Simulation of a Proactive Planning Strategy at a Tank Storage Terminal

A Case Study at Vopak Terminal Amsterdam Westpoort

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Technische Universiteit Delft

TU Delft Delft University of Technology

Challenge the future

Simulation of a Proactive Planning Strategy at a Tank Storage Terminal

A Case Study at Vopak Terminal Amsterdam Westpoort

by

P.B.K. Noordhoek Hegt

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This thesis is confidential and cannot be made public until May 14, 2023.

TU Delft
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Preface

Looking back on this graduation project, it was a tumultuous, but enjoyable, experience. When the time came for me to search for a graduation project, I knew immediately that I wanted a company-based project because to this point I had had relatively little work experience. As I had recently finished a research project on marine handling, I thought it interesting to follow up on this topic. So when I was told by my uncle, who works for Vopak, that they might be looking for a graduate intern, I was excited and hopeful that I could further expand my knowledge in the marine handling field.

At first, the project assigned to me by Vopak was to look at the vessel clearance process. This is a process where the customer checks whether it is possible for a specific vessel to be handled at the respective Vopak terminal based on its specifications. This is a small process, which did not meet the demands for a TU Delft graduation project, so the scope quickly grew to the vessel handling process as a whole, from vessel clearance to vessel departure.

Thus, the process analysis started, during which the major pitfall for graduate interns is to let the company influence your thinking and your conclusions. Just a small amount of students is able to withstand this, and I am sorry to say that I was not one of them. To make matters more difficult, I had two intermediaries at the company, one at Vopak headquarters and one at the terminal, each with a different vision for this project. This led me down a road which I began to realize would make no difference once I had reached the end.

Luckily, I managed to pull myself together just in time to steer the project in the direction that I wanted, and more importantly, that I thought was best for the company. The result is the report that you have in your hands right now, of which I am extremely proud and which carries with it an experience that I will remember for the rest of my life.

I would, first of all, like to thank Erik Lankamp and Mark Noordhoek Hegt for giving me the opportunity to conduct my graduation project at Royal Vopak. Their guidance, knowledge, and enthusiasm helped me to complete this project. Secondly, I would like to thank Martijn de Gier for allowing me to use the facilities and data at Vopak Terminal Amsterdam Westpoort, without which I would not have been able to generate this result. I would also like to thank all other colleagues who have helped or supported me in thus journey, especially the innovation team at Vopak headquarters. Furthermore, I would like to thank my family and friends for their continued support during not only this project, but during all of my studies.Last, but definitely not least, I would like to specially thank dr.ir. Hans Veeke and prof.dr. Rudy Negenborn for their enthusiastic guidance from within the university.

It has been an incredible and valuable journey and I sincerely hope you enjoy reading the rest of this report.

P.B.K. Noordhoek Hegt
Delft, May 2018

Executive Summary (English)

In 2017, 61% of all petroleum products in the world was transported by sea. Tank storage terminals are needed to store and throughput these products land inward. A high demand puts pressure on tank storage terminals to efficiently handle and service incoming vessels. If this is not sufficiently done, heavy congestion is the result causing long waiting times for vessels and high demurrage costs for the customer.

This research proposes methods to deal with or decrease the amount of congestion at a tank storage terminal. The research was done at Vopak Terminal Amsterdam Westpoort (VTAW). The methods proposed in this research are proved by calculating the impact of the various methods on the seaside performance of the terminal using a discrete event simulation.

Problem statement and analysis

Compared to other industries, tank storage terminals have a relatively low level of automation, innovation, and planning. This is partly due to the fluctuating oil market and the flexibility it demands. After analysis of the current process at VTAW, the following specific issues, that are similar to those found within the industry in literature, came to light at VTAW:

- High amount of idle time
- Little or inefficient collaboration
- Low level of planning
- High waiting times
- High customer demurrage costs

Under these circumstances, VTAW and the tank storage industry are looking for ways to increase operational efficiency to accommodate the growing demand of vessels to be handled at the terminals, without the need to expand the infrastructure.

At VTAW, the reactive planning procedure turned out to be the underlying cause for many of the above mentioned issues. A proactive planning strategy could potentially prevent the interrupts and simultaneously relieve terminal congestion by controlling the arrival distribution of vessels. Thus, the objective of the research project can be stated as follows:

- *Assess the impact of the implementation of a proactive planning strategy at Vopak Terminal Amsterdam Westpoort with respect to the terminal seaside performance.*

Methodology

To compare the current and future states of the terminal, a number of key performance indicators (KPIs) are measured. The relevant KPIs measured for VTAW are listed below:

- Jetty occupancy
- Waiting time

- Turnaround time
- Laytime
- Demurrage

To be able to assess the impact of forward planning on VTAW, the terminal was modeled using a discrete event simulation. The simulation uses actual data retrieved from VTAW to gather the necessary time distributions for each individual step within the vessel handling process. The simulation models two jetties, which are reserved for seagoing vessels. The model was written in Lazarus and it uses a discrete event simulation add-on package called Tomas. The trace function in the Tomas package was used to verify the model. After running the simulation, the model was validated by comparing the current state simulation results with the actual KPI values. These results can be seen in Table 1. To

Table 1: Comparison of simulation and actual current state KPI results

KPI	Actual Result	Simulation Result
Vessels	247	247,4
Jetty Occupancy Rate	79,97%	79,18%
Waiting Time	34 Hours	38,26 Hours
Turnaround Time	55,41 Hours	56,1 Hours
Laytime	79,39 Hours	82,2 Hours
Demurrage	27700 Dollars	28700 Dollars

be able to give an accurate representation of the seaside performance of the terminal, the above KPIs have been incorporated into an equation to determine the Terminal Seaside Performance (TSR). The TSR integrates the KPIs into both Vopak and customer needs to make one equation:

$$TSR = \frac{\text{Vopak Performance} + \text{Customer Satisfaction Performance}}{2} * 100$$

In total, 30 experiments were tested using the simulation. The inputs for these experiments were combinations of three variables: time of planning, maximum customer delay, and interrupts. Based on the data and experience, the following realistic and feasible values for these variables were derived:

Table 2: Input values for each variable

Time of Planning	Maximum Customer Delay	Interrupts
1 day	50%	All interrupts
2 days	100%	No surveyor interrupts
3 days		No interrupts
4 days		
5 days		

The time of planning and maximum customer delay determine the level of forward planning at the terminal. The third variable, interrupts, determines the state of the interrupts at the terminal, which influences the turnaround time and the jetty occupancy rate.

Results and recommendations

The results are categorized per interrupt state of the terminal, to be able to clearly see the effects of forward planning and interrupt prevention. Figure 1 shows the TSR results for all 30 experiments. The figure clearly shows the performance increase due to forward planning, as well as the impact of the prevention interrupts in the process. The best forward planning experiment, as indicated in the figure, would be the following case:

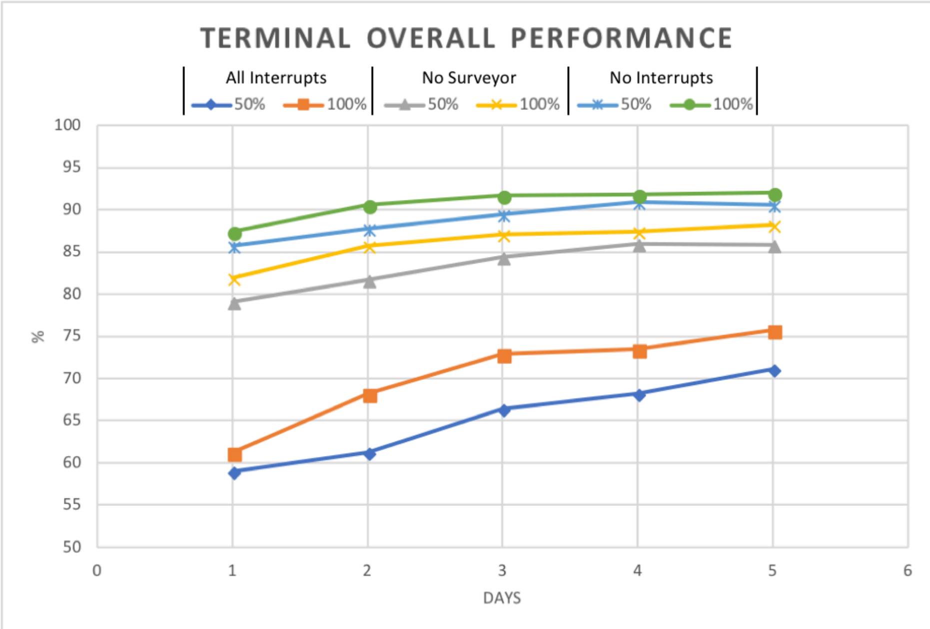

Figure 1: TSR results for all 30 experiments

- **Time of planning:** 3-5 days
- **Maximum customer delay:** 100%
- **Interrupts:** No interrupts

However, this case takes no interrupts into account. This is difficult to achieve and hence it is safe to say this is a long term goal for the terminal. In the short term, the best option for the terminal would be to tackle the surveyor interrupts, judging by the large gap between the bottom two and the middle two trend lines. Thus, for the short term, the best method to work towards is the following:

- **Time of planning:** 4-5 days
- **Maximum customer delay:** 100%
- **Interrupts:** No surveyor

Finally, in the current state of the terminal, the best performance increase can be achieved by implementing forward planning. The bottom trend line shows a possible performance increase of 15% at best, with the implementation of the following method:

- **Time of planning:** 5 days
- **Maximum customer delay:** 100%
- **Interrupts:** All interrupts

Considering the results, it is recommended that VTAW starts looking at possibilities regarding forward planning with the customer. This would allow the terminal to control the arrival distribution of vessels and handle the high jetty occupancy rate without the long waiting times. Another major step could be made by looking into the exact nature of the various interrupts and collecting specific data for these interrupts. This would allow VTAW to prevent or provide alternative solutions for the interrupts that have the most impact on seaside performance.

