourth edition). *Prentice Hall International Series in Industrial and Systems Engineering*. doi: 10.2307/1268124 23

Cachon, G. & Fisher, M. (1997). Campbell soup's continuous replenishment program: Evaluation and enhanced inventory decision rules. *Production and Operations Management*, *6*(3), 266–276. doi: 10.1111/j.1937-5956.1997.tb00430.x 22

Cassandras, C. G. & Lafortune, S. (2008). *Introduction to discrete event systems* (2th ed., Vol. 37) (No. 10). Springen. doi: 10.1016/s0005-1098(01)00113-3 22

Cook, R. L. & Rogowski, R. A. (1996). Applying jit principles to continuous process manufacturing supply chains. *Production and Inventory Management Journal*, *37*(1), 12–16. 21

de Lara, J., Guerra, E., Boronat, A., Heckel, R. & Torrini, P. (2014). Domain-specific discrete event modelling and simulation using graph transformation. *Software and Systems Modeling*, *13*(1), 209–238. doi: 10.1007/s10270-012-0242-3 x, x, x, 25

Jahangirian, M., Eldabi, T., Naseer, A., Stergioulas, L. K. & Young, T. (2010). Simulation in manufacturing and business: A review. *European Journal of Operational Research*, *203*(1), 1–13. Retrieved from `http://dx.doi.org/10.1016/j.ejor.2009.06.004` doi: 10.1016/j.ejor.2009.06.004 22, 25

Jung, J. Y., Blau, G., Pekny, J. F., Reklaitis, G. V. & Eversdyk, D. (2004). A simulation based optimization approach to supply chain management under demand uncertainty. *Computers and Chemical Engineering*, *28*(10), 2087–2106. doi: 10.1016/j.compchemeng.2004.06.006 22

King, P. L. (2019). *Lean for the Process industry dealing with complexity* (2nd ed.). Taylor & Francis Group. 20

King, P. L., Kroeger, D. R., Foster, J. B., Williams, N. & Proctor, W. (2008). Making

CEREAL not CARS. *Industrial Engineer*, *40*(12), 34–37. x, x, x, 20, 21

Koumanakos, D. P. (2008). The effect of inventory management on firm performance. *International Journal of Productivity and Performance Management*, *57*(5), 355–369. doi: 10.1108/17410400810881827 21

Law, A. M. (2015). *Simulation Modeling and Analysis.* x, x, x, x, x, x, 22, 23, 24, 25, 26

Mehra, S., Inman, R. A. & Tuite, G. (2006). A simulation-based comparison of batch sizes in a continuous processing industry. *Production Planning and Control*, *17*(1), 54–66. doi: 10.1080/09537280500363883 22

Negahban, A. & Smith, J. S. (2014). Simulation for manufacturing system design and operation: Literature review and analysis. *Journal of Manufacturing Systems*, *33*(2), 241–261. Retrieved from http://dx.doi.org/10.1016/j.jmsy.2013.12.007 doi: 10.1016/j.jmsy.2013.12.007 22, 25

Özgün, O. & Barlas, Y. (2009). Discrete vs. Continuous Simulation: When Does It Matter? *27th International Conference of The System Dynamics Society*(6), 1–22. 25

Panwar, A., Nepal, B. P., Jain, R. & Rathore, A. P. S. (2015). On the adoption of lean manufacturing principles in process industries. *Production Planning and Control*, *26*(7), 564–587. Retrieved from http://dx.doi.org/10.1080/09537287.2014.936532 doi: 10.1080/09537287.2014.936532 21

Sargent, R. G. (2010). Verification and validation of simulation models. *Proceedings - Winter Simulation Conference*(February), 166–183. doi: 10.1109/WSC.2010.5679166 26

Shah, N. (2005). Process industry supply chains: Advances and challenges. *Computers and Chemical Engineering*, *29*(6 SPEC. ISS.), 1225–1235. doi: 10.1016/j.compchemeng.2005.02.023 20

Vieira, A. A., Dias, L. M., Santos, M. Y., Pereira, G. A. & Oliveira, J. A. (2018). Setting an industry 4.0 research and development agenda for simulation – A literature review. *International Journal of Simulation Modelling*, *17*(3), 377–390. doi: 10.2507/IJSIMM17(3)429 25

Appendix A - Data catalog

#	Internalcode	Description	Sensorcode	Sensor Description	Type
Supply					
1	C406	Unloading station 1	FT406	Flow rate	L/H
			FT406 CNTD	Accumulated flow, resets on CIP	L
			?????	In-use(1), available (0)	Bin
2	C408	Unloading station 2	FT408	Flow rate	L
			FT408 CNTD	Accumulated flow, resets on CIP	L/H
			?????	In-use(1), available (0)	Bin
3	C415	Unloading station 3 (bio)	FT415	Flow rate	L/H
			FT415 CNTD	Accumulated flow, resets on CIP	L
			?????	In-use(1), available (0)	Bin
Main storage					
#	**Internalcode**	**Description**	**Sensorcode**	**Sensor Description**	**Type**
4	401	Warm storage tank 185KL	LT401	Level	L
			T401 USTAT	Status of the tank	L
			T401 MtrlID	Content code	Int
5	402	Cold storage tank 1 185KL	LT402	Level	L
			T402 USTAT	Status of the tank	L
			T402 MtrlID	Content code	Int
6	403	Cold storage tank 2 185KL	LT403	Level	L
			T403 USTAT	Status of the tank	L
			T403 MtrlID	Content code	Int
7	404	Cold storage tank 3 185KL	LT404	Level	L
			T404 USTAT	Status of the tank	L
			T404 MtrlID	Content code	Int
8	405	Cold storage tank 4 185KL	LT405	Level	L
			T405 USTAT	Status of the tank	L
			T405 MtrlID	Content code	Int
9	406	Cold storage tank 5 (bio) 185KL	LT406	Level	L
			T406 USTAT	Status of the tank	L
			T406 MtrlID	Content code	Int
Buffer					
#	**Internalcode**	**Description**	**Sensorcode**	**Sensor Description**	**Type**
10	001	Buffertank 1 95KL	LT001	Live Storage volume	L
			T001 USTAT	Status of the tank	L
			T001 MtrlID	Content code	Int
11	002	Buffertank 2 95KL	FT002	Live Storage volume	L
			T002 USTAT	Status of the tank	L
			T002 MtrlID	Content code	Int
12	003	Buffertank 3 (bio) 95KL	FT003	Live Storage volume	L
			T003 USTAT	Status of the tank	L
			T003 MtrlID	Content code	Int
13	004	Buffertank 4 (bio) 95KL	FT004	Live Storage volume	L
			T004 USTAT	Status of the tank	L
			T04 MtrlID	Content code	Int
Piping					
#	**Internalcode**	**Description**	**Sensorcode**	**Sensor Description**	**Type**
14	C401	Pipe from C406 & C408 and 401 to cold storage tank 402 to 405	FT401	Flow rate	L/H
			FT401 CNTD	Cumulative flow rate, resets on CIP	L
15	C701	Pipe from 402, 403,404, 405 to 001 & 002	FT00101	Flow rate	L/H
			FT00101 CNTD	Cumulative flow rate, resets on CIP	L
16	C702	Pipe from 406 to 003 & 004 (bio)	FT70201	Flow rate	L/H
			FT702 CNTD	Cumulative flow rate, resets on CIP	L
Factory demand					
#	**Internalcode**	**Description**	**Sensorcode**	**Sensor Description**	**Type**
17	HE501	Pasteurizer 1	HE501 USTAT	Status of HE501	Int
			FT502	Flow rate to HE501	L
18	HE502	pasteurizer 2	HE502 USTAT	Status of HE501	Int
			FT502	Flow rate to HE501	L

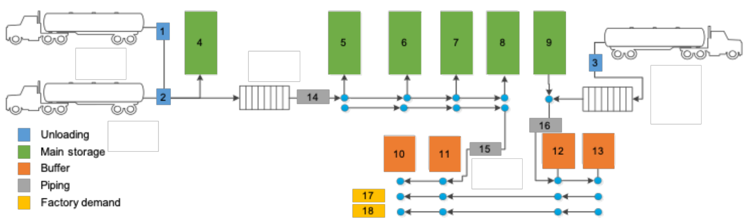


Figure 1: Available system data.

Appendix B - Photos physical layer

Figure 2: Main storage 185KL and unloading

Figure 3: Buffer storage 95KL

Appendix C – Data cleaning, mutation and processing

The data delivered by company X is logged on system change, so when nothing happens no data is logged. Furthermore, when changes are happening to the system a lot of data is logged. To make this type of data usable the following data mutations found in Figure 4.

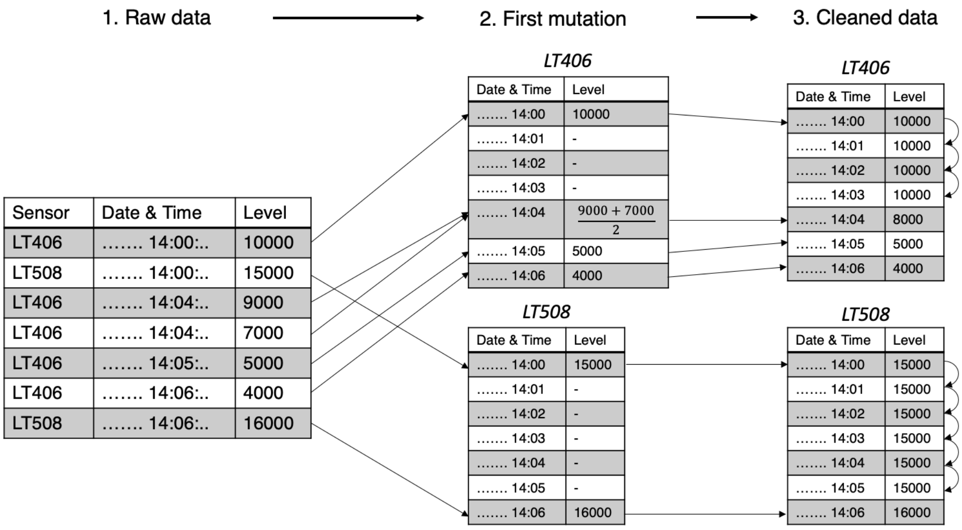


Figure 4: Data mutation

Using the data mutations, a clean datasheet with a timestamp and according value is created for each of the sensors.

Delivery

The data that is used is of a flow transmitter (FT) on each of the unloading stations. For the deliveries we define a new variable OPERATINGSTATUS, for each of the unloading stations, that has two different states where 0 is a state where nothing is happening and 1 is where a delivery is being made.

Table 1: Delivery data analysis

OPERATINGSTAT	Definition
1, In operation	FT >5 OR Previous value FT >5 (to account for drops in flow)
0, not in operation	Other

Using this binary status indicator, a new dataset is created to log the beginning, end time and date of each delivery. This is done using the statuses defined in table 2

Table 2: Delivery duration data analysis

DELIVERYSTAT	Definition
Start time	OPERATINGSTAT = 1 AND previous OPERATINGSTAT = 0
End time	OPERATINGSTAT = 0 AND previous OPERATINGSTAT = 1

Storage

For the main storage data is used from the level transmitters that are located in each of the main and buffer storage tanks. When plotting the (cleaned) tank level data against time, a graph like the one found in Figure 5.

Figure 5: Example of tank level data

From this a status needs to be derived, we define the statuses found in the table below. The parameters are defined after trial and error and can be found in Table 3.

Table 3: Tank status value assignment

TANKSTAT	Definition
1. Empty	LT value <3000
2. Filling	Current LT value – previous LT value >= 350
3. Draining	Current LT value – previous LT value <= -350
4. Product waiting	All non-assigned values

Using the newly defined values a fifth TANKSTAT value is added: Cleaning in place (CIP). This value is assigned for 45 minutes after a tank goes from a draining status to an empty status and can be found in Table 4.

Table 4: Tank status 'CIP' definition

TANKSTAT	Definition
5. CIP	IF TANKSTAT = Empty AND Previous TANKSTAT = Draining Then for 45 values (45 min) CIP

System capacity

The calculation for system capacity is not as simple as subtracting the maximum capacity with the current storage volume. This is due to regulations concerning batch traceability and tank cleaning requirements. Therefore, the limitations using tank status found Table 5 have been defined regarding available capacity.

Table 5: Available capacity based on tank status

TANKSTAT	Available capacity
1. Empty	185KL
2. Filling	185KL – current volume
3. Draining	0
4. Product waiting	If tank has not been drained in this storage cycle, then: 185KL – current volume Else: 0
5. CIP	0

Storage cycles

To determine average storage time and amount, the different storage cycles need to be mapped. A script is written to analyze the data and create a new table with the columns found in Table 4.21 and a storage cycle per row.

Table 6: Storage cycles information

Entity	Definition
TANKID	Tank number
Cycle number	Previous number + 1
Start cycle	When status = ‘Empty’ and next status = ‘Filling’
End cycle	When status = ‘Draining’ and next status = ‘Empty’
Cycle amount	Max level during cycle

The entities are visualized in a sample dataset found in Figure below. The difference between the start (date & time) and end of the cycle is the cycle time. It is important to note that the time for the whole cycle is determined from the first deposit in the tank. So: the cycle time is equal to the cycle time of the ‘oldest’ ingredient A in the tank. An illustration of this principle can be found in Figure 6.

