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Reducing disturbances on the sunflower oil production at the Cargill Multiseed

by

L. Wissink

to obtain the degree of Master of Science
at the Delft University of Technology,

An electronic version of this thesis is available at http://repository.tudelft.nl/.

Preface

This report documents my master thesis, performed in graduating at the Delft University of Technology, Section Transport Engineering and Logistics, Department of Maritime and Transport Technology, Faculty of Mechanical, Maritime, and Materials Engineering. The goal of my research was to solve problems encountered in production of oil and the meal loading at the Cargill Multiseed. I would like to take this opportunity to thank the people who have helped me during my research. First of all I would like to warmly thank Jan [redacted] and Jurjen [redacted], my supervisors at Cargill, for thier excellent guidance. They were always willing to make time to discuss my progress, findings and ideas. Their guidance and help is more than appreciated.

My thanks and appreciation also goes out to Wouter W.A. Beelaerts van Blokland, my daily supervisor at TU Delft. He was always prepared to think along and discuss ways to move forward. I want to thank him for his efforts in reading my writings and giving me constructive feedback and suggestions. His help and guidance is very much appreciated. Also, I would like to thank Dingena Schott for her guidance and support helping me finish my research.

Finally I would like to thank my friends and family for their infinite love and support. Especially my parents for their never ending encouragement and support through my whole study, and my grandmother who supported me through my studies.

L. Wissink
Delft, May 2019

Summary

Background: An oil production company is able to achieve more profit (from an operational perspective) by increasing their output by reducing disturbances on the production process or by decreasing their costs. The production process should be stable and keep running. This research is conducted at Cargill sunflower seed crush the Multiseed'. A gap exists between the desired performance of sunflower oil and meal pellets production and the current performance. This research is performed to improve the stability of the production process and find solutions to remove the disturbances by identifying storage capacity problems and problems within the outbound logistics of sunflower meal pellets.

Method: The research approach is based upon the DMADE method – that consists of a study phase (Define, Measure, Analyse) and an improve phase (Design and Evaluate). Literature was researched to find the best suitable improvement methods for logistic systems. Sunflower meal pellets are a by-product of the oil production process and are stored in silos. It was found that silos filling up was the largest disturbance on the oil production. Because of this the production needed to slow down or stopped. A case study is performed, and the current state of the outbound logistics for sunflower meal pellets was measured. By analysing the current state measurements, constraints in the loading process were identified by applying the theory of constraints process improvement method. These are the throughput capacity of the truck loading station, the throughput capacity of the vessel loading station and the available loading hours. Next, using the theory of lean manufacturing waste in the loading process were identified to identify how the constraint may be exploited. From the analysis, by exploiting or elevating the constraints new design solutions were introduced. 1. Increase storage capacity of the silos, 2. Create a by-pass for simultaneously loading, 3. Reduce changeover time and 4. Create new station for removing/reattaching roof cover of truck + time slots. A discrete event simulation model was constructed to evaluate the performance of the new designs with an experimental plan. The 4 design solutions and the current state that functioned as the base case were evaluated with 4 input scenarios that varied in production rate, transport pick-up and included rain. As rain was found to be a large interruption in the vessel loading process. They were tested on Loss of production, throughput operating efficiency, silo utilization, average waiting time of trucks, turnaround time and on-time-delivery.

Results: Evaluating the design solutions showed that creating a by-pass for simultaneously was most beneficial to remove the disturbance on the oil production there was no longer any loss of production. Additionally, this solution also provided the best performance improvements on truck and vessel handling operations. The second best design was creating a new station for removing/reattaching roof cover of truck + time slots. The production was no longer disrupted by full silos and there was also a significant performance increase of the vessel and truck handling operations.

Concluding: Disturbances in the oil production can be identified and removed by following the structured DMADE framework. When combining this with the process improvement methods theory of constraints and lean manufacturing a detailed analysis of the current state can be performed. By solving the constraints and removing waste new design solutions can be found to remove the disturbances and increase the stability of the oil production process.

Samenvatting

Achtergrond: Een olieproductiebedrijf is in staat om meer winst te maken (vanuit een operationeel perspectief) door de productie te verhogen door verstoringen in het productieproces te verminderen of door de kosten te verlagen. Het productieproces moet stabiel zijn en blijven draaien. Dit onderzoek wordt uitgevoerd bij de Cargill Zonnebloemolie productie fabriek de 'Multiseed'. Er bestaat een kloof tussen de gewenste prestaties van de productie van zonnebloemolie en meelpellets en de huidige prestaties. Dit onderzoek wordt uitgevoerd om de stabiliteit van het productieproces te verbeteren en oplossingen te vinden om de verstoringen weg te nemen door opslagcapaciteitsproblemen en het identificeren van problemen in de uitgaande logistiek van zonnebloemmeelpellets.

Methode: De onderzoekmethode is gebaseerd op de DMADE-methode - die bestaat uit een studiefase (Definiëren, Meten, Analyseren) en een verbeterfase (Ontwerpen en Evalueren). Een literatuurstudie is toegepast om de meest geschikte verbetermethoden voor logistieke systemen te vinden. Zonnebloemmeelkorrels zijn een bijproduct van het olieproductieproces en worden opgeslagen in silo's. De zonnebloemmeelkorrels zijn een bijproduct van het olieproductieproces. Gebleken is dat het vullen van silo's de grootste verstoring van de olieproductie was. Hierdoor moest de productie worden vertraagd of gestopt. Er casestudie is uitgevoerd om de huidige staat van de uitgaande logistiek voor zonnebloemmeelpellets in kaart te brengen. In de analyse van de huidige toestandsmetingen zijn met het behulp van het toepassen van de theorie van beperkingen verschillende beperkingen in het laadproces geïdentificeerd. Dit zijn de doorvoercapaciteit van het laadstation van de vrachtwagen, de doorvoercapaciteit van het laadstation van het schip en de beschikbare laaduren. Vervolgens zijn aan de hand van de theorie van Lean Manufacturing verliezen in het laadproces geïdentificeerd. Door het wegnemen van de verliezen kunnen de beperkingen worden weggenomen. Vanuit de analyse konden door het benutten of opheffen van de beperkingen nieuwe ontwerpoplossingen worden geïntroduceerd. 1. Verhoging van de opslagcapaciteit van de silo's, 2. Creëer een aftakking voor gelijktijdig laden, 3. Verminderen van de omschakeltijd en 4. Creëer een nieuw station voor het verwijderen/plaatsen van het dak van de vrachtwagen + tijdsloten. Een discreet event simulatiemodel was geconstrueerd om de prestaties van de nieuwe ontwerpen te evalueren aan de hand van een experimenteel plan. De 4 ontwerpoplossingen en het huidige systeem die fungeert als basisscenario werden geëvalueerd met 4 invoerscenario's die varieerden in productiesnelheid, transportvolume en met of zonder regen. Uit de metingen was gebleken dat regen veelal een grote onderbreking bleek te zijn in het laadproces van de schepen. De ontwerpoplossingen werden getest op verlies van productie, operationele efficiëntie van de doorvoer, gebruik van de silo's, gemiddelde wachttijd van vrachtwagens, doorlooptijd en tijdige levering.

Resultaten: Het evalueren van de ontwerpoplossingen toonde aan dat het creëren van een aftakking voor gelijktijdig zeer gunstig was om de verstoring van de olieproductie op te heffen, er was niet langer sprake van productieverlies in het productieproces. Bovendien leverde deze oplossing ook de beste prestatieverbeteringen op het afhandelen van vrachtwagens en schepen. Het op een na beste ontwerp was het creëren van een nieuw station voor het verwijderen/plaatsen van het dak van de vrachtwagen + tijdsloten. De productie werd niet langer onderbroken door volle silo's en er was ook een aanzienlijke prestatieverhoging van de scheeps- en vrachtwagenbehandelingsactiviteiten.

Conclusie: Storingen in de olieproductie kunnen worden opgespoord en verholpen door het gestructureerde DMADE-methode te volgen. In combinatie met de procesverbeteringsmethoden kan een gedetailleerde analyse van de huidige stand van zaken worden uitgevoerd. Door het

oplossen van de beperkingen en het verwijderen van verliezen kunnen nieuwe ontwerpoplossingen worden gevonden om de verstoringen te verwijderen en de stabiliteit van het olieproductieproces te verhogen.

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1 Introduction

This chapter starts with the research context of this study followed by a practice analysis and the research problem. After that, the boundaries are defined by means of the research objective, questions and the scope. Next, the approach of this research and the contribution to science and practice is described. Finally, an outline of this thesis is given.

1.1. Research context

Cargill, Incorporated is an American privately held global corporation based in Minnetonka, Minnesota, and incorporated in Wilmington, Delaware. Founded by William Wallace Cargill in 1865, it is the largest privately held corporation in the United States in terms of revenue. Cargill operates in 70 countries and employs around 155,000 people worldwide (Cargill, 2018). Its major businesses are trading, purchasing and distributing agricultural commodities. Furthermore, they provide in financial and industrial products and services.

In 1958, Cargill B.V. was established in the Netherlands in a commodity trading operation. Headquartered at Schiphol Amsterdam, the Netherlands, Cargill B.V. employs around 2200 people across 11 production sites in the country. Their production plants process raw agricultural commodities into products such as cocoa and chocolate (Zaandam, Deventer), sweeteners (Sas van Gent), malt (Swalmen), vegetable oils (Amsterdam, Gent, Rotterdam), and animal nutrition (Amsterdam, Velddriel).

One of Cargill's production sites is the Cargill 'Multiseed', from here on referred to as the Multiseed, located in the Amerikahaven in the harbour of Amsterdam. The crush and refinery plants at this production site produce Crude Sunflower Oil (CSFO), Refined Sunflower Oil (RSFO) and Sunflower Meal Pellets (SFMP) from sunflower seeds. [redacted] the crush is part of Cargill Agricultural Supply Chain (CASC) business unit and the refinery of Global Edible Oil Solutions (GEOS). This research is performed at [redacted] and focuses on the daily operations of the crush, the refinery is considered the biggest customer of the crush for CSFO.

1.1.1. Cargill Multiseed

In Figure 1.1, an overhead view is shown of the Cargill Multiseed facility (from here on referred to as Multiseed) in the Amerikahaven. Sunflower seeds are crushed to extract crude oil and separate the CSFO from the meal. CSFO is either refined in the refinery or traded on the market. Refining of oil removes the impurities such as fatty acids, metal compounds, wax, dirt, and gums present in the oil or reduce them to a level that their harmful effects are to a minimum and the oil is suitable for human consumption (Pal et al., 2015). Impurities are naturally present in the seeds or formed during harvesting, storage or in the extraction process.

Food-processing companies process RSFO in their products. RSFO is preferred since it is suitable for human consumption. Some common products processed from RSFO are frying oil, salad dressings and butter. Alternatively, the RSFO is bottled and distributed to retail stores. Sunflower meal (mainly the crushed hulls of the seeds) is a by-product from the crushing process;

it is moulded into pellets and sold to farmers or business-to-business. SFMP are added as an ingredient for animal food, farmers mix them with other nutrition into a well-balanced diet.

- SFMP contains mainly protein (30–32%) and fibre (18–20%). SFMP have a maximum humidity of 12% and are cooled till a maximum of 5 °C above ambient temperature to prevent micro bacterial growth. Maximum levels of undesirable substances in meal pellets are specified by European legislation. SFMP have a length between 3–5 cm and a density between 400 and 620 kg/m^3.
- CSFO with a temperature of about 50 degrees is stored in large storage tanks of [redacted] MT. To prevent settling of the CSFO, the tanks are continuously stirred. CSFO is non-transparent and has a density of around 910 and 920 kg/m^3. Under normal conditions, the crush will produce an excess of 10 Mt the refinery can handle.

Figure 1.1: Overhead view Multiseed in the Amerikahaven of Amsterdam.

1.1.2. Logistics at Multiseed

The supply chain of the crush starts with the import of sunflower seeds from growing countries e.g. Bulgaria, Romania or Hungary. A seagoing vessel transports the seeds to the Multiseed where they are discharged and stored at the two flat storages. Seeds are reclaimed and send to the crush where the oil is separated from the meal. Sunflower seeds contain around 44% crude oil and 56% meal. CSFO is stored in one of the four large storage tanks with a maximum storage capacity of [redacted] MT. SFMP can be stored in the two silos each with a maximum storage capacity of [redacted] MT. Customers usually contract a third-party transport company to collect their products. The supply planner, stationed at the main office in Schiphol, distributes the planned transport time, day and order size to the customers and transport companies. Loading takes place at the Multiseed, SFMP and RSFO can both be loaded to trucks and vessels, CSFO can only be loaded to vessels. Around [redacted]% of SFMP is loaded to vessels and the remaining [redacted]% to trucks.

1.2. Practice analysis

Multiseed was built in 1980, due to the increasing demand for oil and innovations in the production process the production has increased. As result, the logistics for vessels and trucks also increased. During a typical production day, disturbances on the intake and output such as a shortage of seeds, personnel, logistics (vessels or trucks), or insufficient storage capacity in tanks or silos can cause the oil production to no longer go as planned. The disturbances can eventually cause the production to slow down or even be stopped. As this will result in a loss of revenue, this should be avoided. The storage capacity of the oil tanks is quite large, [redacted] there is not a lot of flexibility in the planning, when it starts raining or other problems in the loading process arise, this can quickly become a problem.

1.3. Research problem

As the problem analysis showed, the limited storage capacity in the silos increases the tension on the outbound logistics. Uncertainties such as rain, equipment failures or delays in transport can cause shifts in the loading schedule and result in long waiting hours for trucks and increase costs. Due to the long waiting times and poor customer service level, [redacted] Better management of the planning or improvements in the handling operations could lower stock-levels in the silos, reduce costs and improve the customer service level. We define the problem in the following problem definition:

Low storage capacity in the silos for sunflower meal pellets disrupt the throughput of sunflower oil at the Multiseed. In order to ensure that production keeps running, the output must be increased, which creates an increasing tension on the outbound logistics. Resulting in longer waiting hours and extra costs. By analysing the current state, redesigning and evaluating an increased performance can be achieved.

1.4. Research scope and objectives

1.4.1. Research scope

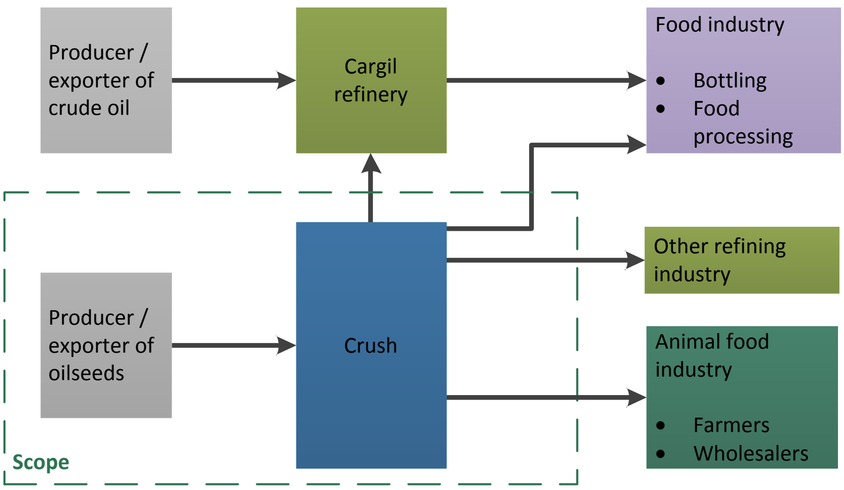

Figure 1.2: Supply chain Multiseed

Figure 1.2 shows the supply chain of the crush and the refinery of Cargill. This research is performed at the department CASC and will focus on the daily operations of the crush, the outbound logistics of the refinery is out of scope and the refinery will be seen as the largest customer for crude oil. The logistic movements for oil trucks at the weighing bridge can delay the process for a maximum period of 5 minutes and is neglected in this research.

1.4.2. Objectives and deliverables

From the previous described problem statement in Section 1.3 and the scope of the research the following research objective is derived:

Identify current processes and constraints in the supply chain of the Multiseed to increase the *reliability, the customer service level and lower the inventories by better control over the supply and transport demand.*

From this research objective the following deliverables are followed:

- Identification of the current processes in the supply chain of the Multiseed.
- Recommendations for Multiseed services for process improvements within the supply chain.
- Improved customer service level and planning flexibility

1.5. Research questions

The following main research question is formulated based on the previous research objective:

> *How can the disturbances on the throughput of sunflower oil be reduced and the flexibility be increased by improving the outbound logistics of sunflower meal pellets at the Cargill Multiseed?*

To answer this main research question, sub-questions are derived:

1. What framework and methodologies can be used from literature to find and evaluate solutions to reduce disturbances on the production of sunflower oil?
2. What criteria can be used to assess the different solution alternatives?
3. What is the current state of the oil production?
4. How is the outbound logistic for SFMP organized?
5. What is limiting the oil production and how can it be improved?
6. What design alternatives can reduce disturbances on the oil production and improve the performance of the outbound logistics?
7. How can the design alternatives be modelled in a discrete event simulation?
8. What is the best design alternative for the developed scenarios to be implemented for Cargill?

1.6. Research approach

The research approach will use the research design DMADE in Figure 1.3 of dr. W.W.A. Beelearts van Blokland Beelearts van Blokland (2018). The steps in this in design are: Design, Measure, Analyse, Design and Evaluate. This design is based on the traditional DMAIC approach from the lean six sigma methodology. In the design step, future state scenarios for improvement are developed and assessed. The evaluate step evaluates the performance and the impact on the resources for the developed future state scenarios.

Define
The define phase formulates the research problem for this research. In order to come to a tangible problem, it describes the research context, field of research, research scope, research question and sub questions. A literature study is performed to identify process improvement theories, performance criteria, performance indicators and research methods.

Measure
The measurement phase measures the current state of the system including numbers, product flows and quality of the processes.

Analyse
Results found in the previous step are evaluated and identify possible limitations in the system.

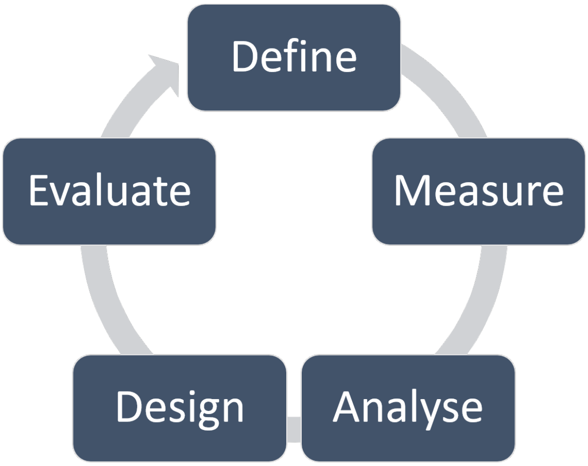

Figure 1.3: Research approach DMADC.

Design
Once the bottlenecks have been identified, they can be removed. In this step, new solutions and future states are designed, and their influence on the quality of the processes is addressed.

Evaluate
New solutions are implemented after which the performance is measured and the impact this has on the resources. After that, the new solutions are compared with each other in the discussion. And finally, it describes the additions to theory and practice.

1.7. Outline of thesis

	Chapter	Sub-questions
Define	1. Introduction	
	2. Literature	1, 2
Measure	3. Current state situation	3, 4
Analyse	4. Current state performance analysis	5
Design	5. Design alternatives	6
	6. Discrete event simulation	7
Evaluate	7. Results	8
	8. Conclusion and Recommendations	

2
Literature

The literature study has the purpose to provide a background for this research. By using scientific papers, journals and other sources a clear image on the research topics and methods is created. The literature study addresses the following sub-questions.

1. What framework and methodologies can be used from literature to find and evaluate solutions to reduce disturbances on the production of sunflower oil?

2. What criteria can be used to assess the different solution alternatives?

Each section or subsection can be related to a sub research question at the end of this chapter a conclusion is made based on these questions.

2.1. Process improvement theories

Many different methodologies regarding process improvement theories can be found in the literature. In this section, a number of these methodologies are discussed. Started with Lean, then Six Sigma, Lean Six Sigma, Theory of Constraints, Total Quality Management, Critical Path Method, Phase-Gate and lastly Critical Chain.

2.1.1. Theory of constraints

Goldratt and Cox (1984) presented the Theory Of Constraints (TOC) in his book ‘The Goal’ in 1984. It hands companies and organizations a tool to help achieve their goal. The goal of an organisation can be measured with the operational measurements throughput, inventory and operating expenses. TOC focuses on the constraint(s) of a system. According to Gupta and Boyd (2008) each system must have at least one constraint that determines its performance. The constraint is the limiting factor and impacts the performance of the whole system. In TOC, constraints are considered positive, the presence of constraint(s) provides an opportunity to improve the system’s performance (Mahapatra and Sahu, 2006). By exploiting and/or eliminating constraints in the chain the efficiency of the whole chain is improved. TOC is a continuous improvement process illustrated in Figure 2.1 consisting five process steps as follows (Rahman, 1998).

1. *Identify the system’s constraint(s):* Constraint can be physical (equipment, materials, people) or managerial (procedures, rules or methods). Identifying constraints can be done by evaluating processes, for example, high throughput times or long queues in the system.

2. *Decide how to exploit the system’s constraint(s):* Elevating a physical constraint may be achieved by increasing its effectiveness. Capacity loss because of unnecessary downtime or untimely supply of semi-finished products should be eliminated. Managerial constraints should not be elevated but replaced with a new policy or method that improves the system’s throughput.

3. *Subordinate everything else to the above decision:* Processes and components in the system should be adjusted to achieve the constraint's maximum effectiveness.

4. *Elevate the system's constraint(s):* If the actions taken in the exploiting step are not enough, more rigorous improvements should be implemented to increase its throughput. Such as investments in new equipment or new process designs.

5. *If the constraint was broken in the previous steps, repeat the process from step 1:* Once a bottleneck is broken, it is no longer the limiting factor. The process should now be repeated from step 1, another bottleneck is now the limiting factor of the systems performance.

TOC derived nine rules from the Optimized Production Technology (OPT) theory that are valid for each system Mahapatra2006.

1. Flows must be balanced not the capacity.
2. The utilization level for non-constraints is determined by the constraints in the system not its own capacity.
3. Running the non-bottleneck process at a higher capacity is of no use when this leads to queues at the bottleneck.
4. An hour lost at a bottleneck is an hour lost for the total system.
5. An hour lost at a non-bottleneck is just an illusion as it does not increase the total throughput of the system.
6. Bottlenecks dictate both the throughput and inventories in the system.
7. The transfer batch and process batch may differ not and oftentimes should not be equal.
8. The process should be variable, not fixed.
9. All bottlenecks should be considered while creating a process schedule. The lead time is the result of the schedule and cannot be calculated beforehand.

Drum-buffer-rope methodology in TOC and material utilization in a production process. The (production) schedule of the bottleneck acts as the **drum** and sets the rhythm. Other processes follow this rate and are linked to this as it were via a **rope**. The bottleneck signals the upstream processes when to increase or slow down production. When disruptions occur in the upstream processes, the supply at the bottleneck decreases and eventually runs out. Placing an inventory **buffer** in front or after the bottleneck to account for the variations in supply and demand, assures that the process at the bottleneck never has to wait. Waiting is considered a waste and should be prevented.

2.1.2. Total quality management

Total Quality Management (TQM) is a management methodology for continuous improvement that has been developed over the years. The methodology is proactive in contrast to older reactive methods, where quality problems are only corrected when they emerge (Reid and Sanders, 2013). .. showed that implementation of TQM throughout the supply chain leads to improved performance. As defined by Kiran (2016), "Total Quality Management (TQM) consists of organization-wide efforts and an integrated system of principles, methods and best practices to install and make a permanent climate in which an organisation continuously improves its ability to deliver high-quality products and services to the customers."

Management is committed to all its members to participate in the development process and urges employees to identify and address quality issues in processes, products, services and environments (Dahlgaard et al., 2007). A production process can be viewed as an integrated system of successive parts in which each part is the customer (Veeke et al., 2008). TQM focuses on customer

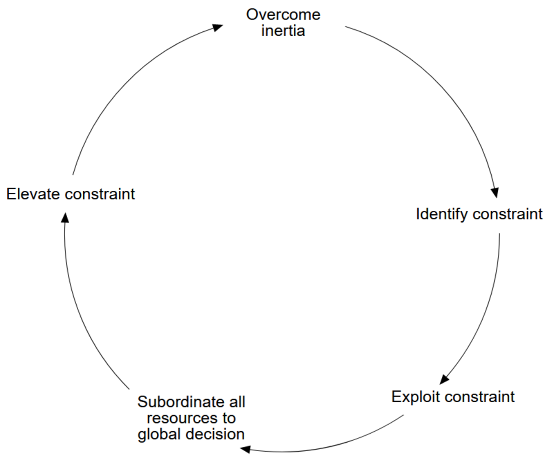

Figure 2.1: Process of continuous improvement TOC (Rahman, 1998)

satisfaction; each customer should receive a high-quality. Goetsch and Davis (2013) describe quality or customer satisfaction as the capability to meet customer's requirements and expectations.

The quality improvement follows the plan-do-study-act (PDSA) cycle, the first step is to evaluate current processes, identify the required quality and generate improvement plans. In the second step, the improvements are implemented, and the quality is measured for further evaluation. In the third step study, the collected data is analysed to see if the quality has increased. In the final step act, takes actions based on the results in the previous step to achieve the desired quality. If the implementations were a success, they can be implemented organisational wide. Afterwards, the process starts again from step 1 (Reid and Sanders, 2013).

2.1.3. Lean manufacturing

Lean manufacturing is a constant improvement process and focuses on eliminating non-value adding activities and increasing the value of the customer, at the lowest possible cost. Its overall objective is to increase its responsiveness to change in the customer's demand. Successful implementation requires the contribution of all employees and departments involved. Organisations should train their employees to learn to recognize and eliminate waste in their work. Lean manufacturing is largely applied in manufactures supply chains to optimize internal logistics processes.

Krafcik (1988) introduced the term lean manufacturing within the International Motor Vehicle Program (IMVP) of the Massachusetts Institute of Technology (MIT). The methodology finds its origin in lean principles developed by Toyota (Dailey, 2003) and became known to the general public after the book 'The machine that changed the world' by James P. Womack, Daniel T. Jones and Daniel Roos (Womack et al., 1990). Lean aims to improve flow, process times, throughput times, inventories, defects and overall equipment effectiveness (Bhasin, 2015). Systems should change from push to pull, in pull systems. In these systems, the demand dictates the production rate. An example of pull is Just-In-Time (JIT) production, manufacturing work should only begin when an order is made. Eventually, this should result in lower inventories and lower inventory holding costs (Nave, 1995). According to Bhasin (2015) seven different types of waste exist, the TIMWOODS: Transport, Inventory, Motion, Waiting, Over-production, Over-processing, Defects and Skills further explanation of this is shown in Table 17.