Executive Summary (Nederlands)

In 2017 werden 61% van alle petroleum producten over zee getransporteerd. Tank terminals zijn nodig om deze producten land inwaarts door te voeren. Een hoge vraag zet veel druk op tank terminals om inkomende zeeschepen zo efficiënt mogelijk te behandelen. Als er vertraging optreedt, kan dit leiden tot opstoppingen met als gevolg lange wachttijden voor zeeschepen en hoge demurrage kosten voor de klant. Dit onderzoek draagt een methode voor om de druk op de tank terminal te verkleinen. Het onderzoek is gedaan bij Vopak Terminal Amsterdam Westpoort (VTAW). De methodes die aangedragen zijn in dit onderzoek zijn bewezen door middel van het berekenen van de impact van de verschillende methodes op de seaside performance van de terminal met behulp van een discrete event simulatie.

Probleemstelling en analyse

Vergeleken met andere industrieën hebben tank terminals een relatief lage graad van automatisering, innovatie en planning. Dit komt gedeeltelijk door de fluctuerende olie markt en de flexibiliteits eis die daarmee gepaard gaat. Na het analyseren van het huidige process bij VTAW, kwamen de volgende problemen aan het licht, die vergelijkbaar zijn met de problemen gevonden in de literatuur:

- Hoog percentage idle time
- weinig of inefficiënte samenwerking
- laag niveau van planning
- Hoge wachttijden
- Hoge demurrage kosten voor de klant

Onder deze omstandigheden zijn VTAW en de gehele tank terminal industry manieren aan het onderzoeken om de operationele efficiëntie te verhogen om zo de groeiende vraag van zeeschepen aan te kunnen zonder daarbij de infrastructuur uit te breiden. Bij VTAW, bleek de reactieve planning procedure de onderliggende oorzaak voor het grootste deel van de genoemde problemen. Een proactieve planningsstrategie zou zogeheten interrupts kunnen voorkomen en tegelijkertijd de druk op de terminal kunnen verlagen door het aankomstpatroom van zeeschepen te controleren. Zodoende kan de doelstelling van dit onderzoek als volgt geformuleerd worden:

- *Bepaal de impact van de implementatie van een proactieve planningsstrategie bij Vopak Terminal Amsterdam Westpoort met betrekking tot de terminal seaside performance.*

Methodologie

Om de huidige en toekomstige staat van de terminal te vergelijken, zijn een aantal key performance indicators (KPIs) gemeten. De KPIs die voor VTAW gemeten worden zijn:

- Bezettingsgraad
- Wachttijd

- Doorlooptijd
- Ligtijd
- Demurrage

Om de impact van forward planning te kunnen bepalen, is de terminal gemodelleerd aan de hand van een discrete event simulatie. De simulatie maakt gebruik van VTAW data om de benodigde tijd ditributies te verkrijgen voor elke individuele processtap van het verwerken van zeeschepen. De simulatie modelleert twee kades die alleen zeeschepen ontvangen. Het model is in Lazarus geschreven met behulp van de add-on package Tomas voor de discrete event simulatie. De trace functie in het Tomas pakket is gebruikt om het model te verifiëren. Na het runnen van de simulatie, kon het model gevalideert worden door de resultaten uit de simulatie te vergelijken met de werkelijke resultaten van de KPIs. Deze vergelijking is te zien in Table 3. Om een accurate representatie van de seaside performance van de terminal te geven, zijn de bovengenoemde KPIs geïntegreerd in een vergelijking die de Terminal Seaside Performance (TSR) berekent. De TSR integreert de KPIs in zowel Vopak als klant eisen om uiteindelijk één vergelijking te maken:

Table 3: Vergelijking van de resultaten uit de simulatie en de werkelijkheid

KPI	Werkelijkheid	Simulatie
Zeeschepen	247	247,4
Bezettingsgraad	79,97%	79,18%
Wachttijd	34 Hours	38,26 Hours
Doorlooptijd	55,41 Hours	56,1 Hours
Ligtijd	79,39 Hours	82,2 Hours
Demurrage	27700 Dollars	28700 Dollars

$$TSR = \frac{\text{Vopak Performance} + \text{Klanttevredenheid Performance}}{2} * 100$$

In totaal zijn er 30 experimenten getest met behulp van de simulatie. De inputs van deze experimenten zijn combinaties van drie variabelen: Tijd van planning, Maximale klant vertraging en interrupts. Gebaseerd op de data en op ervaring, zijn de volgende realistische en mogelijke input waarden voor deze variabelen verkregen:

Table 4: Input waarden voor elke variabele

Tijd van Planning	Maximale Klant Vertraging	Interrupts
1 dag	50%	Alle interrupts
2 dagen	100%	Geen surveyor interrupts
3 dagen		Geen interrupts
4 dagen		
5 dagen		

De tijd van planning en maximale klant vertraging bepaald het niveau van forward planning van de terminal. De derder variabele, de interrupts, bepaald de staat van de interrupts op de terminal en heeft invloed op de doorlooptijd van schepen en de bezettingsgraad van de kades.

Resultaten en aanbevelingen

De resultaten zijn gecategoriseerd aan de hand van de staat van de interrupts van de terminal om duidelijk het effect te zien van forward planning en het voorkomen van interrupts. Figuur 2 laat de

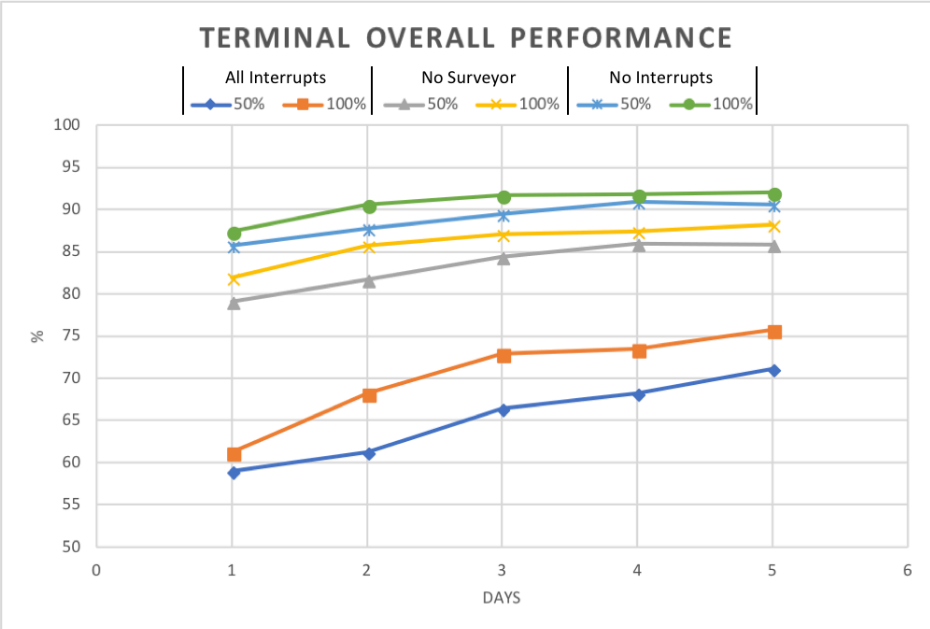

Figure 2: TSR resultaten voor alle 30 experimenten

TSR resultaten zien voor alle 30 experimenten. De figuur laat duidelijk de performance groei zien die veroorzaakt is door forward planning. Het laat ook goed de impact van het voorkomen van interrupts in het proces zien. Het experiment met de beste resultaten blijkt de volgende:

- **Tijd van planning:** 3-5 dagen
- **Maximale klant vertraging:** 100%
- **Interrupts:** Geen interrupts

Echter neemt deze experiment aan dat er geen interrupts in het proces meer voorkomen. Dit is ingewikkeld om te bewerkstelligen and dus zou dit gezien kunnen worden als een lange termijn doelstelling voor de terminal. Op de korte termijn, zou de beste optie voor de terminal zijn om de surveyor interrupts uit het proces te halen gezien de performance groei die dit laat zien in de figuur. Dus, voor de korte termijn, zou het volgende experiment het beste doel zijn om naartoe te streven:

- **Tijd van planning:** 4-5 dagen
- **Maximale klant vertraging:** 100%
- **Interrupts:** Geen surveyor

Ten slotte zou, in de huidige staat van de terminal, de beste performance groei te bewerkstelligen zijn door middel van het implementeren van forward planning. De onderste trend line in de figuur laat een mogelijke performance groei zien van maar liefst 15%, mits het volgende experiment wordt geïmplementeerd:

- **Tijd van planning:** 5 dagen
- **Maximale klant vertraging:** 100%
- **Interrupts:** Alle interrupts

Gezien de resultaten, is het aanbevolen dat VTAW samen met de klant gaat kijken naar mogelijkheden betreffende forward planning. Dit zou de terminal ruimte geven om het aankomstpatroon van zeeschepen te controleren om zo de hoge kadebezetting te kunnen accommoderen en de wachttijden te kunnen verminderen. Een andere grote stap kan gemaakt worden door te kijken naar de specifieke oorzaken en redenen voor de interrupts. Door meer gedetailleerde informatie te verschaffen hierover zou VTAW alternatieve oplossingen kunnen vinden voor de meest invloedrijke interrupts of zou het deze zelfs volledig kunnen voorkomen.