Table 7: Pasteurizer status and definition

OPERATINGSTAT	Definition
1. In operation	Other
0. Not in operation	FT value <100 and previous FT value <100 and penultimate FT value <100

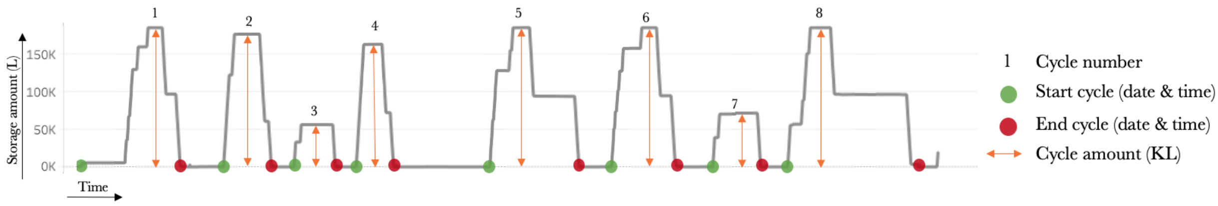


Figure 6: Illustration of storage cycle analysis

Factory demand

For the factory demand we use data from the two pasteurizers that are in use. Both pasteurizers (HE501 & HE502) are fitted with flowmeters and again a binary status is defined for each of the pasteurizers. The definition of this value is established using trial and error.

Demand cycles

To determine average operation time and amount, the different operation cycles need to be mapped. A script is written to analyze the data and create a new table with the columns found in table 8 and an operation cycle per row.

Table 8: Analysis for demand cycles based on operating stat of the pasteurizer

Entity	Definition
PASID	Pasteurizer number
Cycle number	Previous number + 1
Start cycle	OPERATINGSTAT = 1 AND previous OPERATINGSTAT = 0
End cycle	OPERATINGSTAT = 0 AND previous OPERATINGSTAT = 1
Cycle amount	Cumulative flow/60

To determine the time in between operation cycles, the different ‘empty’ cycles are also mapped. This is done using a script that operates in the same way, using the principles found in table 9.

Table 9: Analysis for empty demand cycles based on operating stat of the pasteurizer

Entity	Definition
PASID	Pasteurizer number
Cycle number	Previous number + 1
Start cycle	OPERATINGSTAT = 0 AND previous OPERATINGSTAT = 1
End cycle	OPERATINGSTAT = 1 AND previous OPERATINGSTAT = 0

Appendix D – Detailed system analysis

Arrivals

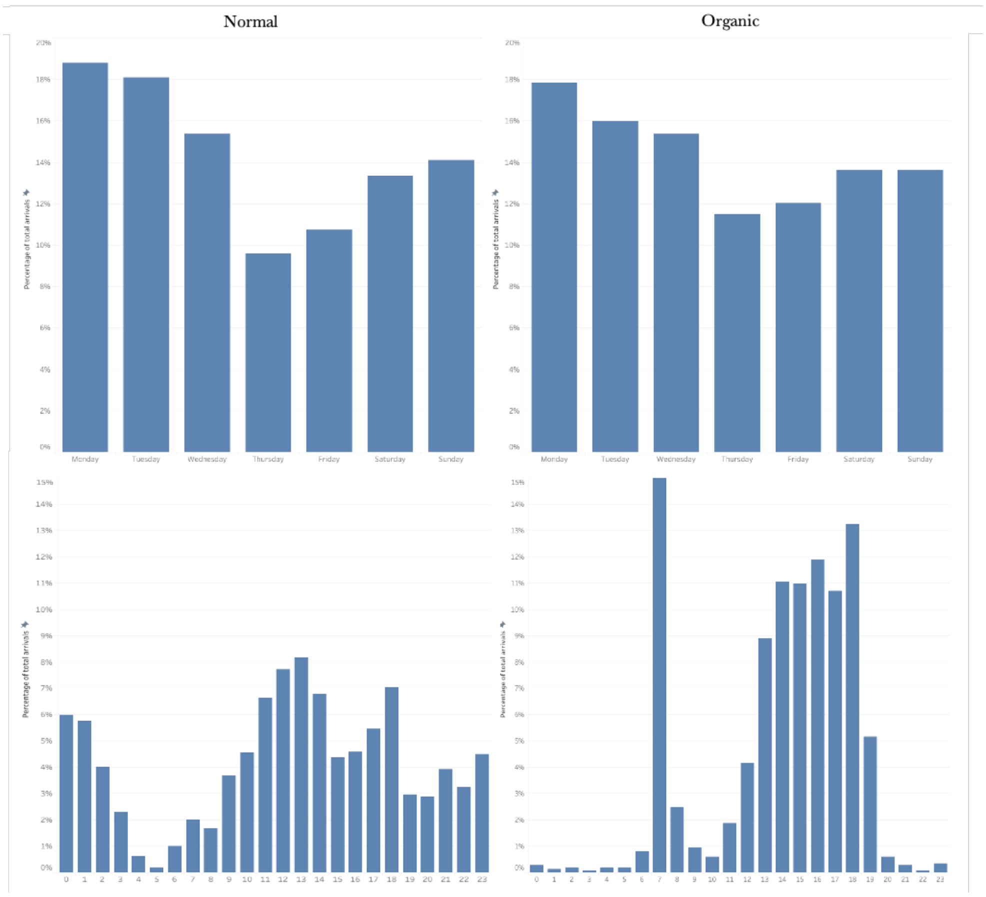


Figure 7: Arrivals per weekday and hour for both normal and organic ingredient A

Table 10: Conclusions on arrival analysis

Normal	Organic
1. More than half (52.2%) of the deliveries is made in the first three days of the week.	1.Almost half (49.2%) of the deliveries is made in the first three days of the week.
2.Between 4:00-7:00 there are almost no deliveries	2. Almost all deliveries are between 6:00 and 20:00 (97.7%)
3.Most of the deliveries (63.6%) are during the hours of 8:00-20:00	3. 18.3% of the deliveries is between 6:00-9:00, more than 14% between 7:00-8:00.
4.The remaining deliveries happen between 20:00-8:00 with a peak just after midnight	4. Almost no deliveries between 20:00 and 6:00 (2.3%)

Main storage

In figure 8 the available main storage capacity has been visualized for normal ingredient A (top) and bio (bottom). For the normal ingredient A storage bins of 15k have been used, for organic ingredient A the bins are 6K.

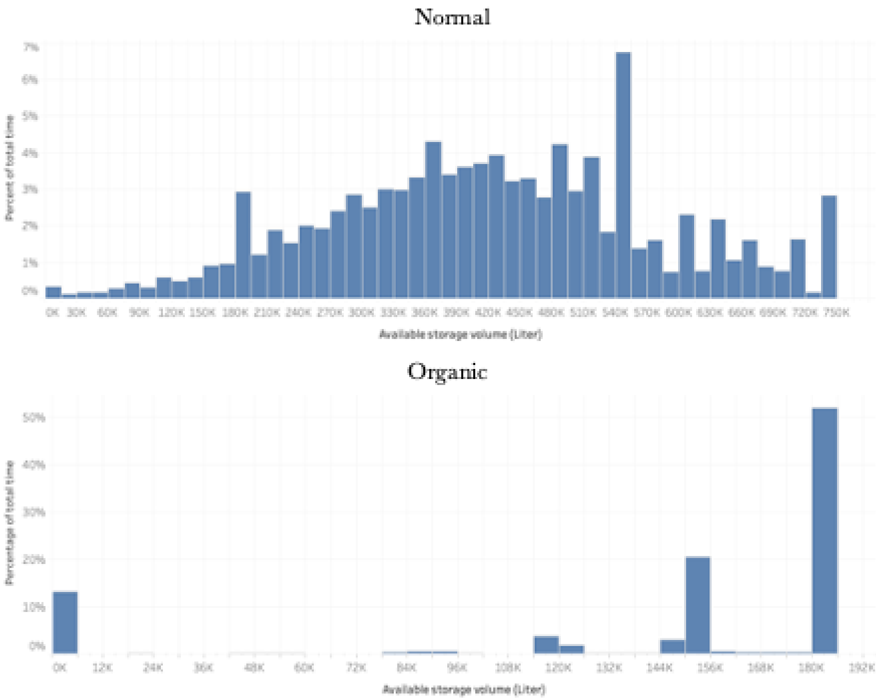


Figure 8: Available volume main storage as percentage of time

Table 11: Conclusions available volume

Normal	Organic
1. Average available capacity is 418,731 Liter 2. Only in 0.85% of the analyzed time there was between 0-15K Liter capacity 3. Only in 2.17% of the analyzed time there was less than 115K Liter capacity 4. 5.01% of the analyzed time all available storage capacity is available	1. Average available capacity is 144,834 Liter 2. In 13.2% of time the available capacity was below 15k, and most probably this time the capacity was 0. 3. 52.2% of the time more than 180k capacity is available, this corresponds with an empty or near empty tank. 4. Remaining peaks between 114k-120k and 144k-156k correspond for 5.78% and 26.37% of the time respectively. These values correspond with a common (low) tank level where this capacity remains.

Buffer storage

Next the buffer storage is analyzed in the same way as is done for the main storage. This analysis starts with the available capacity in the system.

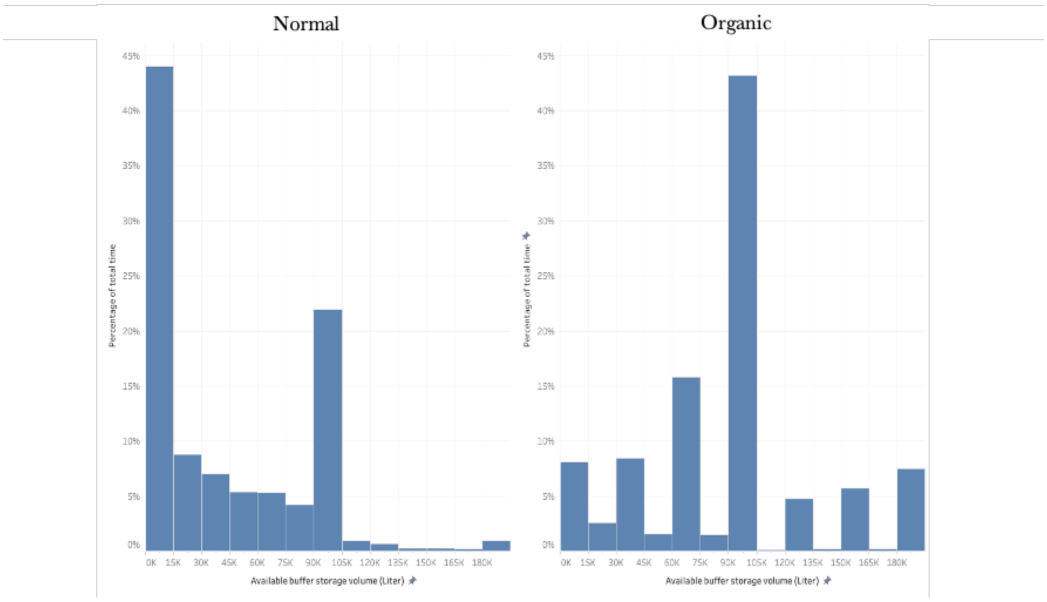


Figure 9: Available volume buffer storage as percentage of time

Table 12: Conclusions on available buffer volume

Normal	Organic
1. Almost half the time (44.01%) of the time no storage capacity is available. In this case both tanks are either: full, being drained or being cleaned 2. One fifth of the time (21.94%) between 90k-105k Liters is available. This corresponds with one tank being occupied and one tank being available. 3. In 30.71% of the analyzed time the available buffer storage is between 15k-90k. 4. Only for 0.97% of the analyzed time, more than 180k liter is available, this corresponds with the availability of two tanks. This is in line with the working method of keeping the buffer tanks occupied, that came forward from interviews with operations.	1.For 8.14% of the time available capacity is between 0K-15k. This corresponds with both tanks either being: full, being drained or being cleaned. 2.For 43.25% of the time available capacity is between 90k-105k. This corresponds with one tank being occupied and one tank being available. 3.For 7.51% of the analyzed time, more than 180k liter is available, this corresponds with the availability of two tanks. This is in line with the working method of keeping the buffer tanks occupied, that came forward from interviews with operations.

Appendix E– Additional analysis

This additional analysis presents results that do not come forward in the main reports but that were obtained when conducting the data analysis. These start with a main storage tank status analysis for normal ingredient A storage, followed by organic ingredient A.

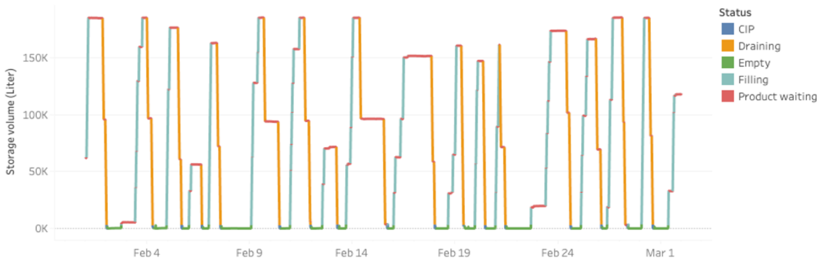


Figure 10: Example of tank status analysis

Using this status assignment, it is possible to create the figure below with a status overview for the four main 185KL storage tanks for 'normal' ingredient A. This overview is based on data between the 1st of February and the 30th of April 2019.