A value stream map can help to identify waste within the supply chain, starting from the delivery of raw materials to the final delivery to the customer. The VSM shows all product flows, information flows, processes and physical goods in the supply chain. After analysing the VSM, all non-value-adding activities are eliminated, and the remaining processes streamlined. In the final step, the results of the improvements are reviewed, and the evaluation process is repeated in search of new waste (Dailey, 2003).

2.2. Simulation

Computer based simulation is considered a suitable approach to investigate and understand supply chains and logistic systems (Terzi and Cavalieri, 2004). They are often used when the system is complex, it is difficult to analyse or when there are many stochastic variables and uncertainties (Manuj et al., 2009). Discrete Event Simulation (DES) and Systems Dynamic (SD) are two modelling approaches often encountered in modelling of supply chains and logistic systems (Ahumada and Villalobos, 2009; Schepers and Van Kooten, 2006). According to the findings of (Byoung Kyu Choi and Kang, 2013) DES is used more frequently than SD. However, they found no clear distinction in the usage of either modelling approaches to problems at a strategic level or tactical/operational level.

2.2.1. System Dynamics simulation

SD is concerned with the mathematical modelling of dynamic systems based on a simplified representation of the actual system. SD models are part of the broader category of continuous simulation models, in which the state of a system changes dynamically, e.g. continuously over time. Systems are considered as a whole instead of a single entity (Doebelin, 1998). The problem dynamics are represented in feedback loops found in the control theory. By using response analyses, differential equations can be derived that describe the dynamic behaviour of the system. Figure 2.2 shows the steps in the modelling process.

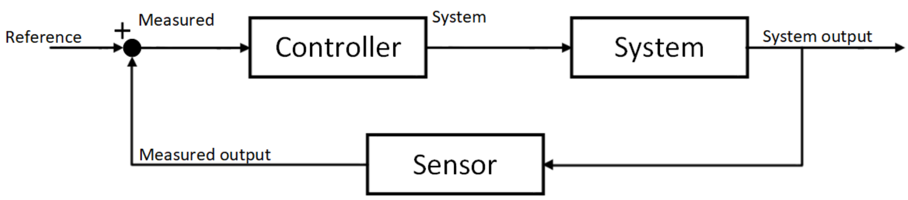

Figure 2.2: Process flow of connecting an actual dynamic system to its response.

2.2.2. Discrete Event simulation

DES has been developed for optimising supply chains, transport and logistics processes in manufacturing plants (Tako and Robinson, 2012). Today, DES is also being used increasingly in other fields such as health care, warehousing and computer system design (Brailsford et al., 2014). Operational research specialists regard DES as the most important simulation approach (Brailsford et al., 2014). Contrary to continuous modelling where the state of the systems changes continuously, the state changes at discrete time steps or when events occur. The main benefits of this approach are the shortened simulation time and reduced computing power. Events take place instantaneously and subsequently change the system state from one to another. Supply chains and logistics processes are characterised by the uncertainties and their stochastic behaviour. The capability to model these variations in statistical distributions makes this simulation approach a very suitable research tool (Manuj et al., 2009). A DES model is constructed using five fundamental building blocks that are as follows (Brailsford et al., 2014; Fishman, 2001):

Entities: An item that passes through the system, such as vehicles in a transport system, orders in a supply chain or people in a hospital.

Queues: Entities wait before being worked on, for example a parking lot, a buffer in front of a production station or a waiting room in a hospital.

Activities: Work that is performed on an entity, for example loading or unloading a truck, transport or machinery.

Resources: The resources must be available to perform activities for example operators, equipment or a doctor in a hospital.

For this research, the DES Salabim package was chosen to create a model. As a student, the researcher gained some experience with the DES package Tomas. Tomas works in combination with Delphi Rad Studio and is written in the Pascal programming language. However, this program is outdated and no longer supported. Therefore, alternative open source DES software packages with similar functionalities to Tomas were explored. Preferably in the Python programming language as the researcher already gained some experience with this in other projects. Some popular open source packages are dSOL (Java), SimJulia (Julia), Simmer (R), Salabim (Python) and SimPy (Python). As alternative MATLAB was also an option, as a license is available through the university. Salabim is an open source DES software package developed in Python by Ruud van der Ham. The package is based on Tomas and the even older package Must. It follows the Simula activate/passivate/hold paradigm similar to Tomas and other DES software packages (van der Ham, 2018). Simpy another Python package does follow this paradigm and is more difficult to understand and develop models. In functionalities, Salabim is comparable or even more extensive than Tomas, a comparison can be found in Appendix C.C.6. Important functionalities in Salabim are hold, wait, trace and animations. Salabim's main elements are Components, Resources, Queues, Distributions, Condition and Animations.

2.2.3. DES model development

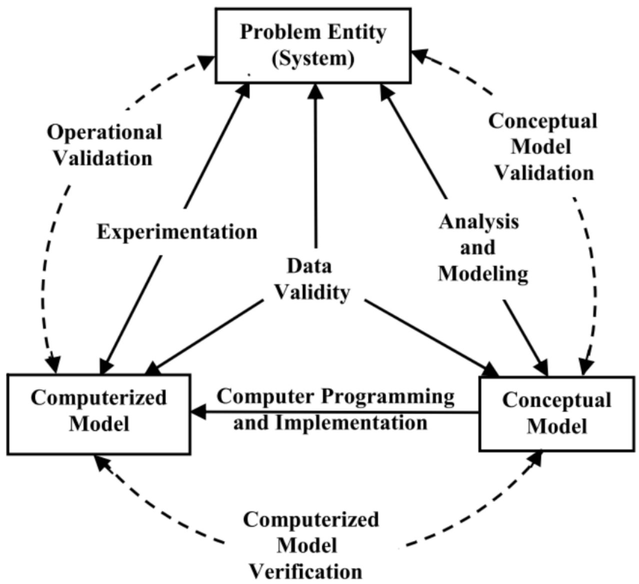

Figure 2.3: Model development paradigm (Sargent, 2007).

Sargent (2007) presented a model development paradigm to create a computer simulation model. Figure 2.3 presents a graphical representation of this paradigm. It consists of three main components; the system, conceptual model and computerised model. The system is a current situation or entity to be modelled. The conceptual model is a representation of the problem entity to be investigated and the computerized model is the implementation of the conceptual model in a computer simulation software package. Verification and validation of a computer simulation model is required to verify that it is a correct representation of the problem and that it is reasonable for the intended purpose. The linkages show the relation of verification and validation between the components.

2.3. Key performance indicators

Organizations use key performance indicators to measure the quality and performance of their services and products. Monitoring these allows an organization to reveal its performance at all levels and assess whether it improved or deteriorated and where it needs to focus in an improvement process. KPIs are used by management to monitor whether they meet predefined goals. Since this is important, a considerable effort is being made in research in various fields and companies can know where to intervene and improve.

2.3.1. Production Key Performance Indicators

According to the theory of lean manufacturing, production processes should be stable. To assess the stability, two performance indicators can be used to by manufactures the Process Stability [%] or Stability Factor [%] (Meier et al., 2013; Cargill, 2018). The latter is used by Cargill, measures the variability of a production process and represents the percentage of production that lies within the first and third quartile for a certain time-period. The closer the quartiles are together the less variability in the dataset. Figure 2.4 shows how the quartiles of a dataset is determined. At Q1, at least 75% of the datapoints are greater than Q1. The stability factor is calculated with as the fraction of Q1 divided by Q3.

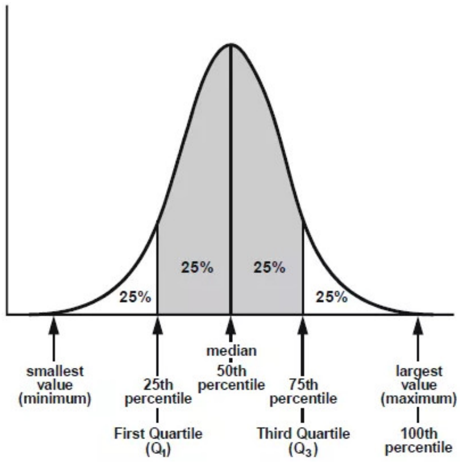

Figure 2.4: Quartiles of a dataset (Nandi, 2019)

The maximum production a plant can produce at the set rate is defined as the maximum theoretical tonnage (T_T). This is the maximum production capacity the plant can achieve, expressed in relation to the unit of time: an hour, a day, a week, a month or a year. Losses in the production can have various circumstances such as poor plant operations, an unbalance production line, unavailable products or insufficient storage space. The Production Loss (PL) can be calculated with Equation 2.1 (Pintelon and Muchiri, 2008). A metric to compare the actual production with the theoretical production is the Operating Throughput Effectiveness (OTE) (Muthiah and Huang, 2007). The calculation of this metric is given in Equation 2.2.

$$\mathrm{PL} = \mathrm{T_T} - \mathrm{T_{ACT}} \tag{2.1}$$

$$\mathrm{OTE} = \frac{\text{Good output product from plant } \left(P_{g(F)}\right)}{\text{Theoretical attainable product output from plant in total time } \left(P_{F(th)}\right)} \tag{2.2}$$

2.3.2. Delivery Key Performance Indicators

For the delivery to the customer, the wishes of the customer should be mapped and converted to a set of goals. Planning and delivery are different processes and it is important to evaluate the performance separately. The differences between both processes are shown in Figure 2.5.

For both processes, the performance indicators can now be defined to take the right measures to optimize each process individually and the delivery as a whole to ultimately improve the customer satisfaction. There are many planning indicators in the literature.

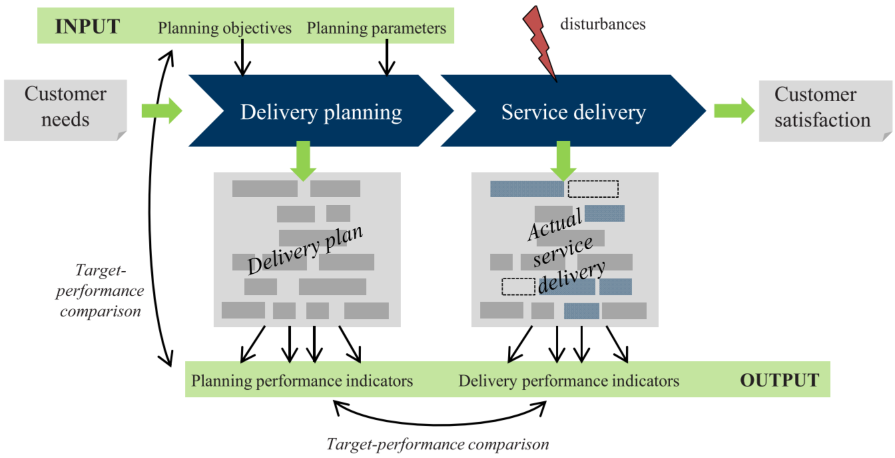

Figure 2.5: Parameters and performance indicators for service delivery as defined by Meier et al. (2013)

A widely used performance indicator for measuring supply chain performance is the On-Time-Delivery-In-Full (Stadtler and Kilger, 2008; Eaidgah et al., 2018). It shows the percentage of orders handled within the agreed time and without defaults. In UNCAD (2016) Parwani and No (2014) different performance indicators have been defined for understanding and controlling the performance of land and water operations for delivery of products. These are turnaround time, waiting time and On-Time-Delivery. Turnaround time is defined as the moment of arrival to the moment of departure. Waiting time is the total time that a machine or vehicle is waiting before working on it. Another widely used KPI are operating costs of a process or inventory holding cost. A widespread corporate vision is that costs should be minimized, and the quality or output maximized.

The utilisation factor is often used to measure the performance of equipment, resources, buffers or equipment (Meier et al., 2013). It measures how much of the available time the machine is in use. Machines that are at rest do not add value and are waiting which is waste. For buffers, the utilization factor is defined as the average capacity present in the buffer over a period of time.

A summary of the KPIs found in the literature is given in Table 2.1

Table 2.1: Key performance indicators

KPI	Unit	Description	Literature
Stability factor	[%]	Percentage of production days within the first and third quartile	(Cargill, 2018)
Operating Throughput Effectiveness	[%]	Metric to compare actual production with theoretical production	(Muthiah and Huang, 2007)
Production loss	[MT]	Difference between theoretical and actual production	(Pintelon and Muchiri, 2008)
Average waiting time	$\frac{hours}{truck}$	Average time waiting before loading after registration at gate.	(Parwani and No, 2014)
Average turnaround time	$\frac{hours}{truck}$	Average time a truck is at the terrain, from registration at the guard to departure from the terrain departure	(Parwani and No, 2014)
On-time delivery	[%]:	Proportion of delivery processes, which are completed within the time window promised to the customer	(Meier et al., 2013); (Karim et al., 2010)
Average turnaround time	$\frac{hours}{vessel}$	Average time a vessel stays at berth	(UNCAD, 2016)
On-time delivery	[%]:	Proportion of delivery processes which are completed within the time window promised to the customer.	(Meier et al., 2013)
Average waiting time	$\frac{hours}{vessel}$	Average time vessel waits at berth departure	(UNCAD, 2016)
Utilization factor	[%]	Percentage of resource utilization capacity over a time-period.	(Meier et al., 2013); (Karim et al., 2010)
OPEX	[€]	Operating expenses	(Stadtler and Kilger, 2008)

2.4. Conclusion

1. What framework and methodologies can be used from literature to find and evaluate solutions to reduce disturbances on the production of sunflower oil?

The literature describes several process improvement methods, of these, The Theory Of Constraints, Lean Manufacturing and Total Quality Management are most commonly applied for improving logistics processes. Total quality management focuses on improving the quality for the customer. Lean manufacturing searches for non-value adding activities in the logic processes. The non-value adding processes can be categorized in one of the seven types of waste. After, removing the waste from the process, the logistic process as a whole should improve. Theory of constraints looks for bottlenecks that constrain the throughput of a system. After identification of the bottlenecks , they can be exploited, increased or completely removed. After removing the bottlenecks, the continuous improvement cycle is restarted as a new bottleneck will be constraining the system.

2. What criteria can be used to assess the different solution alternatives?

The maximum production a plant can produce at the set rate is defined as the maximum theoretical tonnage (T_T). This is the maximum production capacity the plant can achieve. Losses in the production can have various circumstances such as poor plant operations, unavailable products or insufficient storage space. The Production Loss (PL) the Operating Throughput Effectiveness (OTE) are metrics to compare the actual production with the theoretical production is (Muthiah and Huang, 2007).

For the delivery to the customer, the wishes of the customer should be mapped and converted to a set of goals. Planning and delivery are different processes and it is important to evaluate the performance separately. The performance indicators can be defined to take the right measures to optimize each process individually and the delivery as a whole to ultimately improve the customer satisfaction. In UNCAD (2016) and Parwani and No (2014),different performance indicators have been defined to measure the performance of the delivery to customers for landside and waterside processes. These are the turnaround time, waiting time and On-Time-Delivery. Turnaround time is defined as the moment of arrival to the moment of departure. Waiting time is the total time that a machine or vehicle is waiting before working on it. Another widely used KPI are operating costs or inventory holding cost. The utilisation factor is often used to measure the performance of equipment, resources, buffers or equipment (Meier et al., 2013). This indicates how much of the available time the machine is in use.

3

Current state situation

This chapter analyses the Multiseed in the Amsterdam Harbour by first going over the generalities including the sunflower oil meal industry perspective and that of Cargill specifically, as well as main actors and their relationship to each other. Secondly, the flows within the Multiseed are assessed. Finally, the main components, landside and waterside processes are analysed. The chapter addresses the following sub-questions.

3. What is the current state of the oil production?

4. How is the outbound logistic for SFMP organized?

3.1. Cargill organisation and market

The Cargill Multiseed is part of Cargill B.V. Netherlands that has its main office in Schiphol. It is the largest producer of Crude Sunflower Oil (CSFO) and Sunflower Meal Pellets (SFMP) in the Benelux. The factory was put to use in 1980, at the time it was operated to produce SFMP for farmers. However, innovations and developments in the market such as increasing demand for bio-diesel caused the price of CSFO to rise and Cargill to shift its focus towards the production of CSFO, with SFMP no longer its main product but a by-product of the production process. [redacted] The consumption of SFMP in the Netherlands is projected to stay stable in 2018 and only a slight decrease of 1% is expected for the whole EU market.

Sunflower seed, oil and meal are agricultural commodities traded on the commodity market. The supply of seeds is subject to random supply shocks, such as droughts, extreme rainfall, diseases or war (Hong-Mo Yeh, 2003). Harvest takes place during a short period once a year. Factors such as rain or little sunshine affect the harvest and make it difficult to forecast the supply of seed for the next year. Sudden shortages or oversupply can create considerable price instability. Furthermore, CSFO and SFMP can be replaced with substitute products, price variations of substitute products will affect the demand and market price. Sunflower oil (crude and refined) is sold in a future contract, forward contracts and on the spot market. For SFMP there is no future market, they can either be sold in forward contracts or on the spot market. Their characteristics are explained below (Pindyck, 2001):

Spot market: At the spot market, commodities are traded directly between the buyer and seller. The commodity is exchanged at the current rate and payment is made right away. Buyers expect an immediate delivery or in the near future 5-7 days. Typically, commodities are sold in large volumes since it practically not possible to deliver the products immediately.

Forward contracts: In a forward contract, the buyer and seller agree to buy or sell the commodity at a predefined date in the future with specified price, quantity and delivery conditions. A forward contract is a derivative contract, an enforceable agreement, that has a value derived from the price of the commodity. In this context, enforceable means that the customer or Cargill can demand the other party to deliver or collect the products. Forward contracts are used to reduce risks for negative price fluctuations. Companies buy at the current price to reduce the risk of losing value, this is also called hedging.

Future contracts: A future contract is a highly standardized forward contract. They are traded on commodity exchanges just like stocks on the stock exchange and are used to speculate on the price in the future. Contrary to forward contracts, the delivery does often not take place since the contract already changed hands before the actual delivery date. However, sometimes actual delivery takes place. Like in forward contracts, parties can enforce each other to deliver.

3.2. Supply chain planning

Managing the supply chain of the crush is the task of the business unit Cargill Agricultural Supply Chain (CASC). In addition to the Multiseed, it also manages the agricultural factories in the Benelux and England. CASC, Cargill has multiple plants in the Benelux region, tactical planning decides for each factory the type of seed it should crush and the production rate. Guruprasad et al. (2017) define supply chain planning as: *"Supply Chain Planning (SCP) is the forward-looking process of coordinating assets to optimize the delivery of goods, services and information from supplier to customer, balancing supply and demand"*. SCP is generally classified in three levels: long-term, mid-term, and short-term or often referred to as strategic, tactical and operational planning (Stadtler, 2005; Fleischmann et al., 2008).

Strategic planning is the task of the management of Cargill. Decisions on large capital investments in the long future and the company strategy are made at this level. This includes for example, a new location for a production site, opening and closing of a production plant or entering a new market. Tactical planning at Cargill concerns with the decisions such as production planning, forecasting, demand planning and sales, the seed supplier or energy provider. Operational planning defines the actions that should be taken in terms of days or hours, for example, transport planning, daily production planning (e.g. work schedule for personnel at Multiseed and daily production rate), real-time planning and scheduling daily maintenance tasks.

3.2.1. Production planning and sales

The production planning and sales in tactical planning [redacted] They determine the production rate based on accurate forecasting of the price of oil and meal and other developments in the market. This business is margin driven, according to the commerce department (Appendix E.3) the plant should produce at maximum rate if the margin is positive. The margin is defined as the selling price of sunflower oil and meal subtracted with the procurement and production costs in $\$/MT$ seed. Lowering down the production rate reduces the efficiency of the production process, proportionally more energy is needed to achieve the same production. Between the crush and refinery there is a high level of synergy, lowering the production can increase the costs for the refinery. [redacted] Furthermore, waste from the refinery is added as a feed grade to the meal pellets. [redacted]

In the last year, [redacted] of the produced oil was refined in the refinery, the remainder was sold in future contracts or to other Cargill refineries. An overview of the customer order for SFMP can be viewed in Appendix D. Customers forecast their need of sunflower meal and oil for the coming month(s). They contact the sales department (commerce) about the order. [redacted] A forward contract describing the total quantity, quality and delivery conditions is created and booked in [redacted] an Enterprise Resource Planning (ERP) software package. Forward contracts for sunflower meal are on average for a period of [redacted] months. The average contract length in the years 2016-2017 was [redacted] months.

3.2.2. Transport planning

Transport planning tries to control the supply and transport demand with the inventory as a buffer. Customers inform the planner at Schiphol of their transport preferences at the beginning of the month. [redacted] the planner creates day-to-day planning for trucks and vessels. A weekly schedule is sent to the customer and their respective transport company. However, the planning is not strict, it changes more often than not. The definitive planning is communicated one day in advance. In case of disruptions in the loading process (e.g. emergency breakdowns or rain) or production process, the planner will determine whether the planning must change, a new planning will be distributed to the customers and transport companies. Before the end of his shift, the planner communicates the truck loading hours for the next day to the transport companies. The loading hours for trucks may change from day-to-day.

3.3. Production

The production of sunflower oil and meal pellets in the crush starts with the supply of seeds from storage, after which the meal and oil are separated and stored. Most of the oil is refined in the refinery, the rest is sold on the market. The SFMP, RSFO are eventually loaded to a vessel or truck. A diagram of the product flows at the Multiseed is shown in Figure 3.1.

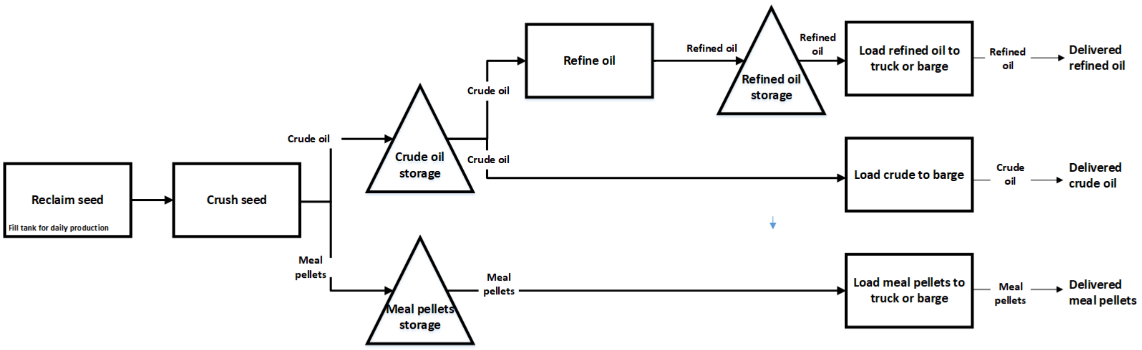

Figure 3.1: Production, storage and delivery of RSFO, CSFO, and SFMP

3.3.1. Production stability

Cargill measures the performance of their production processes with the stability factor. This indicates how many of the production days in a given time period the production lies within the first and third quartile. Q1 shows that at least 3/4 of the production days the production was greater than Q1 and Q3 shows that at least 3/4 of the production days the production was not greater than Q3. The stability factor is calculated as the quotient of the quartiles, the closer the first quartile and third quartile are together, the more stable the production. In general, the production process of refined oil is more stable than the production of crude oil. For the months February through March, the stability factor for the refinery was [redacted]% and for the crush [redacted]%.

3.3.2. Production losses

The Multiseed was put to use in 1980, at the time it was built for the production of SFMP. However, the continuously growing demand for oil in the food and bio-diesel industry, changed this perspective. Because of the higher price for CSFO, Sunflower Meal Pellets (SFMP) are now seen as a by-product of the production process. Process stability is one of the most important concepts in the theory of lean manufacturing, to ensure a stable process any disruptions on it need to be eliminated (Bhasin, 2015).

Table 3.1 shows the disturbance on production process divided by the input and output. The largest disturbance was the unavailable storage space in the silos. To eliminate the disruption, the input and output flows to and from the silo should be better aligned or the storage space should be increased. [redacted] CSFO is necessary for the production of refined oil and loss of production means a loss in revenue. Furthermore, RSFO is sold on the spot market and future market. Matching the demand with the supply requires extensive knowledge on hedging and other financial tools. In periods low market demands, oil is stored in floating storage vessels to wait for better market price while the production continues. This is out of scope for this research assignment. Further analysis will therefore focus on improving the output flow or increasing the storage capacity. The output flow is determined by the outbound logistics for SFMP. To identify how the output flow is configured, this research will analyse the current performance of the outbound logistics at the Multiseed.

Table 3.1: Production loss due to disturbances on production crush

Description	**Percentage of total output delay**
Input restriction	
No Feed (Raw Material, Seed)	9.29%
No Feed (Raw Material, Seed) – Delayed new crop	10.01%
No Feed (Raw Material, Seed) Logistics (Trucks, Barges, ...)	22.10%
No People	7.82%
No Utilities	0.17%
Other	1.62%
Output restriction	
Full meal tanks	**46.74%**
Full oil tanks	2.26%
Total	**100.00%**

3.4. Storage

Figure 3.2: Rented storage capacity from IGMA in period October 2017 – September 2018

Silos will get full if they are not emptied in time. This can have multiple reasons e.g. interruptions in the loading process, inadequate planning or sudden increase in production. Interruptions in the loading process may be caused by for example, vessels or trucks being late, rain or equipment failures. To ensure that production continues whilst the silos are full, barges can be rented [redacted] These are delivered by a pusher to the quay of the Multiseed. The cost price for this is on average €[redacted] per MT per day Cargill B.V. (2018), for larger quantities, the cost of this quickly rises. [redacted] Figure 3.2 shows the extra hired storage space in the period from October 2017 to September 2018. Especially in the months November – April the acquired space was much higher than in the summer months. Sunflower seeds are harvested only once a year for a short period in September. In the aforementioned period when a lot of extra storage capacity was required, the sunflower seeds have just been harvested. The supply of sunflower seeds is large, the cost price of the seeds is low, and the margin is high. Therefore, Cargill wants to produce at the maximum capacity. However, these months have the most days where it rains for longer consecutive periods, snowfall or frozen rivers. Due to the higher production rate, the silos fill up faster and the production of oil is more vulnerable to disruptions extra storage capacity is required more often.

3.5. Outbound logistics SFMP

3.5.1. Resources

Employees

Both the crush and refinery are continuous production plants, a guard must always be present at the guard station. Generally, loading takes place between 6:00 and 22:00. In the past a night shift was operated occasionally [redacted] Operators work in shifts of 8 hours, including a one-hour break, starting at 6:00 and 14:00. On weekdays, two operators are present during the loading hours, one for loading of RSFO and one for SFMP. Night and weekend shifts require only one operator since there is no loading of trucks.

Figure 3.3: In the left image the entrance gate with barriers, guard station and weighbridge are displayed, the image on the right shows the silos for storage of SFMP.

In front of the entrance is a parking lot where trucks can wait until it's their turn. The entrance shown in Figure 3.3 is closed by barriers operated by the guard. Without permission, the facility may not be entered. Just past the barriers, a weighbridge is integrated into the road surface where the weight of the trucks can be measured before and after loading. The weight of trucks is important for two reasons, the measurements are used to invoice the customer and secondly to determine whether trucks do not weigh more than the maximum allowed weight. In the European Union, different rules apply per country regarding the maximum allowed weight. This is expressed in the weight per axle, which is usually around 10,000 tonnes per axle. For trucks travelling through Germany, the maximum weight is 40 MT, in Belgium 44 MT and in the Netherland 50 MT. This equates to a gross load weight of 25 MT, 29 MT and 33 MT respectively.