Abbreviations

Abbreviation	Explanation
LNG	Liquid Natural Gas
VTAW	Vopak Terminal Amsterdam Westpoort
TUD	Technische Universiteit Delft
KPI	Key Performance Indicators
cbm	Cubic meters
A2D	Arrival to Departure
DSA	Delft Systems Approach
MOT	Mode of Transport
PROPER Model	Process Performance Model
FCFS	First Come First Serve
NOR	Notice of Readiness
ETA	Estimated Time of Arrival
PDL	Process Description Language
IAT	Inter Arrival Time
TSR	Terminal Seaside Performance
VHP	Vessel Handling Process

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Introduction

Billions of dollars, high standards, and a high fluctuating market. These are typical characteristics of the oil industry. The 2017 worldwide oil demand was over 2 million barrels per day [Gilchrist,2017]. Of all petroleum products in the world, 61% is transported by sea [TB&P,2017]. Tank storage companies such as Vopak offer the petroleum trade tank storage to use as both a buffer and a means of linking sea to land. Vessel handling is a key process that essentially defines the efficiency of a terminal. It involves all procedures and measures taken to safely perform loading or discharging operations. the vessel handling process at Vopak will be the main focus of this thesis. It will be analyzed using 2016 data and personal experiences from all parties involved in the process. This chapter will serve as an introductory chapter to further explain the goal of this graduation project and to provide information regarding Vopak and the marine handling industry.

1.1. Vessel handling

The vessel handling procedure at a tank storage terminal is a complex process involving strict coordination between multiple parties. Royal Vopak is the world's leading independent tank storage company and has been in the business for over 400 years [Vopak,2000]. Vopak stores bulk liquid products and gases such as oil, chemicals, LNG, biofuels, and vegoils. In the Netherlands, the majority of Vopak's terminals are located at the Port of Rotterdam. This is not surprising, as the Port of Rotterdam is the largest liquid bulk port in Europe [PortofRotterdam,2000]. In fact, 47% of the goods handled in the Port of Rotterdam, in metric tonnes, are Liquid bulk, as can be seen in Figure 1.1. Furthermore, Figure 1.2 shows that approximately 66% of this liquid bulk is transported to and from Rotterdam by water. Thus, vessel handling is a large and important part of the daily operations at Vopak.

Vopak's terminals are currently operating at near full capacity. Acquiring new tanks and the build of a new terminal is expensive and so Vopak is seeking other ways to accommodate a potential growth in demand for tank storage. Vopak is looking to optimize the vessel handling procedure to be able to increase the amount of vessels it is able to handle within the current infrastructure. Optimizing the vessel handling process offers advantages not only to Vopak, but possibly also to their customers as an increase in efficiency often leads to financial savings. Thus the aim of Vopak regarding the vessel handling procedure is clear: optimize the Vessel handling process to increase the overall terminal efficiency.

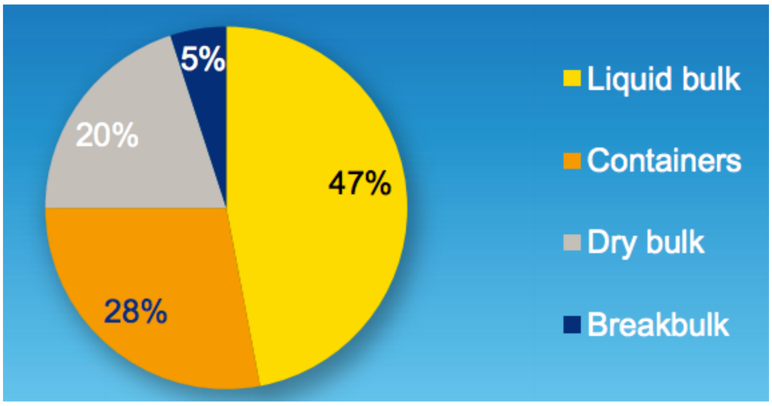

Figure 1.1: Ratio of goods handled in the Port of Rotterdam [vdBerg,2014]

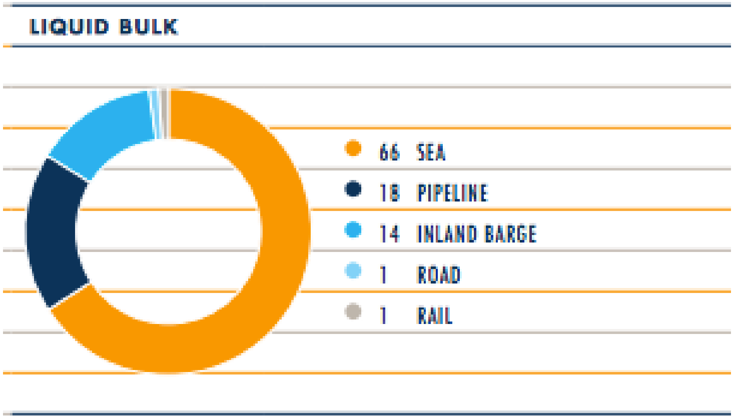

Figure 1.2: Modal split of liquid bulk at the Port of Rotterdam [PortofRotterdam,2009]

This research will provide means to analyze supply chains, identify bottlenecks and idle time, and find ways to improve the efficiency of the chain by conducting a case study into the vessel handling procedure at Vopak and showing how performance can be increased.

1.2. Literature study

Before analyzing and optimizing the vessel handling process, it is important to understand the industry and the context of the problem. The following section summarizes the most important parts of the existing literature studied: (1) Tank storage infrastructure, (2) planning and scheduling, (3) Problems and limitations within the industry, (4) Data sharing in the maritime industry.

1.2.1. Tank storage infrastructure

Tank storage is a business that requires a large sense of responsibility. Most liquid bulk that is stored is, if leaked, highly damaging to the environment and sometimes create high risk health hazards. Thus, environmental and safety requirements are a significant factor in the selection and design of the storage tanks used by the petroleum industry [SPE,2013]. Tank storage terminals consist of two main infrastructure assets, tanks and jetties. The two most widely used storage tanks for petroleum products are fixed roof tanks and floating roof tanks [Sölken,2009]:

- *Fixed roof:* a cylindrical steel shell with a cone- or dome-shaped roof that is permanently affixed to the tank shell.

- *Floating roof:* an open-topped cylindrical steel shell equipped with a roof that floats on the surface of the stored liquid, rising and falling with the liquid level.

Jetties are used to berth vessels. All necessary infrastructure to handle vessels, such as loading arms, are located on the jetty.

1.2.2. Planning and scheduling

Tank storage terminals can be divided into two areas, sea-side and land-side. Sea-side operations consist of berthing, loading, and discharging operations. Land-side operations consist of both tank storage operations as well as inter-modal transport operations regarding trains and trucks. The planning and scheduling of vessels at a tank storage terminal has to do with the sea-side operations and is often reffered to as the berth allocation problem. Berth allocation is the allocation of certain vessels at the berth at a specific time during the time period of planning so that the vessel can carry out loading and unloading activities at the terminal [Budipriyanto,2011]. There are three main types of berth allocation principles, or strategies [Taranaki,2016]:

- *First Come First Serve:* A vessel takes its place in the berthing queue only when the Ship's Master or her agent has informed the terminal it is ready for operations.
- *Guaranteed Berth:* the right to occupy an exclusive berth and will usually be allocated within a specified regular weekly or monthly time slot but may, at the terminal's discretion, be a permanent allocation within a specified time frame.
- *Priority Berth:* certain vessels have preferred status for the purposes of being able to berth

1.2.3. Problems and limitations within the industry

The oil industry is a high fluctuating market, which takes its toll on the tank storage industry. Customers often plan their operations and product blends according to last minute information regarding prices and availability. This complicates the planning and scheduling process at liquid bulk terminals. The following are the main problems and limitations that are dealt with in the tank storage industry [Bogers,2017]:

- *Uncertainty in vessel arrival times:* Vessel arrival times deviate often due to changes in customer planning or environmental circumstances.
- *Uncertainty in vessel berth times:* Vessel berth times differ due to vessel specifications or other causes outside of the terminal's control.
- *Last minute customer order deviations:* Due to the fluctuating market, multiple order deviations are often received at the last moment.
- *low level of process predictability and reliability:* The uncertainties cause an inability to reliably predict arrival and berthing operation times.
- *Low level of collaboration:* There is a low efficiency regarding the collaboration between the various parties involved in the vessel handling process.

1.2.4. Data sharing in the maritime industry

The Business Performance Innovation Network conducted a study in partnership with maritime industry technology leaders, Navis, and XVELA into the role of innovation in the maritime supply chain. The following two citations summarize the current state of innovation and collaboration within the maritime industry [BPI_Network,2017]:

- ”the shipping industry currently faces significant problems from inefficiency and waste due to aging technology infrastructure and business processes that are hamstrung by a lack of real-time information sharing and ineffective collaboration.”
- ”The findings of this report underscore the critical need for the shipping industry to improve collaboration and efficiency through the adoption of new technology-driven models and processes. Perhaps because it has been preoccupied and constrained by the economic challenges it faces, but also because many of its members are just plain resistant to change, the industry has been far too slow to enter the digital age.”

The study is based on a survey of more than 200 executives and professionals from terminal operators, carriers, logistics providers, vessel owners, port authorities, shippers, consignees, and other members of the global ocean supply chain. Regarding Vopak, there are a few conclusions from this study that are interesting and useful for moving forward towards a better collaboration with partners in the Vopak supply chain. The three most interesting outcomes, from a Vopak perspective, are the results shown in Figure 1.3. The first outcome shows that coordination, planning, transparency, and sharing of data and information is a key area for improvement within the maritime supply chain. The following two outcomes reveal the roadblocks that hold back possible innovations and the reasons for not embracing new innovations.