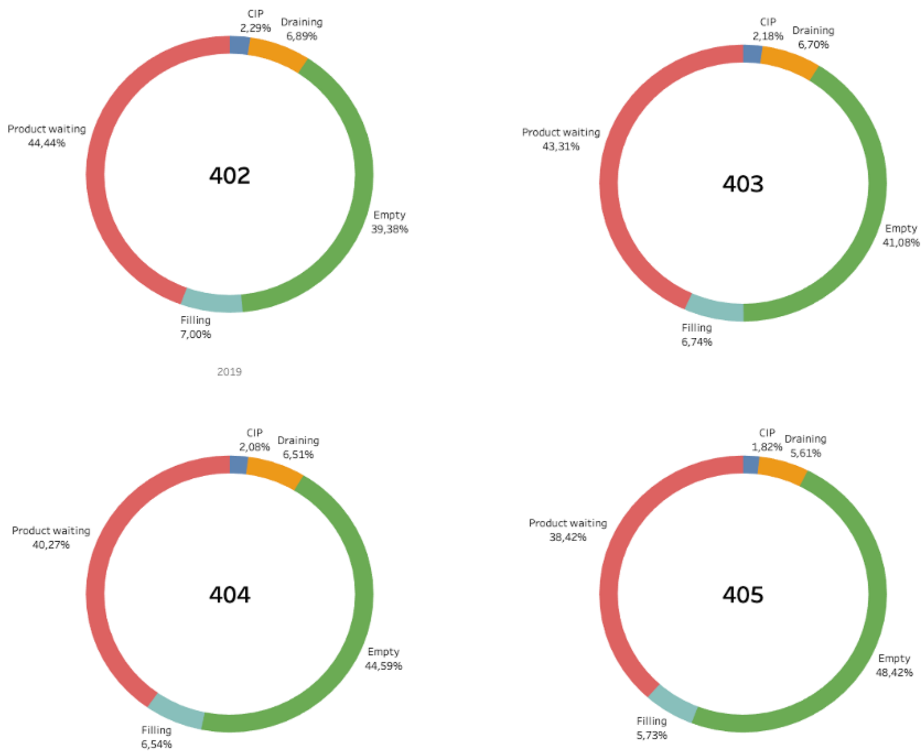


Figure 11: Status analysis of main storage tanks

Table 13: Conclusions on tank statuses

Observations from tank status distribution normal ingredient A
1. The first tank (401) is the most used tank when comparing non-empty status. A sequential pattern is found for the other tanks.

Next the data is aggregated for all four tanks that are part of 'normal' ingredient A system and differentiated for each weekday. Now the number of 'full' tanks available is analyzed.

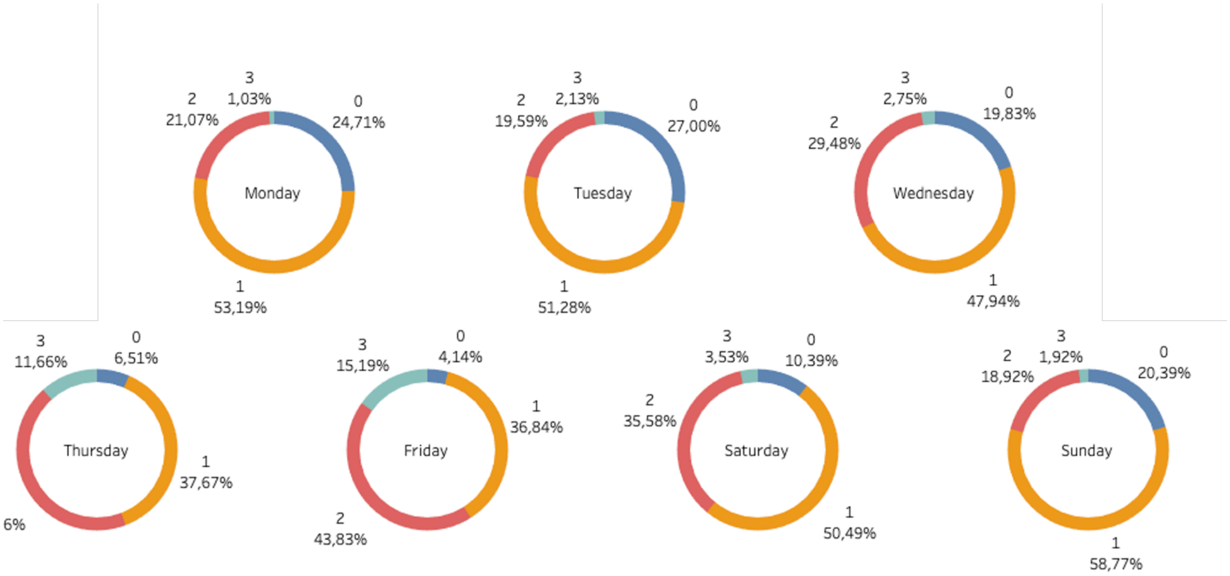


Figure 12: Amount of full tanks available as percentage of time per weekday

Table 14: Conclusions on available full tanks

Observations from full tank availability normal ingredient A
1. Tuesday is the day with the largest percentage of zero tanks available (27.00%)
2. Friday is the day with the lowest percentage of zero tanks available (4.14%)

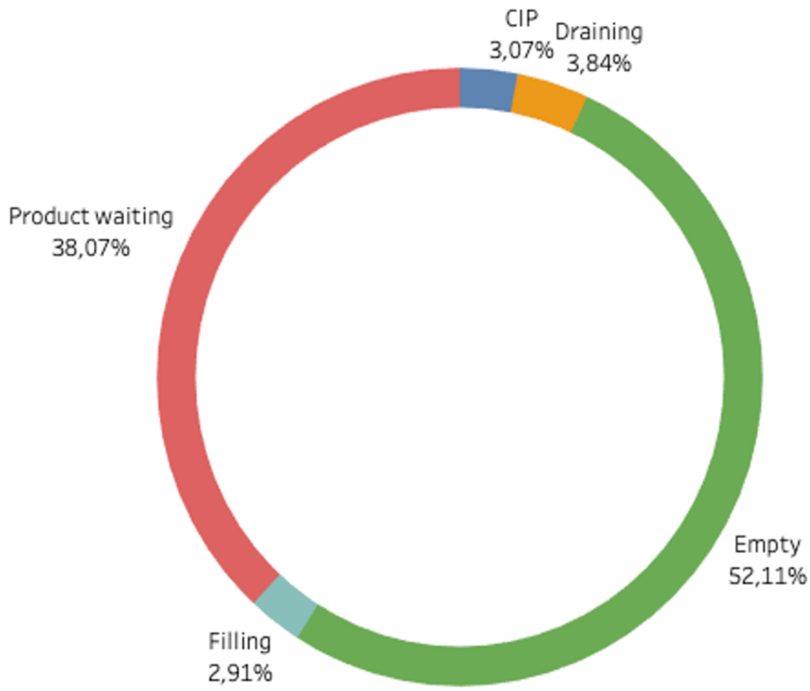


Figure 13: Organic tank statuses as percentage of time

Table 15: Conclusions on organic tank statuses

Observations from tank status distribution organic ingredient A
1. The status distribution is larger than all non-bio storage in terms of empty time
2. CIP status is larger than any non-bio tank, which signals that more cycles are present
3. Draining and filling is lower than any of the non-bio tanks which signals that volumes are less

Appendix F – Fitting distributions

Weekly ingredient A usage (X)

Using the historical data the figure below is created, showing the distribution of the weekly factory ingredient A demand during 2019.

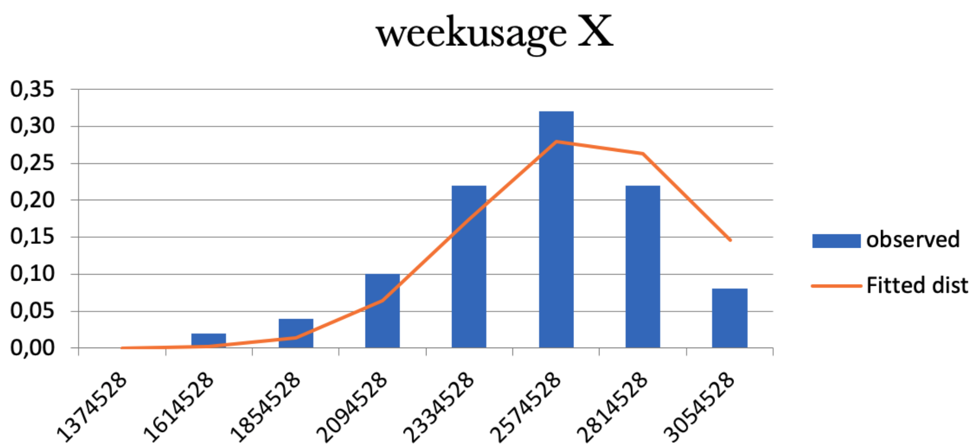


Figure 14: Fitting of weekly throughput (X)

Fitted distribution:
Normal: $\mu = 2407261 and \sigma^2 = 321691$
Chi square: 14,06714045
aggregated error: 8,00 < 14,06714045 -> do not reject h0

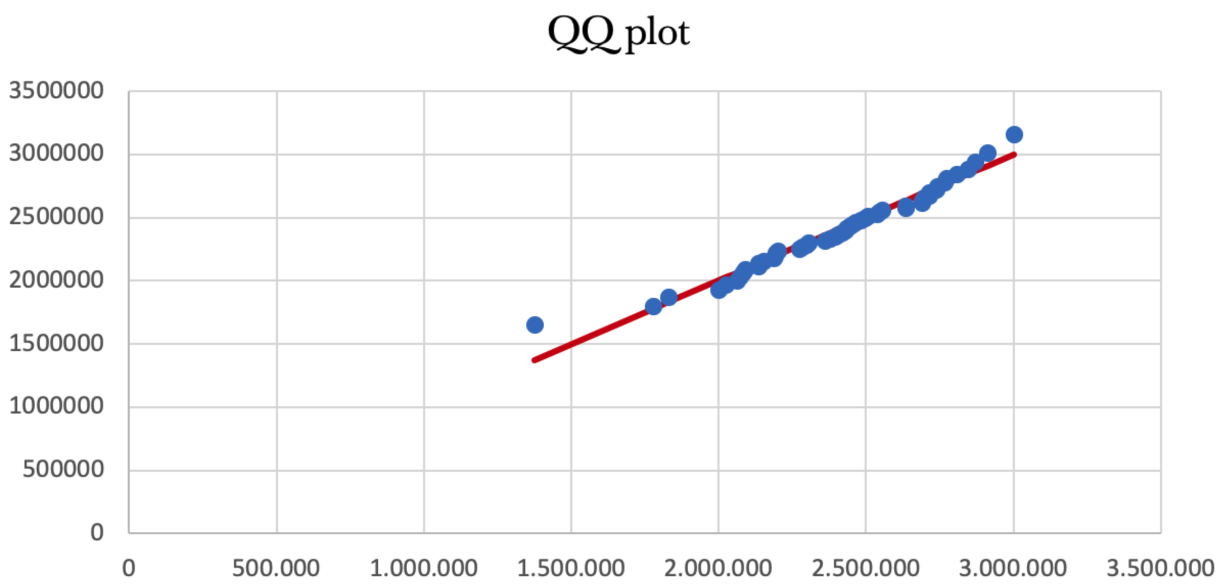


Figure 15: QQ-plot of throughput distribution

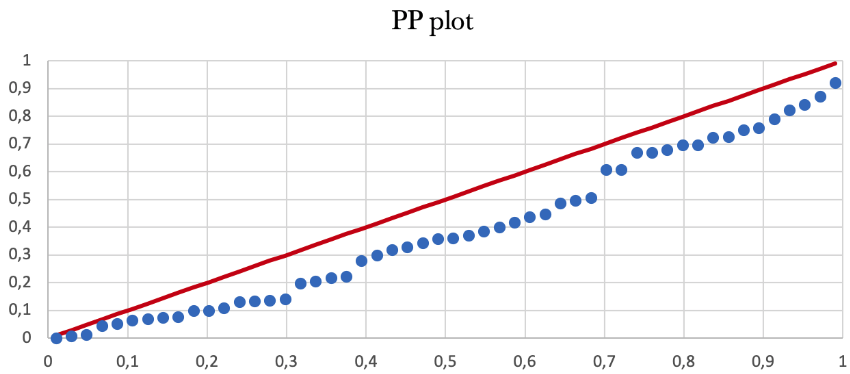


Figure 16: PP-plot of throughput distribution

Weekly over/under shoot (S)

Using the historical data the figure below is created, showing the distribution of the weekly over/undershoot during 2019.