Crude oil storage

Crude oil is pumped via a pipeline to one of the [redacted] storage tanks with a capacity of [redacted] MT. The crush crushes two types of sunflower seeds, normal and high oleic seeds. Oil of similar quality is stored in the same tank. High oleic oil has at least 82% oleic acid, [redacted]

[redacted] After it is refined, the high oleic oil is better for human consumption and can be used in cosmetics due to its longer shelf life (Pal et al., 2015).

During operation one tank is usually empty, one is used for production and two are examined for quality control. A sample is taken and send to an external lab where its properties are examined as is required by the Food Safety Quality and Regulatory (FSQR). This process usually takes 1-3 days, during this period the storage tank cannot be used. [redacted] From Table 3.1 loss in production due to limited storage space was only **1.19%** of the total loss.

Meal pellets storage

Meal pellets are transported via chain conveyors to the silos shown in Figure 3.3 and dropped from above into the silo. Two distance sensors mounted at the top measure the inventory levels by converting the measurements to tonnages. This is not really an accurate method. Material builds up in the silo and will in time become more compact or compressed due to the increasing consolidation stress. Because of the higher density, the tonnage measurements from the sensors can be lower than the actual tonnage. Furthermore, the top layer of the material in the silo is not flat, material accumulates near the wall and could cause higher readings. Also, measurements fail when the silos are almost empty, and the pellets are located in the cone the lower part of the silo.

[redacted] A screw at the bottom helps in breaking formed arcs and removes adhered material against the walls. Silos are vulnerable when material falls from a high height, which can eventually lead to premature wear (Schulze et al., 2008). According to the maintenance expert, this is negligible for the SFMP silos since the SFMP are soft and break easily. Thus, the silos may be completely discharged.

Loading stations

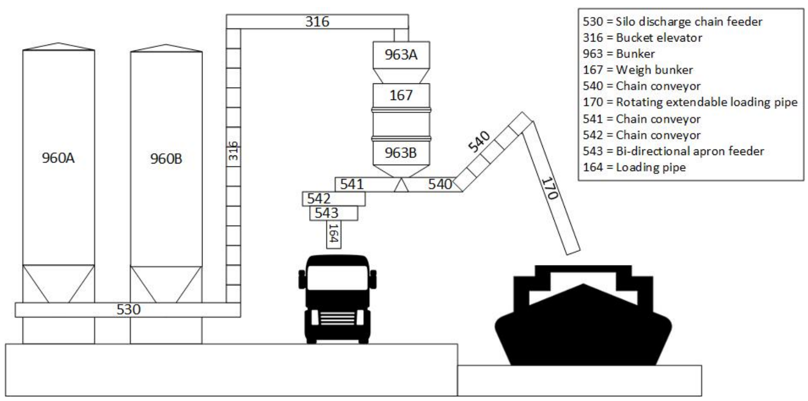

Figure 3.4: Meal pellet load-out station

The station for truck loading is located approximately 200 meters from the guard station. The waiting area in front of the station can accommodate up to two trucks. Inside the station, there is space for only one truck at a time. Due to safety requirements, drivers are not allowed to be on top of the truck to remove or attach the rooftop cover without fall protection. This is only accessible inside the loading station. Loading must be carried out by the operator who is familiar with the system and the safety measures.

Figure 3.4 displays a schematic overview of the loading stations. The output capacity for each conveyor in the chain of conveyors are given in Table 3.2. After discharge from the silo, a chain conveyor transports the pellets to the bucket elevator, to the weigh bunker. This configuration does not allow simultaneously loading of trucks and vessels since there is only one feed system to the weigh bunker. Changing from trucks to vessels and vice versa takes approximately [redacted]

Table 3.2: Load-out capacity of load-out systems

Switching between the two modalities multiple times per day is therefore not recommended as valuable loading time is lost. From the weigh bunker the pellets are transported with a chain conveyor either to the truck station or the vessel station. Inside the truck station, a bi-directional apron feeder feeds the SFMP through an extendable pipe into the truck. The apron feeder can move on rails and be positioned above the truck to reach the edges. A dust skirt is mounted at the end of the pipe to reduce the amount of dust released during loading. Despite that the apron feeder can move on rails and feed in two directions, sometimes it is not able to reach all areas of the truck. Loading must be stopped, and the truck is repositioned below the feeder.

The vessel loading station is located at far-right side of the quay. The quay has a length of [redacted] meters. [redacted] Sometimes it is a bit of puzzling and good coordination between the planners for oil and meal vessels is required. A bucket elevator feeds the pellets to the top of the loading pipe. The pellets fall through the pipe exit into the vessel. Similar to the loading pipe in the truck loading station, a dust skirt is mounted at the end of the pipe to reduce the release of dust during loading. The pipe can be positioned in a circular motion over the filling area of the vessel and extended to reach the outer edges. To reach all areas of the vessel, it must be repositioned over the filling zone below the loading pipe. Repositioning is also required to equally distribute the weight of the pellets and prevent tilting of the vessel. While the vessel is being moved, loading is stopped. [redacted]

Vehicles

Customers for SFMP can choose to pick up their product from the Multiseed by truck, barge or coaster. In the financial years 2016-2017 and 2017-2018, [redacted]% of SFMP was loaded on ships and the remainder on trucks. For overseas destinations, there is the possibility to load on a coaster. Crude oil is usually transported to another refinery, as this goes in large volumes, there is only loading to barges. Figure 3.5

Truck: Used for inland transport, there are two types of trucks, with a single or double semi-trailer. Depending on the destination, 25-33 MT can be loaded into the container at a time. Trucks are advantageous since transport is directly to the customer. The average tonnage per truck over the period 2017-2018 was 28.3 MT.

Dry bulk cargo barge: Dry bulk cargo barge varies in size from 350 - 1500 MT. Barges are constructed with an outer hull and a barge hold. They can be equipped with covers of various types. Generally, these covers are fabricated of fibreglass or steel. They can be lifted or rolled away for access to the barge hold, or cargo box.

Coaster: Coasters are shallow-hulled ships, they sail below or near the coast and can make

(a) Oil barge. From "Wikimedia Commons," by G. O'Beirne, 2005. Licensed under CC BY 2.5

(b) Bulk barge. From "Wikimedia Commons," by M. Kauffmann, 2005. Licensed under CC BY 2.0 DE.

(c) Coaster. From "Wikimedia Commons," by S.J. de Waard, 2008. Licensed under CC BY 3.0.

(d) Bulk truck. From "Wikimedia Commons," by B. Lewis, 2013 Licensed under CC BY 2.0r

Figure 3.5: Transport modalities that visit the multiseed.

crossings to England. Their size varies between 2000-4000 MT.

Liquid bulk cargo barge: Liquid bulk cargo barge varies in size from 350 - 1500 MT. Barges have a large storage tank that can transport liquid or pressurized gasses.

3.5.2. Handling process trucks

In this section, an overview of the order process is presented and the individual parts of the process (landside and waterside) are discussed. As it can be seen in Figure 3.7 the process begins with creation of order and arrival of the transport company at the Multiseed. Next the actual loading process and after documentation delivery of the transport company to the customer.

Trucking market

Cargill's largest customers for SFMP are mainly resellers or animal food producers. Resellers store the pellets in a shed from where they serve local farmers in the area. Some have their own trucks but most of them hire a transport company to collect the products. The Multiseed has [redacted] visiting its premises by truck, [redacted] Based on data, [redacted] Truckers are subject to strict government regulations regarding working hours. To maximize their revenue, truck drivers need to be on the road.

Landside process

The landside process is displayed in Figure 3.7, the process starts with the order booking and creating a transport planning, in the next step the actual handling at the Multiseed is performed and finally delivery to the customer. Creation of orders and the transport planning was discussed in Sections 3.2.1 3.2.2. Once the trucking company receives confirmation on the loading day and hours, it plans it routes and trucks are sent to the Multiseed.

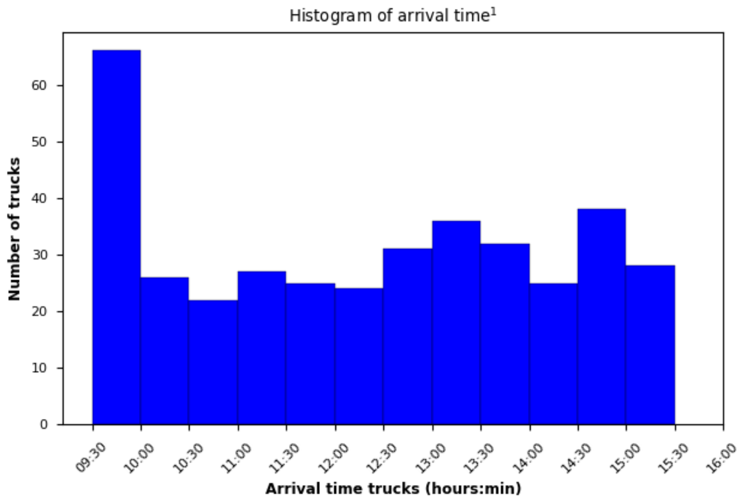

Figure 3.6: Arrival time trucks

The handling process starts at the arrival of the truck at the gate. Upon arrival, the trucker parks his vehicle at the designated parking area outside the terrain and manually registers at guard office that is located next to the entrance gate. When the guard is available, the documentation is checked and if everything is in order (e.g. previous payments have been fulfilled and the trucker complies to the safety regulations), the trucker goes back to his vehicle and waits until he is called by the guard. There may be a maximum of two trucks on the terrain, as the first truck is being loaded, the next truck can line up to be immediately loaded afterwards. A first-In-First-Served (FIFS) queuing management is applied. Once inside the terrain, the trucker parks at the weighbridge and waits until weighing is completed. The trucker continues to the parking area in front of the loading station to wait if the loading station is not available or the operators are not ready. Next, the trucker positions his truck below the opening of the loading pipes, puts on a safety harness and removes the cover over the truck. Once the loading process begins, the trucker waits until it is completed, performs a check against documentation, reattaches the cover and returns to the weighbridge. Here the truck is weighed again. Finally, the trucker receives the loading documentation and drives out of the terrain. From here on transportation is performed to the customer.

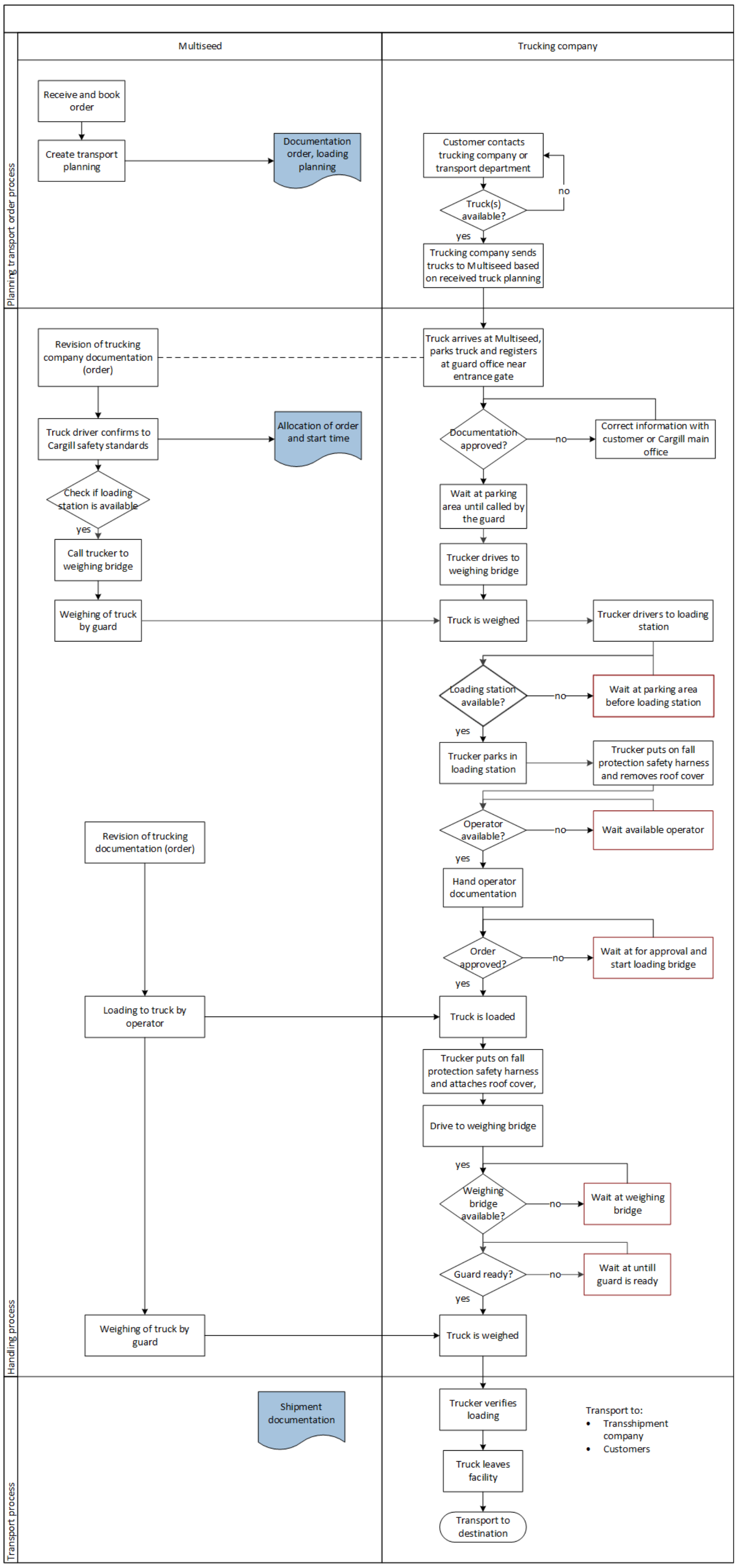

Figure 3.7: Landside handling operations

Day of arrival

Table 3.3 presents the average number of trucks and volume per truck for each day in the week for the past two years. Trucks are only loaded on weekdays; chauffeurs usually do not work on weekends and operators are also less deployable on weekends. More trucks are loaded on Tuesdays, Wednesdays, and Thursdays than on Mondays and Fridays. [redacted] On Monday a coaster can be completed and on Friday's loading can start earlier.

Table 3.3: Truck arrival on weekdays and average volume.

Time of arrival

Arrival time is the time the driver arrives at the Multiseed and registers with the guard. Transporters receive the transport times the day before the pickup day within which they can come to load. They have to report to the gatekeeper at the latest half an hour before the end of the loading hours. Because the loading hours may vary every day, e.g. one day from 10:00 – 16:00 and the next day from 07:00 – 12:00, it is difficult to derive an arrival distribution. Therefore, the arrival times are converted to a fraction between the beginning and end of the loading hours. For example, the loading hours are from 10:00 – 16:00 and a truck arrives at 15:00 six hours after the start of the loading hours, the fraction can be calculated as:

$$\frac{(15:00 - 10:00)}{(16:00 - 10:00} = 0.83$$

The arrival distribution is displayed in Figure 3.6, for this visualization the obtained values were converted to as if each day loading happened between 10:00 and 16:00. In order to obtain comparable data, only days were used in the analysis where the loading hours did not differ too much, i.e. loading should start no earlier than 9:00 and later than 11:00 and end no earlier than 15:30 and later than 17:30. According to the plant supervisor, it regularly happens that for some time no trucks are present on the terrain and then several arrive at the same time. As a result, instead of the planned loading hours, there are only a few hours left to load all trucks.

[1] Arrival times converted to as if each day loading happened between 10:00 and 16:00.

Process times

Figure 3.8 shows an overview of the stations in the landside handling operations with a definition of the process duration.

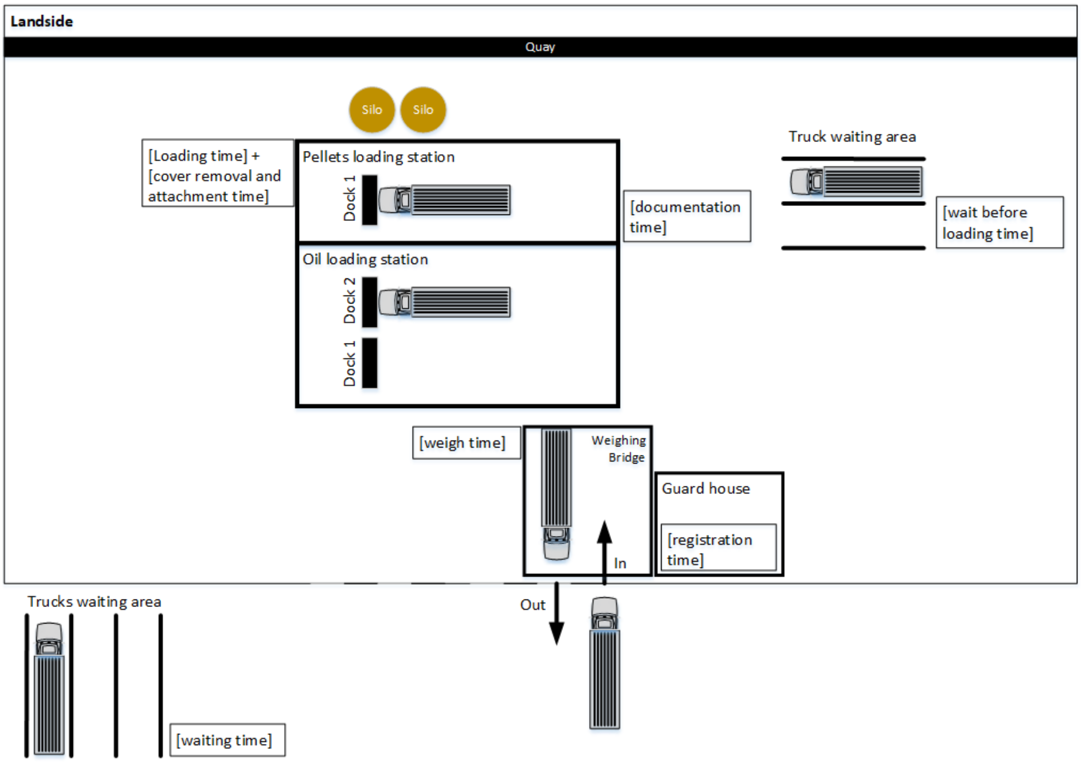

Figure 3.8: Overview terrain for landside operations

Registration time Registration time is the time between arrival and registration, on average registration takes four minutes. After arrival, the driver parks in the designated parking spaces outside the terrain and reports to the guard. Once all forms have been filled in and the order has been approved, the driver can return to his trucks and wait until he is called to the weigh bridge.

Waiting time: Waiting time is defined as the time after successful registration until the moment the truck is weighed. Figure 3.9 shows the measured waiting time of the past two years. This only measures the time waiting outside the terrain and not at the loading station. The average waiting time for a truck was [redacted] minutes. [redacted]

Service time Service time is the time spend on the terrain and includes the weighing-in, waiting at loading station, removal and reattachment cover, documentation, actual loading, and weighing-out. Drivers who visit the Multiseed more often tend to speed up the loading process by loosening or fastening the fasters outside the station so that removal and reattaching of the cover inside the station takes less time. Others may have less experience or motivation, especially after the truck is loaded, it takes can take much longer to reattach the cover. Sometimes reattaching takes more than [redacted] minutes, during this time no other trucks can be loaded. On average removing the cover takes [redacted] minutes, reattaching [redacted] minutes and loading [redacted] minutes. The measured time of the several activities is given in Table 3.4.

Figure 3.9: Waiting time at parking lot trucks

Table 3.4: Measured time for several handling activities

Turnaround time and On-Time-Delivery The turnaround time is defined as the total time a truck has at the Multiseed from the moment of arrival to departure. Figure 3.10 shows the turnaround time in the last two years. On average, trucks were present for [redacted] minutes. Cargill does not measure On-time-Delivery (OTD) for meal pellets trucks, but it does measure OTD for refined oil. A truck for RSFO was not delivered on time if it was present for more than [redacted] [redacted]. The same specification is used to determine the OTD for SFMP trucks. The OTD for truck is then [redacted]%, in comparison, refined oil loading has an On-Time delivery of [redacted]%.

3.5.3. Waiting costs

When drivers waited for more than two hours, they are entitled to compensation of [redacted]€/hour for each additional hour they have to wait. Last year, the total costs Cargill payed for trucks waiting was [redacted] Out of conversations with several truck drivers it became apparent that their biggest annoyance is the long waiting time at the Multiseed. The drivers generate their earnings by transporting goods, standing still means a loss of income. One driver mentioned that he therefore plans his day such that it either starts or ends at the Multiseed in order to waste as little time as possible. [redacted]

3.5.4. Handling process vessels

Vessel market

Customers hire a shipping company to transport from the Multiseed to their own or a nearby port. Shipowners charter their services on the spot market, as contracts are only concluded close to the shipping date, customers and Cargill oftentimes do not know until one day in advance who will ship the product. This complicates the planning process, as a result the definitive planning is only

Figure 3.10: Turnaround time trucks

decided one day in advance. Coasters are only loaded on weekends when there are no trucks. Due to the low storage capacity, it is impossible to build up a large buffer. [redacted]

Waterside process

The waterside process is displayed in Figure 3.11, the handling process starts when a vessel arrives at the Multiseed. Upon arrival, vessels moor at the quay if it is available. However, this does not mean that loading will start immediately. Vessels often arrive during the night or a few hours before the operators are present. Before loading can start, the operator will take two samples, that will be tested for bactors or other impurities. Customers can require a surveyor to be present during loading, he inspects the vessel for residues from previous loads and supervises the loading process. It is up to him to decide if loading can continue during rain or must be stopped. Afterwards, the documentation is finalized, and the skipper leaves the Multiseed to its destination.

Arrival time, Turnaround time and On-Time-Delivery For vessels, it was not possible to use the available datasets to measure the arrival, turnaround time and on-time-delivery. Registration was sometimes already carried out before vessels arrived. When the guards have some spare time, they already prepared the documentation making the datasets invalid.

Costs

Vessels which have been at the quay for more than two days are entitled to compensation in the form of demurrage payments. Ships that are not sailing means a loss of income for the shipping companies. Large coasters are also entitled to this compensation and therefore finishing the coaster has often priority over starting loading of trucks. [redacted]

Sending vessels away before they are completely loaded also results in financial losses. Cargill must refund the difference between the agreed and delivered quantity.

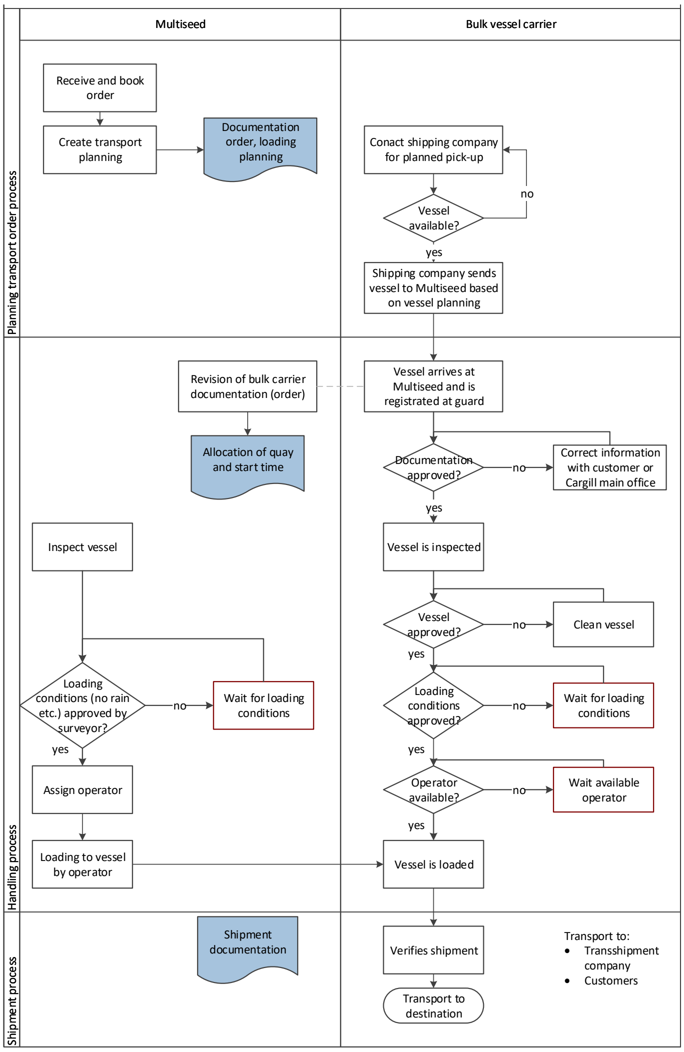

Figure 3.11: Waterside handling operations

3.5.5. Uncertainties

Production

The production rate varies from day, differences in seed quality, hexane quality or environmental conditions (e.g. outside temperature or humidity) affect the production process. Production downtimes are categorized in three categories, Commercial Downtime (CDT), Emergency Downtime (EDT) and Scheduled Downtime (SDT). CDT can be divided in market downtime due to lower demand or logistic downtime caused by lack of available logistics e.g. holidays, low water levels or frozen rivers. In periods of long droughts, the water levels in the rivers drop and vessels cannot carry the normal weight. Production is lowered to accommodate the lack of available transport. Furthermore, to avoid having to stop production, production is lowered when the silos start to fill up. EDT is immediate unscheduled downtime due to machine failure in the production process. SDT is known in advance and included in transport planning. Other disturbances include equipment failure, computer system malfunction or rain.

Delivery

Trucks can get stuck in traffic jams or vessels arrive later than planned causing delays to the delivery planning. Rain is a major uncertainty as loading to vessels cannot be carried out during heavy rain. Water accelerates germination and plants start to grow on the meal. In addition, the contract stipulates that the meal may not contain more than 12% water. The Netherlands has rainfall all year round, however, in the autumn and winter there are more days with long periods of precipitation (). Long periods of precipitation can cause large disruptions to the transport planning. To avoid the plant to stop producing, Cargill will need to acquire extra storage space from IGMA, which will incur additional costs. Other uncertainties in the loading processes include machine failures, computer system faults, unavailable operators or surveyor.

Rain

Data from the period 2015-2018 the closest weather station Schiphol showed that it was raining for 9.6% of the time. Table 3.5 shows the amount of rain days for 2014 - 2017 and the amount of days it was raining for more than five hours straight. Especially in the months November – January there are days with long periods of precipitation.