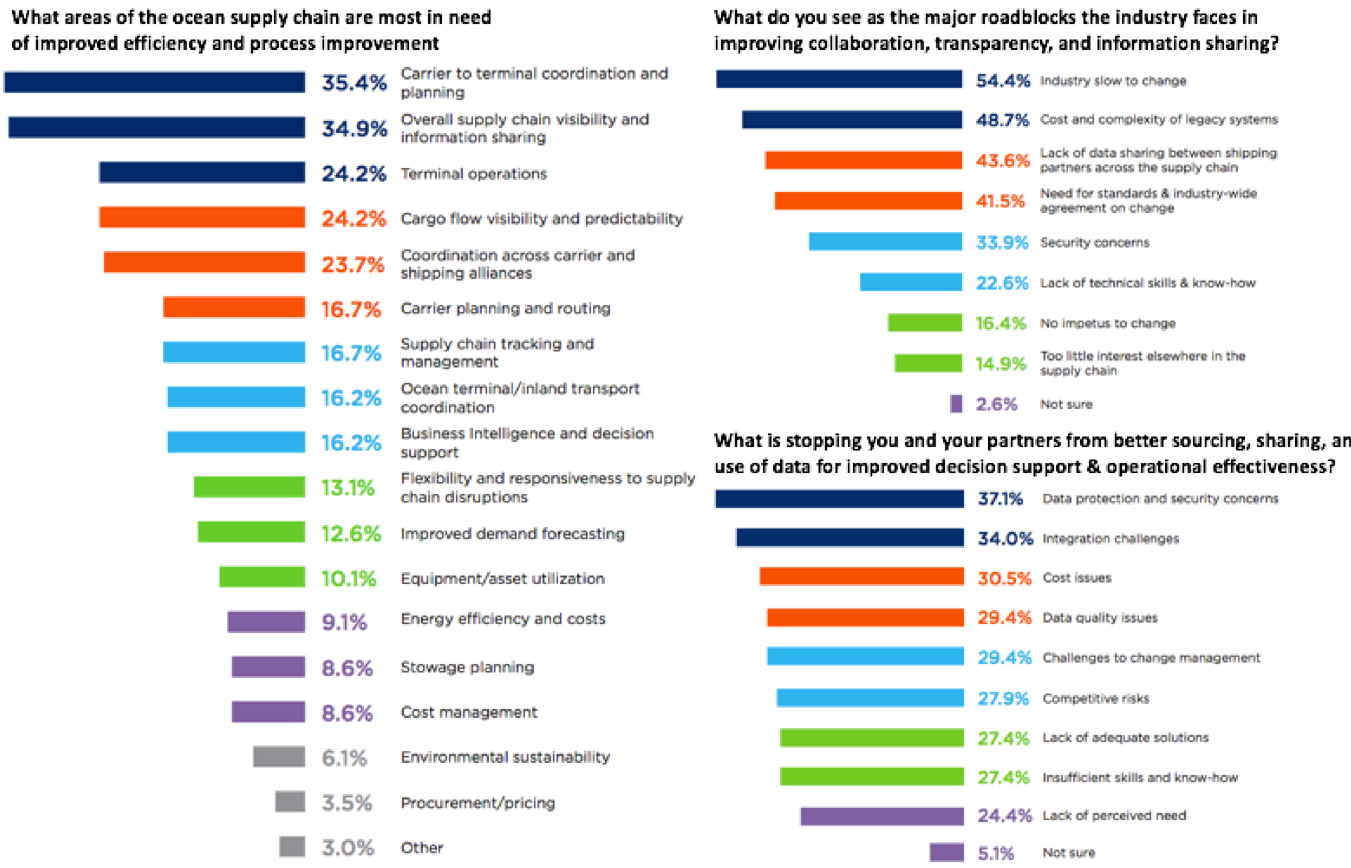

Figure 1.3: Maritime industry survey

The following findings can be concluded from this study:

- There is an increasing need and will from all cooperating parties within the maritime industry to start using data and information sharing to improve coordination, planning, collaboration, and efficiency.
- The financial costs within the maritime industry are relatively high, which is one of the reasons that the industry wary and slow to change. This state of mind must change to make way for an agile way of working.
- Companies within the maritime industry are wary of sharing data due to potential security risks and too much transparency for the competition.

1.3. Need statement

When comparing the tank terminal industry to other industries, especially the container terminal industry, the degree of automation, innovation, and precise scheduling is relatively low-leveled. Tank terminals are falling behind and not yet using the possibilities of modern day technologies to its full potential. This is due to the global differences in procedures and a slow and outdated mentality towards change. This mentality is currently changing and the industry is in need of fresh ideas and injections into the process of tank storage and vessel handling, not just from a technical standpoint, but also from a logistical point of view. This thesis serves to deliver a contribution to that aspect of the industry and help set the next small step towards a more efficient future in tank terminal operations.

1.4. Research scope and objectives

1.4.1. Research scope

The research focuses specifically on the vessel handling process at Vopak Terminal Amsterdam Westpoort. The scope starts at the moment the customer first contacts Vopak, which is usually during the vessel clearance process, and it ends when the vessel has left the terminal. The process can be split into a pre-arrival and arrival-to-departure category, each with an input, output, and black box as is illustrated in Figure 1.4.

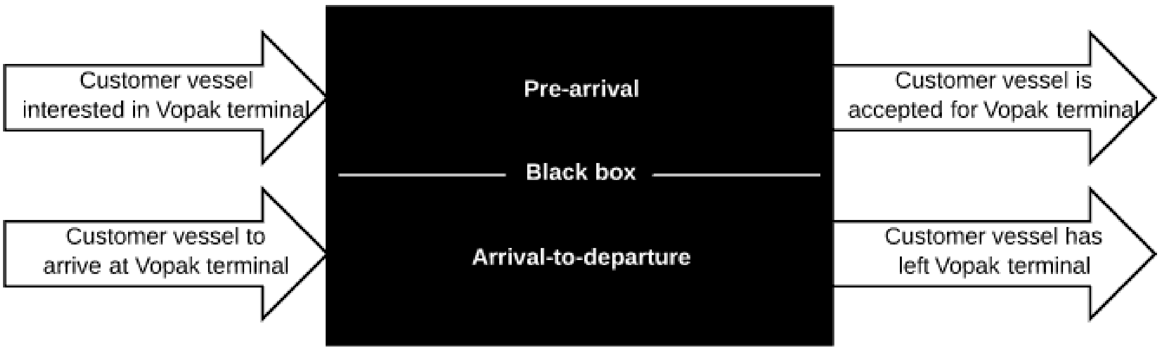

Figure 1.4: Research scope

1.4.2. Research objective and deliverables

The objective of this research is that is must have both academic value and contributions to the TU Delft, as well as practical value to Royal Vopak and specifically to VTAW. Ideally, the added academic and practical value would support and amplify each other. From a Vopak point of view, this research is expected to deliver ways and ideas to optimize the vessel handling process and increase the overall efficiency of the terminal. From a TU Delft point of view, this research is expected to also provide a means to calculate the impact on the terminal if certain ideas or strategies are implemented. These expectations lead to the following main objective:

- *Improve the vessel handling supply chain at Vopak Terminal Amsterdam Westpoort to contribute to the aim of a more efficient overall process and a better terminal performance.*

Along with these objectives are the following deliverables:

- Performance analysis of the current process
- Recommended improvements based on the KPI measurements
- The estimated impact of the recommended improvements.

1.5. Research questions

Taking into account the objective and deliverables above, the main research question can be defined as:

- *How can the vessel handling process at Vopak Terminal Amsterdam Westpoort be improved with respect to efficiency and terminal performance?*

To help answer the main research question, a number of sub-questions have been formulated. These sub-questions will help gather the necessary information and are formulated below:

First, the current vessel handling process must be thoroughly analyzed.

i How is the current vessel handling process organized?

ii What are the expectations and/or restrictions of the customer regarding the vessel handling process?

iii Where in the process does the most idle time and/or delays take place and what are the reasons for these delays?

After gaining a thorough understanding of the current vessel handling process, a more detailed look should be taken at the teams and tasks within Vopak. From this perspective, an analysis should be done to find out where in the process the most progress can be achieved and what the causes of the current problems are.

iv What are the tasks of the personnel organization within Vopak and how is this organized?

Once the problems and the causes in process have been determined, recommendations can be made to solve these problems and ultimately improve the process. Furthermore, the impact of these solutions should be estimated to prove the potential worth of the implementations.

v What is required to improve the current state of the vessel handling process?

vi What is the impact of the solutions on the process and on Vopak as a whole?

Finally, recommendations can be made for further research and improvement of the vessel handling process at VTAW.

1.6. Structure of the report

In this section, an outline is given of the report structure. The different chapters, as well as each chapter's aim is given below in Table 1.1. Figure 1.5 shows the approach that was taken in this research project, and which chapters belong to each part of the approach.

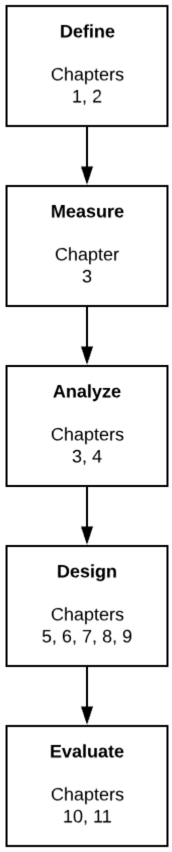

Figure 1.5: Research approach

Table 1.1: Report outline

Chapter		Aim
1	Introduction	The current chapter introduces the research project. It expresses the relevance and reason for this project and summarizes the literature study.
2	Background	Chapter 2 gives more information on Vopak and Vopak Terminal Amsterdam Westpoort specifically. This chapter also explains the current vessel handling procedure. Lastly, it gives the previous research done at Vopak on this subject and gives some examples of recently implemented innovations at VTAW with respect to vessel handling.
3	Problem Analysis	Chapter 3 further explains and quantifies the current problem regarding the vessel handling process at VTAW. The chapter shows how the terminal's performance can be measured and judged and analyzes the current performance of the terminal.
4	Problem Recapitulation	Chapter 4 recapitulates on research project and the problem analysis. This chapter serves to narrow the research question and objective.
5	Conceptual Planning Model	Chapter 5 introduces the conceptual planning model that has been devised to increase terminal performance. The proposed model is thoroughly explained.
6	Model Implementation	Chapter 6 implements the conceptual model introduced in Chapter 5. A simulation model is made in Lazarus/Tomas to be able to simulate the impact of forward planning on the vessel handling process at the terminal.
7	Model Validation and Verification	Chapter 7 serves to verify and validate the simulation model, which was explained in Chapter 6.
8	Experiments	Chapter 8 introduces the various experiments that will be tested using the simulation model.
9	Results	Chapter 9 publishes and explains the results of the experiments tested by the simulation model.
10	Discussion	Chapter 10 will provide a concise summary of the findings in this research project and discuss how the results of this project could change and improve the way Vopak and other tank storage terminals work.
11	Conclusion and Recommendations	Chapter 11 will present the conclusion of the research project and finish the report with recommendations to Vopak based on the findings within this research.