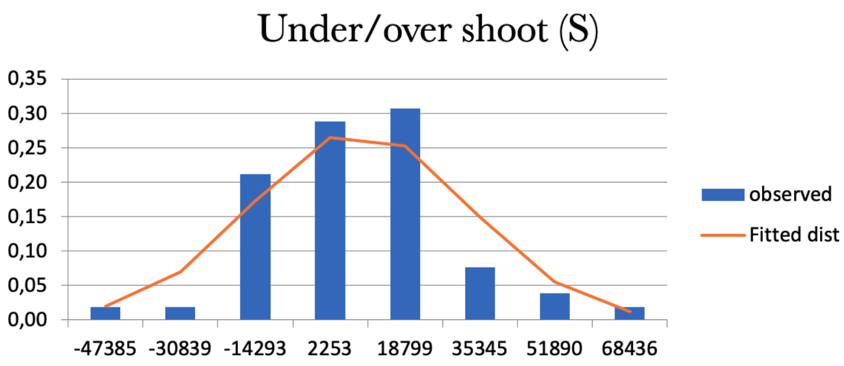


Figure 17: Fitting of weekly over/under shoot (S)

Fitted distribution:
Normal: μ = 596 and σ ^{2}= 23483
Chi square: 14,06714045
aggregated error: 8,307692308 < 14,06714045 -> do not reject h0

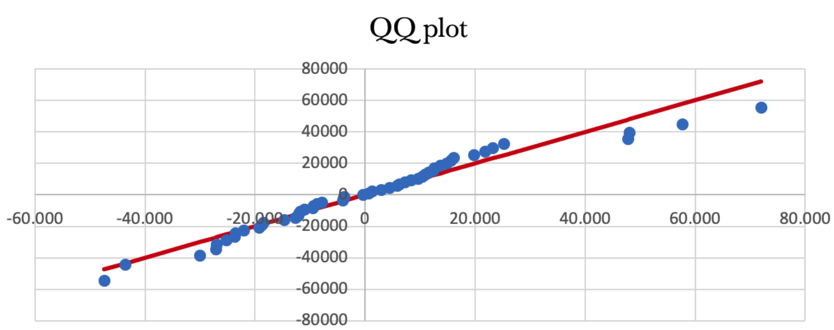


Figure 18: QQ-plot of over/under shoot distribution

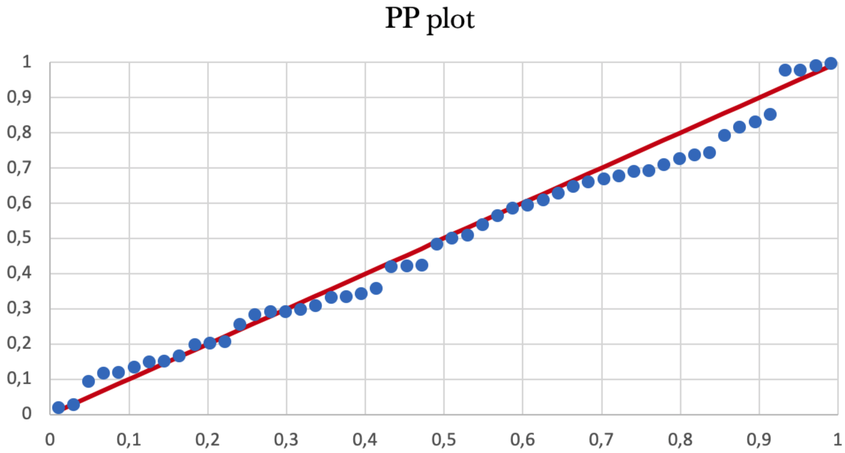


Figure 19: PP-plot of over/under shoot distribution

Demand/delivery misalignment (IC)

Using the historical data the figure below is created, showing the distribution of the (absolute) demand/delivery misalignment.

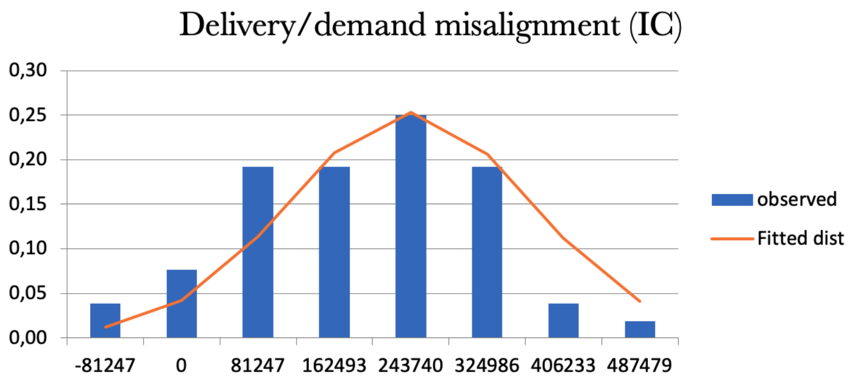


Figure 20: Fitting of weekly demand/delivery misalignment (IC)

Fitted distribution:
Normal: μ = 202302 and σ ^{2}= 125803
Chi square: 14,06714045
aggregated error: 6,15 < 14,06714045 -> do not reject h0

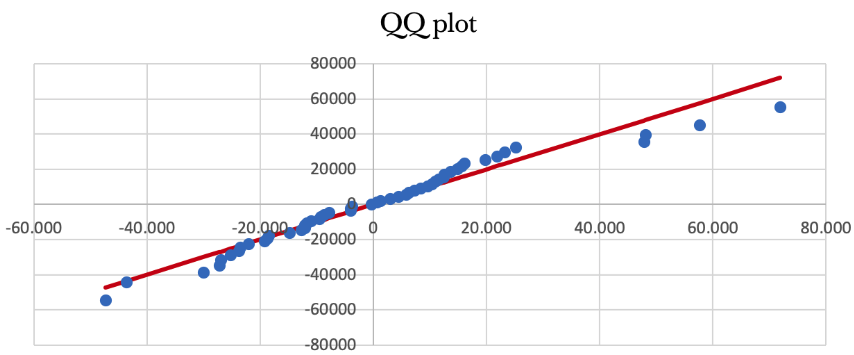


Figure 21: QQ-plot of demand/delivery misalignment distribution

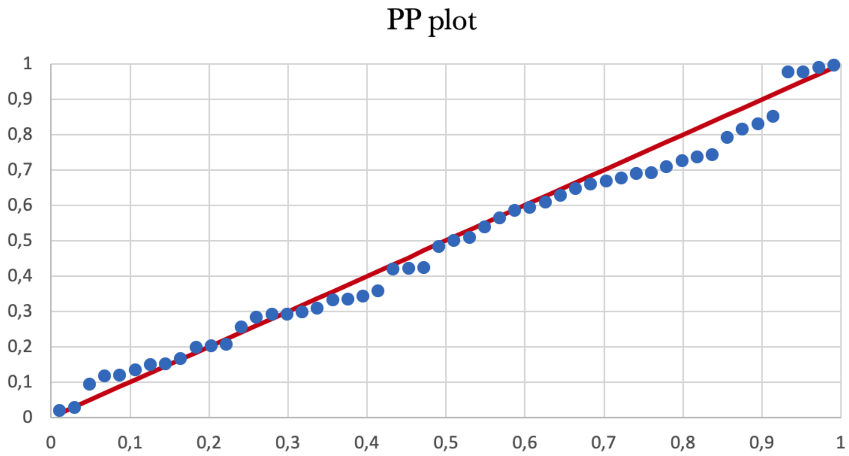


Figure 22: PP-plot of demand/delivery misalignment distribution

Appendix G – Steps to calculating demand & deliveries

1. Determine factory usage X for next week using:

$$Normal: \ \mu = 2407261 \ and \ \sigma^2 = 321691$$

2. Determine an under or overshoot S at the end of the week using:

$$Normal: \ \mu = 596 \ and \ \sigma^2 = 23483$$

3. Next we calculate the total order (delivery) amount, the delivery amount is adjusted for the overshoot of previous week (S(n-1)):

$$D = X + S - S_(n-1)$$

4. The demand/delivery misalignment (IC) is determined using:

$$Normal: \ \mu = 232302 \ and \ \sigma^2 = 125803$$

5. The daily factory usage X is determined using historical daily fractions.

Table 16: Weekly factory usage and deliveries

Day	Factory usage	Deliveries
1	X_1	X_1 + IC_1 + S/7 - S(n-1)
2	X_2	X_2 + IC_2 + S/7
3	X_3	X_3 + IC_3 + S/7
4	X_4	X_4 + IC_4 + S/7
5	X_5	X_5 + IC_5 + S/7
6	X_6	X_6 + IC_6 + S/7
7	X_7	X_7 + IC_7 + S/7
Weekly total	X	D = X + S - S(n-1)

6. Finally the hourly factory usage and deliveries are separately determined using historical hourly fractions.

Appendix H – Product X demand schedules

For normal product X demand, the schedule found in Table 17 is defined.

Table 17: Normal product X demand schedule (liter/hour)

Hour	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0	25000	0	0
5	0	0	0	0	25000	0	0
6	0	0	0	0	25000	0	0
7	0	0	0	0	25000	0	0
8	0	0	0	0	25000	0	0
9	0	0	0	0	25000	0	0
10	0	0	25000	25000	25000	25000	25000
11	0	0	25000	25000	0	25000	25000
12	0	0	25000	25000	0	25000	25000
13	0	0	25000	25000	0	25000	25000
14	0	0	25000	25000	0	25000	25000
15	0	0	25000	25000	0	25000	25000
16	0	0	25000	25000	25000	25000	25000
17	0	0	0	0	25000	0	0
18	0	0	0	0	25000	0	0
19	0	0	0	0	25000	0	0
20	0	0	0	0	25000	0	0
21	0	0	0	0	25000	0	0
22	0	0	0	0	25000	0	0
23	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0

For high product X demand the schedule, found in Table 18 is defined.

Table 18: High product X demand schedule (liter/hour)

Hour	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	25000	25000	25000	25000	25000	25000
5	0	25000	25000	25000	25000	25000	25000
6	0	25000	25000	25000	25000	25000	25000
7	0	25000	25000	25000	25000	25000	25000
8	0	25000	25000	25000	25000	25000	25000
9	0	25000	25000	25000	25000	25000	25000
10	0	0	0	25000	25000	25000	25000
11	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0
16	0	0	25000	25000	25000	25000	25000
17	0	25000	25000	25000	25000	25000	25000
18	0	25000	25000	25000	25000	25000	25000
19	0	25000	25000	25000	25000	25000	25000
20	0	25000	25000	25000	25000	25000	25000
21	0	25000	25000	25000	25000	25000	25000
22	0	25000	25000	25000	25000	25000	25000
23	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0

Appendix I – Product X demand schedules

In this appendix the updated models and changed logics for the 'direct connect' and 'tank park splits' are presented.

Direct connect

A screenshot of the updated model can be found in the figure below. Note that the layout is mostly the same as the current model except for the new product X line (circled).

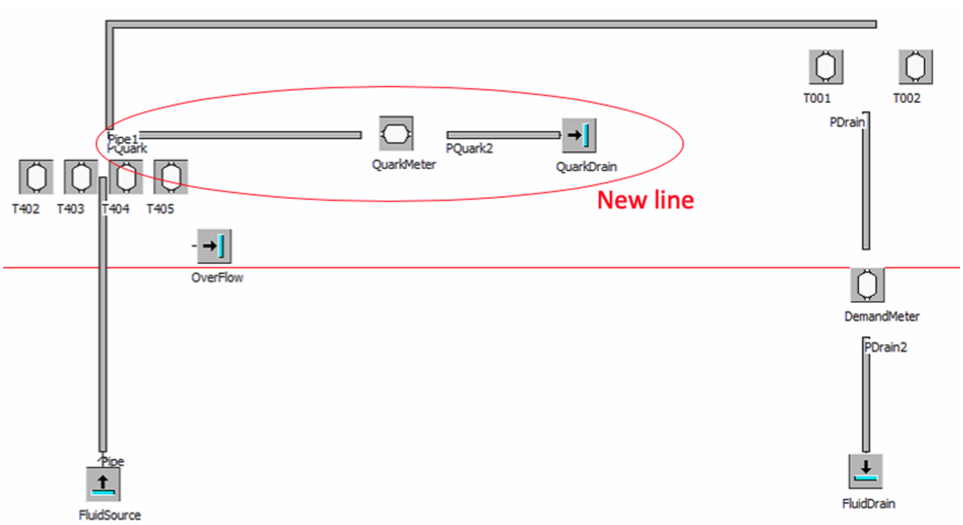


Figure 23: Screenshot of the simulation model direct connect layout

To accommodate the new product X line the logic behind three different events is changed. All three logics are presented with the added or changed parts in green.

1. Logic one is updated to also (hourly) check demand fulfillment for the new line. When no product X demand is present, demand is set to zero and fulfillment to true.

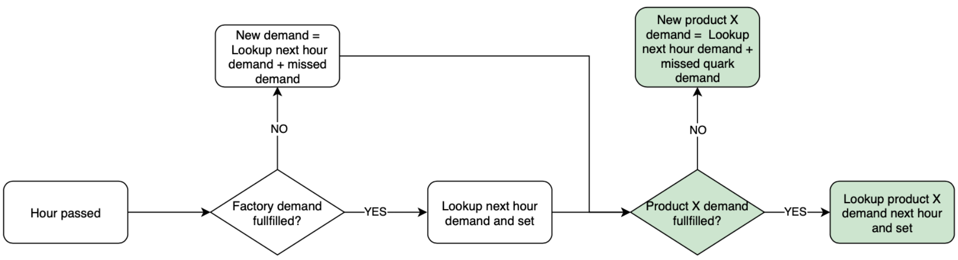


Figure 24: updated method of 'hour passed'.

2. When product X demand is fulfilled within the hour, the additional 'B. Product X demand fullfilled ' becomes active and sets demand as true. This logic is essentially the same as original logic, but for product X.

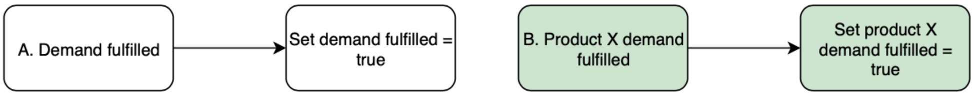


Figure 25: Additional method to 'demand fullfilled'.

3. The final logic that is altered is the 'main tank becomes empty'. For the conventional model an empty main tank only meant that there was a buffer tank being filled from it. This now can mean one of three things: product X demand was being fulfilled from the tank, a buffer tank was being filled from the tank or both. The logic is changed in such a way that it identifies which of the three possible situations it's dealing with.