Table 3.5: Number of days it rained in the past years (KNMI, 2018)

Year	# rain days	over 5 hours
2014	186 (51%)	43 (23%)
2015	193 (53%)	57 (30%)
2016	192 (53%)	48 (25%)
2017	207 (57%)	53 (26%)

3.5.6. Measured Key performance indicators for the Multiseed:

Table 3.6: Measured key performance indicators

KPI	Value	Unit
Production performance		
Silo utilization over 70 %	9.9	[%]
Landside operations		
Average waiting time	0.98	[hours/truck]
Average turnaround time	1.97	[hours/truck]
On-time delivery (OTD) :	75	[%]
Waterside operations		
Average turnaround time	-	[hours/vessel]
On-time delivery (OTD)	93.1	[%]

3.6. Conclusion

3. What is the current state of the oil production?
The production planning and sales in tactical planning lie within the commerce department stationed at the head office in Schiphol. They determine the production rate based on accurate forecasting of the price of oil and meal and other developments in the market. This business is margin driven; the plant should produce at maximum rate if the margin is positive. Cargill measures the performance of their production processes with the stability factor. For the months February through March, the stability factor for the refinery was [redacted]% and for the crush [redacted]%. The largest disturbance was the unavailable storage space in the silos. To eliminate the disruption, the input and output flows to and from the silo should be better aligned or the storage space should be increased.

4. How is the outbound logistic for SFMP organized?
A weekly schedule is sent to the customer and their respective transport company. The changes more often than not due to interruptions in the loading process (e.g. emergency breakdowns or rain). Vessels and trucks can be loaded on weekdays and in weekends only vessels are loaded. Trucks arrive at the Multiseed and register at the guard. Next, they are weighed and loaded. Vessels need to be inspected for loading can start. The arrival pattern of trucks is not evenly distributed, trucks arrive often arrive at the same time, at the beginning and near the end. There is a lot of waiting in the truck loading process. On average, trucks wait for [redacted] minutes before they are weighed in. Vessels have priority over trucks because the effective loading is much faster, [redacted] MT/h compared to [redacted] MT/h. Uncertainties such as rain, emergency breakdowns or equipment malfunctions can interrupt the loading process and cause long delays.

4

Current state performance analysis

This chapter evaluates the performance of the current state situation that was measured in the previous chapter. First, it will identify the constraints in the outbound logistics using the Theory Of Constraints. After identification of the constraining processes, constraints can be removed by eploitation or when this proves to be insufficient, they should be elevated. To discover how the constraint may be exploited, Lean Manufacturing is applied to identify waste found in the processes. This chapter addresses the following sub-question.

5. What is limiting the oil production and how can it be improved?

4.1. Disturbances on the oil production

From the current state analysis, it was found that the 'full silos' was the largest disturbance on the production of CSFO. In there was not enough storage space available, additional storage capacity needed to be acquired in form of barges from IGMA. If the barges were not available or did not arrive in time, the production was slowed down or stopped. Figure 4.1 visualises the extra acquired storage and the production for the period October 2017 – March 2018. In this period, the production rate is higher than normal because of the large margins. The supply of seeds is high, and this lowers the market price of seeds. This period also has the most days with longer periods of rain. It can be seen that when additional storage capacity was acquired the production also decreased. When the storage space was available in time, the loss of production was minimized.

Using the TOC thinking process, 'What to change?', 'What to change to?' and 'How to cause the change?'. Full silos were an undesired effect in the production process of oil. This can be caused by the production rate that was too high, insufficient storage capacity of the silos or the output flow that is not high enough. For the reasons described in Section 3.2.1 and 3.2, reducing the production is out of scope of this research. To remove the disturbance full silos, the storage capacity should be increased, or the output should match or exceed the production. In the next section a further analysis is performed on the outbound logistics to identify possibilities to increase the output.

4.2. Outbound logistics constraint identification

From the literature research in Chapter 2, the Theory of Constraints (TOC) and Lean Manufacturing (LM) continuous improvement methodologies were identified to be best suited for optimization of production processes and logistic systems. LM focuses on removing waste in processes and make them more efficient. Activities that do not add value to a process are waste and should be eliminated. LM includes various tools such as Value Stream Mapping to identify the non-value adding activities. As LM, TOC is also often used to optimize logistic systems. It focuses on improving the throughput and concurrently reduce inventories, operating expenses and increase resource utiliza-

Figure 4.1: Production and additional required storage space for the period 01-10-2017 – 01-04-2018

tion. The continuous improvement cycle of the methodology consists of five essential improvement steps listed below.

1. *Identify the system's constraint(s)*
2. *Decide how to exploit the system's constraint(s)*
3. *Subordinate everything else to the above decision:* Processes and components in the system should be adjusted to achieve the constraint's maximum effectiveness.
4. *Elevate the system's constraint(s)*
5. *If the constraint was broken in the previous steps, repeat the process from step 1*

4.2.1. Critical chain analysis output flow

In order to identify what is constraining the output flow of SFMP, a critical chain analysis is performed. In Figure 4.2, a schematic representation of the chain of conveyors in the load-out system is shown. The conveyors with the lowest throughput capacity are coloured red. From the silos the SFMP are conveyed via a bucket elevator to the weigh bunker and finally to the truck or vessel loading station. The throughput capacity of each conveyor can be found in Table 3.2. The bucket elevator, apron feeder and the chain conveyor for vessels have a maximum throughput capacity of [redacted]MT/h, [redacted] MT/h and [redacted] MT/h respectively.

In weekends, there is only vessel loading and the maximum throughput capacity of the whole chain is [redacted] MT/h. However, on weekdays the total throughput capacity is calculated as the combined throughput capacity of the truck and vessel station. A typical weekday starts with a vessel from 06:00 to 10:00, trucks from 10:00 to 17:00 and again a vessel from 17:00 to 22:00. Since there is no loading during lunch breaks and in the night the maximum throughput capacity would be [redacted] MT/h. This example reveals another resource constraint, the available loading time during the day. It was observed that the effective loading speed of trucks is [redacted] MT/h instead of the theoretical [redacted] MT/h and for vessels this is [redacted] MT/h instead of [redacted] MT/h. Thus, both loading stations are constraining the throughput of the load-out system. Now all constraints constraining the output of SFMP are identified:

1. The throughput capacity of the trucks loading station

2. The throughput capacity of the vessel loading station
3. The available operating hours

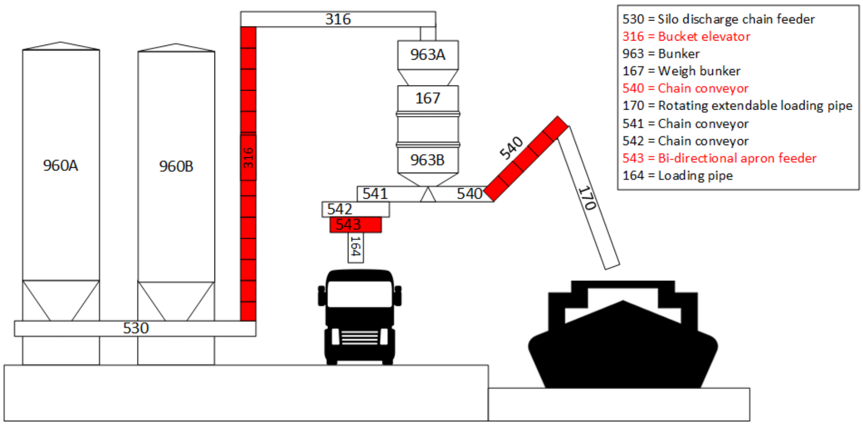

Figure 4.2: Bottleneck identification in load-out system

4.2.2. Waste identification in loading processes

After identification of the bottlenecks, the next step in the five steps by the TOC is exploiting the constraint. This focuses on how the bottleneck can be operated more efficiently with the current resources so that the constraining resource is operating at its maximum throughput. To find how the loading process constraints may be exploited LM is applied. The first step is to identify the non value adding activities within the process. This can be done by recording all activities and register whether they add value or are non-value added. Value Stream Mapping (VSM) is a tool that can help with this process. It is important to identify the value of the activities on the actual loading process. Operations and movements that do not add value are waste. The time or capacity spend at these activities could be more useful when used for for value-added processes.

Truck station

The handling activities inside and in front of the truck loading station are dispplayed in the swimlane of the landside handling operations in Figure 3.7. The activities start at the waiting area in front of the loading station and end when the truck has left the station. Activities are divided in Value Adding (VA), Indirect Value Adding (IVA) and Non Value Adding (NVA). Each activity is listed in Table 4.1 with a short description, the duration and if the activity is non value adding, the type of waste. In addition to the NVA activities found in the loading process for trucks (activities 1–7), some additional wastes were identified. These are depicted in activities I–III. Documentation can be classified as IVA, the step is step is necessary to perform but does not add direct value to the customer. Activities 2, 7, I, II and III are classified as NVA and should be eliminated or reduced from the loading process.

Waiting is the most common type of waste in LM. This is also the case in the truck loading process. Trucks queuing at the parking area means that they are not being worked on and are waiting. Furthermore, during the time the roof cover is removed and reattached the operator is waiting, and the loading station is occupied. In Figure 3.6 in Section, the arrival distribution of trucks is given. It was observed was that trucks do not arrive equally distributed over the loading hours but often arrive at the same time. In the time between the next truck arrival, operators are waiting. Motion is another type of waste, this registers all unneccesary movement of people, equipment or other resources. Due to some design faults, trucks with semi-trailers need to be repositioned

[1] Only for trucks with semi-trailer

Table 4.1: Waste in truck loading process

	Activity	Description	Duration	Type of activity	Type of waste
1.	Drive in and out loading station	Trucker positions his truck below the loading pipe and leaves	[redacted] min	IVA	-
2.	Attach harness and remove cover	Driver must remove roof cover	[redacted] min	**NVA**	Waiting
3.	Documentation	Driver hands papers to operator who checks the order	[redacted] min	IVA	-
4.	Walking	Walking from office to the loading equipment and back	[redacted] min	**NVA**	Motion
5.	Loading	Loading time varies for size of truck	[redacted] min	VA	-
6.[1]	Repositioning	Sometime trucks need to be repositioning below the exit of loading pipe	][redacted] min	**NVA**	Motion
7.	Attach harness and remove cover	Driver should attach roof cover	[redacted] min	**NVA**	Waiting
I	Waiting in front of loading station	If the station is still occupied, trucks are waiting before loading	NA	**NVA**	Waiting
II	Waiting for next truck to arrive	Sometimes there is no truck available for loading and operators will have to wait for the next truck to arrive	NA	**NVA**	Waiting
III	Other: e.g. coffee breaks, toilet visits	Various reasons mostly private	NA	**NVA**	Motion

below the exit of the loading pipe to fill towards the outer edges and the middle. During repositioning loading must stop.

Vessel station

The handling activities at the quay for vessel loading are visualised in swimlane of the waterside handling operations in Figure 3.11. The activities start at the arrival of the vessel at the quay and ends with the vessel leaving. Each activity is listed in Table 4.2 and a description, the duration and for NVA activities the type of waste. Activities 1–6 were measured in the vessel handling process. Other waste that have been identified during the observations are depicted in activities I–IV. Activities 5 and I–IV are classified as NVA and should be eliminated or reduced from the loading process.

During loading, vessels are repeatedly repositioned over the loading area to ensure an equal weight distribution and to reach the outer edges of the cargo compartment. In the Netherlands, it rains for almost 10 % of the time. Especially in the months November – January there are days with continuous periods of precipitation. Since it is not allowed to continue loading when it rains, this waste becomes significantly. During this time, the operator has to wait and is not adding value. Silos will start to fill up and sometimes extra storage capacity is required to prevent slowing down or stopping the production of oil. Furthermore, operators are also waiting when some resources are not available such as the surveyor being delayed or equipment malfunctions.

Table 4.2: Waste in vessel loading process

	Activity	Description	Duration	Type of activity	Type of waste
1.	Take sample	A sample of SFMP is taken to and to a laboratory for quality control	[redacted] min	VA	-
2.	Documentation	Before actual loading some paperwork is filed	[redacted] min	VA	-
3.	Opening cover of cargo compartment	The captain of the vessel removes the cover of the cargo compartment	[redacted] min	IVA	-
4.	Loading	Actual loading of SFMP to the vessel	NA	VA	-
5.	Repositioning	During loading the vessel is often repositioned to ensure even weight distribution	NA	**NVA**	Motion
6.	Closing cover of cargo compartment	The captain of the vessel closes the cover of the cargo compartment	[redacted] min	IVA	-
I	Waiting for surveyor	Sometime the surveyor is late, and loading cannot start until he arrives	[redacted] min	**NVA**	Waiting
II	Waiting for improved weather conditions	When it rains loading must be stopped and is resumed again when it is dry	NA	**NVA**	Waiting
III	Waiting for arrival	Sometimes vessels are delayed, and operators are waiting	NA	**NVA**	Waiting
IV	Other: e.g. coffee breaks, toilet visits	Various reasons mostly private	NA	**NVA**	Motion

4.3. Conclusion

5. What is disturbing the oil production and how can it be improved?
The little available storage space is the largest disturbance on the output of oil in the crush. By increasing the available space or increasing the output flow, these disturbances may be reduced. To identify possibilities for improvements to the output flow, a critical chain analysis was performed. This identified three bottlenecks in the outbound logistics:

1. The throughput capacity of the truck loading station
2. The throughput capacity of the vessel loading station
3. The available loading hours

The first step of the TOC continuous improvement cycle is to exploit the constraints. To identify how the constraints may be exploited lean Manufacturing was applied. Waiting and motion at the station were identified as waste. Removing the waste from the loading processes could increase the throughput at both stations.

5 Design

This chapter will define alternative designs for the SFMP load-out system to reduce the disturbance on the production of oil by solving the problems found in the previous chapter. Next, a selection of the designs is made that will be compared in a simulation. Finally, the chosen designs are explained in more detail in Section. This chapter addresses the following sub-question.

6. What design alternatives can reduce disturbances on the oil production and improve the performance of the outbound logistics?

From the analysis, the limited storage capacity of the silo was found to be the largest disturbance of the oil production. The disturbance may be reduced by solving the storage capacity problems. It was concluded that either the storage capacity should be increased, or the outbound logistics should be improved to increase the output. Alternative SFMP load-out (SLO) designs can be obtained by evaluating the possibilities to increase the available storage space or removing constraints in the outbound logistics. The latter can be done by completing the steps in the TOC continuous improvement cycle. The possible design changes to increase the storage capacity are discussed in Section 5.1 and design changes to improve the outbound logistics are discussed in Section 5.2. Afterwards, a selection is made to be implemented in a simulation model. A more detailed explanation and elaboration of the designs is given in Section 5.3.

5.1. Increase storage capacity

Near the quay, there are two silos for storage of SFMP with a combined storage capacity of [redacted] MT. It is advised to keep the storage level below [redacted] MT to prevent material build up. To increase the available storage space different possibilities exist. The most immediate design change would be to build an extra silo next to the current silos. Alternatively, the silos could be replaced with new silos that have a higher capacity. Both are long-term design changes that are expensive investments. A flexible storage solution could also be an option. An example can be found in the oil industry in which Cargill also finds itself. Oil companies use floating storages to load and store their oil in times the market demand is low. This is also what Cargill currently does when they acquire additional storage space from [redacted]. Cargill has to pay rent and results in additional operational costs. In order to be a suitable option, barges must be able be available at all times and with immediate effect. A cheaper alternative would be to place containers near the quay that can be filled when necessary.

5.2. SLO design alternatives to improve outbound logistics.

The first step of the five steps TOC continuous improvement process was completed in the previous chapter. New SLO design configurations are obtained when completing the remaining steps.

First, the constraints are exploited and if this is not sufficient the constraints should be elevated. Exploiting the constraints can be achieved by removing the waste that was found in the loading processes. From the critical chain analysis, three constraints were found that were constraining the outbound logistics for SFMP:

1. The throughput capacity of the trucks loading station
2. The throughput capacity of the vessel loading station
3. The available operating hours

Waiting was identified as the largest type of waste in the truck and vessel loading processes. Operators had to wait for a truck to arrive and in between loading when the driver was removing and attaching the roof cover. Motion because of repositioning of trucks and vessels during loading was also also identified. By removing the waste in the loading processes, it is possible to make better use of the resources and increase the throughput. For example, waiting of operators or trucks queueing in front of the loading station can be eliminated by ensuring that trucks arrive equally distributed. When there is always a truck present for loading, the throughput of the truck station should increase. A common practice to remove congestion in systems and spread the traffic load is to implement time-slots. Examples in the industry can found at container terminals, train tracks or airports but also at Cargills own plants. For its RSFO trucks, such a system is already in place.

Elevating the constraints may require alternations to the current loading equipment. For example, truck drivers remove and attach the roof cover inside the loading station, in the meantime no loading can take place. Relocating the safety harness equipment outside of the station to a new roofed station could reduce waste inside the loading station and increase the throughput. The third constraint, the available loading hours, can be elevated by stretching the loading hours or implement a night-shift. A non-exhaustive list of possible design alterations is given in Table 5.1. A distinction is made between exploiting and elevating. Also, the design options for the silo capacity are included.

Table 5.1: Alternative SLO design configurations

	Solution	Description
Increase capacity	1.	New silo or increased silo
	2.	Flexible storage space such as floating storage or empty trailers
Elevate truck throughput	3.	Place a new apron feeder with at least 175 MT/h throughput capacity
	4.	Build a second loading station for trucks
	5.	Build a shed and load trucks from the shed with a shovel
	6.	New apron feeder that is able to reach all edges of the truck
	7.	Reduce changeover time by altering conveyor configuration
	8.	Automated cover removal/attachment
	9.	Automated registration and documentation
	10.	Automated extendable loading pipe
Elevate vessel throughput	11.	Build a second vessel station
	12.	Alter load-out equipment with a extendable pipe that can be positioned in a rectangular motion instead of a circular motion
	13.	Build extendable roof
Elevate available loading hours	14.	Create a by-pass to allow simultaneously loading
	15.	Increase loading hours
Exploit truck throughput	16.	Relocate safety harness equipment outside loading station
	17.	Operate time-windows
Exploit vessel throughput	18.	Place coffee maker and sticker maker at station

5.3. Choose new SLO designs

A selection needs to be made from the SLO designs in Table 5.1 to be evaluated in the simulation model. Since it will take too much time too model them all. In consultation with the plant supervisor and the daily operation coordinator, the various design alternatives were discussed. The feasibility and costs are considered when choosing which designs will be modelled. One of the designs that is considered not feasible is to place a roof above the vessel loading station. The roof needs to be able to accommodate small barges but also large coasters. The four most promising SLO designs are: Increase the storage space, create by-pass for simultaneously loading, reduce changeover time, relocate safety-harness equipment outside of loading station with time-slots.

The implementation of time-slots is considered to not be a sufficient option on its own if the loading speed of trucks is not increased. Truck drivers still have to wait and will not be delivered in their allocated time-slot. Also, relocating the safety harness to a new station is expected to not be a feasible option on its own. When trucks arrive all at the same time, there still will lead to congestion at the station. To solve, the problems of both designs they will be combined.

5.4. Chosen SLO designs

Design A: Increase storage capacity

In this design option, the available storage space will be doubled. For this, the implementation (e.g. additional silo, new silos or flexible storage) is not important as long as the capacity is always available. This design will allow for more material build-up to load larger coasters in weekends. Also, this would provide more resilience to uncertainties in the loading processes. Furthermore, it would no longer be necessary to give vessels priority over trucks. Therefore, the performance for the outbound logistics of trucks is expected to improve.

Figure 5.1: Building new silos.

Design B: Create by-pass for simultaneously loading

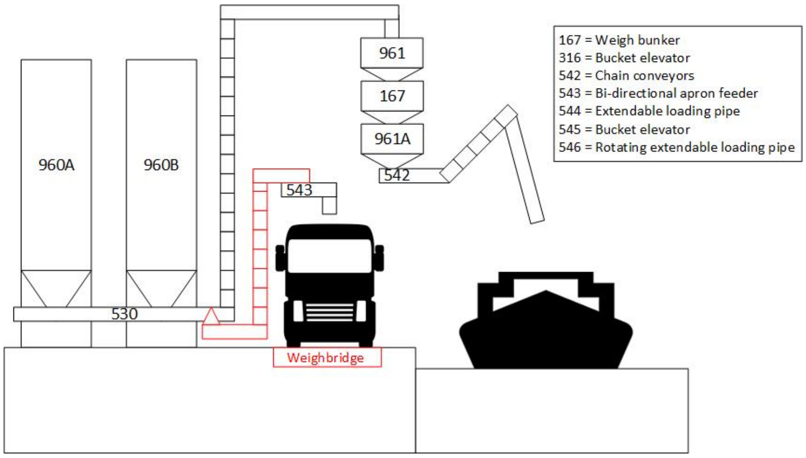

Figure 5.2: By-pass in loading systems

This design option increases the throughput by elevating the available operating hours constraint. It creates a by-pass that allows for simultaneously loading of trucks and vessels hereby doubling the available loading time. Trucks and vessels can be loaded during the whole day since loading of trucks and vessels no longer need to be divided. Trucks no longer have to wait for vessels and vice versa. Therefore, the outbound logistics for both trucks and vessels is expected to improve.

Figure 5.2 shows how such a system could be realized within the current system. The bypass is created at the chain conveyor from the silo to the bucket elevator. Since bypassing the flow after the bucket elevator would halve the throughput capacity. The operator needs to be aware of the amount of product inside the truck. Customers should not receive more product than their order specifies. Furthermore, according to legislation, trucks are not allowed to weigh above the maximum weight. Since the new configuration bypasses, the weigh bunker the amount of product in the truck has to be weighed in a different way. One solution is to place a weigh bridge inside the loading station.

Design C: Reduce changeover time

This SLO design focuses on removing waste of operators waiting for trucks to arrive and remove/attach roof cover. In the current configuration it takes approximately [redacted] minutes to switch between truck and vessel loading. Switching between trucks and vessels multiple times a day is therefore not recommended as already limited available loading time is lost. if the changeover time was reduced such a system could become appealing. The high changeover time is mainly due to the fact that the weighing bunker has to be emptied. By placing a weigh bridge inside the truck station, the changeover time could be reduced significantly.

In this design, trucks are served immediately upon arrival. At the moment the truck driver starts to remove the roof cover, the operator will stop loading the vessel and head to the truck station so that the truck can immediately be loaded. Afterwards, loading of the vessel is resumed. Trucks no longer have to wait for vessels to finish and an increased performance of the outbound logistics of trucks is expected.

Design D: Relocate safety harness equipment to new station and operate time-slots for trucks

As mentioned in Section 5.3, the designs relocate safety harness equipment to new station and time-slots will be combined to a new design. It is expected that the combination will increase the throughput of trucks and thus increasing the throughput of the whole system.

This design focuses on improving the output flow in the truck loading station by removing waste caused by trucks not arriving equally distributed over the loading hours but at the same time. A practical way to prevent congestion and distribute traffic in a network is slot allocation. Such practices can be found in for example container terminals, pick-up points for groceries and airports. But is also applied for RSFO trucks and at other Cargill production plant. By setting time-slots, the time when a truck arrives can be better regulated. When trucks arrive at their slots, queuing of trucks at the gate will be reduced and eventually this should result in lower waiting times and turnaround times for trucks. A computer system will need to be created that allows customers to reserve their time-slots. Also, this provides opportunities for more automation including creation of a transport planning and registering.

Such a system is only effective if Cargill is able to serve its customers at their allocated slot. This requires sufficient loading speed of trucks. This can be achieved by relocating the safety harness equipment to a new station outside the loading station. This focuses on removing the waste of operators waiting on truck drivers to remove/attach the roof cover. This leaves more time available for loading thus increasing the throughput.

5.5. Conclusion

6. What design alternatives can reduce disturbances on the oil production and improve the performance of the outbound logistics?

The disturbance may be reduced by solving the storage capacity problems. It was concluded that either the storage capacity should be increased, or the outbound logistics should be improved to increase the output. To increase the available storage space different possibilities exist. The most immediate design change would be to build an extra silo replace the current silos. Alternatively, a flexible storage could also be an option.

New SFMP Load Out design configurations are obtained when completing the remaining steps of the TOC continuous improvement cycle. First the constraints are exploited and if this is not sufficient the constraints should be elevated. Exploiting the constraints can be achieved by removing the waste that was found in the loading processes. The designs were evaluated for feasibility and costs. The four most promising SLO designs are: Design A: Increase the storage space; Design B: Create by-pass for simultaneously loading;Design C: Reduce changeover time to switch between trucks and vessels; Design D relocate safety-harness equipment outside of loading station with time-slots.

The design configurations will be modelled in a discrete event simulation to compare their performance with the current state. A discrete event simulation can be used to model the configurations without actually building the new stations. A discrete event simulation model will be developed using the model design paradigm. The model will be adapted for the each design solution, and the performance of the design solutions will be evaluated through the KPIs found in the literature. By analyzing the results of the simulations the best design option to be implemented at the Multiseed will be obtained.

6 Discrete event simulation

This chapter creates a discrete event simulation model of the outbound logistics at the Multiseed to compare the performance of the design alternatives that were defined in the previous chapter. First the conceptual model is given in section 6.1. Then the computerized model implementation in Salabim, the model assumptions and model input and output are defined. Next, in Sections 6.5 and 6.6 gives the verification and validation of the model. Finally, the experimental plan, simulation run-time, number of repetitions and the input scenarios are defined in section 6.7. This chapter addresses the following sub-question.

7. How can the design alternatives be modelled in a discrete event simulation?

6.1. Conceptual model

From the literature, the model development paradigm consists of three main components; the system, conceptual model and computerised model. The system is a current situation or entity to be modelled. The conceptual model is a representation of the problem entity to be investigated and the computerized model is the implementation of the conceptual model in a computer simulation software package.

The designs alternatives that are going to be evaluated were discussed in the previous chapter. The scope of the research starts with trucks arriving at the front gate and vessels mooring at the quay and finishes with trucks and vessels leaving. It is important to notice that changes to the production planning and transport planning in case of disruptions are out of scope of this model. For the model, the production will be kept constant and equipment or system failures are out of scope as it would overcomplicate the model. Furthermore, the model does not take actions to acquire additional storage space or additional customers.

A logical representation of the system to be modelled is visualized in Figure 6.1. The flow chart will function as the conceptual model to be implemented in the computer simulation model. It consists of five lanes that represent the specific locations at the Multiseed except for the first lane. The flow chart follows the creation of trucks and vessels that flow through the system via the stations.