2

Background

In Chapter 1, the introduction for this thesis was given along with the reasons for this project. Before striving to optimize the vessel handling procedure, it is important and necessary to understand the current process in detail. Chapter 2 will give a detailed explanation of the various activities at Vopak Terminal Amsterdam Westpoort and accurately describe the vessel handling process and what parties are involved. This chapter will also look into previous research done on this subject at Vopak and what future improvements have already been tested or planned.

2.1. Vopak

Royal Vopak is the world's leading independent tank storage company and has existed for over 400 years. Tank storage is best understood by comparing it to a hotel, but instead of renting out hotel rooms they rent out tanks. Tank storage companies deliver a service by renting out storage space to customers that use this service for one ore multiple of the following reasons:

- *Sea-to-land connection:* Tank terminals provide a means to throughput product from sea to land. The product can be distributed from the terminal through rail, road, or pipeline.
- *Buffer:* Tank storage is often used to hold a buffer of product. In the case of a sudden surge in demand, the product can easily and quickly be distributed inland.
- *Additional services:* Depending on the terminal, various services are offered such as product blending.

Vopak's independence means that its policy towards clients is not influenced by external factors such as oil prices or other companies. This ensures the fair treatment of all customers, regardless of the customer company size or turnover.

Vopak is a multinational company with 67 terminal locations worldwide. 33 of these 67 terminals are fully owned and run by Vopak. This leads to a total worldwide tank storage capacity of almost 36 million cubic meters (cbm) [Vopak,2000].

2.1.1. Vopak Terminal Amsterdam Westpoort

Vopak's newest and most modern terminal in the Netherlands is Vopak Terminal Amsterdam Westpoort (VTAW). VTAW opened for operations in October 2011. The terminal has 41 tanks ranging from 10,000 to 50,000 cbm in capacity. Together, these tanks account for a total of just over 1.2 million cbm of storage capacity. Furthermore, the terminal consists of 8 berths for barges, or inland ships, as well as 3 berths for vessels, or seagoing ships [Vopak,2011].The VTAW layout can be seen in Figure 2.1, in which seagoing vessels can be identified by a red hull. VTAW mainly stores clean petroleum products and offers four additional services:

1 **Additivation:** the adding of a substance to a product to give it certain wanted specifications.

2 **Blending:** the mixing of two products in a precise ratio to create a specific blend.

3 **Butanizing:** The adding of butane gas to a liquid.

4 **Filtration:** the separation of materials of a different chemical composition.

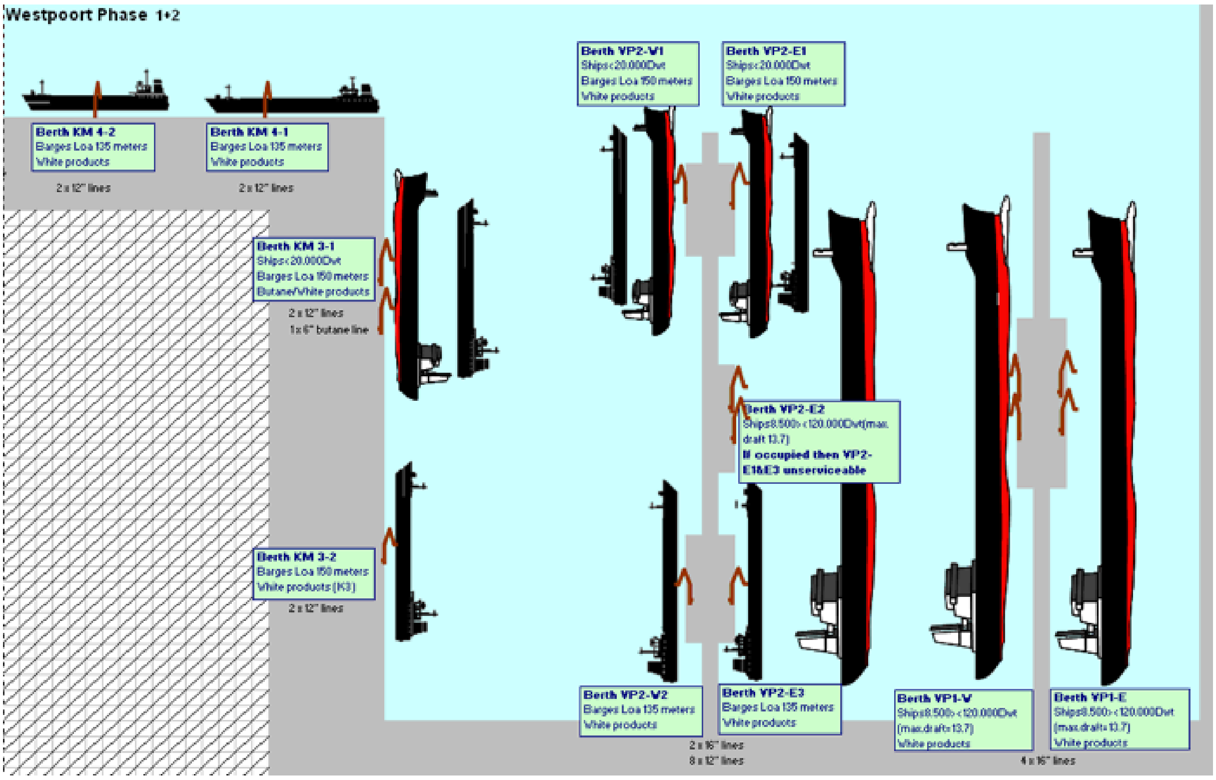

Figure 2.1: Layout of VTAW

2.1.2. Vessel handling process

The vessel handling process at VTAW can be split into two categories: Pre-arrival and Arrival-To-Departure (A2D). The Pre-arrival process consists of all procedures that take place up until the moment the vessel has ended its sea passage and has tendered a Notice of Readiness, meaning the vessel is ready for operation. This includes two key events:

- *Vessel clearance:* this ensures the customer that the vessel is able to berth at the terminal.

- *Order nomination:* this tells the terminal when the vessel is due to arrive and the operation plan of the vessel.

The arrival-to-departure process consists of all procedures taking place from the moment the notice of readiness has been tendered to the moment the vessel has departed the terminal. This can be further categorized into 3 sub-categories:

- *Arrival:* all procedures from the tendering of the notice of readiness to the berthing of the vessel.
- *Operation:* all procedures from the berthing of the vessel to the end of the loading or discharging operation.
- *Departure:* all procedures from the end of the loading or discharging operation to the departure of the vessel.

Figure 2.2 shows a simple flowchart of the overall vessel handling process. The vessel handling process will be further explained in detail in Chapter 3.

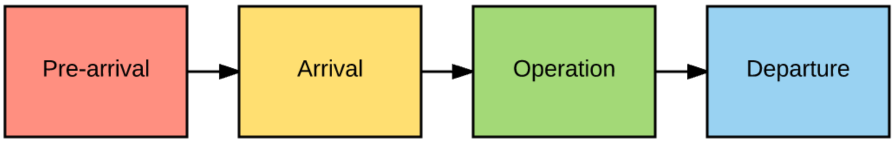

Figure 2.2: Simple model of the vessel handling process at VTAW

2.2. Previous research/benchmarks

Before this graduation project, an intern at Vopak carried out a small-scaled research project as to the reasons for idle times during operations. Fanny Rienstra, the intern, focused solely on the idle times registered by the operations team at VTAW. In total, there are 11 interrupt codes that are registered listed below:

- *WASA:* Waiting for Surveyor Arrival
- *WASU:* Waiting for Surveyor Activities
- *WATF:* Waiting for Technical Failure
- *WAIF:* Waiting for ICT Failure
- *WAVP:* Waiting for Vopak Personnel
- *WAVB:* Waiting for Vessel/Barge
- *WAAI:* Waiting for Available Infrastructure
- *WAFD:* Waiting for Departure
- *WAHO:* Waiting for Hospitality
- *WACO:* Waiting for Customer Orders
- *WAOR:* Waiting for Other Reasons

Rienstra concluded that there are five types of Vopak idle times, registered as interrupt codes, that are of the most influence in the process and make up 83% of the total registered idle time in 2016. These five interrupt codes are explained in more detail below:

- **WASU:** the "Waiting for Surveyor Activities" code gives the amount of time it takes for the surveyor to carry out the necessary activities regarding the product. Although work is being done by the surveyor, it is registered as idle time because Vopak is idle during this time.
- **WAFD:** the "Waiting for Departure" code gives the amount of time it takes from the moment all Vopak activities regarding the ship are finished to the moment the ship has left the jetty.
- **WASA:** the "Waiting for Surveyor Arrival" code gives the amount of time it takes for the surveyor to arrive after the ship has berthed and the surveyor was called.
- **WAAI:** the "Waiting for Available Infrastructure" gives the amount of time a vessel has to wait for an available jetty or pipeline.
- **WAVB:** the "Waiting for Vessel/Barge" code gives the amount of time Vopak must wait for a ship to be ready for operations.