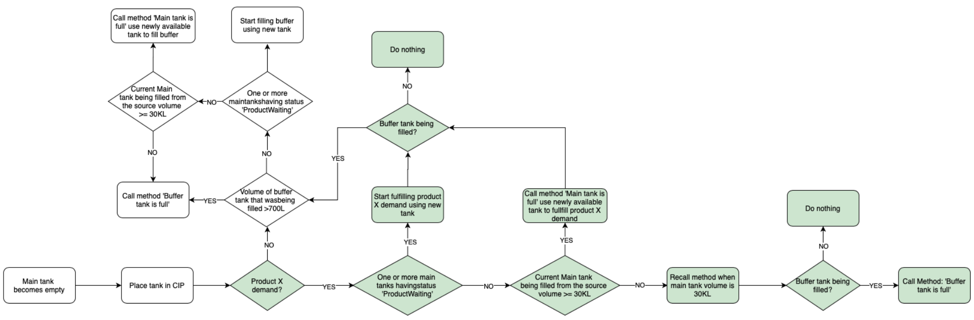


Figure 26: Addition to the method 'Main tank becomes empty'.

Tank park split

A screenshot of the updated model can be found in the figure below. The tank park split layout is quite a simple situation to model. In a way the main tanks act as the buffer tank in the previous layout.

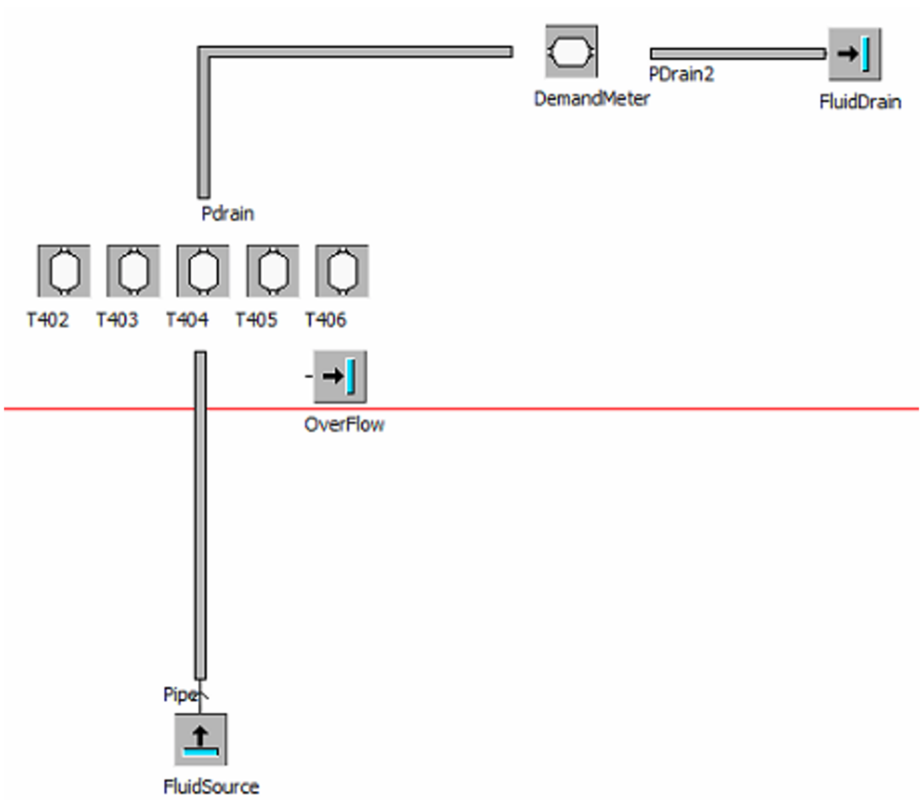


Figure 27: Screenshot of the simulation model tank park split layout

1. The 'hour passed' and 'demand fullfilled' logic remain the same as the conventional model.

2. All logics regarding buffer storage events are removed.

3. The 'main tank is full' logic remains the same.

4. The 'main tank becomes empty logic is changed to the logic found in Figure 28. The division between main and buffer tanks is removed as only the main tanks remain for the tank park split layout.

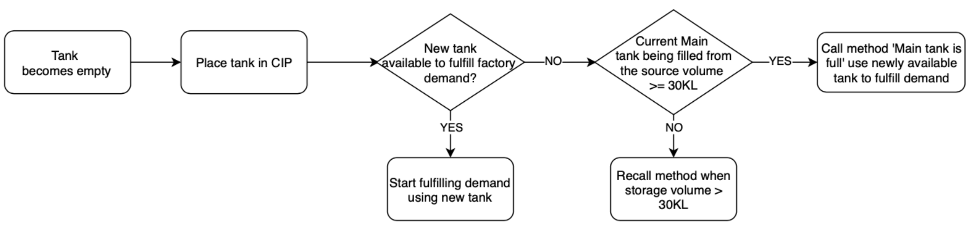


Figure 28: New 'Tank becomes empty' logic

5. The 'intermediate tank level reached' logic remains the same.

Appendix J – Updated delivery fractions

The improved delivery fractions when X is larger than 4,000,000 liters a week and product X demand is present are as found in Table 19.

Table 19: Updated delivery fractions

Hour	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
1	0,021505	0,082042	0,082042	0,082042	0,082042	0,082042	0,082042
2	0,016897	0,068368	0,068368	0,068368	0,068368	0,068368	0,068368
3	0,010753	0,057429	0,057429	0,057429	0,057429	0,057429	0,057429
4	0,004608	0,030082	0,030082	0,030082	0,030082	0,030082	0,030082
5	0,003072	0,008204	0,008204	0,008204	0,008204	0,008204	0,008204
6	0,003072	0,000912	0,000912	0,000912	0,000912	0,000912	0,000912
7	0,016897	0,008204	0,008204	0,008204	0,008204	0,008204	0,008204
8	0,023041	0,016408	0,016408	0,016408	0,016408	0,016408	0,016408
9	0,018433	0,018232	0,018232	0,018232	0,018232	0,018232	0,018232
10	0,039939	0,032817	0,032817	0,032817	0,032817	0,032817	0,032817
11	0,056836	0,03464	0,03464	0,03464	0,03464	0,03464	0,03464
12	0,072197	0,073838	0,073838	0,073838	0,073838	0,073838	0,073838
13	0,078341	0,06381	0,06381	0,06381	0,06381	0,06381	0,06381
14	0,06298	0,08113	0,08113	0,08113	0,08113	0,08113	0,08113
15	0,050691	0,059253	0,059253	0,059253	0,059253	0,059253	0,059253
16	0,0553	0,038286	0,038286	0,038286	0,038286	0,038286	0,038286
17	0,072197	0,025524	0,025524	0,025524	0,025524	0,025524	0,025524
18	0,069124	0,039198	0,039198	0,039198	0,039198	0,039198	0,039198
19	0,081413	0,072015	0,072015	0,072015	0,072015	0,072015	0,072015
20	0,038402	0,028259	0,028259	0,028259	0,028259	0,028259	0,028259
21	0,044547	0,030994	0,030994	0,030994	0,030994	0,030994	0,030994
22	0,044547	0,050137	0,050137	0,050137	0,050137	0,050137	0,050137
23	0,056836	0,036463	0,036463	0,036463	0,036463	0,036463	0,036463
24	0,058372	0,043756	0,043756	0,043756	0,043756	0,043756	0,043756

Appendix K –Results

SafetyStock	Demand/ Delivery Skewness		125M	138M	151M	164M	177M	190M	203M	216M	229M	242M	255M
160000	1	Stockouts/week	1.68	2.18	2.81	3.51	4.10	4.98	6.01	6.95	8.22	9.26	9.78
		Stockout hours	3.38	4.54	6.05	7.95	9.85	12.89	16.84	21.11	28.83	39.95	56.84
		DwellTime Main	21.23	19.45	17.25	16.13	15.59	14.64	13.59	13.14	12.42	12.11	11.61
		DwellTime Buffer	10.24	9.20	8.22	7.50	6.96	6.42	5.91	5.52	5.12	4.78	4.42
		OverFlow %	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		Main Utilization	0.53	0.54	0.53	0.54	0.55	0.56	0.56	0.57	0.57	0.58	0.59
	2	Stockouts/week	1.83	2.38	2.98	3.69	4.40	5.40	6.38	7.54	9.02	9.89	10.05
		Stockout hours	3.66	4.93	6.47	8.39	10.62	13.84	17.87	23.38	32.85	44.15	59.01
		DwellTime Main	19.63	17.76	16.87	15.51	14.78	13.47	13.06	12.36	11.29	11.32	11.42
		DwellTime Buffer	10.09	9.01	8.22	7.48	6.89	6.30	5.87	5.44	4.97	4.69	4.42
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.51	0.51	0.52	0.52	0.53	0.53	0.54	0.55	0.55	0.56	0.58
	3	Stockouts/week	2.12	2.81	3.53	4.43	5.37	6.47	7.69	8.91	10.09	10.78	10.20
		Stockout hours	4.19	5.75	7.55	9.96	12.91	16.66	21.92	28.50	38.48	53.03	70.11
		DwellTime Main	15.58	14.08	13.17	11.90	11.63	10.15	10.18	9.88	9.59	9.16	9.53
		DwellTime Buffer	9.71	8.67	7.86	7.10	6.57	5.93	5.56	5.17	4.82	4.46	4.23
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.46	0.46	0.47	0.47	0.48	0.48	0.49	0.50	0.51	0.51	0.53
220000	1	Stockouts/week	1.38	1.77	2.23	2.72	3.44	3.90	4.79	5.45	6.77	7.66	8.76
		Stockout hours	2.84	3.75	4.90	6.21	8.31	10.00	13.19	16.23	22.52	30.12	43.34
		DwellTime Main	26.03	23.55	21.56	20.09	18.23	17.75	16.51	15.83	14.75	14.44	13.90
		DwellTime Buffer	10.84	9.67	8.77	8.01	7.30	6.81	6.29	5.88	5.44	5.10	4.76
		OverFlow %	0.04	0.03	0.04	0.05	0.05	0.07	0.06	0.07	0.07	0.08	0.09
		Main Utilization	0.59	0.59	0.59	0.60	0.59	0.61	0.61	0.62	0.62	0.63	0.64
	2	Stockouts/week	1.59	1.97	2.38	3.00	3.65	4.20	5.34	6.02	7.53	8.58	9.17
		Stockout hours	3.26	4.16	5.23	6.95	8.87	10.81	14.71	18.03	25.46	34.46	47.79
		DwellTime Main	23.74	22.36	21.07	19.27	17.82	17.10	15.66	15.22	14.02	13.68	13.46
		DwellTime Buffer	10.60	9.57	8.74	7.94	7.28	6.76	6.21	5.82	5.36	5.01	4.70
		OverFlow %	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03
		Main Utilization	0.55	0.57	0.58	0.58	0.58	0.60	0.59	0.60	0.60	0.61	0.63
	3	Stockouts/week	1.87	2.44	3.03	3.75	4.63	5.58	6.72	7.93	8.96	10.11	10.05
		Stockout hours	3.86	5.17	6.73	8.73	11.40	14.62	19.09	25.15	31.97	44.85	60.61
		DwellTime Main	20.80	18.88	17.94	16.12	15.24	14.05	13.23	12.54	12.46	11.80	11.87
		DwellTime Buffer	10.39	9.31	8.47	7.68	7.04	6.47	5.96	5.53	5.20	4.81	4.53
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.50	0.51	0.52	0.52	0.53	0.53	0.53	0.54	0.56	0.56	0.58
280000	1	Stockouts/week	1.08	1.33	1.59	2.11	2.50	2.78	3.38	4.13	4.80	6.12	7.42
		Stockout hours	2.23	2.85	3.53	4.89	6.11	7.12	9.19	12.03	15.27	22.53	33.57
		DwellTime Main	30.12	27.75	25.54	22.93	21.47	20.58	19.23	17.95	17.16	16.25	15.70
		DwellTime Buffer	11.21	10.07	9.17	8.30	7.63	7.11	6.59	6.12	5.73	5.32	4.97
		OverFlow %	0.10	0.11	0.12	0.10	0.13	0.17	0.18	0.16	0.20	0.20	0.22
		Main Utilization	0.64	0.65	0.66	0.65	0.66	0.67	0.67	0.67	0.68	0.68	0.69
	2	Stockouts/week	1.22	1.49	1.79	2.20	2.64	3.05	3.78	4.49	5.38	6.91	7.88
		Stockout hours	2.53	3.19	3.98	5.12	6.47	7.88	10.39	13.10	17.07	25.82	37.17
		DwellTime Main	28.69	26.48	24.59	22.64	21.14	19.95	18.46	17.63	16.69	15.64	15.26
		DwellTime Buffer	11.10	9.98	9.08	8.27	7.62	7.06	6.53	6.08	5.68	5.26	4.93
		OverFlow %	0.01	0.02	0.03	0.02	0.04	0.05	0.04	0.06	0.05	0.06	0.08
		Main Utilization	0.62	0.63	0.64	0.64	0.65	0.66	0.65	0.66	0.67	0.66	0.68
	3	Stockouts/week	1.60	2.06	2.57	3.12	3.78	4.48	5.55	6.49	7.46	8.82	9.47
		Stockout hours	3.34	4.45	5.79	7.37	9.45	11.83	15.65	19.86	25.19	35.37	51.86
		DwellTime Main	25.80	23.17	21.59	19.76	18.54	17.44	15.99	15.34	14.93	14.28	13.74
		DwellTime Buffer	10.82	9.68	8.80	8.01	7.36	6.81	6.26	5.84	5.48	5.09	4.72
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.58	0.58	0.59	0.59	0.59	0.60	0.59	0.60	0.62	0.62	0.63