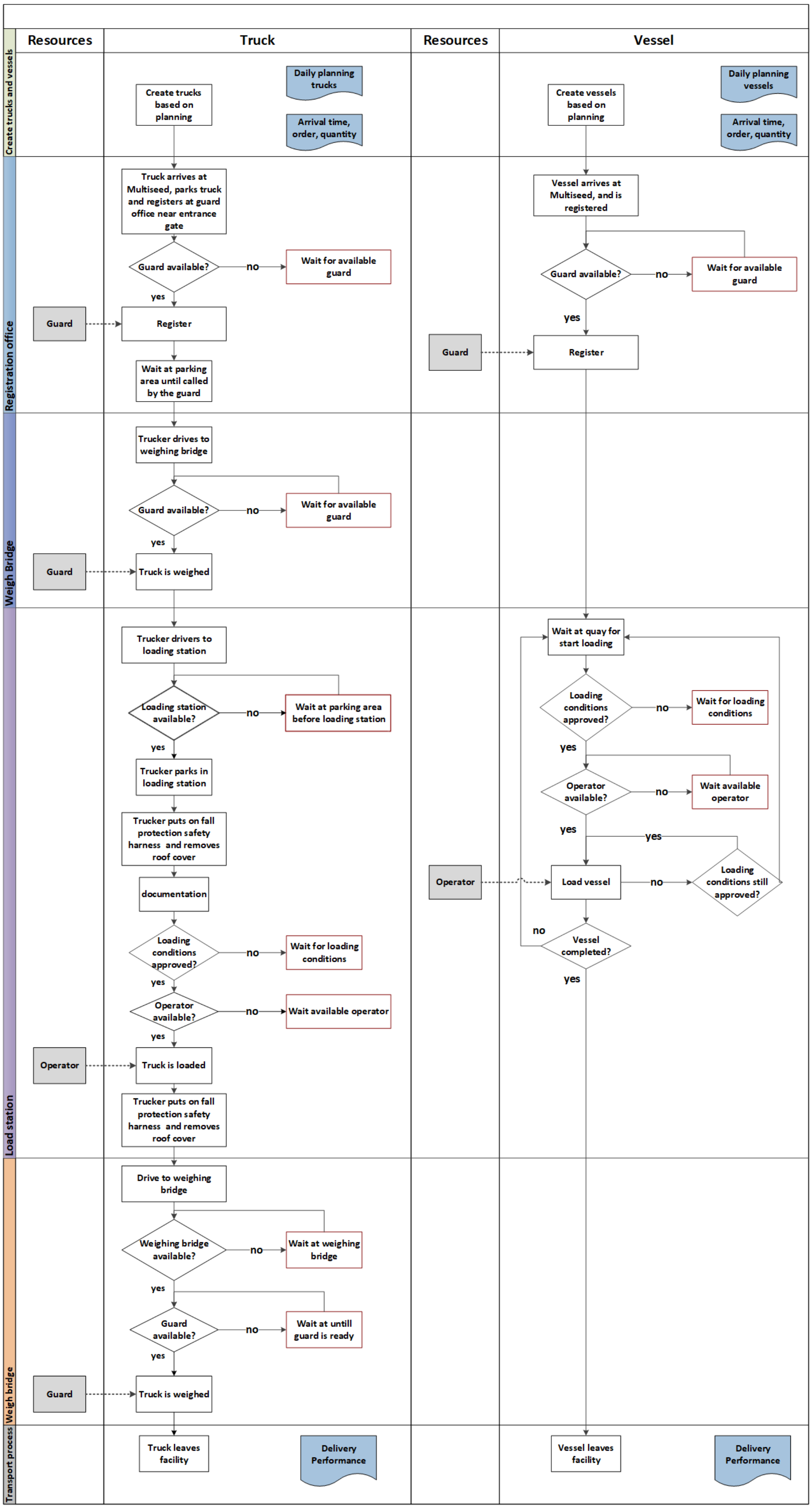

Figure 6.1: Conceptual model cross-functional decision flow chart

6.2. Discrete vs. continuous

The continuous flow behaviour of bulk material flows from the crush to the silo and from the silo the loading stations need to be incorporated in the model. However, continuous behaviour is difficult to interpret in the DES software package Salabim. It uses discrete elements for slows and states are updated at discrete time-steps.

To model the continuous behaviour, the analogy in Fiorini et al. (2007) will be used. The continuous flow is approached by modelling the flow with discrete portions. This is visualized in Figure 6.2. A shows the continuous flow and B the discrete portions. With a constant rate and speed, the amount of material travelled is in bot situations the same. Smaller portions will improve the continuous flow approximation but slows down the simulation and increase the computational requirements. A trade-off will have to be made between accuracy and the simulation speed.

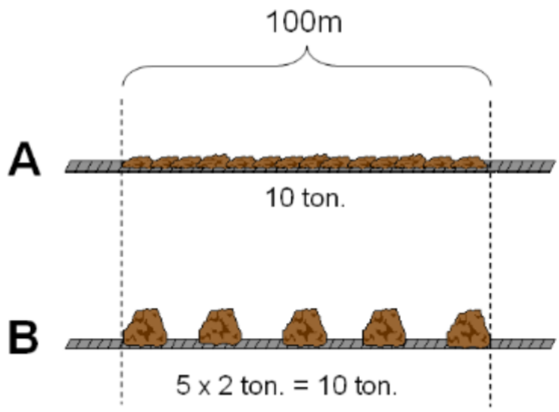

Figure 6.2: Discrete vs. continuous

6.2.1. Model implementation in Salabim

Components are the key elements of Salabim simulations. The model consists of seven active components and one data component the silo. Figure 6.3, visualizes the conceptual model with all components and queues of the simulation model. The stations are visualized with rectangle boxes. For modelling of the continuous flow of SFMP from the crush to the silo and from the silo to the vessel and truck station the concept described in Section 6.2 is applied. The silo level is updated at every predefined time-step. All components, resources, queues, states and distributions in the model are listed below.

Resources: *Operators, Guard, LoadingEquipment, Silo*

Components: *Truck, Vessel, RegistrationOffice, WeighBridge, TruckLoadStation, VesselLoadStation*

Queues: *ArrivalTrucksQueue, WaitingTrucksQueue, WeighingTrucksQueue, ParkingLoadingQueue, TruckLoadingQueue, VesselArrivingQueue, VesselIdleQueue, VesselLoadingQueue*

States: *silo_state, multiseed_state, operating_state*

Distributions: *truckArrival, weighTime, coverRemovalTime, coverAttachmentTime, timeBetweenRain, rainDuration*

Truck and Vessel Generator

The vesselAndTruckGenerator generates Vessel and Truck components with the arrival time and order size based on the provided planning data. The arrival time for trucks is obtained from the derived truck arrival distribution. That was retrieved from real-world data. Vessels are assumed to be present at the start of the vessel loading hours and arrive 1 hour ahead of the start loading hours. When the quay is already occupied, the new vessel will arrive 15 minutes after the previous has left.

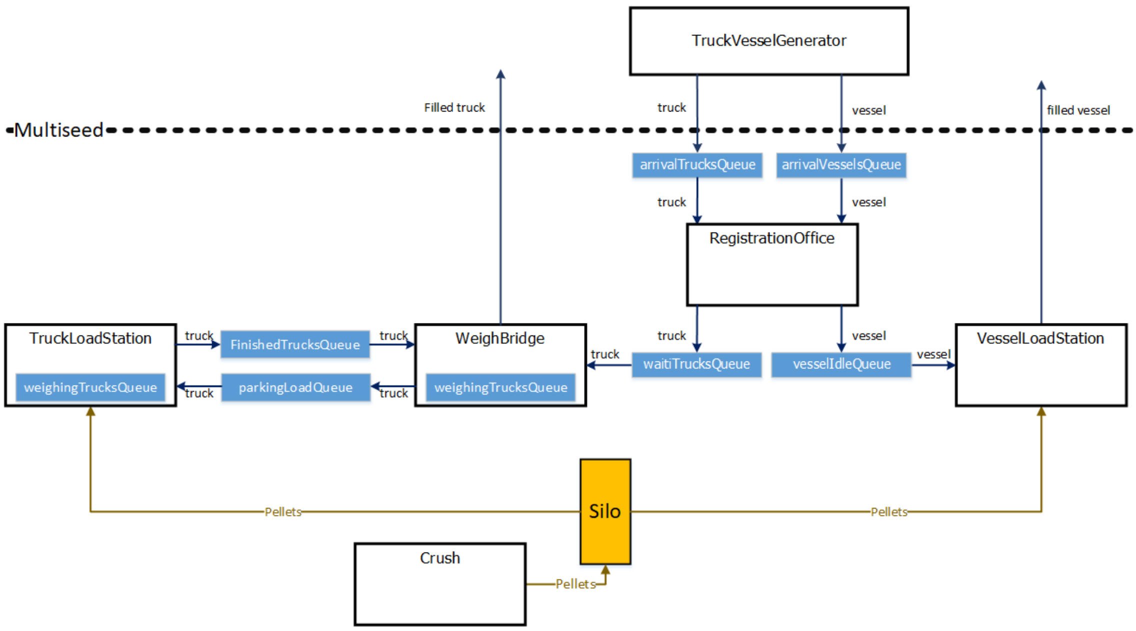

Figure 6.3: Conceptual model discription

When a trucks or vessels arrives, it is placed in the *ArrivalTrucksQueue* or the *ArrivalVesselQueue* and wait for registration to start.

Crush

SFMP from the crush are placed in the silo. Based on the production rate, the silo levels are updated to the new silo level at every discrete time-step. This process is repeated at every predetermined discrete-time step.

Registration office

When the Multiseed is in operation, the *registrationOffice* component will check if a truck or vessel has arrived and request a guard that will perform registration. Trucks that arrive later than theAfterwards, the truck is placed in the *WaitingTrucksQueue* where it will wait until the weigh station is available. Vessels are placed in the *VesselIdleQueue*.

Weigh Bridge

The weighBridge components monitor the *WaitingTrucksQueue* and the *FinishedTrucksQueue*, if there are no more than two trucks at the premises, a new truck may be weighed in. Trucks are removed from the *WeighingTrucksQueue* and placed in the *WeighingTrucksQueue*. A guard is requested from the guard resources. If the guard is available, the truck is weighed in. The component holds for five minutes what was found to be the average weighing time. After weighing, the truck is either place in the TruckLoadingQueue or if the station is already occupied in the the ParkingLoadingQueue. If the *TruckLoadStation* is passive it will be activated. Trucks that are loaded and waiting to be weighed out are removed from the *FinishedTrucksLoadingQueue* and placed in the *WeighingTrucksQueue*. After weighing the truck component is activated and removed from all queues.

Truck Station

The *TruckLoadStation* monitors the *TruckLoadingQueue* and *ParkingLoadingQueue*. Loading can be performed if the silo is available. Before loading can start the states multiseed_state, operating_state and silo_state must be satisfied. During lunch breaks the operating_state and during the night the state is set to *False*. Furthermore, it takes some time to change between truck and vessel loading, in the meantime the silo is not avail for loading. The TruckLoadStation holds for *coverRemovalTime*, the time required for removal of cover. Next, an operator is requested for the truck loading. Before loading starts, it holds for the documentation time. Next loading starts, the silo level and the amount of SFMP in the truck (truck level) are updated to the new states at every discrete time-step. After the truck is filled, the operator is released and the *TruckLoadStation* holds for the *coverAttachmentTime*, the time needed to reattach the cover. The truck is now finished and is removed from the *TruckLoadingQueue* and placed in the *FinishedTrucksLoadingQueue*.

Vessel Station

The *VesselLoadStation* monitors the *VesselIdleQueue*. Loading can be performed if the silo is available, it is not raining, and no more trucks are planned. The states multiseed_state, operating_state and silo_, not_raining state must be satisfied. If it rains, loading is stopped and resumed again when the rain stops. It can happen that in the meantime truck have arrived. However, loading to vessels is not stopped until the silo level is at least below 400 MT. When loading can start the operator is requested and the vessel is placed in the *VesselLoadingQueue*. The silo level and the amount of SFMP in the vessel (vessel level) are updated to the new states at every discrete time-step. When the vessel is full it is removed from the VesselLoadingQueue. The vessel is activated and removed from all queues. If it not full, the vessel is again placed in the *VesselIdleQueue* until the Multiseed will be operated again for loading to vessels.

6.2.2. Model assumptions

In order to create a model of the system assumptions need to be made or the model would become too complex. However, these need to be treated with care, making the wrong assumptions can render not only a false result but also an incorrect understanding of how the real system works. The assumptions made in the current research are:

1. **Trucks and vessels** Truck and Vessel distributions were generated based on provided Truck and vessel data from June 2016 – May 2018, excluding the months August – September in 2017. In these months, this period the crush was crushing rapeseed instead of sunflower seed and there were no trucks since rapeseed is only loaded to vessels.

2. **Discretization continuous processes** For the discrete model, discretization of continuous processes such as the meal production and loading are necessary. Furthermore, a high time-step increases the speed of the model but lowers its accuracy. For all continuous process a discretization of minutes is used. So, the states are updated every five minutes to the new value.

3. **Equipment failure** Equipment and system failures as well as logistic disturbances are not included to the model. Since this requires the model to make changes to the planning or reduce production speed. Also, other system computer system failure and maintenance are not included in the model.

4. **Planning** The planning used for the model is derived from actual loading weeks. Including daily changing loading times and varying numbers of trucks.

5. **Processing times** Processing times including the weighing, registration and the times for loosening and fastening the cover have been derived from measurement results shown in Chapter 3.

6. **Slower loading speed vessels** The boat loading speed is reduced once the boat is filled to 70%. This is done to simulate the behaviour where filling takes more time due repeatedly repositioning of the vessel and required precision towards the end.

7. **Transport on terrain** The distances between the different stations are relatively small, so the time that trucks need to travel between stations was neglected. Furthermore, the model does not include influences on the system due to movements of oil trucks and vessels.

8. **Stopping loading of vessels** In the real-world, if there are trucks waiting, loading to vessels will continue if the storage level in the silo is too high. To simulate this behaviour, when trucks are waiting, loading of vessels continues or if the storage level is below 400 MT loading is stopped.
9. **Lunch breaks** Trucks can be finished at the start of the lunch break, but vessels are immediately interrupted and resumed afterwards.
10. **Trucks on the terrain** At maximum three trucks are allowed on the terrain, one being loaded or weighed and maximum two waiting before loading.
11. **Vessels arriving** Vessels scheduled for arrival while the quay is still occupied will not enter the system before quay becomes available.
12. **Clean vessels** Vessels that arrive are clean, no inspection is required, and loading can immediately start.
13. **No defects** In the real-world, vessels or trucks sometimes receive more than the order specified. However, this will not be included in the simulation model.

Some additional remarks have to be made, one of the assumptions assumes the outbound logistics for RSFO do not affect the outbound logistics for SFMP. The weigh bridge is used both for RSFO trucks and SFMP trucks and may result in delays. However, the time lost is at most five minutes. As trucks almost always have to wait in front of the loading station, the delay will only lessen the waiting time and not affect the time spend inside the loading station. The quay has not enough room for both large oil barges and a large SFMP. However, it is assumed that the planning is not affected due to good coordination between the planners.

Another important notice is that equipment breakdowns are not included in the model as this would overcomplicate the model. Breakdowns reduce the time available for loading and changes to the planning would have to be made. The model is not capable to make these changes on its own.

6.3. Input variables

There are two main types of input data that will be used in this simulation. The first are the model constants or fixed parameters, which are obtained through interviews and measurements. The second is the input data, which is obtained directly from Cargill and provides details on the number of trucks, vessel size, truck arrival pattern and equipment speeds. The fixed parameters for the simulations are listed in Table 6.1 appendix C

Arrival rate

The arrival rate of trucks is based on the arrival distribution that was found in the Analysis in Chapter 3. The empirical data was fitted to a Beta distribution. A graphical representation can be found in Appendix C.

Processing time

Processing times such as cover removal/attaching times, registration times, weighing times and loading rates were derived from the real-world data.

Planning data

For the simulation model a four-week transport planning was created starting from Monday 6:00 AM. This was derived from the obtained data sets in Appendix C. The planning was constructed such that the planned delivery is almost equal to the expected production in that week. The planning shows the amount of trucks and vessel sizes. A separate planning was made for all day loading and loading divided in separate truck and vessel loading. In all day loading, trucks can be loaded from 06:00–17:00 and vessels from 06:00-22:00. Also, the planning was adjusted for the increased production which resulted in a 10% increase in pick-up.

Table 6.1: Fixed parameters simulation model

Parameter	Value
Truck station	
Truck loading rate	[redacted] [MT/h]
Discrete portions truck loading	5 [min]
Remove cover time	[redacted], [redacted] [min] Normal
Remove cover time	[redacted], [redacted] [min] Normal
Vessel load station	
Vessel loading rate	[redacted] [MT/h]
Vessel loading rate (after 70% filled)	[redacted] [MT/h]
Registration time	[redacted] [min]
Discrete portions truck loading	[redacted] [min]
Crush	
Production rate	[redacted] [MT/h]
Discrete portions production	[redacted] [min]
Weigh Bridge	
Weigh-in time	[redacted], [redacted] [min] Normal
Weigh-out time	[redacted], [redacted] [min] Normal
Resources	
Weighing stations	[redacted]
Truck loading stations	[redacted]
Vessel loading stations	[redacted]
Guards	1
Opening hours	06:00 – 22:00

6.4. Output

The output is measured based on the formulated KPIs in Table 6.2. The production performance KPIs will be used to determine whether the disturbance on the production was reduced in the SLO designs. The landside and waterside operation KPIs are used to determine how the outbound logistics of the new SLO designs perform. One additional KPI is introduced to see how susceptible the system would be for interruptions in the loading process. This is measured with the KPI Silo utilisation above 70%. The reasoning behind this is that if the silos are already really full, it can more easily cause the silos to fill up when loading is interrupted and cause disruptions to the oil production process. A level of 70% was chosen as the silos should never be completely filled to prevent material getting stuck.

Table 6.2: Key performance indicators for simulation model

KPI	Unit	Goal
Production performance		
Production Loss (PL)	[MT]	↓
Operating Throughput Effectiveness (OTE)	[%]	↑
Silo utilization over 70 %	[%]	↓
Landside operations		
Average waiting time	[hours/truck]	↓
Average turnaround time	[hours/truck]	↓
On-time delivery (OTD) :	[%]	↑
Waterside operations		
Average turnaround time	[hours/vessel]	↓
On-time delivery (OTD)	[%]	↑

6.5. Model Verification

Verification of the simulation is necessary to make sure the logic is implemented as designed (Pujawan et al., 2015). .. describes verification as *"Verification is determining that a computer simulation performs as intended."* A program with errors may generate incorrect output, and could lead to wrong conclusions (Kleijnen, 1995). Once the computer simulation model is created, the programming code needs to be checked for faulty implementation and errors ('bugs'). Several techniques are available, but due to the complexness of the simulation model non will give the perfect answer. During creation of the simulation, its output should constantly be checked for correctness. Intermediate results are obtained from the trace function capabilities within Salabim. The following verification checks were performed:

Model Correctness: Debugging and analysis of components were performed during building of the simulation. The modular design makes it possible to assess the performance of each component separately. Errors occurred during running were solved and implemented in the final model design. The correctness is subjective as assumptions made affect the behaviour in contrast to the real-world situation.

Balance checks: Salabim offers comprehensive animations such as labels, graphs and static data to visualize queues, resources, components and levels. These were used to visualize queue lengths and entities flowing through the system. Entities that leave the system should also have left all queues. A level indicator showed the current storage level of the silo. This was monitored to check whether the level was updated to the production or loading rate.

Event tracing: Like many other DES software packages, Salabim includes a trace function that monitors all entities in the system and updates to the system' state at each time step or event. This allows the researcher to follow the processes step by step and help discover whether the system' logic follows the predefined logic.

Runtime visualization: Salabim features a variety of animations such as labels, graphs, counters and queue statistics that can be used to visualize the resources, components, state and levels. For instance, to verify if components have really exited the system or display the levels of a resource. After filling or emptying the silo, the levels must be updated to reflect the new system state.

Input Checks: This check verified if the model input was to the specifications. Trucks and vessels need be to the daily planning, process durations or rates. Trucks and vessels should arrive at their arrival time, the silo level should be filled and emptied to the specified production and loading rates. Entities should enter and leave queues again after the process is completed.

Faults: Errors can slip into the model due to human mistakes. Bad coding or incorrect specifications can change the behaviour of the model. During this check errors were identified and corrected to their true value. Bugs in coding are identified by the IDE and prevented by following good coding structures. If, there were any errors left they were discovered by monitoring the entitities through the animations and intermediate results in the trace function.

Sensitivity analysis

In order to determine whether the model performs as expected under different conditions a sensitivity analysis is performed. For this analysis, the KPIs average turnaround time trucks and vessel turnaround time will be evaluated for different truck and vessel loading speeds. With a higher loading speed, a shorter loading time is expected for trucks and vessels. To check if the system behaves in this way the loading speed of trucks is altered for five different scenarios a speed of [redacted] MT/h, [redacted] MT/h, [redacted] MT/h, [redacted] MT/h, [redacted] MT/h. For the vessel speed, the scenarios are [redacted] MT/h, [redacted] MT/h, [redacted] MT/h, [redacted] MT/h and [redacted] MT/h. With [redacted] MT/h the real world measured truck speed and [redacted] MT/h the measured vessel loading speed. The results of the sensitivity analysis for the changed loading speeds are displayed in Figures 6.4 and 6.5. This analysis shows that the model behaves as expected and no outliers are found.

Figure 6.4: Sensitivity analysis truck waiting time for varying truck loading speed.

Figure 6.5: Sensitivity analysis truck waiting time for varying truck loading speed.

6.6. Model validation

Validation can be used for calibration of the model and to check whether the model is the correct representation of the real-world. Validation will be performed to the levels in the silos. Figure 6.6 visualizes the real-world measurement data vs. the output of the simulation. To quantify whether the data is a good fit of the real-world data a regression analysis was performed. The results of this analysis are shown in Table 6.3. The model seems to be overall a good representation of the real-world with a reasonable R-squared regression coefficient of 0.83. A higher regression coefficient is unlikely to be achieved because of the assumptions that were made on the irregular behaviour of the real-world. For example, operators almost never start exactly at 6:00 AM with loading but maybe take a cup of coffee first. Also, the lunch brake time is not really strict and can vary from time to time. In the graphs it can also be seen that on sunday the operators continued loading after 22:00 while on other days loading stopped prematurely. While the model assumes that loading takes place between 6:00 – 22:00. In order to improve the model, more data needs to be gathered. Such as loading speeds for different vessel types, the operator who is loading the pellets, the client, truck type and many more. Due to the limited available time this will not be included in the model.

Figure 6.6: Comparison silo level for simulation data vs. acquired real system data

Table 6.3: Regression data

Regression data				
Multiple correlation coefficient R	0.91			
R-squared	0.83			
Adjusted smallest squared	0.83			
Standard error	89.1			
Observations	1932			
	Coefficients	**Standard error**	**T- statistics data**	**P-value**
Intersection	90.3	4.9	18.6	4.43E-71
Simulation	0.94	0.0096	98.7	0

6.7. Experimental plan

The developed design solutions will be simulated in the discrete event simulation model. Different simulation runs are achieved by changing the seed number in the model. A different seed number changes the input parameters such as waiting times, operating times etc. After simulation, the results are evaluated and the best scenarios for the Multiseed can be identified. All configuration will be evaluated for different input scenarios to see how the system behaves under different input. The current situation will function as the 'base case' to evaluate the performance the new design solutions in comparison. The experimental plan is given in Table 6.6.

6.7.1. Warm up period and simulation run time

Looking at the run length of a simulation, simulations may be classified in terminating and non-terminating. The first has a specific end time or state (i.e. closing of a supermarket) while the latter will reach a steady-state after a certain time period. The model created can be viewed as terminating as the Multiseed closes from 22:00 to 06:00. All truck entities should have left the system and the queues must be empty. Only vessels may remain in the system but should have been removed from the loading and waiting queues. Every day, the system starts with a new silo level and different transport planning. Because of these characteristics no steady-state will be reached and a start-up time and run length will not have to be determined. Since the planner normally creates a planning for just one week in advance, the pattern tends to repeat itself every week. To evaluate, how the system performs after a month of running without intervention of the planner the system is evaluated for a standard month of 28 days or 4 weeks. A planning is created for four different weeks based on actual planning data. The total sum of the output and production should be close to each other. The planning data that is used as input of the model can be found given in Appendix C.

6.7.2. Number of replications

The required number of replications is influenced by the mean and the standard deviation and the results may be influenced by the stochastics input data. A student-t distribution can be used to determine the likeliness that the result lies within a range of the true mean. The formula in Equation 6.1 was used to calculate the minimum required experiments. For this simulation the error should be below 5%, this gave a minimum required number of 97.3 repetitions. To assure that the error is below 5% in all simulations, the simulation was ran for 150 repetitions.

$$\bar{X} \pm t_{m-1,1-\alpha/2}\frac{s}{\sqrt{n}} \tag{6.1}$$

$$N(m) = \left(\frac{S(m)t_{m-1,1-\alpha/2}}{\bar{X}(m)\epsilon}\right)^2 \tag{6.2}$$

t = Student's t-distribution

$\bar{X}$ = sample mean, the average of all observations

μ = estimated mean

σ = sample deviation, square root of sample variance

n = sample size

ϵ = error

An initial setup the simulation ran for 50 repetitions to evaluate the standard deviation. The required number of experiments was 97. To be sure the simulation is runned for 150 repetitions.

$$\left(\frac{16.65 * 1.985}{67.12 * 0.005}\right)^2 = 97.06 \tag{6.3}$$

6.7.3. Experiments

Besides the SLO designs that were created in Chapter 5, input scenarios will be defined. These are used to see how the system behaves under different input scenarios. From Figure 4.1 it has become clear that rain is one of the largest influences on the the loading of vessels and is one of the main reasons Cargill requires additional storage space. Therefore, the model will be evaluated for a dry period and a period with rain. In the busy months (November–March), the production is run at maximum capacity. This is another input scenario; a 10% increase of the production rate is chosen. To accommodate the increase of production the transport should also increase with 10%. Furthermore, this is also the period with the most days with consecutive periods of rain. Therefore, the final scenario that is chosen is the increased production with rain. An overview of the input scenarios is given in Table 6.4.

Table 6.4: Input scenarios

Input scenario	Production rate	Rain
Average production (AP)	Normal	No
Increased production (IP)	High	No
Average production and rain (APR)	Normal	Yes
Increased production and rain (IPR)	High	Yes

The configuration variables that are changed for the different SLO designs are listed in Table 6.5. In the bypass SLO design, trucks and vessels are loaded simultaneously and requires the presence of an additional operator. The time-slots SLO design uses a uniform arrival distribution to simulate the time-slot behaviour and trucks arriving at the start of their slot. Both SLO design changeover time and bypass allow trucks and vessels to visit the entire day.

Table 6.5: Configuration variables

Configuration variable	Value	Unit
Storage capacity	[redacted]; [redacted]	MT
Loading hours	All day; divided	[hours]
Truck arrival rate	Empirical; uniform	[min]
Operators	1; 2	[#]
Changeover time	5; 20	[min]

In Table 6.6 an overview of the experiments is given. All experiments will be evaluated for the four input scenarios. This results in a total of 20 experiments that will be researched and evaluated. The results of the experiments will be shown and discussed in the next Chapter.