Figure 2.3 shows the distribution of the above mentioned interrupt codes. As can be seen from this figure, the WASU interrupt code is by far the most registered code. This is not unusual as almost all vessels need some sort of surveyor activity done and, as explained earlier, this code is somewhat controversial because although Vopak might be idle during this time, the time is not necessarily wasted.

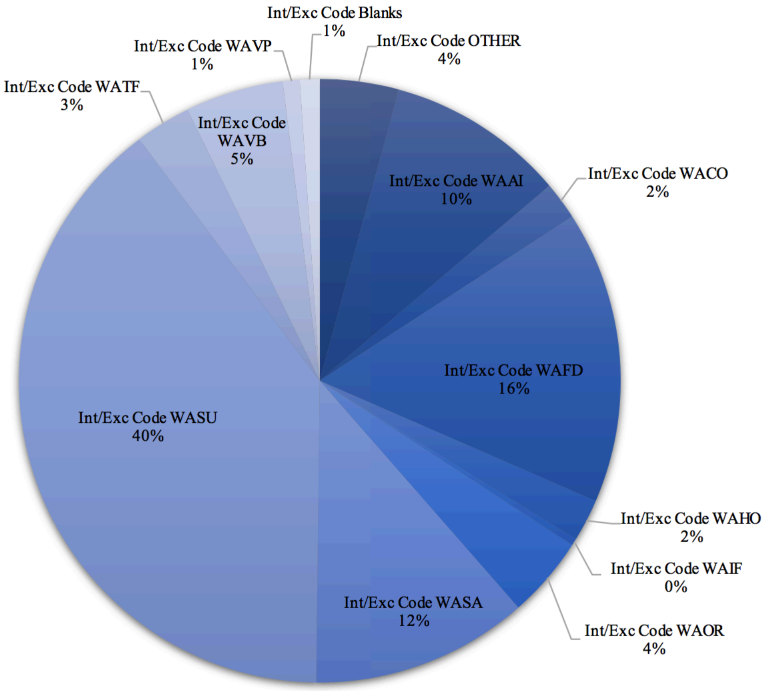

Figure 2.3: Distribution of interrupt codes in 2016 at VTAW [Rienstra,2017]

Rienstra's goal in her thesis was to assess the sources of delays for vessels handled at VTAW. Her results show that the sources having the most impact on these delays are the movement of operations, number of order lines, and the amount of product pumped. Using the data for these sources, she created a prediction tool to predict the amount of idle time/delay a vessel will experience. Unfortunately, the tool had an extremely high mean error, making it unusable for the terminal. Hence, this tool will not be used further in this research, however Rienstra's data regarding interrupts will prove useful in the remainder of this project.

2.3. Current improvements

Within Vopak, there is an innovation team that is constantly working to simplify and increase efficiency on a terminal through the implementation of new innovations. There are a few ideas that will have been implemented during the course of this graduation project. As these changes could affect the performance of the terminal, these innovations will not be taken into account in the analyses in this report because most of the analyses are based on 2016 data. The (to be) implemented new innovations are summarized below.

2.3.1. Surveyor on terminal

As stated before, Rienstra's research confirmed that a large part of Vopak idle time is due to waiting on surveyor arrival and activities. A surveyor, from a company that will be referred to in this report as Company S, checks the quality of a product in a lab located at their Company S headquarters, outside the terminal. Company S is a company with close relations to Vopak and were willing to show the average times for the most frequently requested quality checks, which can be seen in Table 2.1. Company S is about a 15 minute drive from VTAW. This means that to check a product's quality, at least 45 minutes is lost to driving to and from the terminal without taking into account unforeseen traffic circumstances. This is almost one third of the time for the total quality check, which is a considerable amount of time during which no participating party is doing anything of value to the process.

In September, Vopak opened a new office and lab for Company S surveyors at VTAW. The idea is to have surveyors on site to diminish travel time to vessels and tanks. This should make the surveyor activities at VTAW faster, more efficient, and more predictable.

Table 2.1: Average quality check times

Quality Check Product	Average Time (hr)
Ultra Low Sulphur Diesel	3.0
Gasoil	2.6
Gasoline	3.5
Biodiesel	3.5

2.3.2. Vessel clearance tool

VTAW currently uses a recently implemented vessel clearance tool. Vessel clearance is done by customer services. This process used to be done completely manually, meaning that a customer service employee manually checked the ship specifications with the jetty specifications to determine if the vessel was compatible with one of the VTAW jetties. Aside from the fact that this is relatively time consuming, the human eye is prone to making mistakes. These mistakes could have large financial consequences due to the high amount of extra time it takes to handle a wrongly accepted vessel that is not able to use the usual infrastructure. The new vessel clearance tool automatically generates a matrix containing the compatible jetties when the vessel Q88 form is uploaded. It also generates a standardized email such that only the customer and vessel names must be inserted. This tool lessens the workload of the customer services team, such that they can focus more on their other terminal related activities. In VTAW, customer services and planners are one team and thus this tool is important to make this an efficient fusion.

2.4. Summary

In this chapter, the background of Vopak and its vessel handling process has been introduced. Vopak is the world's leading independent tank storage company and has been in the business for over 400 years. This graduation project will focus on the Vopak Terminal Amsterdam Westpoort, as the vessel handling process here is the most modern and automated.

Previous research has been done on the subject of vessel handling by a Vopak intern, Fanny Rienstra. She created a tool to predict the amount of idle time a certain vessel would be subjected to upon arrival. Due to the high mean error, this tool is not usable within this research. However Rienstra's data regarding interrupts will be taken into account for the remainder of this report.

Currently, the innovation team at Vopak is already implementing new ideas at VTAW. Two of these new innovations are an on site lab for surveyors to be able work at VTAW, diminishing their travel time, and a vessel clearance tool that automatically generates an email containing a matrix of compatibility information for the vessel and the jetties.

In the next chapter, the exact workings of the vessel handling process will be further explained. Also, the problems within the vessel handling process will be analyzed and properly formulated.

3

Problem Analysis

The previous chapter gave background information on Vopak as a company and an overall brief explanation of the different steps within the vessel handling procedure at VTAW. This chapter aims to formulate the process in more detail and acquire the problems within the process. This will be done through the use of the Delft Systems Approach and the calculation of the terminal KPIs.

3.1. Delft Systems Approach

The Delft System Approach (DSA) is essentially a way of thinking. It focuses primarily on bridging the gap between theory and practice. There are four main reasons for the gap between theory and practice [Veeke,2008]:

1 The difference between finding a solution in theory and in practice.

2 The time pressure of management

3 The fashion consciousness of business management science

4 The perception of "importance"

DSA aims to close this gap between theory and practice through three different viewpoints:

1 Extending the multidisciplinary character as far as possible

2 To find a solution, start with a common perception of the problem

3 Combining qualitative and quantitative modelling

DSA starts with systems thinking. Systems thinking is the art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of underlying structure [Richmond,1987]. The idea of systems thinking is to take any process and view it from a simple perspective of, possibly, multiple systems and subsystems. A system is, depending on the researcher's goal, a collection of elements that is discernible within the total reality. These discernible elements have mutual relationships and (eventually) relationships with other elements from the total reality [Veeke,2008].

3.1.1. Black box

The first step in the DSA is to go back to basics. A simple black box containing the terminal function, input, output, requirements/goals, and KPIs (Key Performance Indicators). The black box is used as a tool to take away all procedures and assumptions that have grown to be part of the process as time has passed. It can help generate a fresh image on the process and transfer the focus of attention back to the primary functions and goals of the terminal. The black box of VTAW can be seen below in Figure 3.1.

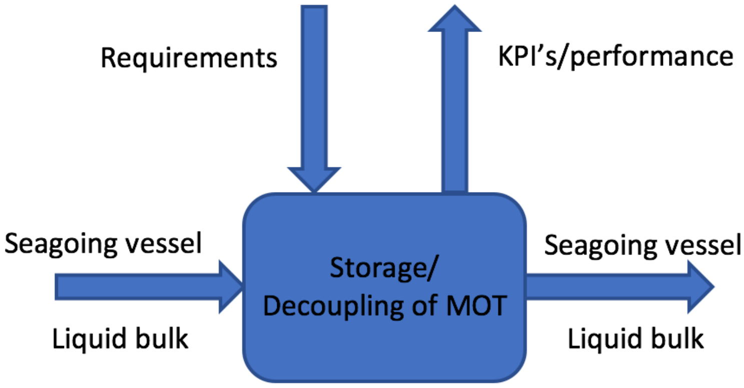

Figure 3.1: VTAW black box

VTAW is a tank storage terminal, however, the underlying function of the terminal is essentially the decoupling of different modes of transport. The terminal can be seen as a tool used by liquid bulk companies to store, but ultimately distribute their product inland or overseas. As this project focuses on seagoing vessels, the input and output of the black box is liquid bulk. Furthermore, the terminal is bound to certain overall requirements and goals as stated below. Some requirements are subjected to sub-requirements that are linked.

- Prevent demurrage for the customer by handling vessels within the predicted time
- Minimize vessel turnaround time
  - Maintain a minimum average flow of 1200 cbm
  - Flexible blending under the condition that operations start upon arrival
  - Minimize idle time
- Minimize vessel waiting time at Ijmuiden
- Maintain an average jetty occupancy of 60 - 70%

Lastly, KPIs are used to rate the performance of the terminal based on the said requirements. KPIs give an indication as to what level the terminal requirements have been met. Currently, VTAW are not actively and accurately measuring KPIs, so relevant KPIs have been created in conformity with VTAW and the requirements mentioned above. To measure the performance of the terminal, the KPIs, and the requirements to which they are tested, must be quantified if possible. Quantifying the requirements makes it simple to determine the performance of the terminal by checking whether the KPI value lies above or below the required value, or , if the goal is minimization, how close the value is to the theoretical minimum. The quantified requirements or goals for the terminal are listed below. These values will be used to determine the terminal performance.