Figure 29: Conventional no product X

SafetyStock	Demand/ Delivery Skewness		125M	138M	151M	164M	177M	190M	203M	216M	229M	242M	255M
160000	1	Stockouts/week	0.00	0.01	0.00	0.03	0.04	0.05	0.02	0.06	0.13	0.13	0.14
		Stockout hours	0.00	0.02	0.01	0.05	0.10	0.11	0.05	0.14	0.33	0.33	0.37
		DwellTime Main	30.40	26.85	24.91	22.34	20.59	19.53	18.07	16.92	15.99	14.95	14.21
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00
		Main Utilization	0.76	0.76	0.76	0.76	0.76	0.77	0.77	0.77	0.77	0.77	0.77
	2	Stockouts/week	0.00	0.01	0.01	0.01	0.02	0.02	0.07	0.05	0.06	0.21	0.20
		Stockout hours	0.01	0.01	0.02	0.03	0.03	0.05	0.15	0.12	0.12	0.58	0.55
		DwellTime Main	28.58	25.25	23.32	21.79	19.82	18.68	17.08	16.19	15.27	13.81	13.23
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.74	0.74	0.74	0.75	0.75	0.75	0.75	0.75	0.75	0.74	0.75
	3	Stockouts/week	0.01	0.00	0.01	0.01	0.03	0.03	0.10	0.10	0.15	0.12	0.23
		Stockout hours	0.02	0.00	0.03	0.02	0.07	0.05	0.25	0.23	0.41	0.26	0.62
		DwellTime Main	24.60	21.96	19.64	18.42	16.46	15.50	13.89	13.30	12.58	11.87	11.24
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
220000	1	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01
		DwellTime Main	35.48	31.45	29.00	26.64	24.01	22.63	21.36	19.83	18.81	17.53	16.79
		OverFlow %	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02
		Main Utilization	0.81	0.80	0.81	0.81	0.80	0.81	0.81	0.81	0.81	0.81	0.81
	2	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		DwellTime Main	34.03	29.87	27.55	25.71	23.73	21.73	20.68	19.08	18.05	16.69	16.01
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.79	0.78	0.79	0.79	0.79	0.79	0.80	0.79	0.79	0.79	0.79
	3	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		DwellTime Main	29.33	26.92	24.36	22.60	20.38	19.24	17.81	16.09	15.53	14.98	14.02
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.73	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.75	0.75
280000	1	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		DwellTime Main	39.90	35.98	32.66	30.34	27.38	25.65	24.19	22.70	21.14	20.20	19.05
		OverFlow %	0.06	0.06	0.05	0.07	0.06	0.06	0.08	0.07	0.07	0.07	0.06
		Main Utilization	0.86	0.86	0.86	0.87	0.85	0.86	0.87	0.87	0.86	0.87	0.87
	2	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		DwellTime Main	38.47	34.64	31.69	28.73	27.19	24.98	23.68	21.76	20.81	19.57	17.98
		OverFlow %	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.02	0.01
		Main Utilization	0.84	0.84	0.84	0.84	0.85	0.84	0.85	0.84	0.85	0.85	0.84
	3	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		DwellTime Main	34.42	31.65	28.56	26.04	24.41	22.15	21.10	19.20	18.35	17.50	16.46
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.78	0.79	0.79	0.78	0.79	0.78	0.79	0.78	0.79	0.80	0.79

Figure 30: Split tank park no product X

SafetyStock	Demand/ Delivery Skewness		180M	193M	206M	219M	232M	245M	258M	271M	284M	297M	310M
160000	1	Stockouts/week	6,93	7,47	7,72	7,76	7,38	6,51	5,39	4,10	2,97	2,01	0,84
		Stockout hours	29,21	36,07	44,73	54,54	68,20	84,03	99,97	116,14	131,77	146,04	160,40
		DwellTime Main	15,36	15,19	14,26	13,93	13,25	13,40	13,48	13,37	13,60	13,85	14,49
		DwellTime Buffer	6,68	6,22	5,73	5,35	4,94	4,62	4,31	4,01	3,77	3,60	3,45
		OverFlow %	0,01	0,03	0,02	0,03	0,06	0,13	0,39	0,85	1,93	3,54	6,61
		Main Utilization	0,55	0,57	0,57	0,59	0,59	0,62	0,64	0,67	0,70	0,73	0,77
	2	Stockouts/week	6,92	7,41	7,74	7,73	7,28	6,44	5,30	4,09	3,01	1,98	0,87
		Stockout hours	29,90	36,73	45,66	56,08	69,85	84,74	100,44	115,60	130,53	146,11	160,20
		DwellTime Main	14,69	14,40	13,44	13,13	12,47	12,69	13,09	13,31	13,53	13,69	14,26
		DwellTime Buffer	6,65	6,17	5,67	5,29	4,88	4,59	4,31	4,04	3,80	3,60	3,45
		OverFlow %	0,00	0,00	0,00	0,00	0,01	0,05	0,24	0,72	1,70	3,35	6,26
		Main Utilization	0,54	0,55	0,55	0,57	0,57	0,60	0,63	0,66	0,70	0,72	0,76
	3	Stockouts/week	7,09	7,54	7,75	7,62	7,07	6,02	4,91	3,86	2,94	1,89	0,72
		Stockout hours	33,30	41,09	50,67	61,26	74,07	89,22	103,22	117,06	131,89	147,36	161,74
		DwellTime Main	12,07	11,36	10,54	10,64	10,88	10,94	11,67	12,19	12,77	13,04	13,77
		DwellTime Buffer	6,39	5,88	5,41	5,08	4,79	4,48	4,25	4,00	3,77	3,55	3,41
		OverFlow %	0,00	0,00	0,00	0,00	0,00	0,00	0,07	0,40	1,32	3,02	6,40
		Main Utilization	0,49	0,50	0,50	0,51	0,53	0,55	0,59	0,63	0,67	0,71	0,75
220000	1	Stockouts/week	6,93	7,45	7,71	7,77	7,51	6,69	5,48	4,25	3,02	2,02	0,89
		Stockout hours	26,28	33,19	41,28	51,41	63,99	80,41	98,23	114,25	129,91	145,34	159,70
		DwellTime Main	18,68	18,12	17,12	16,19	15,68	15,15	14,94	14,63	14,47	14,33	14,82
		DwellTime Buffer	7,08	6,55	6,04	5,58	5,18	4,79	4,42	4,10	3,84	3,63	3,47
		OverFlow %	0,05	0,08	0,08	0,10	0,18	0,33	0,73	1,35	2,52	4,12	7,19
		Main Utilization	0,61	0,63	0,63	0,64	0,65	0,66	0,68	0,70	0,73	0,75	0,78
	2	Stockouts/week	6,89	7,40	7,69	7,82	7,45	6,64	5,42	4,20	3,02	2,02	0,90
		Stockout hours	26,63	33,81	42,27	52,03	64,78	81,42	98,25	113,84	129,57	144,83	159,71
		DwellTime Main	18,24	17,52	16,18	15,80	15,19	14,46	14,64	14,66	14,40	14,26	14,67
		DwellTime Buffer	7,07	6,52	5,99	5,57	5,17	4,76	4,44	4,14	3,86	3,64	3,47
		OverFlow %	0,01	0,02	0,01	0,02	0,05	0,13	0,48	1,20	2,29	3,95	6,96
		Main Utilization	0,60	0,61	0,61	0,62	0,63	0,64	0,67	0,70	0,72	0,74	0,78
	3	Stockouts/week	6,82	7,36	7,65	7,66	7,26	6,41	5,15	4,05	2,97	1,88	0,78
		Stockout hours	30,06	37,30	46,58	56,56	69,28	84,16	100,23	114,24	129,71	146,58	160,74
		DwellTime Main	15,53	14,89	13,62	13,48	13,24	13,38	13,38	13,83	13,80	13,69	14,15
		DwellTime Buffer	6,86	6,32	5,79	5,41	5,06	4,74	4,41	4,15	3,86	3,60	3,44
		OverFlow %	0,00	0,00	0,00	0,00	0,00	0,01	0,15	0,69	1,73	3,70	6,96
		Main Utilization	0,54	0,55	0,54	0,56	0,58	0,60	0,63	0,67	0,70	0,72	0,76
280000	1	Stockouts/week	6,96	7,44	7,66	7,74	7,45	6,70	5,51	4,25	3,07	2,05	0,97
		Stockout hours	23,51	31,36	38,45	47,80	61,25	77,80	96,68	112,95	128,82	144,56	158,74
		DwellTime Main	21,90	20,25	19,61	18,45	17,73	16,71	16,26	15,69	15,07	14,82	15,16
		DwellTime Buffer	7,40	6,73	6,24	5,77	5,33	4,91	4,51	4,17	3,88	3,65	3,49
		OverFlow %	0,18	0,19	0,25	0,27	0,45	0,66	1,23	2,05	3,08	4,81	7,71
		Main Utilization	0,67	0,67	0,69	0,69	0,70	0,70	0,72	0,73	0,75	0,76	0,80
	2	Stockouts/week	6,96	7,38	7,63	7,73	7,43	6,72	5,51	4,19	3,06	2,05	0,96
		Stockout hours	23,85	31,39	38,81	48,47	61,76	78,47	96,33	112,77	128,49	143,97	158,72
		DwellTime Main	21,37	20,00	19,19	17,92	17,36	16,44	16,08	15,63	15,19	14,78	15,04
		DwellTime Buffer	7,38	6,74	6,23	5,76	5,33	4,90	4,53	4,19	3,91	3,67	3,50
		OverFlow %	0,05	0,06	0,08	0,09	0,22	0,37	0,88	1,76	2,96	4,59	7,54
		Main Utilization	0,66	0,66	0,68	0,67	0,69	0,69	0,71	0,73	0,75	0,76	0,79
	3	Stockouts/week	6,77	7,32	7,65	7,74	7,32	6,58	5,29	4,03	2,99	1,97	0,86
		Stockout hours	26,90	34,31	42,50	52,25	65,74	80,45	97,30	112,78	128,41	145,12	159,75
		DwellTime Main	18,70	17,77	16,63	15,98	15,36	15,44	15,25	15,18	14,64	14,32	14,53
		DwellTime Buffer	7,18	6,57	6,06	5,63	5,22	4,88	4,54	4,22	3,91	3,64	3,47
		OverFlow %	0,00	0,00	0,00	0,00	0,01	0,07	0,34	1,13	2,27	4,27	7,50
		Main Utilization	0,60	0,61	0,61	0,62	0,63	0,66	0,68	0,71	0,72	0,74	0,77