Table 6.6: Experimental plan

SLO Designs	Storage	Loading hours	Truck arrival rate	Operators	Changeover time
Current	[redacted]	Divided	Empirical	1	20
Storage	[redacted]	Divided	Empirical	1	20
By-pass	[redacted]	All day	Empirical	2	20
Changeover	[redacted]	All day	Empirical	1	5
Time-slots + Harness station	[redacted]	Divided	Uniform	1	20

6.8. Conclusion

7. How can the design alternatives be modelled in a discrete event simulation?
From the literature, the model development paradigm consists of three main components; the system, conceptual model and computerised model. The system is a current situation or entity to be modelled. The conceptual model is a representation of the problem entity to be investigated and the computerized model is the implementation of the conceptual model in a computer simulation software package. The conceptual model uses flow charts to describe the system behaviour. This is then implemented in the discrete event simulation package Salabim. After creation, the model was validated and verificated. The design alternatives are simulated for 150 repetitions for four different input scenarios: Average Production (AP), Increased Production (IP), Average Production + Rain (APR) and Increased Production + Rain (IPR).

7
Results

This chapter compares the performance of the different design solutions and presents recommendations for implementation of the best solution scenario. This chapter adressess the following sub-question.

8. What is the best design alternative for the developed scenarios to be implemented for Cargill?

The simulation model ran for the defined SFMP load-out designs (SLO designs) and the four input scenarios (i.e. Average Production (AP), Increased Production (IP), Average Production + Rain (APR) and Increased Production + Rain (IPR)). The results were generated with help of the statistical tools available within Python and the Salabim package. All KPIs will be described through the mean and standard deviation.

7.1. Disturbance on production of oil

The main objective of this research is to reduce the disturbances on the oil production. This should be achieved by keeping the storage from filling up. The most important KPIs to measure the disturbances are the Production Loss and Silo Utilization factor above 70%. The simulation results for the design solutions and input scenarios are given in Table 7.1 and Figure 7.1. Input scenario IPR shows the worst performance. As this increases the tension on the outbound logistics. The first column shows the KPI results of the current state SLO design. The results are used to determine how the new design perform in comparison. In the current system the Production loss in the IPR scenario was around [redacted] MT and the silos were filled above 70% for 17.5% of the time. Thus, making the system susceptible to interruptions in the loading process. It can be seen that for all new SLO designs, the loss of production was reduced or removed. Meaning that disruptions on oil were also reduced. Design B is the best design solution to remove the disturbances on the oil production. No production loss was recorded, and the silos were filled above 70% for only 1.5% of the time. Designs B and D also eliminated the loss of production, but utilization was slightly higher compared to design B, 2.5% and 2.6%. In design C the utilization was increased to 34.9%. In design C, the production loss was increased; this can be explained since this solution does not give priority over vessel loading to truck loading. In the current state, when it starts to rain truck loading does not start until the silo is below an acceptable level. Operators are waiting until the rain stops and will resume loading the vessel. In this design, this is no longer the case. When it is finally dry, loading of the vessel was again interrupted because a truck had arrived.

7.2. Output performance

The other objectives of this research were to reduce tension on the outbound logistics, reduce truck waiting times and increase the flexibility of the truck planning. Long waiting hours of trucks was one of the largest complaints by truck drivers. The measured KPIs for the different SLO designs

Table 7.1: Simulation results on the disturbances on the production for the design solutions and four input scenarios

		Current		Design A		Design B		Design C		Design D	
		mean	**stdev**	**mean**	**stdev**	**mean**	**stdev**	**mean**	**stdev**	**mean**	**stdev**
AP	Production Loss	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTE	99.6%	1.4%	100.0%	0.2%	100%	0%	100.0%	0.1%	100%	0%
	Silo utilization over 70 %	2.7%	4.2%	0.4%	1.3%	1.7%	0.5%	5.5%	3.1%	1.3%	0.4%
IP	Production Loss	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTE	99.2%	1.5%	100%	0.1%	100%	0%	99.6%	0.5%	100%	0%
	Silo utilization over 70 %	4.7%	4.7%	0.8%	1.8%	1.4%	0.4%	21.3%	8.9%	1.7%	0.5%
APR	Production Loss	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTE	99.5%	2.1%	100.0%	0.0%	100%	0%	99.8%	0.3%	100%	0%
	Silo utilization over 70 %	3.0%	4.7%	0.3%	1.0%	1.7%	0.4%	12.4%	6.0%	1.6%	0.6%
IPR	Production Loss	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTE	96.2%	4.4%	99.8%	0.5%	100%	0%	97.9%	1.2%	99.9%	0.9%
	Silo utilization over 70 %	17.3%	14.0%	2.5%	4.2%	1.5%	0.4%	34.9%	8.0%	2.6%	2.7%

Figure 7.1: Simulation results of the design solutions and four input scenarios, on the left the production loss and on the right the silo utilization factor over 70%.

and input scenarios are shown in Table 7.2 and illustrated in Figures 7.1 and 7.2. For all design solutions the performance for the landside operations was improved.

Figure 7.2: Simulation results of the design solutions and four input scenarios, on the left the turnaround time of trucks and on the right the on-time-delivery of trucks.

Table 7.2: Simulation results on the outbound logistics for the design solutions and four input scenarios

		Current		Design A		Design B		Design C		Design D	
Scenario	**KPI**	**mean**	**stdev**	**mean**	**stdev**	**mean**	**stdev**	**mean**	**stdev**	**mean**	**stdev**
AP	Wait trucks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	TAT trucks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTD trucks	0.84	0.06	0.86	0.05	0.99	0.01	0.99	0.01	0.99	0.00
	TAT vessels	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTD vessels	0.97	0.04	0.97	0.02	0.97	0.00	0.97	0.02	0.97	0.00
IP	Wait trucks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	TAT trucks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTD trucks	0.67	0.08	0.77	0.07	0.98	0.01	0.98	0.02	0.97	0.01
	TAT vessels	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTD vessels	0.97	0.01	0.97	0.02	0.97	0.00	0.87	0.07	0.97	0.00
APR	Wait trucks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	TAT trucks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTD trucks	0.76	0.08	0.84	0.06	0.99	0.01	0.99	0.01	0.95	0.02
	TAT vessels	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTD vessels	0.97	0.03	0.97	0.01	0.97	0.00	0.94	0.05	0.97	0.00
IPR	Wait trucks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	TAT trucks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTD trucks	0.49	0.11	0.71	0.01	0.99	0.01	0.98	0.02	0.90	0.04
	TAT vessels	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OTD vessels	0.86	0.18	0.96	0.00	0.97	0.00	0.71	0.12	0.97	0.03

7.2.1. Waiting time

First the waiting time for trucks will be analysed as waiting was one of the largest complaints of truck drivers. Furthermore, to be able to ask its customers a premium on trucks, the performance should be increased. In designs A, B, C and D the waiting time was reduced with 42.0%, 90.6%, 86.7% and 81.3% respectively. The best SLO design to reduce waiting hours was design B: create a by-pass for simultaneously loading. This was expected since trucks can arrive the from 06:00–17:00 and it is less likely that multiple trucks are already waiting. Furthermore, trucks do not have to wait for vessels to finish loading. This is also visible in Design B were similar results were expected. In design D, it is important that there is almost no waiting time in order for Cargill to deliver a truck on its allocated slot. Improvements are visible for the first three scenarios but in the IPR scenario the waiting time for trucks was on average 19 minutes.

7.2.2. On-Time-Delivery Trucks

Another important measurement is the OTD for trucks. OTD measures the percentage of trucks that were delivered in time. Trucks that were not loaded at all were also included as not delivered in time. In the current state, the OTD is only 49% for the input scenario IPR. In SLO designs B and D the OTD performance increased to 99% and 90% for the IPR input scenario which is quite significant. Furthermore, the OTD for trucks did increase for design A to 71%, a great performance increase but not best result in comparison.

7.2.3. OTD and Turnaround time vessels

In design A, B, and D, for input scenario IPR, the turnaround time for vessels decreased with 21.3%, 43.3% and 37.2% respectively. However, in design C the turnaround for vessels increased with 58.6% and the OTD for vessels was reduced to only 71%. Design B: create a by-pass for simultaneously loading gives the best performance and design C the worst. This was expected as vessels can be loaded from 06:00-22:00. There is enough available time to load vessels during the day and they do not need to stay overnight. In design C, loading of vessels is continuously interrupted for loading of trucks resulting in vessels not being fully loaded before the end of the day.

Figure 7.3: Results of On-Time-Delivery vessels for different input scenarios

The overall best performance to improve the outbound logistics was design B: creating a by-pass. This showed improvements to all KPI. For the worst scenario IPR, the average waiting time was only [redacted] minutes a decrease of 90.6%. The vessel turnaround time was [redacted] minutes, a decrease of 43.3%

7.3. Conclusion

8. What is the best design alternative for the developed scenarios to be implemented for Cargill?

It can be seen that all new SLO designs except for the Design D, the loss of production was reduced. This means that the disruptions were also reduced or completely removed. The overall best choice to reduce the disturbances is design B, creating a by-pass for simultaneously loading. The silo level was on average only 1.5% of the time filled above 70%. There were no production losses for either scenario. The next best solution is a tie between Design B and E.

For all design solutions the performance for the landside operations was improved. Simultaneously loading and a shorter changeover time almost completely eliminated the waiting time for trucks. However, the turnaround time for vessels and the OTD worsened. Furthermore, operating time-windows has a significant effect on the performance. Waiting in the scenario for no rain was reduced by more than 70%. However, in the scenario with longer periods of rain the OTD was 77.5%. If time-slots cannot be guarenteed this implementation will not be succesfull. Removing waste in the loading process also reduced the waiting times and turnaround times for trucks.

8
Conclusion and Recommendations

The following main research question is formulated based on the previous research objective:

> *How can the disturbances on the throughput of sunflower oil be reduced and the flexibility be increased by improving the outbound logistics of sunflower meal pellets at the Cargill Multiseed?*

The research question can be answered by following the DMADE structured framework starting with Define, Measure and Analysis of the current state, disturbances in the oil production were identified. It was found that the storage capacity was not large enough and the outbound logistics should be improved. In the Design phase new SLO designs were obtained by solving the storage capacity problems and removing constraints in the outbound logistics. With a discrete event simulation the models were evaluated through KPIs. In the Evaluate phase, the best improved design solutions to reduce the disturbances on the oil production were obtained by comparing the performance. Finally, recommendations for the best design to be implemented were given. The developed discrete event simulation model can be expended and adjustet to test new alternative design solutions to improve the performance of the outbound logistics and thus reduce the disturbances on the oil production. The discrete event simulation model can adjusted and extended to test new alternative design solutions to improve the performance of the outbound logistics and reducing the disturbances on the oil production process. This research fills the gap that exists in the literature about reducing disruptions to bulk goods by removing restrictions in the loading of the byproduct through the application of lean manufacturing and the theory of constraints. In addition, a discrete event simulation model was created to improve the loading of bulk goods.
An extensive answer was obtained by answering the research sub-questions and will now be briefly outlined.

1. What framework and methodologies can be used from literature to find and evaluate solutions to reduce disturbances on the production of sunflower oil?
The literature describes several process improvement methods, of these, The Theory Of Constraints, Lean Manufacturing and Total Quality Management are most commonly applied for improving logistics processes. Total quality management focuses on improving the quality for the customer. Lean manufacturing searches for non-value adding activities in the logic processes. The non-value adding processes can be categorized in one of the seven types of waste. After, removing the waste from the process, the logistic process as a whole should improve. Theory of constraints looks for bottlenecks that constrain the throughput of a system. After identification of the bottlenecks , they can be exploited, increased or completely removed. After removing the bottleneck; the continuous improvement cycle is restarted as a new bottleneck will be constraining the system.

2. What criteria can be used to assess the different solution alternatives?
The maximum production a plant can produce at the set rate is defined as the maximum theoretical tonnage (T_T). This is the maximum production capacity the plant can achieve. Losses in the

production can have various circumstances such as poor plant operations, unavailable products or insufficient storage space. The Production Loss (PL) the Operating Throughput Effectiveness (OTE) are metrics to compare the actual production with the theoretical production is (Muthiah and Huang, 2007).

For the delivery to the customer, the wishes of the customer should be mapped and converted to a set of goals. Planning and delivery are different processes and it is important to evaluate the performance separately. The performance indicators can be defined to take the right measures to optimize each process individually and the delivery as a whole to ultimately improve the customer satisfaction. In UNCAD (2016) and Parwani and No (2014),different performance indicators have been defined to measure the performance of the delivery to customers for landside and waterside processes. These are the turnaround time, waiting time and On-Time-Delivery. Turnaround time is defined as the moment of arrival to the moment of departure. Waiting time is the total time that a machine or vehicle is waiting before working on it. Another widely used KPI are operating costs or inventory holding cost. The utilisation factor is often used to measure the performance of equipment, resources, buffers or equipment (Meier et al., 2013). This indicates how much of the available time the machine is in use.

3. What is the current state of the oil production?
The production planning and sales in tactical planning lie within the commerce department stationed at the head office in Schiphol. They determine the production rate based on accurate forecasting of the price of oil and meal and other developments in the market. This business is margin driven; the plant should produce at maximum rate if the margin is positive. Cargill measures the performance of their production processes with the stability factor. For the months February through March, the stability factor for the refinery was [redacted]% and for the crush [redacted]%. The largest disturbance was the unavailable storage space in the silos. To eliminate the disruption, the input and output flows to and from the silo should be better aligned or the storage space should be increased.

4. How is the outbound logistic for SFMP organized?
A weekly schedule is sent to the customer and their respective transport company. The changes more often than not due to interruptions in the loading process (e.g. emergency breakdowns or rain). Vessels and trucks can be loaded on weekdays and in weekends only vessels are loaded. Trucks arrive at the Multiseed and register at the guard. Next, they are weighed and loaded. Vessels need to be inspected for loading can start. The arrival pattern of trucks is not evenly distributed, trucks arrive often arrive at the same time, at the beginning and near the end. There is a lot of waiting in the truck loading process. On average truck wait for [redacted] minutes before they are weighed. Vessels have priority over trucks because the effective loading is much faster, [redacted] MT/h compared to [redacted] MT/h. Uncertainties such as rain, emergency breakdowns or equipment malfunctions can interrupt the loading process and cause long delays.

5. What is disturbing the oil production and how can it be improved?
The little available storage space is the largest disturbance on the output of oil in the crush. By increasing the available space or increasing the output flow, these disturbances may be reduced. To identify possibilities for improvements to the output flow, a critical chain analysis was performed. This identified three bottlenecks in the outbound logistics:

1. The throughput capacity of the truck loading station
2. The throughput capacity of the vessel loading station
3. The available loading hours

The first step of the TOC continuous improvement cycle is to exploit the constraints. To identify how the constraints may be exploited lean Manufacturing was applied. Waiting and motion at the station were identified as waste. Removing the waste from the loading processes could increase the throughput at both stations.

6. What design alternatives can reduce disturbances on the oil production and improve the performance of the outbound logistics?
The disturbance may be reduced by solving the storage capacity problems. It was concluded that either the storage capacity should be increased, or the outbound logistics should be improved to increase the output. To increase the available storage space different possibilities exist. The most immediate design change would be to build an extra silo replace the current silos. Alternatively, a flexible storage could also be an option.

New SFMP Load Out design configurations are obtained when completing the remaining steps of the TOC continuous improvement cycle. First the constraints are exploited and if this is not sufficient the constraints should be elevated. Exploiting the constraints can be achieved by removing the waste that was found in the loading processes. The designs were evaluated for feasibility and costs. The four most promising SLO designs are: Design A: Increase the storage space; Design B: Create by-pass for simultaneously loading;Design C: Reduce changeover time to switch between trucks and vessels; Design D relocate safety-harness equipment outside of loading station with time-slots.

7. How can the design alternatives be modelled in a discrete event simulation?
From the literature, the model development paradigm consists of three main components; the system, conceptual model and computerised model. The system is a current situation or entity to be modelled. The conceptual model is a representation of the problem entity to be investigated and the computerized model is the implementation of the conceptual model in a computer simulation software package. The conceptual model uses flow charts to describe the system behaviour. This is then implemented in the discrete event simulation package Salabim. After creation, the model was validated and verificated. The design alternatives are simulated for 150 repetitions for four different input scenarios: Average Production (AP), Increased Production (IP), Average Production + Rain (APR) and Increased Production + Rain (IPR).

8. What is the best design alternative for the developed scenarios to be implemented for Cargill?
It can be seen that all new SLO designs except for the Design D, the loss of production was reduced. This means that the disruptions were also reduced or completely removed. The overall best choice to reduce the disturbances is design B, creating a by-pass for simultaneously loading. The silo level was on average only 1.5% of the time filled above 70%. There were no production losses for either scenario. The next best solution is a tie between Design B and E.

For all design solutions the performance for the landside operations was improved. Simultaneously loading and a shorter changeover time almost completely eliminated the waiting time for trucks. However, the turnaround time for vessels and the OTD worsened. Furthermore, operating time-windows has a significant effect on the performance. Waiting in the scenario for no rain was reduced by more than 70%. However, in the scenario with longer periods of rain the OTD was 77.5%. If time-slots cannot be guaranteed this implementation will not be successful. Removing waste in the loading process also reduced the waiting times and turnaround times for trucks.

8.1. Recommendations

From the results, it was found that creating a bypass to allow for simultaneously loading is the best design option to reduce the disturbances on the oil production and improve the performance of the outbound logistics. However, this design requires an extra operator to be present. Another possibility would be to instruct the truck drivers to operate the loading equipment themselves or automate the loading process. The second-best design option to reduce the production loss was to improve the throughput by using time slots and relocating the harness equipment to remove/attach the cover to a new station. Also, in this solution the performance of the outbound logistics improved. The third option is to increase its storage capacity this is a great solution to reduce disturbance on the oil production but does not give a good performance increase for truck and vessel loading.

8.2. Contributions to science

This research fills the gap that exists in the literature about reducing disruptions to the production of bulk goods by removing restrictions in the loading of the byproduct through the application of lean manufacturing and the theory of constraints. In addition, a discrete event simulation model was created to analyze and improve the loading of bulk goods.

8.3. Research limitations

One of the limitations of this study was the available data, from which the correct value could not immediately be derived. Much had to be remeasured or combined from different data sets. In the measurements of the loss in production, no distinction was made on the underlying cause such as rain or the failure of the machines, making it difficult to draw conclusions. More research and data collection can be done so that these can also be included. This research reduced its scope to focuses on removing the disturbances on the production caused by the full silos. Other disturbances such as the input restrictions could also improve the stability of the production process. The input scenarios only take rain into account as an interruption to the loading process, This excludes interruptions caused by machine or system failures that can also affect the loading process. Furthermore, research in different truck/boat ratios is not included, but it could be interesting to see what influence this has on the behaviour of the design solutions.

8.4. Future research

- Alternative SLO designs may be evaluated with the created simulation model.
- Besides full silos other disturbances on the oil were identified such as unavailable seed or utilities. More research can be done on these disturbances to increase the stability of the production process.
- Automation for selecting time-slots and documentation could further remove waste in the loading process and speed up the registration process.
- Research can be done on automation of the loading processes to increase the efficiency of the loading stations and replace the operator(s).
- New research could be done to investigate whether lowering the production could be beneficial to reduce the disturbances and additionally reduce operating costs on the outbound logistics.

A

Scientific paper

Reducing disturbances on the sunflower oil production at the Cargill Multiseed

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***Abstract*—This paper addresses a problem at Cargill Multiseed, where a gap exists between the desired performance of the production of sunflower oil and the current. This research is performed to improve the stability of the production process by removing the disturbances. After identifying the restrictions on the input and output of the production process, it was found that full meal silos were the largest disturbance. New design solutions were obtained by analyzing the current state and subsequently develop new design alternatives. A discrete event simulation model was developed to compare the performance of the new designs through the predefined KPIs. It was found that increasing the available storage space and improving the efficiency of the outbound logistics the disturbance on the oil production could be reduced. The best design solution was creating a by-pass that allows for simultaneously loading of trucks and vessels, which focuses on increasing the available loading hours.**

***Index Terms*—outbound logistics, production disturbance, storage capacity, discrete event simulation, theory of constraints, lean manufacturing**

I. Introduction

An oil production company is able to achieve more profit (from an operational perspective) by increasing their output by reducing disturbances on the production process or by decreasing their costs. The production process should be stable and keep on running. This research is conducted at Cargill sunflower seed crush the Multiseed' in the Amerikahaven in the harbour of Amsterdam, which is part of the business unit Cargill Agricultural Supply Chain(CASC) located at Schiphol Airport. A gap exists between the desired performance of sunflower oil and meal pellets production and the current performance. This research is performed to improve the stability of the production process and find solutions to remove the disturbances by identifying storage capacity problems and problems within the outbound logistics of sunflower meal pellets.

II. Method

A. Research approach

The research approach is based upon the DMADE method – Define, Measure, Analyse, Design, Evaluate. The DMADE approach is derived from the known Six Sigma methodology DMAIC method that consists of a study phase (Define, Measure, Analyse) and an improve phase (Improve, Control). However, this research will follow the improve step since there is no implementation in the real-world system. Instead of the “Improve and Control” steps, the ‘Improve’ phase is replaced by a ‘Design’ phase, where future state scenarios are developed for improvements and also tested. During the Evaluate phase, the impact of the different scenarios on assets and resources for improvement are evaluated.

B. Theory of constraints

The theory of constraints (TOC) was first presented by Goldratt in his book 'The goal' in 1984, it hands companies and organizations a tool to help achieve their goal. The goal of an organisation can be measured with the operational measurements throughput, inventory and operating expenses. TOC focuses on removing the system’s constraint(s), it presumes that each system must have at least one constraint that determines its performance [1]. The presence of constraint(s) provides an opportunity to improve the system’s performance. By exploiting and/or eliminating the constraints, the efficiency of the whole system improves. The TOC continuous improvement process consists of five process steps [2].

1) *Identify the system’s constraint(s)*
2) *Decide how to exploit the system’s constraint(s)*
3) *Subordinate everything else to the above decision*
4) *Elevate the system’s constraint(s)*
5) *If the constraint was broken in the previous steps, repeat the process from step 1*

C. Lean Manufacturing

Lean manufacturing (LM) is a constant improvement process and focuses on eliminating non-value adding activities and increasing the value of the customer, at the lowest possible cost [3]. LM was introduced in [4], and finds its origin in lean principles developed by Toyota. LM aims to improve flow, process times, throughput times, inventories, defects and overall equipment effectiveness [5]. Seven types of waste exist, the TIMWOODS: Transport, Inventory, Motion, Waiting, Over-production, Over-processing, Defects and Skills. A Value Stream Map (VSM) is a tool from lean that can be used to identify wasteful activities. The VSM shows the (information and product) flows and processes in a system. All wasteful activities should be removed to achieve a better performance of the system as a whole. After implementation, the improvement process is repeated to identify new wasteful activities.

D. Discrete Event Simulation

Computer based simulations are used when the system is complex, it is difficult to analyse or when there are many stochastic variables and uncertainties [6]. Two modelling approaches often encountered in analyzing logistic systems are Discrete Event Simulation (DES) and System Dynamics (SD). The capability to model uncertainties and stochastic behaviour of supply chains and logic systems makes DES a suitable tool. Contrary to continuous modelling approaches, the system state changes at discrete time steps. Events take place instantaneously and subsequently change the system state from one to another. The main benefits of this approach are the shortened simulation time and reduced computing power.

A DES model is constructed using five fundamental building blocks Entities, Queues, Activities and Resources [7]. For this research, the DES Salabim package was chosen to create a model. Salabim is an open source DES software package developed in Python by Ruud van der Ham. Important functionalities in Salabim are hold, wait, trace and animations. Salabim's main elements are Components, Resources, Queues, Distributions, Condition and Animations.

[8] presented a model development paradigm to create a computer simulation model. It consists of three main components; the system, conceptual model and computerised model. System is the current situation or entity to be modelled, the conceptual model is a representation of the problem entity to be investigated and the computerized model is the implementation of the conceptual model in a computer simulation software package. Verification and validation of a computer simulation model is required to verify that it is a correct representation of the problem and that it is reasonable for the intended purpose.

E. Key Performance Indicators

Organizations use key performance indicators to measure the quality and performance of their services and products. Monitoring these allows an organization to reveal its performance at all levels and assess whether it improved or deteriorated and where it needs to focus in an improvement process.

Production Key Performance Indicators: To assess the stability of the production, two performance indicators can be used the Process Stability [%] or Stability Factor [%] [9], [10]. The Stability Factor measures the variability of a production processes. The maximum production a plant can produce at the set rate is defined as the maximum theoretical tonnage (T_T), expressed in relation to the unit of time: an hour, a day, a week, a month or a year. Losses in the production can have various circumstances such as poor plant operations, an unbalance production line, unavailable products or insufficient storage space [11]. The Operating Throughput Effectiveness (OTE) is a metric to compare the actual production of a plant with the theoretical production.

Delivery Key Performance Indicators: For the delivery to the customer, the wishes of the customer should be mapped and converted to a set of goals. Planning and delivery are different processes and it is important to evaluate the performance separately. For both processes, the performance indicators can now be defined to take the right measures to optimize each process individually and the delivery as a whole to ultimately improve the customer satisfaction.

[12] [13] defined several performance indicators for understanding and controlling the performance of the delivery and handling for land and water operation such as turnaround time, waiting time and On-Time-Delivery. Turnaround time is defined as the moment of arrival to the moment of departure. Waiting time is the total time that a machine or vehicle is waiting before working on it. Another widely used KPI are operating costs of a process. A widespread corporate vision is that costs should be minimized, and the quality or output maximized. The utilisation factor measures the performance of equipment, resources or buffers [9]. It measures how much of the available time the machine is in use. Machines that are at rest do not add value and are waiting which is waste. For storage, the utilization factor is defined as the average capacity present in the storage over a period of time. A summary of the KPIs found in the literature is given in Table I

III. Define

Sunflower seeds are crushed to extract crude sunflower oil (CSFO) and separate the oil from the meal. Sunflower meal (mainly the crushed hulls of the seeds) is a by-product from the crushing process; it is moulded into

TABLE I
KEY PERFORMANCE INDICATORS

KPI	Unit	Source
Stability Factor	[%]	[10]
Operating Throughput Effectiveness	[%]	[11]
Production Loss	[MT]	[14]
Average Waiting Time	[min]	[13]
Average Turnaround Time	[min]	[13]
On-time-Delivery	[%]:	[9]
Utilization Factor	[%]	[9]
Costs	[$]	[15]

pellets and sold to farmers who mix them into their animal feed. Sunflower meal pellets (SFMP) contain healthy fibers and protein. Sunflower seeds contain around 44% CSFO and 56% SFMP. Around [redacted]% of the CSFO is refined, the remaining is traded on the market. Refining of oil removes the impurities present in the oil or reduce them to a level that their harmful effects are to a minimum and the oil is suitable for human consumption [16]. The production of sunflower oil and meal pellets may be disturbed by restrictions on the available resources in the input or the output.

Production planning and sales lies within the commerce department stationed at the head office in Schiphol. The production is margin driven, the rate is determined based on accurate forecasting of the price of oil and meal and other developments in the market. Sunflower seed, oil and meal are agricultural commodities traded on the commodity market. The supply of seeds is subject to random supply shocks, such as droughts, extreme rainfall, diseases or war [17]. Harvest takes place during a short period once a year. Especially the months after harvest, the margins are very good. Sudden shortages or oversupply in the market can cause price instabilities. Also, price differences of substitute products can affect the price of CSFO, RSFO and SFMP.