- **Average waiting time:** Minimize (as close to 0 as possible)
- **Average turnaround time:** Minimize (idle time as close to 0 as possible)
- **Jetty occupancy rate:** 60-70%
- **Average demurrage cost:** Minimize (as close to 0 as possible)

Process Boundaries

The black box in Figure 3.1 is subject to certain boundaries. These boundaries are important to keep in mind before looking into the detailed process any further. The boundary at VTAW is set between the land-side and sea-side operations. In the rest of this report, the assumption will be made that the land-side infrastructure has no influence on the arrival planning of vessels. All tanks at VTAW are long term contract tanks. This means that the tanks at VTAW are assigned to long term customers and are not used by, for example, last-minute oil traders. All jetties accommodating seagoing vessels have an almost identical build and offer pipeline infrastructure to any of these tanks. Thus, the arrival of vessels is not influenced by land-side infrastructure, regardless of vessel size, product, customer, or blend.

3.1.2. PROPER Model

The function in the black box model in Figure 3.1 symbolizes the terminal, or in the case of this project, the entire vessel handling process. According to DSA, one should always consider at least three aspects and their interrelations: the material flow, the order flow, and the resource flow [Veeke,2008]. This is done in what is called a PROPER (PROcess-PERformance) model. The model contains three aspects: order, product, and resource. These three aspects are part of a larger transform function. All aspects are transformed to realize the handling of the vessels. The control function coordinates the transformations by generating executable tasks derived from the orders and by assigning usable resources [Veeke,2008]. Combining this information with the aforementioned requirements and KPIs makes it possible to create a PROPER model symbolizing the vessel handling process from a terminal point of view. The PROPER model is shown below in Figure 3.2 and each aspect of the model is further explained in the rest of the chapter.

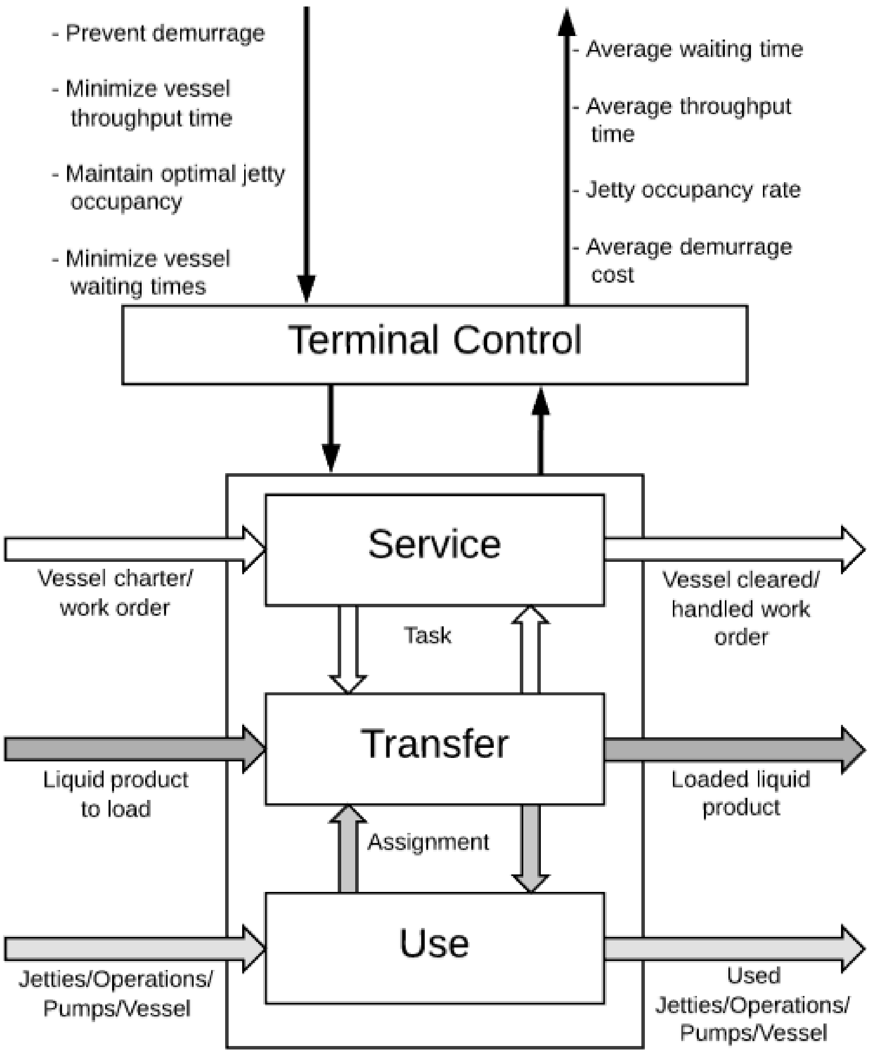

Figure 3.2: VTAW PROPER model

3.2. Process Analysis

The PROPER model in Figure 3.2 provides a good brief understanding of the terminal. To accurately and fully understand the different processes within the terminal, however, each aspect of the model will be described in more detail. After reading the process descriptions below, a good sense of understanding should be achieved regarding the vessel handling process at VTAW.

Order

The pre-arrival part of the process is essentially the order flow. In the case of a storage terminal this is somewhat complex as the order often changes during the procedure, however, these changes are minor and solely concerning blends so this will not be taken into account. To understand the transformation within the order flow, the pre-arrival process must be understood first. The pre-arrival process model can be seen in Figure 3.3 and is explained below.

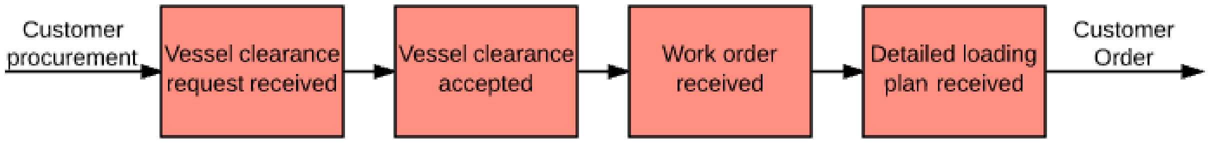

Figure 3.3: Pre-arrival process at Vopak

Vessel clearance

Vessel clearance is a process step that must be taken for the customer to ensure that a certain vessel is able to dock at the respective Vopak terminal. The customer sends Vopak customer service a Q88 form of the ship. A Q88 is a form containing all of a vessel's specifications. Customer service puts the received Q88 form into the vessel clearance tool, which automatically generates a matrix containing each jetty and whether or not the ship would be able to berth. This information is then sent back to the customer, whom decides whether or not to send the vessel to the respective Vopak terminal. Just two parties, the customer and customer service, are active during the pre-arrival process.

Work order

Aside from the vessel clearance procedure, a work order must be sent to Vopak customer services before arrival. The work order must contain all details that could be relevant to operations. Without a work order, customer service will not accept a tendered NOR. Thus, to avoid delay, it is of importance that this is done correctly before arrival.

Thus, the order flow of the vessel handling process starts with the chartering of a vessel by the customer, during which Vopak is contacted to clear the vessel. Through the pre-arrival process, this is transformed into a final work order received by Vopak, from which moment planning can start. The order flow of VTAW can be seen in Figure 3.4.

Figure 3.4: VTAW order flow

Product

The rest of the process, arrival to departure, is part of the product flow because all actions are involved in the transfer of the liquid bulk to or from the vessel. To fully understand the process and its boundaries regarding this project, each part of the process concerning product flow is explained below.

Arrival

The planning team at Vopak keeps track of the expected time of arrival (ETA) of each ship, however, operational services can not be planned yet as a ship's ETA is not 100% reliable and Vopak works with a FCFS policy. Once a vessel arrives at the Racon Buoy Ijmuiden, it tenders a Notice of Readiness (NOR) to Vopak customer services. If the vessel's work order has been received and is in order, the NOR is accepted and the vessel is placed at the back of the FCFS line. Once a jetty is available, the vessel is called in to the terminal. Vopak's planning team confirms the plan to operations. The vessel is given a lock slot and the pilot and tug boats are ordered. Upon arrival at the jetty, the tug boats release the vessel. The arrival process is considered finished once the vessel is all fast and ready for operations to start. In total, 4 parties are active during the arrival process. Vopak agencies is in charge of the pilots and tug boats, the vessel/customer is in charge of tendering the NOR, customer service is in charge of accepting the NOR, and the Port of Amsterdam is in charge of the lock schedule. An overview of the arrival process can be seen in Figure 3.5.

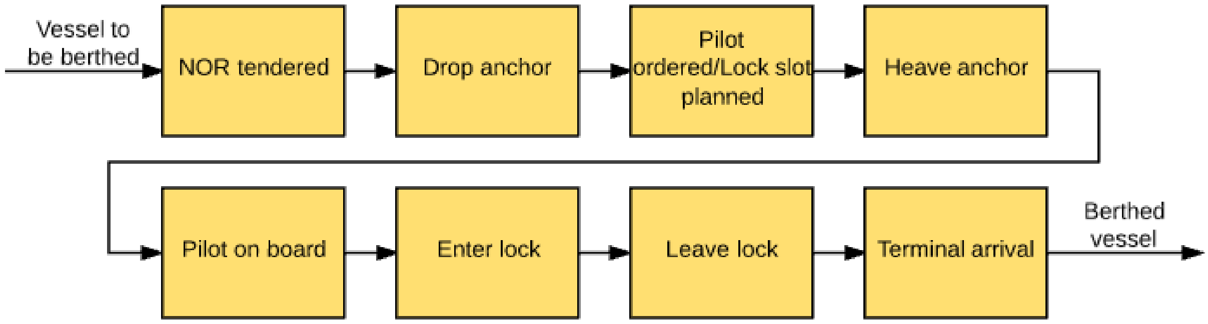

Figure 3.5: Arrival process at Vopak

Operation

Before operations can start, the Vopak operator makes sure the loading arm and hose is connected to the vessel. Then the operator, chief officer of the ship, and the surveyor meet to agree on the final work order. This is susceptible to change on a last minute basis due to possible product price changes or other relevant factors. When all parties have agreed, the loading or discharging process can start. These two processes are separately explained below. A full overview of the operations process can be seen in Figure 3.6.