Figure 31: Conventional with normal product X

SafetyStock	Demand/ Delivery Skewness		180M	193M	206M	219M	232M	245M	258M	271M	284M	297M	310M
160000	1	Stockouts/week	3,56	4,38	5,21	5,99	7,06	8,05	9,05	9,72	10,57	9,97	8,62
		Quark stockouts/week	0,28	0,20	0,16	0,04	0,08	0,00	0,04	0,00	0,04	0,04	0,00
		Stockout hours	7,25	9,30	11,65	14,18	18,08	22,57	28,58	36,18	49,22	66,70	86,45
		DwellTime Main	15,10	14,10	13,17	12,96	12,20	11,31	11,17	11,28	10,33	10,49	10,84
		DwellTime Buffer	9,24	8,29	7,51	6,95	6,34	5,82	5,40	5,08	4,60	4,32	4,09
		OverFlow %	0,02	0,02	0,03	0,03	0,04	0,03	0,03	0,04	0,04	0,10	0,27
		Main Utilization	0,56	0,57	0,57	0,58	0,58	0,58	0,59	0,61	0,60	0,62	0,65
	2	Stockouts/week	3,62	4,46	5,21	6,34	7,21	8,37	9,25	10,08	10,40	10,06	8,68
		Quark stockouts/week	0,16	0,16	0,12	0,08	0,00	0,08	0,04	0,08	0,00	0,00	0,00
		Stockout hours	7,33	9,44	11,62	14,90	18,37	23,26	29,09	37,69	49,83	66,55	86,18
		DwellTime Main	14,40	13,28	12,83	11,73	11,49	10,57	10,51	10,43	10,27	10,08	10,52
		DwellTime Buffer	9,22	8,26	7,54	6,81	6,30	5,74	5,36	4,99	4,65	4,32	4,09
		OverFlow %	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01	0,04	0,16
		Main Utilization	0,55	0,55	0,56	0,55	0,56	0,56	0,57	0,59	0,60	0,61	0,63
	3	Stockouts/week	4,22	5,15	6,19	7,22	8,34	9,26	10,21	10,71	11,13	10,29	8,72
		Quark stockouts/week	0,60	0,40	0,60	0,56	0,52	0,28	0,24	0,16	0,24	0,00	0,00
		Stockout hours	8,49	10,83	13,63	16,77	21,12	25,63	32,15	40,57	52,98	69,78	88,85
		DwellTime Main	11,02	10,48	9,53	9,15	8,60	8,76	8,43	8,61	8,12	8,52	8,95
		DwellTime Buffer	8,81	7,92	7,12	6,50	5,92	5,56	5,12	4,82	4,42	4,19	3,98
		OverFlow %	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,05
		Main Utilization	0,50	0,51	0,51	0,51	0,52	0,53	0,53	0,54	0,55	0,56	0,59
220000	1	Stockouts/week	3,23	3,88	4,45	5,36	6,28	7,10	8,22	9,13	9,84	9,70	8,35
		Quark stockouts/week	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		Stockout hours	6,73	8,42	10,21	13,03	16,39	20,30	26,32	34,31	46,45	63,06	83,97
		DwellTime Main	18,13	17,17	16,56	15,48	14,45	14,04	13,30	13,11	12,51	12,22	12,26
		DwellTime Buffer	9,69	8,75	8,01	7,31	6,69	6,20	5,71	5,32	4,91	4,55	4,25
		OverFlow %	0,05	0,08	0,11	0,12	0,10	0,13	0,11	0,13	0,14	0,23	0,50
		Main Utilization	0,61	0,62	0,63	0,63	0,62	0,63	0,64	0,65	0,65	0,67	0,69
	2	Stockouts/week	3,17	3,84	4,53	5,42	6,33	7,29	8,43	9,31	9,90	9,63	8,36
		Quark stockouts/week	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		Stockout hours	6,62	8,26	10,31	12,99	16,36	20,70	26,73	34,74	46,31	63,71	84,04
		DwellTime Main	17,80	16,63	15,82	14,71	14,05	13,37	12,67	12,49	12,38	12,06	12,09
		DwellTime Buffer	9,72	8,77	7,98	7,28	6,69	6,17	5,68	5,28	4,93	4,57	4,27
		OverFlow %	0,01	0,01	0,03	0,02	0,02	0,02	0,02	0,03	0,06	0,11	0,32
		Main Utilization	0,60	0,60	0,61	0,60	0,61	0,62	0,62	0,63	0,65	0,66	0,68
	3	Stockouts/week	3,49	4,27	5,11	6,23	7,19	8,07	9,08	9,92	10,23	9,82	8,27
		Quark stockouts/week	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		Stockout hours	7,13	9,12	11,43	14,76	18,37	22,59	28,67	37,83	49,53	66,36	87,59
		DwellTime Main	14,72	14,02	13,21	11,92	11,55	11,49	11,07	10,71	10,77	10,48	10,83
		DwellTime Buffer	9,49	8,55	7,77	7,00	6,44	6,01	5,55	5,14	4,82	4,48	4,20
		OverFlow %	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,13
		Main Utilization	0,54	0,55	0,55	0,54	0,55	0,57	0,57	0,58	0,59	0,60	0,63
280000	1	Stockouts/week	3,01	3,60	4,21	4,97	5,71	6,56	7,53	8,55	9,30	9,32	8,05
		Quark stockouts/week	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		Stockout hours	6,36	8,00	9,87	12,38	15,29	19,32	24,58	32,39	43,52	60,54	82,01
		DwellTime Main	21,50	20,07	18,91	17,82	16,87	16,12	15,23	14,84	14,31	13,62	13,39
		DwellTime Buffer	10,02	9,02	8,21	7,52	6,94	6,40	5,92	5,49	5,09	4,69	4,35
		OverFlow %	0,20	0,22	0,27	0,28	0,30	0,32	0,27	0,31	0,36	0,43	0,77
		Main Utilization	0,67	0,67	0,68	0,68	0,68	0,69	0,69	0,70	0,71	0,71	0,72
	2	Stockouts/week	3,01	3,60	4,18	4,96	5,79	6,61	7,66	8,57	9,31	9,19	8,08
		Quark stockouts/week	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		Stockout hours	6,35	7,96	9,72	12,32	15,44	19,42	24,85	32,73	43,66	60,66	81,93
		DwellTime Main	21,28	19,61	18,53	17,36	16,53	15,79	14,80	14,48	14,17	13,75	13,31
		DwellTime Buffer	10,02	9,03	8,24	7,52	6,92	6,41	5,90	5,49	5,10	4,72	4,37
		OverFlow %	0,07	0,07	0,08	0,11	0,11	0,11	0,09	0,12	0,18	0,29	0,55
		Main Utilization	0,66	0,66	0,66	0,66	0,67	0,67	0,67	0,69	0,70	0,71	0,72
	3	Stockouts/week	3,06	3,69	4,45	5,36	6,20	7,25	8,18	9,04	9,60	9,40	8,00
		Quark stockouts/week	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		Stockout hours	6,37	7,95	10,09	12,75	15,89	20,34	25,93	34,06	45,77	62,47	83,95
		DwellTime Main	18,62	17,08	16,19	14,89	14,39	13,70	13,48	13,03	12,86	12,40	12,50
		DwellTime Buffer	9,92	8,92	8,09	7,37	6,79	6,26	5,81	5,40	5,03	4,67	4,35
		OverFlow %	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,05	0,27
		Main Utilization	0,61	0,60	0,61	0,60	0,61	0,62	0,63	0,64	0,65	0,66	0,68

Figure 32: Direct connect with normal product X

SafetyStock	Demand/ Delivery Skewness		180M	193M	206M	219M	232M	245M	258M	271M	284M	297M	310M
160000	1	Stockouts/week	0.01	0.01	0.02	0.02	0.05	0.07	0.15	0.06	0.13	0.15	0.29
		Stockout hours	0.01	0.01	0.03	0.03	0.10	0.14	0.42	0.16	0.35	0.45	1.01
		DwellTime Main	20.55	19.48	17.83	16.85	15.70	14.68	13.67	13.44	12.54	12.09	11.21
		OverFlow %	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00
		Main Utilization	0.77	0.78	0.77	0.77	0.77	0.77	0.77	0.78	0.77	0.77	0.77
	2	Stockouts/week	0.00	0.00	0.04	0.02	0.04	0.03	0.09	0.09	0.14	0.13	0.31
		Stockout hours	0.01	0.00	0.07	0.04	0.09	0.05	0.21	0.21	0.40	0.35	1.08
		DwellTime Main	19.81	18.42	16.42	15.78	15.25	14.25	13.15	12.78	11.85	11.39	10.45
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.76	0.76	0.75	0.75	0.76	0.76	0.75	0.76	0.76	0.76	0.75
	3	Stockouts/week	0.01	0.03	0.01	0.04	0.06	0.09	0.08	0.15	0.29	0.32	0.29
		Stockout hours	0.02	0.05	0.02	0.07	0.12	0.22	0.18	0.43	0.87	1.10	1.12
		DwellTime Main	16.27	15.37	14.22	13.34	12.65	11.52	11.07	10.32	9.42	9.19	8.94
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.71	0.72	0.72
220000	1	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
		DwellTime Main	24.18	22.61	21.01	19.80	18.67	17.23	16.26	15.80	14.94	14.08	13.53
		OverFlow %	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02
		Main Utilization	0.82	0.82	0.82	0.82	0.82	0.81	0.81	0.82	0.82	0.81	0.82
	2	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		DwellTime Main	23.25	21.69	19.91	18.97	17.69	16.92	15.92	15.29	14.14	13.70	12.98
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.80	0.80	0.79	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
	3	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03
		DwellTime Main	19.62	18.77	17.92	16.47	15.55	14.62	13.77	13.15	11.98	11.66	11.14
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.74	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
280000	1	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
		DwellTime Main	27.73	25.38	24.06	22.43	21.07	19.72	18.77	17.51	17.03	16.10	15.51
		OverFlow %	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.08	0.07	0.07
		Main Utilization	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.86	0.87	0.87	0.87
	2	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		DwellTime Main	26.51	24.92	23.27	21.19	20.33	19.50	18.32	17.24	16.60	15.52	14.99
		OverFlow %	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01
		Main Utilization	0.85	0.85	0.85	0.84	0.85	0.86	0.85	0.85	0.86	0.85	0.85
	3	Stockouts/week	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Stockout hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		DwellTime Main	23.44	22.12	20.81	19.52	18.17	17.45	16.27	15.49	14.49	13.83	13.04
		OverFlow %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Main Utilization	0.79	0.79	0.80	0.80	0.79	0.80	0.80	0.80	0.79	0.79	0.79

Figure 33: Tank park split with normal product X

SafetyStock	Demand/ Delivery Skewness		230M	243M	256M	269M	282M	295M	308M	321M	334M	347M	360M
160000	1	Stockouts/week	4,40	5,68	6,86	7,93	9,16	10,13	11,15	11,59	11,05	9,81	7,58
		Quark stockouts/week	1,00	1,16	1,12	1,00	0,92	1,04	0,96	0,96	0,64	0,76	0,60
		Stockout hours	8,43	11,30	14,52	18,10	23,23	29,40	37,81	49,34	65,91	85,52	108,50
		DwellTime Main	12,58	11,46	11,12	10,95	10,38	9,96	9,70	9,46	9,66	9,50	9,90
		DwellTime Buffer	8,63	7,59	6,90	6,39	5,87	5,41	5,00	4,62	4,32	4,00	3,77
		OverFlow %	0,07	0,05	0,05	0,06	0,05	0,05	0,06	0,07	0,12	0,19	0,58
		Main Utilization	0,60	0,59	0,60	0,61	0,61	0,61	0,62	0,63	0,64	0,65	0,68
	2	Stockouts/week	4,56	5,64	6,87	7,99	9,28	10,43	11,26	11,66	11,18	9,55	7,50
		Quark stockouts/week	1,08	1,08	1,32	1,04	1,04	1,16	1,12	0,88	0,88	0,44	0,52
		Stockout hours	8,73	11,23	14,53	18,18	23,10	29,77	37,88	49,48	65,96	86,07	108,40
		DwellTime Main	11,91	11,32	10,53	10,40	9,80	9,40	9,09	9,07	8,96	9,54	9,74
		DwellTime Buffer	8,55	7,68	6,89	6,37	5,83	5,35	4,94	4,60	4,25	4,05	3,79
		OverFlow %	0,02	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,03	0,13	0,45
		Main Utilization	0,58	0,58	0,58	0,59	0,59	0,59	0,60	0,61	0,62	0,65	0,67
	3	Stockouts/week	5,53	6,90	7,89	9,13	10,62	11,39	12,07	12,36	11,70	9,95	7,88
		Quark stockouts/week	2,20	2,56	2,20	2,16	2,80	2,28	1,92	1,56	1,44	0,96	1,08
		Stockout hours	10,55	13,83	16,58	20,43	25,91	31,47	39,22	50,61	66,60	85,96	107,57
		DwellTime Main	9,69	8,71	8,69	8,15	7,31	7,48	7,63	7,47	7,53	8,11	8,37
		DwellTime Buffer	8,12	7,17	6,62	6,03	5,39	5,08	4,77	4,41	4,12	3,92	3,68
		OverFlow %	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,26
		Main Utilization	0,55	0,54	0,55	0,55	0,55	0,56	0,57	0,57	0,58	0,61	0,63
220000	1	Stockouts/week	3,84	4,97	6,10	7,38	8,58	9,61	10,31	10,91	10,47	9,27	7,32
		Quark stockouts/week	0,08	0,08	0,20	0,16	0,04	0,16	0,08	0,04	0,00	0,00	0,00
		Stockout hours	7,42	9,96	13,05	17,18	22,33	28,46	36,69	48,05	64,70	85,03	107,71
		DwellTime Main	15,05	13,90	13,30	12,91	12,29	11,79	11,59	11,16	11,09	11,00	11,00
		DwellTime Buffer	9,11	8,08	7,31	6,70	6,17	5,70	5,29	4,87	4,52	4,19	3,90
		OverFlow %	0,22	0,17	0,17	0,18	0,15	0,15	0,19	0,19	0,27	0,44	0,88
		Main Utilization	0,64	0,63	0,64	0,65	0,65	0,65	0,66	0,67	0,68	0,70	0,72
	2	Stockouts/week	4,00	4,93	6,20	7,32	8,58	9,58	10,36	10,95	10,53	9,22	7,27
		Quark stockouts/week	0,24	0,12	0,20	0,08	0,16	0,08	0,00	0,12	0,00	0,00	0,00
		Stockout hours	7,71	9,92	13,27	16,95	21,97	28,30	36,38	48,38	64,88	84,39	107,60
		DwellTime Main	14,17	13,88	12,99	12,65	11,78	11,56	11,33	10,66	10,79	11,00	11,01
		DwellTime Buffer	9,03	8,14	7,33	6,73	6,17	5,71	5,30	4,84	4,52	4,22	3,93
		OverFlow %	0,08	0,09	0,07	0,07	0,05	0,05	0,06	0,05	0,12	0,31	0,75
		Main Utilization	0,62	0,63	0,63	0,64	0,63	0,64	0,65	0,65	0,67	0,69	0,71
	3	Stockouts/week	4,44	5,39	6,67	7,88	9,22	10,23	11,13	11,47	10,61	9,22	7,22
		Quark stockouts/week	0,80	0,56	0,84	0,92	0,92	0,80	0,68	0,60	0,16	0,08	0,08
		Stockout hours	8,57	10,85	14,15	17,93	23,07	29,18	37,47	49,17	65,38	86,24	107,99
		DwellTime Main	12,14	11,82	10,99	10,64	9,82	9,70	9,32	9,17	9,84	9,60	9,87
		DwellTime Buffer	8,80	7,97	7,18	6,56	5,96	5,52	5,09	4,72	4,49	4,15	3,87
		OverFlow %	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,10	0,45
		Main Utilization	0,58	0,58	0,58	0,59	0,58	0,59	0,59	0,60	0,63	0,64	0,67
280000	1	Stockouts/week	3,54	4,59	5,80	7,13	8,18	9,16	9,98	10,48	10,30	9,18	7,15
		Quark stockouts/week	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		Stockout hours	6,86	9,24	12,49	16,99	22,06	28,38	36,66	47,47	64,17	84,14	107,83
		DwellTime Main	16,73	15,94	15,08	14,41	13,94	13,37	12,96	12,50	12,31	12,10	11,79
		DwellTime Buffer	9,34	8,31	7,49	6,85	6,34	5,87	5,43	5,01	4,62	4,28	3,96
		OverFlow %	0,44	0,44	0,39	0,38	0,40	0,36	0,39	0,42	0,52	0,80	1,27
		Main Utilization	0,68	0,68	0,68	0,69	0,69	0,70	0,70	0,71	0,72	0,73	0,75
	2	Stockouts/week	3,58	4,59	5,80	7,03	8,12	9,21	9,94	10,48	10,27	9,00	7,07
		Quark stockouts/week	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		Stockout hours	6,93	9,26	12,52	16,69	21,64	28,02	36,43	47,76	63,67	84,86	108,19
		DwellTime Main	16,49	15,97	15,11	14,28	13,86	13,17	12,85	12,34	12,21	12,07	11,91
		DwellTime Buffer	9,34	8,36	7,53	6,89	6,37	5,88	5,44	5,02	4,65	4,30	3,98
		OverFlow %	0,23	0,25	0,23	0,20	0,22	0,18	0,20	0,20	0,29	0,58	1,15
		Main Utilization	0,67	0,68	0,68	0,68	0,69	0,69	0,70	0,70	0,71	0,73	0,75
	3	Stockouts/week	3,72	4,77	5,97	7,12	8,32	9,44	10,21	10,64	10,20	8,95	7,02
		Quark stockouts/week	0,00	0,04	0,04	0,00	0,04	0,00	0,00	0,00	0,00	0,00	0,00
		Stockout hours	7,30	9,68	12,80	16,49	21,36	27,61	36,20	47,84	64,75	85,39	108,13
		DwellTime Main	15,06	14,47	13,36	12,96	12,32	11,57	11,59	11,50	11,33	11,40	11,26
		DwellTime Buffer	9,33	8,31	7,50	6,86	6,31	5,79	5,38	4,99	4,62	4,30	3,97
		OverFlow %	0,01	0,01	0,01	0,01	0,01	0,00	0,01	0,01	0,03	0,23	0,75
		Main Utilization	0,63	0,64	0,63	0,64	0,64	0,64	0,65	0,67	0,68	0,70	0,72