Sunflower seeds are imported from growing countries e.g. Bulgaria, Romania or Hungary. A seagoing vessel transports the seeds to the Multiseed where they are discharged and stored at the two flat storages. From there, seeds are reclaimed and send to the crush, the CSFO is stored in large storage tanks and the SFMP is stored in the two silos next to the quay. Customers usually contract a third-party transport company to collect their products. The supply planner, stationed at the main office in Schiphol, distributes the transport planning with the time, day and order size to the customers and the respective transport companies.

Loading takes place at the Multiseed, SFMP and RSFO are loaded to trucks and vessels, CSFO is only loaded to vessels. Around [redacted]% of SFMP is loaded to vessels, the remaining to trucks. Interruptions in the loading process due to e.g. rain, equipment failures or unavailable transport can restrict the output flow. Causing the silos or storage tanks to fill up, which results in disruptions to the oil production. Vessels cannot be loaded during rain; water accelerates germination and plants start to grow on the meal. To prevent the production to slow down or even stopped, additional storage space is acquired. The costs for the additional storage capacity increase the operating costs. It was observed that trucks often have to wait for vessels to finish loading. One of the reasons is that loading to vessels has priority over truck loading because of the higher loading capacity. On average trucks were waiting for [redacted] minutes at the parking area. Trucks that have to wait for more than two hours are entitled to a compensation.

IV. Analysis

From the current state measurements, it was discovered that the 'full silos' was the largest disturbance on the production of CSFO as shown in Table II. Especially in the months November–March, when the production rate is high because of the higher margins more storage capacity was acquired. Using the TOC thinking process, 'What to change?', 'What to change to?' and 'How to cause the change?'. It was found that the disturbance, 'full silos' can be caused by a too high production rate, insufficient storage capacity or the output flow that is not high enough. Evaluating the effects on reducing the production rate requires extensive knowledge on market trading and financial tools and is out of scope of this research. Therefore to eliminate the disturbance 'full silos', the storage capacity should be increased, or the output flow should match or exceed the production rate.

TABLE II
PRODUCTION LOSS OF CRUSH DUE TO DISTURBANCES

Description	Perc. of total output delay
Input restriction	
No Feed (Raw Material, Seed)	9.29%
No Feed (Raw Material, Seed) – Delayed new crop	10.01%
No Feed (Raw Material, Seed) Logistics (Trucks, Barges, ...)	22.10%
No People	7.82%
No Utilities	0.17%
Other	1.62%
Output restriction	
Full meal tanks	**46.74%**
Full oil tanks	2.26%
Total	**100.00%**

To identify possibilities for improvement to the output of SFMP, a critical chain analysis from the theory of constraints was applied. Three constraints were identified:

1) The throughput capacity of the truck loading station
2) The throughput capacity of the vessel station
3) The available operating hours

The next step in the TOC improvement cycle is finding how the constraints may be exploited. Exploiting focuses on how the constraint can be operated more efficiently with the current resources so that the constraining resource is operating at its maximum throughput. To identify how the loading process constraints may be exploited LM was applied. All activities in the loading process were recorded whether they add value or are non-value adding. Non-value adding activities are waste and should be removed from the process. The time or capacity spend at these activities could be more useful when used for value-added processes.

Activities are divided in Value Adding (VA), Indirect Value Adding (IVA) and Non Value Adding (NVA). Each activity is listed in Table III with a short description, the duration and if the activity is non value adding, the type of waste. In addition to the NVA activities found in the loading process for trucks (activities 1–7), some additional wastes were identified. These are depicted in activities I–III. Documentation can be classified as IVA, the step is step is necessary to perform but does not add direct value to the customer. Activities 2, 7, I, II and III are classified as NVA and should be eliminated or reduced from the loading process.

TABLE III
WASTE IN TRUCK LOADING PROCESS

	Activity	Description	Dur. [min]	Type of activity	Type of waste
1.	Drive in and out loading station	Trucker positions his truck below the loading pipe and leaves		IVA	-
2.	Remove cover	Driver removes roof cover from truck		**NVA**	Waiting
3.	Documentation	Driver hands papers to operator		IVA	-
4.	Walking	Walking between office and loading equipment		**NVA**	Motion
5.	Loading	Loading time varies for size of truck		VA	-
6.[1]	Repositioning	Sometime trucks need to be repositioned below the pipe exit		**NVA**	Motion
7.	Attach cover	Driver attaches roof cover over the truck		**NVA**	Waiting
I	Waiting in front of station	If the station is still occupied, trucks need to wait before loading	NA	**NVA**	Waiting
II	Waiting for next truck to arrive	Sometimes no truck is available for loading and operators need to wait for the next to arrive	NA	**NVA**	Waiting
III	Other: e.g. coffee breaks, toilet visit	Various reasons mostly private	NA	**NVA**	Motion

TABLE IV
WASTE IN VESSEL LOADING PROCESS

	Activity	Description	Dur. [min]	Type of activity	Type of waste
1.	Take sample	A sample of SFMP is taken and send to a lab for quality control		VA	-
2.	Documentation	Before actual loading some paperwork is filed		VA	-
3.	Opening cargo compartment	The captain of the vessel removes the cover of the cargo compartment		IVA	-
4.	Loading	Actual loading of SFMP to the vessel	NA	VA	-
5.	Repositioning	During loading the vessel is often repositioned to ensure an even weight distribution	NA	**NVA**	Motion
6.	Closing cargo compartment	The captain of the vessel closes the cover of the cargo compartment		IVA	-
I	Waiting for surveyor	Sometime the surveyor is late. Loading cannot start until he arrives		**NVA**	Waiting
II	Waiting for good weather conditions	When it rains loading is stopped and resumed again when it is dry	NA	**NVA**	Waiting
III	Wait for vessel arrival have to wait	Sometimes vessels are delayed, and operators	NA	**NVA**	Waiting
IV	Other: e.g. coffee breaks, toilet visit	Various reasons mostly private	NA	**NVA**	Motion

Waiting was found to be the largest type of waste in the truck loading process. Trucks queuing at the parking area are standing still and are not being worked on. Also, during the time the roof cover is removed/reattached the loading station is occupied and the operator is waiting. Furthermore, it was observed was that trucks do not arrive equally distributed over the loading hours but often arrive at the same time at start and near the end. In the time between the next truck arrival, operators are waiting. Another type of waste found was motion. Due to some design faults, trucks with semi-trailers need to be repositioned below the exit of the loading pipe to fill towards the outer edges.

V. DESIGN

It was found that either the available storage space needed to be expanded or the output flow needed to increase. To expand the available storage space, different possibilities exist. The most immediate design change would be to build an extra silo next to the current silos. Alternatively, the silos could be replaced with new silos that have a higher capacity. Both are long-term design changes that are expensive investments. A flexible storage solution was also considered to be an adequate alternative. For example a floating storage that is found in the oil industry or placing empty containers near the quay.

New SFMP Load Out design configurations were obtained by completing the remaining steps of the TOC

[1] Only for trucks with semi-trailer

continuous improvement cycle. First the constraints were exploited and when this is was not sufficient the constraints were elevated. Exploiting the constraints was achieved by removing the waste that was found in the loading processes. Waiting was identified as the largest type of waste in the truck and vessel loading processes. By removing the waste in the loading processes, it is possible to make better use of the resources and increase the throughput. For example, waiting of operators or trucks queueing in front of the loading station can be eliminated by ensuring that trucks arrive equally distributed. When there is always a truck present for loading, the throughput of the truck station should increase. A common practice to remove congestion in systems and spread the traffic load is to implement time-slots. Examples in the industry can found at container terminals, train tracks or airports

Elevating the constraints may require alternations to the current loading equipment. For example, truck drivers remove and attach the roof cover inside the loading station, in the meantime no loading can take place. Relocating the safety harness equipment outside of the station to a new roofed station could reduce waste inside the loading station and increase the throughput. The third constraint, the available loading hours, can be elevated by stretching the loading hours or implement a night-shift. A non-exhaustive list of possible design alterations is given in Table V.

TABLE V
ALTERNATIVE SLO DESIGN CONFIGURATIONS

Sol.	Description
1.	New silo or increased silo
2.	Flexible storage space
3.	A new apron feeder with higher throughput capacity
4.	Build a second loading station for trucks
5.	Build a shed and load trucks from the shed with a shovel
6.	A new apron feeder that reaches all edges of the truck
7.	Reduce changeover time by altering conveyor configuration
8.	Automated cover removal/attachment
9.	Automated registration and documentation
10.	Automated extendable loading pipe
11.	Build a second vessel station
12.	Change equipment with an extendable pipe that can be positioned in a rectangular instead of a circular motion
13.	Build extendable roof
14.	Create a by-pass to allow simultaneously loading
15.	Increase loading hours
16.	Relocate safety harness equipment outside loading station
17.	Operate time-slots
18.	Place coffee maker and sticker maker at station

A. Choose new SLO designs

In consultation with the plant supervisor and the daily operation coordinator, a selection was made from the SLO designs in Table V to be evaluated in the simulation model. The various design alternatives were discussed on their feasibility and cost. The implementation of time-slots was considered not to be a sufficient solution on its own, truck drivers still need to wait if the loading speed of trucks was not increased. Also, relocating the safety harness to a new station was expected to not be sufficient. To solve, the problems in both design solutions they were combined. The four SLO designs that were chosen to be investigated are: Design A: Increase the storage space; Design B: Create by-pass for simultaneously loading; Design C: Reduce changeover time to switch between trucks and vessels; Design D relocate safety-harness equipment outside of loading station with time-slots. In designs B and C, the available loading hours do not need to be divided in separate truck and vessels loading hours. Trucks can come any time during the day and are immediately served upon arrival.

B. Discrete event simulation

In order to compare the performance of new design configurations a discrete event simulation model was developed using the model design paradigm. The model was adapted for the each design solution, its performance was measured with predefined KPIs. Different simulation runs are achieved by changing the seed number in the model. A different seed number changes the input parameters such the arrival rate or the time spend at an activity. The conceptual model in Figure 1 is a representation of the problem entity to be investigated. The conceptual model was then implemented in the discrete event simulation software package Salabim. After creation, the model was validated and verificated. Four input scenarios were defined to see how the system behaves under different input. It was found that rain is one of the largest interruptions on the vessel loading process and one of the main reasons additional storage space was required. Therefore, the model will be evaluated for a dry period and a period with rain. The defined input scenarios are Average Production (AP), Increased Production (IP), Average Production + Rain (APR) and Increased Production + Rain (IPR).

C. Experimental plan

Warm up period and simulation run time: Simulations may be classified in terminating (i.e. closing of a supermarket) and non-terminating. Non-terminating simulations reach a steady-state after a certain time period. The developed model is a terminating as the terrain closes for the night from 22:00 to 06:00. All truck entities should have left the system and the queues must be empty. Only vessels are allowed remain in the system, no steady-state will be reached. In the real-world, the

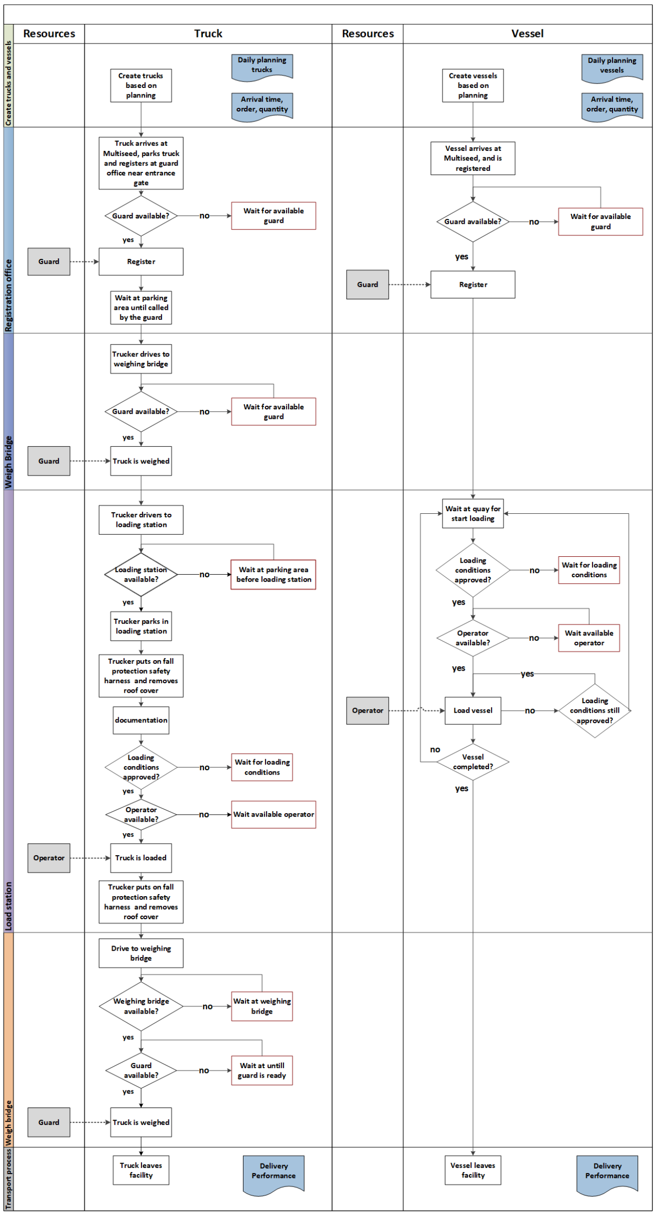

Fig. 1. Conceptual model of discrete event simulation

planner normally creates a planning for just one week in advance, the pick-up pattern tends to repeat itself every week. To evaluate, how the system performs after a month of running without intervention of the planner the system was evaluated for a standard month of 28 days or 4 weeks. A planning was created for four different weeks based on actual planning data, where the total sum of the output was close to the production.

Number of replications: The required number of replications is influenced by the mean and the standard deviation and the results may be influenced by the stochastics input data. A student-t distribution can be used to determine the likeliness that the result lies within a range of the true mean. The formula in Equation **??** was used to calculate the minimum required experiments. For this simulation the error should be below 5%, this gave a minimum of 97.3 repetitions. To assure that the error is always below 5%, the simulation was repeated for 150 repetitions.

$$N(m) = \left(\frac{S(m) t_{m-1,1-\alpha/2}}{\bar{X}(m)\epsilon} \right)^2 \tag{1}$$

Experiments: All new SLO designs were evaluated four the four input scenarios. The current situation functioned as the 'base case' to evaluate and compare the performance the new design solutions. The experimental plan is given in Table VI.

TABLE VI
EXPERIMENTAL PLAN

SLO Designs	Storage	Loading hours	Truck arr. rate	Operators	Change-over time
Current	[redacted]	Divided	Emp.	1	20
Design A	[redacted]	Divided	Emp.	1	20
Design B	[redacted]	All day	Emp.	2	20
Design C	[redacted]	All day	Emp.	1	5
Design D	[redacted]	Divided	Unif.	1	20

VI. EVALUATE

A. Results

Disturbance on production: The main objective of this research is to reduce the disturbances on the oil production. This should be achieved by keeping the storage from filling up. The most important KPIs to measure the disturbances are the Production Loss and Silo Utilization factor above 70%. In the current system the Production loss in the IPR scenario was around [redacted] MT and the silos were filled above 70% for 17.5 % of the time. Thus, making the system susceptible to interruptions in the loading process. It was found that in all new SLO designs, the loss of production was reduced or removed. Meaning that disruptions on oil were also reduced. Design B is the best design solution to remove the disturbances on the oil production. No production loss was recorded, and the silos were filled above 70% for only 1.5% of the time. Designs B and D also eliminated the loss of production, but utilization was slightly higher compared to design B, 2.5% and 2.6%. In design C the utilization was increased to 34.9%.

Outbound logistics performance: For all design solutions the performance for the landside operations was improved. In designs A, B, C and D the waiting time was reduced with 42.0%, 90.6%, 86.7% and 81.3%

respectively. However, in design C the turnaround time for vessels increased with 58.6% and the OTD for vessels was reduced with 15%. Furthermore, operating time-slots has a significant effect on the performance. Waiting in the scenario for no rain was reduced by more than 70%. However, in the scenario with longer periods of rain the OTD was 77.5%. If time-slots cannot be guaranteed this implementation will not be succesful. Removing waste in the loading process also reduced the waiting times and turnaround times for trucks.

B. *Conclusion*

By following the DMADE structured framework starting with Define, Measure and Analysis of the current state, disturbances in the oil production were identified. It was found that the storage capacity was not large enough and the outbound logistics should be improved. In the Design phase new SLO designs were obtained by solving the storage capacity problems and removing constraints in the outbound logistics. With a discrete event simulation the models were evaluated through KPIs. In the Evaluate phase, the best improved design solutions to reduce the disturbances on the oil production were obtained by comparing the performance. Finally, recommendations for the best design to be implemented were given. The developed discrete event simulation model can be expended and adjustet to test new alternative design solutions to improve the performance of the outbound logistics and thus reduce the disturbances on the oil production. The discrete event simulation model can adjusted and extended to test new alternative design solutions to improve the performance of the outbound logistics and reducing the disturbances on the oil production process.

C. *Recommendations*

From the results, it was found that creating a bypass to allow for simultaneously loading is the best design option to reduce the disturbances on the oil production and improve the performance of the outbound logistics. However, this design requires an extra operator to be present. Another possibility would be to instruct the truck drivers to operate the loading equipment themselves or automate the loading process. The second-best design option to reduce the production loss was to improve the throughput by using time slots and relocating the harness equipment to remove/attach the cover to a new station. Also, in this solution the performance of the outbound logistics improved. The third option is to increase its storage capacity this is a great solution to reduce disturbance on the oil production but does not give a good performance increase for truck and vessel loading.

D. *Contributions to science*

This research fills the gap that exists in the literature about reducing disruptions to the production of bulk goods by removing restrictions in the loading of the byproduct through the application of lean manufacturing and the theory of constraints. In addition, a discrete event simulation model was created to analyze and improve the loading of bulk goods.

E. *Research limitations*

One of the limitations of this study was the available data, from which the correct value could not immediately be derived. Much had to be remeasured or combined from different data sets. In the measurements of the loss in production, no distinction was made on the underlying cause such as rain or the failure of the machines, making it difficult to draw conclusions. More research and data collection can be done so that these can also be included. This research reduced its scope to focuses on removing the disturbances on the production caused by the full silos. Other disturbances such as the input restrictions could also improve the stability of the production process. The input scenarios only take rain into account as an interruption to the loading process, This excludes interruptions caused by machine or system failures that can also affect the loading process. Furthermore, research in different truck/boat ratios is not included, but it could be interesting to see what influence this has on the behaviour of the design solutions.

F. *Future research*

- Alternative SLO designs may be evaluated with the created simulation model.
- Besides full silos other disturbances on the oil were identified such as unavailable seed or utilities. More research can be done on these disturbances to increase the stability of the production process.
- Automation for selecting time-slots and documentation could further remove waste in the loading process and speed up the registration process.
- Research can be done on automation of the loading processes to increase the efficiency of the loading stations and replace the operator(s).
- New research could be done to investigate whether lowering the production could be beneficial to reduce the disturbances and additionally reduce operating costs on the outbound logistics.

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B
Data

B.1. Truck arrival

Figure B.1: Truck arrival distribution for weekdays. From left to right, top to bottom: Monday, Tuesday, Wednesday, Thursday, Friday

B.2. Vessel arrival

Figure B.2: Truck arrival distribution for weekdays. From left to right, top to bottom: Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday

C

Discrete event simulation model

This chapter provides a more detailed description of the model design. First, it describes the Salabim software package used to design the model. Next if gives a summary of the functionalities that are present. Next, the implementation of the model in Salabim and the components in the model are given. This appendix gives a

C.1. Salabim

The software package Salabim will be used to create a discrete event simulation model of the Multiseed. Salabim was developed by Ruud Harms, it is an open source package build in Python. Python offers many other packages that can be used alongside Salabim. Python is a modern programming language that is very popular in the field of engineering and is open source. The reviewer has some experience with the programming language and wanted to get better acknowledge with the language. Salabim was founded with the same working principles as Thomas and Must. It includes similar functionalities to Thomas such as *hold*, *standby* and *wait*. Pysim, another discrete event simulation in Python lack these functionalities. Furthermore, it comprises queue handling, resources, statistical sampling and monitoring. Some of the important functionalities within Salabim are listed below.

activate: Activate is the way to turn a data component into a live component. If you do not specify a process, the generator function process is assumed

hold: Hold is the way to make a, usually current, component scheduled.

passivate: Passivate is the way to make a, usually current, component passive. This is essentially the same as scheduling for time=inf

cancel: Cancel has the effect that the component becomes a data component.

standby: Standby has the effect that the component will be triggered on the next simulation event

request: Request has the effect that the component will check whether the requested quantity from a resource is available. It is possible to check for multiple availability of a certain quantity from several resources. By default, there is no limit on the time to wait for the resource(s) to become available.

wait: Wait has the effect that the component will check whether the value of a state meets a given condition.
available. It is
possible to check for multiple state

interrupt: With interrupt components that are not current, or data can be temporarily be interrupted. Once a resume is called for the component, the component will continue

resume: Resumes interrupted components

C.2. Animations

Animations are a very powerful when creating a discrete event simulation model. It can help visualize the model behaviour and aid in getting a better understanding of the model. Furthermore, it can help making outsiders understand what is happening in the simulation. Animations are also a great tool in the verification of the simulation model. Visualizing queues and elements can help determine whether the model follows the designed logic. Faults and errors in the simulation can be more easily discovered. Salabim includes many functionalities to create animations, including texts, graphs, queues, states and elements. Graphs can show how many trucks are waiting or how long trucks have been waiting on average. States can be active, passive or other. The current state may be visualized with a colour, or text de scription. Furthermore, the Salabim package monitors queues and states and provide animation to visualize the queue statistics. The graphic user interface that was created for the simulation model is shown in Figure C.1. From left to right and top to bottom the visible elements are interaction buttons, the simulation time, length of truck waiting queue, truck and vessel planning. The bottom halve shows an animation of the model components, resources and states. When a component is active it is coloured red.

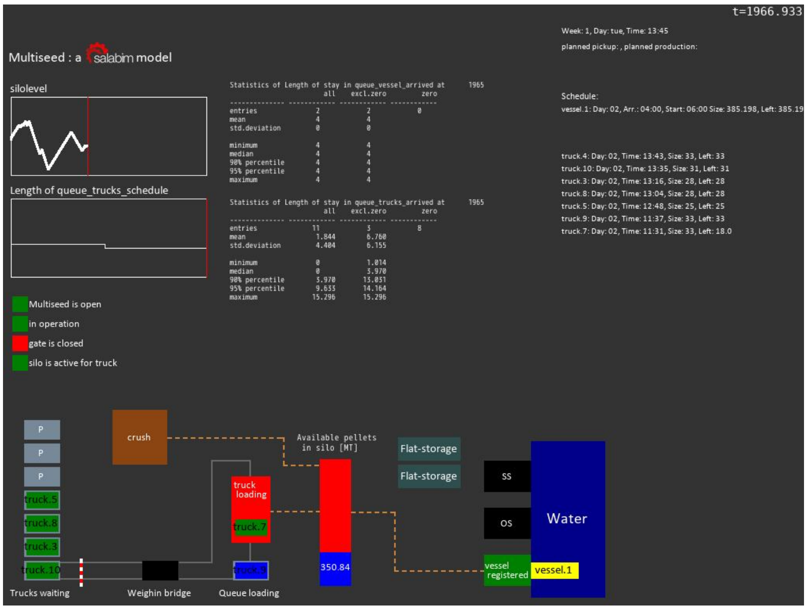


Figure C.1: Graphic User Interface with animation of simulation model

C.3. Implementation

Components are the key elements of Salabim simulations. The model consists of seven active components and one data component the silo. The components are visualized with rectangle boxes. The crush is a green box and is activated on each predetermined time-step. This fills the silo with SFMP. For modelling of the continuous behaviour of the bulk material flows from the crush to the silo and from the silo to the vessel and truck station the concept in Fiorini et al. (2007) is applied. The states are updated at every new time-step. All components, resources, queues, states and distributions in the model are listed below.

Resources: *Operators, Guard, LoadingEquipment, Silo*

Components: *Truck, Vessel, RegistrationOffice, WeighBridge, TruckLoadStation, VesselLoadStation, Crush, Silo*

Queues: *ArrivalTrucksQueue, WaitingTrucksQueue, WeighingTrucksQueue, FinishedTrucksLoadingQueue, ParkingLoadingQueue, TruckLoadingQueue, ArrivingVesselQueue, VesselIdleQueue, VesselLoadingQueue*

States: *silo_state, multiseed_state, operating_state, silo_state*

Distributions: *truckArrival, weighTime, coverRemovalTime, coverAttachmentTime, timeBetweenRain, rainDuration*

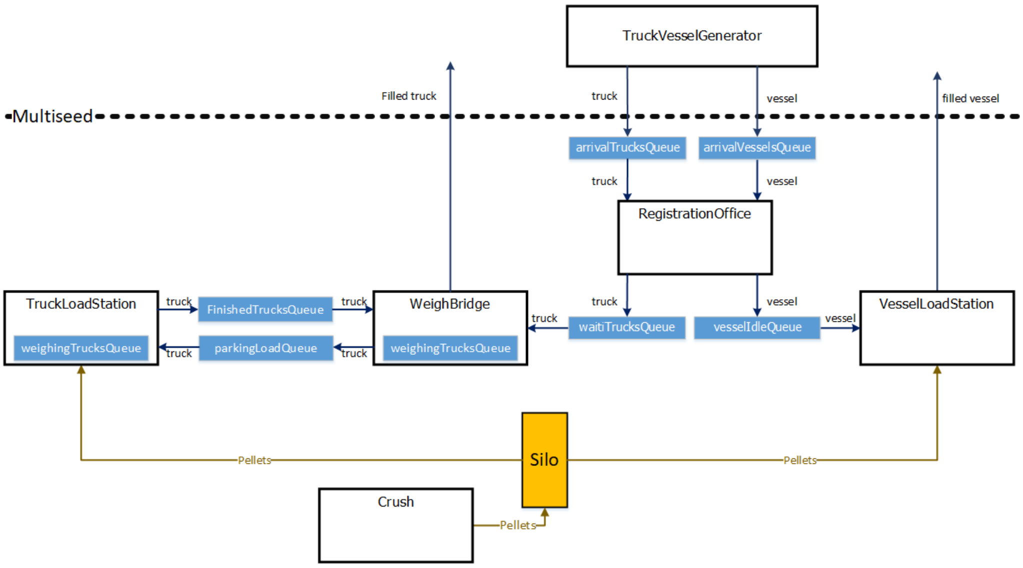


Figure C.2: Meta-model of simulation in Salabim

C.4. Arrival time distributions

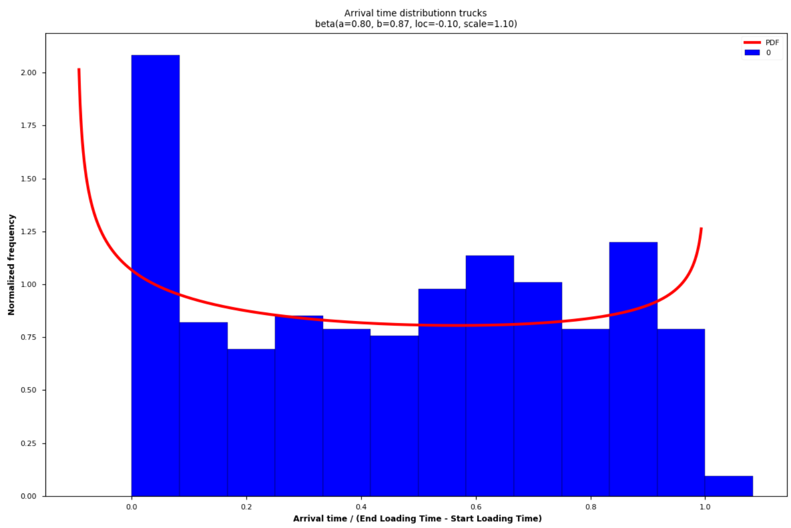


Figure C.3: Truck arrival distribution

C.5. Results

Figure C.4: Comparison waiting time trucks for different input scenarios

Figure C.5: Comparison OTD vessels for different input scenarios

C.6. Planning for different production scenarios

Table C.1: Normal truck and vessel planning

	Day	# trucks	vessels [MT]		truck times	vessel times
week 1:	mon	[redacted]	[redacted]	[redacted]	11:00 - 16:30	06:00 - 11:00, 16:30 - 22:00
	tue	[redacted]	[redacted]	[redacted]	10:00 - 17:00	06:00 - 10:00, 17:00 - 22:00
	wen	[redacted]	[redacted]	[redacted]	10:00 - 17:30	06:00 - 10:00, 17:30 - 22:00
	thu	[redacted]	[redacted]	[redacted]	11:00 - 17:00	06:00 - 11:00, 17:00 - 22:00
	fri	[redacted]	[redacted]	[redacted]	10:00 - 16:00	06:00 - 10:00, 16:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 2	mon	[redacted]	[redacted]	[redacted]	11:00 - 15:30	06:00 - 11:00, 15:30 - 22:00
	tue	[redacted]	[redacted]	[redacted]	10:00 - 16:30	06:00 - 10:00, 16:30 - 22:00
	wen	[redacted]	[redacted]	[redacted]	10:00 - 17:30	06:00 - 10:00, 17:30 - 22:00
	thu	[redacted]	[redacted]	[redacted]	10:00 - 16:30	06:00 - 10:00, 16:30 - 22:00
	fri	[redacted]	[redacted]	[redacted]	10:00 - 16:00	06:00 - 10:00, 16:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 3	mon	[redacted]	[redacted]	[redacted]	06:00 - 12:00	12:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	10:00 - 16:30	06:00 - 10:00, 16:30 - 22:00
	wen	[redacted]	[redacted]	[redacted]	10:00 - 17:00	06:00 - 10:00, 17:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	12:00 - 22:00	06:00 - 12:00
	fri	[redacted]	[redacted]	[redacted]	10:00 - 15:00	06:00 - 10:00, 15:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 4	mon	[redacted]	[redacted]	[redacted]	10:00 - 15:00	06:00 - 10:00, 15:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	10:00 - 16:30	06:00 - 10:00, 16:30 - 22:00
	wen	[redacted]	[redacted]	[redacted]	10:00 - 17:00	06:00 - 10:00, 17:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	10:00 - 17:30	06:00 - 10:00, 17:30 - 22:00
	fri	[redacted]	[redacted]	[redacted]	06:00 - 12:00	12:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	

Table C.2: New planning with increased truck and vessel loading hours

	Day	# trucks	vessels [MT]		truck times	vessel times
week 1:	mon	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	wen	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	fri	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 2:	mon	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	wen	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	fri	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 3:	mon	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	wen	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	fri	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]		06:00 - 22:00
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 4:	mon	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	wen	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	fri	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	

Table C.3: Total production and pick-up for increased production scenario

Table C.4: Increased production truck and vessel planning

	Day	# trucks	vessels [MT]		truck times	vessel times
week 1:	mon	[redacted]	[redacted]	[redacted]	11:00 - 16:30	06:00 - 11:00, 16:30 - 22:00
	tue	[redacted]	[redacted]	[redacted]	10:00 - 17:00	06:00 - 10:00, 17:00 - 22:00
	wen	[redacted]	[redacted]	[redacted]	10:00 - 17:30	06:00 - 10:00, 17:30 - 22:00
	thu	[redacted]	[redacted]	[redacted]	11:00 - 17:00	06:00 - 11:00, 17:00 - 22:00
	fri	[redacted]	[redacted]	[redacted]	10:00 - 16:00	06:00 - 10:00, 16:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]		06:00 - 22:00
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 2	mon	[redacted]	[redacted]	[redacted]	11:00 - 15:30	06:00 - 11:00, 15:30 - 22:00
	tue	[redacted]	[redacted]	[redacted]	10:00 - 16:30	06:00 - 10:00, 16:30 - 22:00
	wen	[redacted]	[redacted]	[redacted]	10:00 - 17:30	06:00 - 10:00, 17:30 - 22:00
	thu	[redacted]	[redacted]	[redacted]	10:00 - 16:30	06:00 - 10:00, 16:30 - 22:00
	fri	[redacted]	[redacted]	[redacted]	10:00 - 16:00	06:00 - 10:00, 16:00 - 22:00
	sat	0				06:00 - 22:00
	sun	0				06:00 - 22:00
week 3	mon	[redacted]	[redacted]	[redacted]	06:00 - 12:00	12:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	10:00 - 16:30	06:00 - 10:00, 16:30 - 22:00
	wen	[redacted]	[redacted]	[redacted]	10:00 - 17:00	06:00 - 10:00, 17:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	12:00 - 22:00	06:00 - 12:00
	fri	[redacted]	[redacted]	[redacted]	10:00 - 15:00	06:00 - 10:00, 15:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]		06:00 - 22:00
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 4	mon	[redacted]	[redacted]	[redacted]	10:00 - 15:00	06:00 - 10:00, 15:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	10:00 - 16:30	06:00 - 10:00, 16:30 - 22:00
	wen	[redacted]	[redacted]	[redacted]	10:00 - 17:00	06:00 - 10:00, 17:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	10:00 - 17:30	06:00 - 10:00, 17:30 - 22:00
	fri	[redacted]	[redacted]	[redacted]	06:00 - 12:00	12:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	

Table C.5: Increased production truck and vessel planning and extended hours

	Day	# trucks	vessels [MT]		truck times	vessel times
week 1:	mon	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	wen	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	fri	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 2	mon	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	wen	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	fri	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 3	mon	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	wen	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	fri	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
week 4	mon	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	tue	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	wen	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	thu	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	fri	[redacted]	[redacted]	[redacted]	06:00 - 17:00	06:00 - 22:00
	sat	[redacted]	[redacted]	[redacted]	06:00 - 22:00	
	sun	[redacted]	[redacted]	[redacted]	06:00 - 22:00	

Table C.6: Total production and pick-up for increased production scenario

[redacted]

C.7. Comparison Salabim and Tomas

Google Discussiegroepen

Re: Salabim functionality in comparison with Tomas

Ruud van der Ham 5-okt-2018 18:36
Gepost in de groep: **salabim**

```
Please find below a comparison of salabim and Tomas, two DES packages.

This overview is doubtless biased (the author is the core developer of salabim)
and may contain incorrect
or incomplete information. Other contributors, particularly Tomas users and
developers, are invited to update
the information given below.

Unavoidably, this overview is also a comparison between Delphi/Pascal and
Python.

General
=======
The DES packages salabim and Tomas are quite similar, not in the least because
they are both more or less derived
from Must (by Ruud van der Ham, the author of salabim).

Basic process functionality
===========================
The basic process functionality is comparable with some terminology
differences:

salabim                                  Tomas
---------------------------------------- ------------------------------------
yield activate for current component      N/A
activate for other component             Resume, Start
yield passivate for current component    Suspend
passivate for other component            N/A
yield hold for current component         Hold
hold for other component                 N/A
yield cancel for current componen        Finish, FinishAndDestroy
cancel for other component               Cancel
interrupt (stacked)                      Interrupt, Pause (not stacked?)
yield standby, standby                   Standby
---------------------------------------- ------------------------------------

Extended process functionality
==============================
Both salabim and Tomas support resources, although salabim supports reneging
and the claimers and
requesters and claimers queues are just standard queues with all advantages of
monitoring and animating.
Salabim also contains so called anonymous resources, that are not present in
Tomas.
```

```
On top of that, salabim has a very powerful State class which allows a
condition to be checked (wait)
without the overhead of standby.

Queue handling
==============
Basic queue handling is similar, with different terminology.
As queues are handled as a standard 'ABC class', a very rich idiom is present.
For instance, looping over (all) elements in a queue is more intuitive in
salabim:

salabim                                  Tomas
---------------------------------------- ------------------------------------
for ship in arrivals:                    Ship:=Arrivals.FirstElement;
   ...                                   While Ship<>Nil Do
                                             Begin
                                             ...
                                             Ship:=Arrivals.Successor(Ship)
                                             End;

Also in salabim, several queries can be done without a call, like:
    if c in arrivals:
or
    first = arrivals[0]
, but the more conventional, Tomas like constructs are still available.

In salabim the queue length and the length of stay in a queue are automatically
monitored.
I am not sure if and how that works in Tomas.

The content of a queue can be animated in salabim with just one statement.
In Tomas that requires more work, as far as I know.

Monitors
========
Tomas' collections are similar to salabim's monitors and both packages support
visualization on
a time scale.
Salabim has more options to get statistics, like percentiles and number of
entries between a lowerbound
and upperbound.
Histograms are presented quite differently. Salabim still uses text histograms,
that are fully customizable.
Tomas supports more modern graphical histograms, with less flexibility.
Salabim's collected time series can be easily exported to other (statistical or
presentation) packages, like
matplotlib, numpy or pandas. I am not sure about Tomas.

Animation
=========
Salabim has an advanced, optionally realtime, 2D animation engine that can also
be used to produce high
quality videos out of the box.
Tomas?
```

```
GUI
===
Tomas uses the advanced Delphi GUI components, which make it a snap to build
nice forms and generate
high-quality output.
In salabim that is much more complicated, if at all possible.

Statistical sampling
====================
Salabim offers more statistical distributions to sample from.

Reliability
===========
I think both packages can be used to acquire reliable results.
The random generators can both provide reproducibility.

The trace functionality of salabim is more elaborate and even shows the line
numbers. Therefore it is
arguably easier to validate a model in salabim.

Python is a dynamic, non-typed, language, which might lead to errors that are
hard to find.
Delphi/Tomas, on the other hand, is fully typed and will detect some errors
already at compile time.

Speed
=====
Execution speed in Tomas is superior to salabim, due to the host language.
In the Python ecosystem, there's an alternative runtime system, called PyPy
that makes execution
much faster. Benchmarks with older versions of salabim showed that Tomas models
run appr. 2 times
faster under PyPy.

Development time is another issue. I personnally think that Python is superior
in that respect,
not in the least by the availability of sophisticated IDEs, debugging and
testing tools.
Also there is much more material for Python than Delphi/Pascal to learn the
language and environment.

Other aspects
=============
Tomas is available under a commercial (relatively expensive) Delphi license, a
free community,
restricted Berlin license or the open source Lazarus project. It runs under
Windows, OSX and Linux.

Python is fully open source, free and available under Windows, OSX, Linux and
iOS. Therefore, salabim models
can be even be developed and run on iPad/iPhone !

Salabim is released under the MIT license and is fully open source.
```

Tomas license conditions are not very clear (at least to me). It is for sure not fully open source, as of now.

Salabim has a very active user group and offers (free or commercial) support options.
Tomas ?

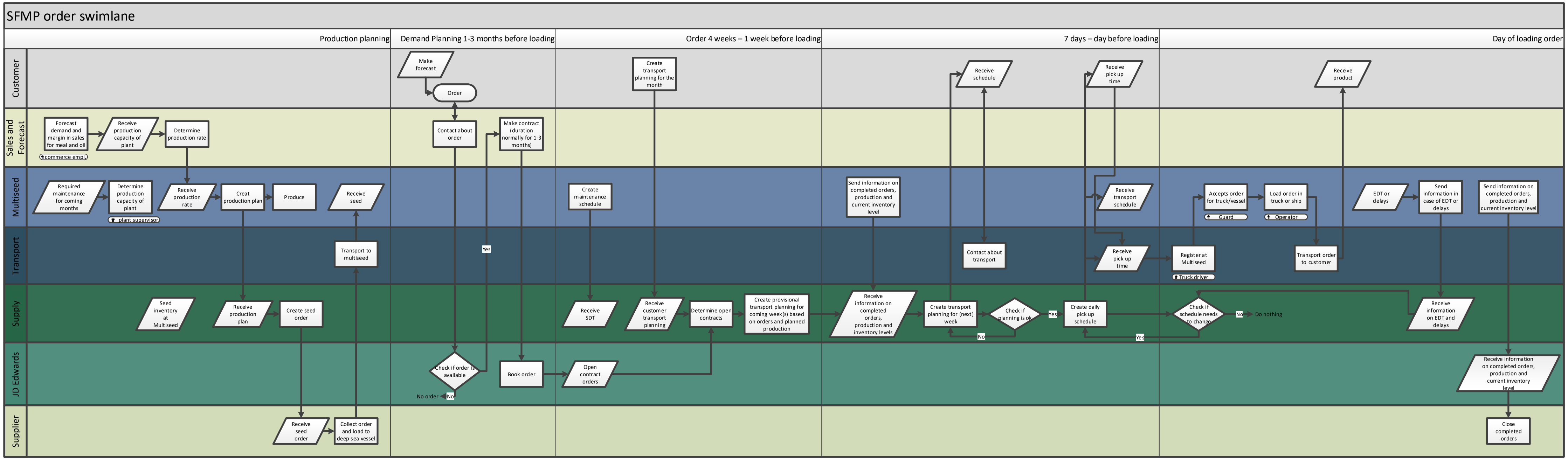
Python an extremely large and nearly fully open source library (machine learning, web interface, database,
statistics, graphics, I/O, etc.). Delphi?
Compared to Delphi, Python has far more developers and users, which might make it easier to find developers and testers.

Finally
=======
Experience, personal preferences and specific needs will for sure influence the choice of a Discrete Event
Simulation package.
Please observe that there are several other DES packages available:
- SimPy, under Python with a quite different API and rather limited functionality
- SimJulia, like SimPy under Julia
- Simmer, like SimPy under R
- DSOL, a not very well maintained package under Java.
- ...

On Friday, 5 October 2018 11:26:25 UTC+2, Lars Wissink wrote:

> Dear Ruud,
>
> > During my studies I worked with the Tomas simulation package created by H. Veeke. However, I have more experience with programming in Python and would therefore like to use your Salabim package for my graduation project. How do you compare the two packages on functionallity, reliability and speed?
>
> Best, Lars

D
SFMP order swimlane



SFMP order swimlane
Production planning
Demand Planning 1-3 months before loading
Order 4 weeks – 1 week before loading
7 days – day before loading
Day of loading order
Customer
Sales and Forecast
Multiseed
Transport
Supply
JD Edwards
Supplier
Forecast demand and margin in sales for meal and oil
commerce empl.
Receive production capacity of plant
Determine production rate
Required maintenance for coming months
Determine production capacity of plant
plant supervisor
Receive production rate
Creat production plan
Produce
Receive seed
Transport to multiseed
Seed inventory at Multiseed
Receive production plan
Create seed order
Receive seed order
Collect order and load to deep sea vessel
Make forecast
Order
Contact about order
Make contract (duration normally for 1-3 months)
Yes
Check if order is available
No order
No
Book order
Open contract orders
Create maintenance schedule
Receive SDT
Create transport planning for the month
Receive customer transport planning
Determine open contracts
Create provisional transport planning for coming week(s) based on orders and planned production
Send information on completed orders, production and current inventory level
Receive information on completed orders, production and inventory levels
Create transport planning for (next) week
Check if planning is ok
No
Yes
Receive schedule
Contact about transport
Create daily pick up schedule
Receive pick up time
Receive transport schedule
Receive pick up time
Register at Multiseed
Truck driver
Check if schedule needs to change
No
Do nothing
Yes
Accepts order for truck/vessel
Guard
Load order in truck or ship
Operator
Transport order to customer
Receive product
EDT or delays
Send information in case of EDT or delays
Receive information on EDT and delays
Send information on completed orders, production and current inventory level
Receive information on completed orders, production and current inventory level
Close completed orders

E Interviews

E.1. Interview with Thomas, planning strategies

1. Q — What are your activities at Cargill?

   A — Thomas performs research in improving the planning strategy and developing guidelines for all Cargill CASC plants. Three levels of planning exist, strategic, tactical and operational.

2. Q — What kind of guidelines are we talking about?

   A — S&OP stands for sales and operations planning, is something we are trying to implement at our factories. Currently, (strategic) planning decisions are made by the local manager. For example Tom, manager of Benelux determines strategy for the Cargill Multiseed plant and the plants in this region. We are trying to define guidelines, so we have an equal strategy and working methods for all our plants. The main goal is to integrate sales and operations. S&OP consists of multiple levels, it will be almost impossible to define equal guidelines for all plants since cultures and plants differ. However, the top strategic, tactical and some operational levels, we want to be more in agreement.

3. Q — What are current planning strategies at Multiseed, who decides on the production rate and who on sales?

   A — Current planning is especially focused on booking contracts. Commerce determines strategy for the long/midterm. They receive possible production, operating costs and maintenance schedule from the plant manager. Based on the achievable margin they will decide on the production rate and type of seed.

   For most of the time, they will decide to run the plants at full power. The more the factory produces, the lower the variables costs per MT. Products from the plant will eventually enter the trade market. This is also called a push system. Cargill management have a background in the trading business, which is why this business mindset has penetrated very far.

   J. [redacted] was not in full agreement with these statements, the plant will indeed lower its production rate if demand declines or switch to a different if this is now better in the market. Commerce can decide to produce and store sunflower meal and switch to crushing of rapeseed.

The market for sunflower oil and meal is called a commodity market. There is no real product differentiation in terms of quality, mainly on the price. Therefore, Cargill directly competes with its competitors on the market.

4. Q — What are the limitations of this planning strategy?

    A — Currently, at some facilities in the world there is no information on the daily stock. Planning performed by the supply department at Schiphol is only 10% if whole planning (strategic, tactical, operational). This is mainly operational part of planning, booking contracts and setting pick up time and dates.

5. Q — What should the new system be capable of?

    A — New system should better adapt and include the demand planning and demand curve -> How we should meet the demand, what quantities we need to store. Currently this information is not available.

6. Q — What are one of the implementations you are thinking of integrating sales and operations?

    A — We are starting to implement SAP a more mature ERP system. This will give us a lot more data to manage our supply chain. Furthermore we are looking at ways to improve and control production on the demand

E.2. Interview with Operator

1. Q — What are the steps you need to take before you can begin loading of truck or barge?

   A — Before loading of truck or barge, all documents must be collected from the guard; in the past these were provided immediately by the guard to the truck driver at time of registration. Due to increasing regulations this is no longer allowed. The operator walks to the control room where he prints two stickers for the sample jars. These are required for quality control. [redacted] From here he starts loading the truck or barge. The conveyors are started within BPS (a computer program). The new loading station for barges has a loading capacity of approximately [redacted] MT/h. The operator thinks this loading speed is limited by the lateral conveyor, all other equipment in the system should be capable of loading with a higher rate. Meal from the bunker is reclaimed, it falls in a bunker; here the material is weighed before it goes to the lateral conveyor and dropped in the barge.

2. Q — What are the limitations of the current system?

   A — The loading pipe near the quay can rotate and move in lateral direction. [redacted]

   The rotational and lateral movement of the pipe makes filling close to the edges very difficult. [redacted]
   The operator is constantly working on the height of the pipe on the material. To prevent dust, the pipe (outlet) must be properly positioned on the material. If the material flows too fast, it creates large dust clouds. This is not allowed due to various health regulations. A dust suction system is present but switched off since it was always full and malfunctioning.

   Determining the height of the pipe has become difficult since the pipe ending is covered by a dust skirt.

   Due to the rotational movement of the pipe, the barge is only filled left and right of the operator. The middle is section is unreachable, because of this the captain has to move barge to deposit the material over the whole area.

   [redacted]

   During the construction of the quay loading station, windscreen wipers were installed. However, they were not working properly. Dust particles that are released during loading form a layer on the glass causing the wipers to function properly anymore. During rain (some customers do not mind being loaded during rain), the operator has to clean his windows with an external wiper. Valuable loading time is lost.

3. Q — What are is the loading speed of trucks

   A — Loading speed of trucks is around [redacted] MT/h. However, trucks also have to move their truck to completely fill the truck causing delays in the loading process.

4. Q — What are arriving patterns of barges and trucks?

A — Trucks do not arrive at the Multiseed equally distributed over the day. There are high peaks in the morning and at the end of the day. In between, operators sit and wait for a new truck. Barges normally arrive on time; they are almost never loaded immediately because of the paperwork that needs to be done beforehand. Furthermore, customers often require a surveyor to be present during the loading process. When he is not available, the operator has to wait.

5. Q — Do you have any other suggestions or performance improvements you want to share with me?

A — I have to a lot of walking, handing out forms to the truck drivers and [redacted]

A new loading pipe for barges should be able to fill near the edge of a barge.

Conveyor at truck loading station should be extended to prevent truck drivers from having to re-position their truck.

Reintroduce a night shift and/or take on new personnel. They can reload stocks and clean stations. Operators have to work a lot of extra shifts and overtime to finish loading of trucks before the night.

E.3. Interview with Tom: Member of commerce department

1. Q — On what information do you determine the production rate for the Multiseed

A — There are several things, first we receive the maintenance schedule and possible production rate from the plant manager. Next, we forecast the demand and price of the product in the market. Based on all the gathered information and the price for the commodities in the market a production schedule is created.

Production costs are divided in fixed and variable costs, together they are the total costs. As an example he creates a back-of-the-envelope calculation: [redacted]

The margin is €10 per MT. Margin normally variates between €0-40 or even below. To achieve the highest possible revenue, the Multiseed should run at full production rate. Even when margin is negative production continuous to be able to serve customers, contract need to be fulfilled or bought back. Sometimes margins for rapeseed oil are better than for sunflower oil, the crush can then be operated to crush rapeseed instead. The Multiseed will only stop producing if the revenue no longer covers our fixed costs.

2. Q — The Multiseed sees increasing costs for waiting hours and demurrage, how do you include these extra costs in your margin?

A — For the Multiseed we take €1 per MT extra costs. This seems a little bit of a simplification but he could not provide me with a more elaborated answer.

3. Q — What influences the price of seed?

A — After the harvesting, the price normally drops due to immediate increase in supply and picks up again in the months after until the next harvest. This also depends on weather conditions, when a large harvest is expected the price decreases and vice versa.

4. Q — What influences the price of oil?

A — Oil is traded in future contracts on the future market. Here we speculate on the price of oil. Since Cargill is at first a trading company a lot of paper trading takes place without actual delivery. However, sometime the oil is delivered, the crush produces oil of very high quality and we do not want to deliver this oil. Oil of lower quality is bought and stored. Cargill produces very high quality oil, instead of delivering the good quality oil we want to deliver the lower quality oil that is stored externally. The price of a commodity is driven by the supply and demand. When companies keep a lot of oil in inventory, the supply decreases and price increases. All this makes the question of how much we need to produce difficult. In the end, we want to produce as much as possible. It must also be noted that sunflower oil is a commodity that can be substituted with other oil for instance palm oil or rapeseed oil. This all influences the market price.

5. Q — What influences the price of sunflower meal since this is not traded on the future market?

A — That's accurate, sunflower meal is sold on the spot market and forward contract. The same mechanics apply as for sunflower oil, the price is determined on supply and demand in the market. Sunflower is also a substitute product and thus the market can be volitile for disruptions such as fire or bad harvest. Ultimately, the price is determined on the price on the spot market. Farmers select different ingredients in their animal feed. Based on the price of all products they will determine their demand. Hedging protects farmers for large price variations, they 'lock' in the price. This is done in forward contract, the price is often

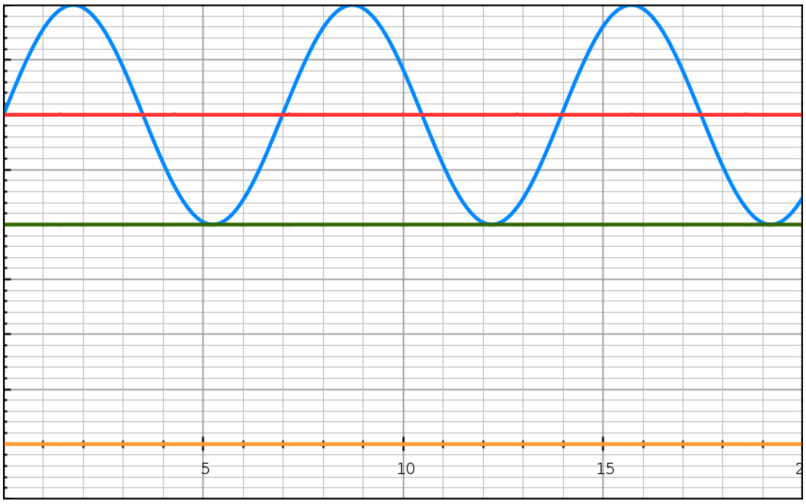


Figure E.1: Schematic representation how the margin is determined.

lower than the spot market price, but the price could decrease meaning they have paid too much or increase and thus they will get it for a lower price. Forward contracts can vary for a period for 1-6 months. Almost all meal is sold in forward contracts.

6. Q — How many months in advance does meal and oil need to be sold?

   A — Oil is mostly sent to the refinery, thus does not need to be sold. Also, we have large storage tanks for the oil. Meal we want to have completely sold one month in advance. Sometimes, there is still some left, we then have to lower the price.

7. Q — Do you want to deliver per barge/coaster or truck?

   A — Customers and Cargill prefers loading to trucks since then we can ask a premium price. This will be around €[redacted] per MT. Customers, like trucks since they can get it themselves and remove the middleman. Sadly, the current situation at the Multiseed prevents us from asking a premium. Furthermore, we need to load to barges since the loading speed for trucks is not adequate to keep up with the production resulting in silos to fill up.

8. Q — Why don't you store the meal and load trucks from a storage facility?

   A — Storage of meal costs around €[redacted] per MT. Since the margin is normally around €10 this means there is almost no margin left.

9. Q — You need to deliver your customers meal, is it possible to deliver the customer via another company?

   A — No, we do not buy our meal via another company, or let customer load somewhere else.

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