Figure 34: Direct connect high product X

Appendix L – Comparison layouts

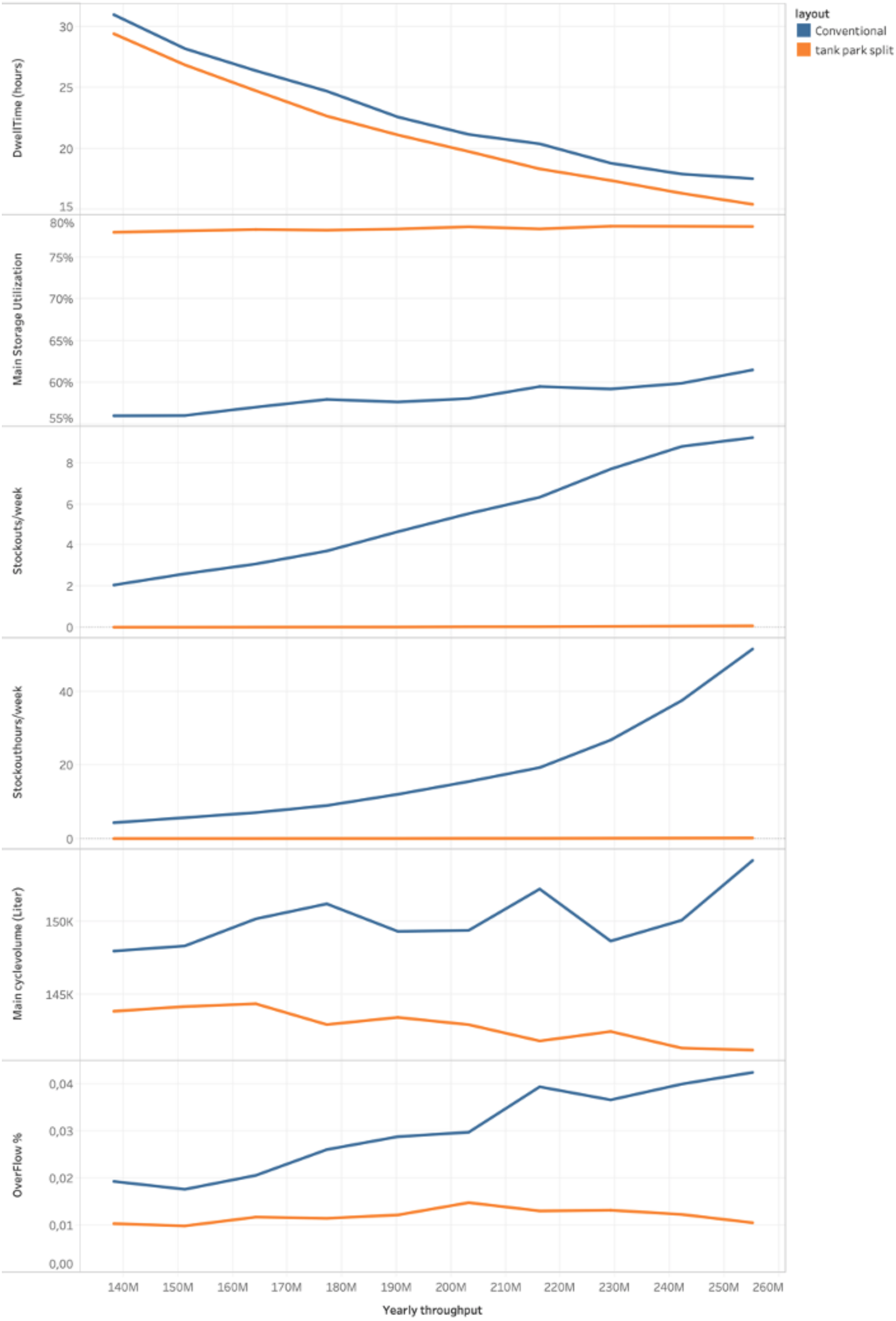


Figure 35: KPI development no product X scenario

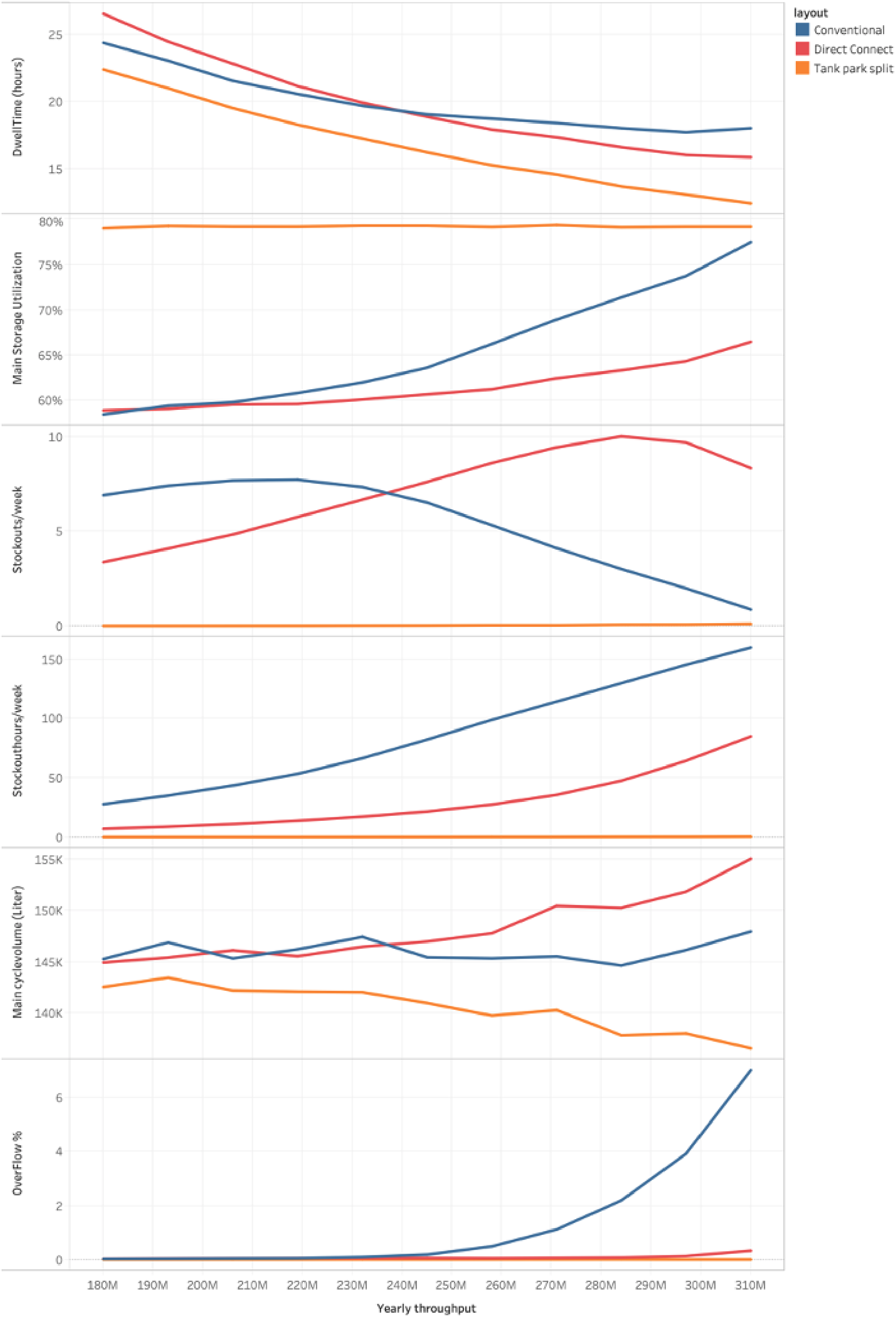


Figure 36: KPI development medium product X scenario

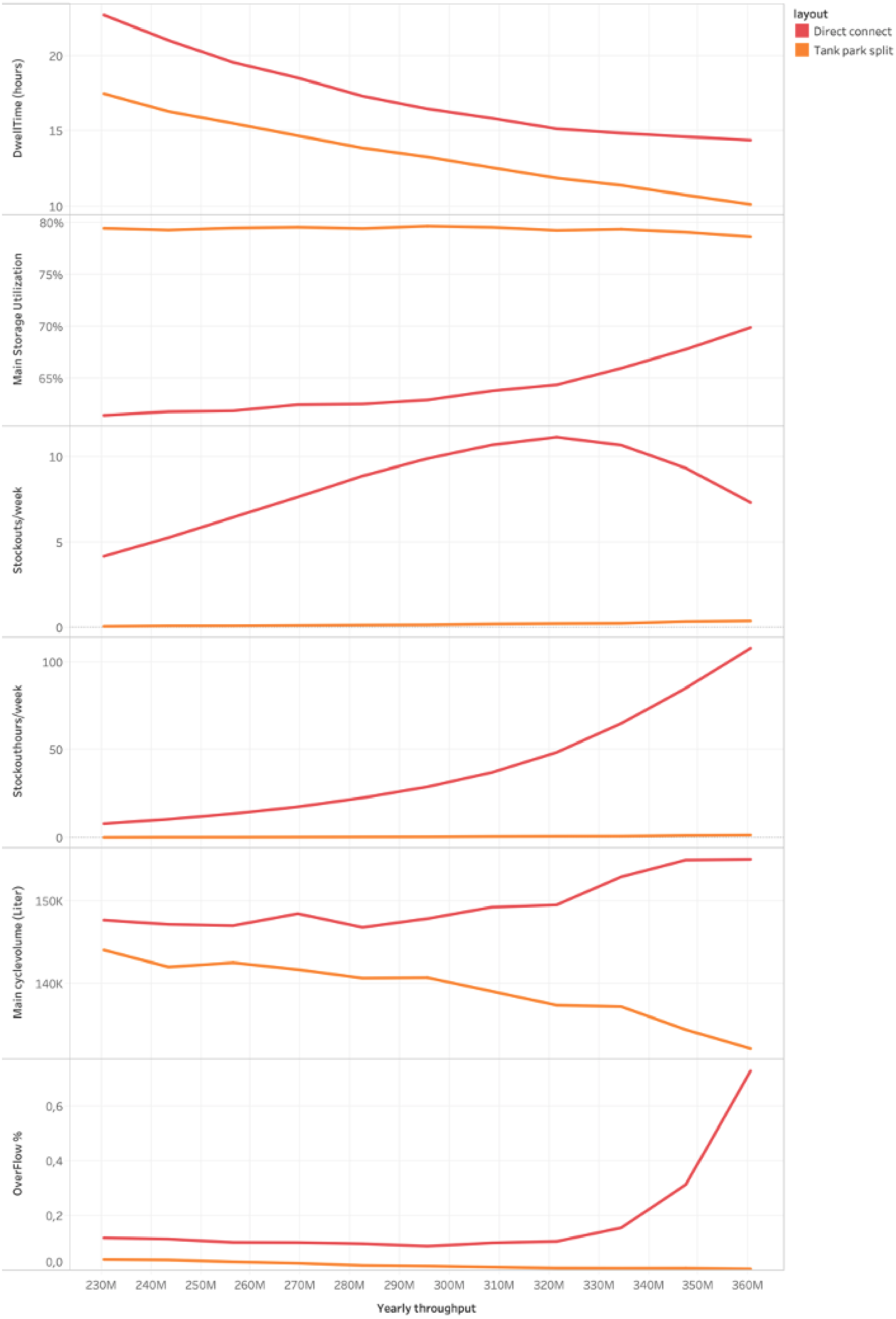


Figure 37: KPI development high product X scenario