- **Loading**
  During a loading process, the product is moved from the tank to the vessel. After having checked with the control room, the first parcel is loaded into the vessel tank. After each parcel, the surveyor checks if the quality and quantity is good and as agreed upon. If all parcels have been loaded and the quality has been checked, the next order, if applicable, is loaded in the same sequence. When all orders are completed, the loading operation is finished and the hose is disconnected. After the surveyor is done with the quality report, the vessel is clear to leave.

- **Discharging**
  During a discharging process, the product is moved from the vessel into the tank. After having checked with the control room, the first foot of the first parcel is discharged and the surveyor checks the quality of this first foot of product. If the first foot of product is good, the rest of the parcel is discharged. This is repeated for all parcels. After all parcels are discharged, the quality is checked in the Vopak tank once more. When all orders have been completed, the loading operation is finished and the hose is disconnected. After the surveyor is done with the quality report, the vessel is clear to leave.

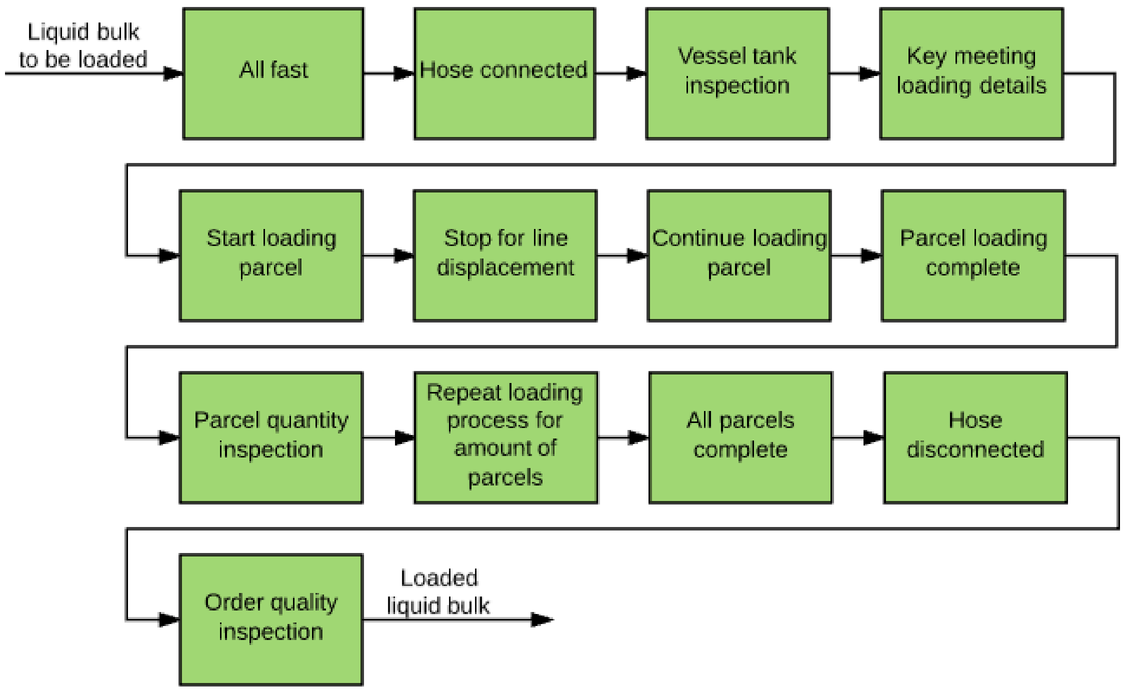

Figure 3.6: Operation process at Vopak (Loading)

Departure

The departure process is similar to arrival. It is important to try to get the ship to leave the jetty as soon as possible to clear the way for the next vessel. When a vessel is ready to depart, the pilot and tug boats are ordered and a lock schedule is planned. Once the pilot and tug boats have arrived and all the paper work is complete and in order, the vessel may depart and is guided through the port and lock. An overview of the departure process is shown in Figure 3.7.

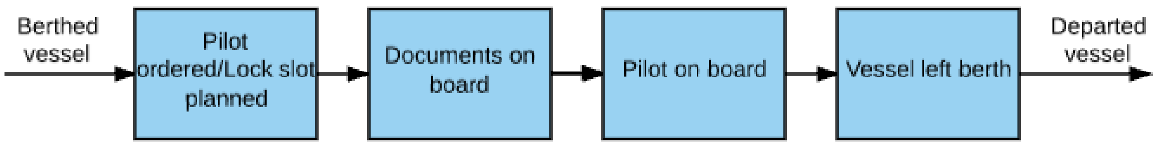

Figure 3.7: Departure process at Vopak

As stated before, the above 3 sub-processes belong to the product flow. The function of the product flow is to transfer the liquid bulk and in doing so, transforming the liquid product to load into loaded liquid product, whether it be from the vessel to the tank or the tank to the vessel. Thus, the product flow can be visualized by the model in Figure 3.8.

Figure 3.8: VTAW product flow

Resource

The last aspect of the PROPER model is resource. This implies all resources used during the vessel handling process at VTAW. Within the subject of process optimization, it is important that use of available resources is maximized and used to their full capacity under the condition that it does not slow down the process. As stated previously, the tanks are rented out with long term contracts meaning it does not matter whether the tank is empty or full and so tanks are not seen as a resource. The resources directly affecting the vessel handling process are the following:

- Jetties
- Operations team
- Pumps
- Vessel

The resource flow consists of these four resources as input and transforms these into used resources. Do keep in mind that a used resource does not necessarily mean it is used up, an example being human workers. The resource flow model can be seen in Figure 3.9

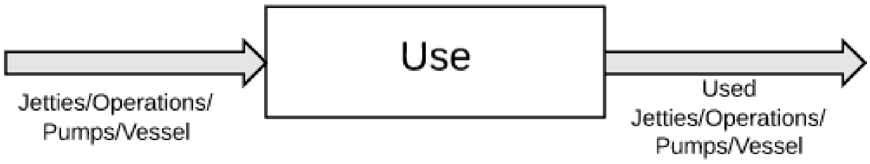

Figure 3.9: VTAW resource flow

3.3. Performance measurement

The DSA analysis in the previous section ultimately obtained a PROPER model that describes the transformation of orders, products, and resources during the vessel handling process. The transfer flow can be seen as the heart of the operation. It obtains the work order, or task, from the service flow and uses the resources to complete this task. The question now is where in this model, and in the process, is (the most) room for improvement? This question will be answered through analysis of the current terminal performance. The order flow and the resource flow will temporarily be put aside. The product flow transformation is where the actual process of vessel handling takes place. When zooming in on this part of the model, three aforementioned components can be distinguished: arrival, operation, departure. The previous section has thoroughly explained the three processes, whereas this section will focus on the requirements affecting, and the KPIs that are influenced by, these processes.

Arrival

The arrival process model is shown in Figure 3.10, in which a waiting vessel is transformed into a vessel ready for loading or discharging. The average waiting time is calculated from the moment the vessel has notified the terminal it is ready for loading or discharging by tendering an NOR to the moment the vessel is called in to the terminal. These two timestamps can be taken out of the arrival process to measure the KPI. The average demurrage cost is also influenced by the arrival process as the waiting time is included in the laytime of a vessel.

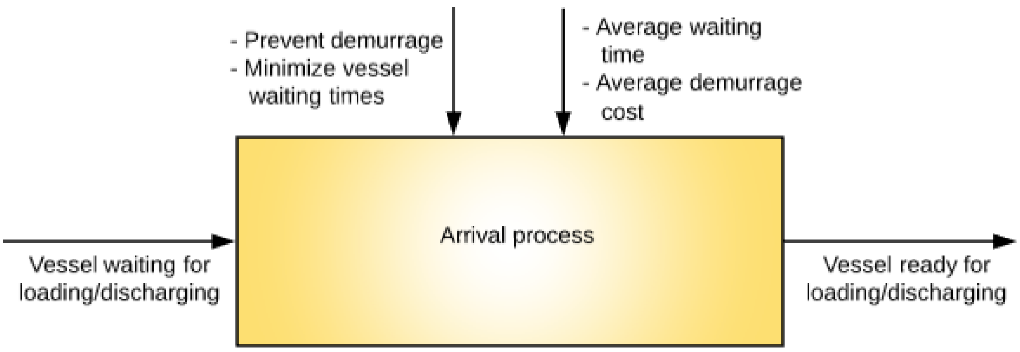

Figure 3.10: Arrival process model

Operation

The operation process model is shown in Figure 3.11. This process transforms the liquid product to be loaded into loaded liquid product. The three KPIs influenced by this process are the turnaround time, jetty occupancy rate, and demurrage cost. The turnaround time is measured through subtracting the departure timestamp with the berthing timestamp. The turnaround time affects the jetty occupancy rate as a more efficient operation would lead to a shorter turnaround time, which would lead to a lower jetty occupancy rate. The demurrage is also affected by the amount of time the operation takes. The exact demurrage rules are described later on in this report.

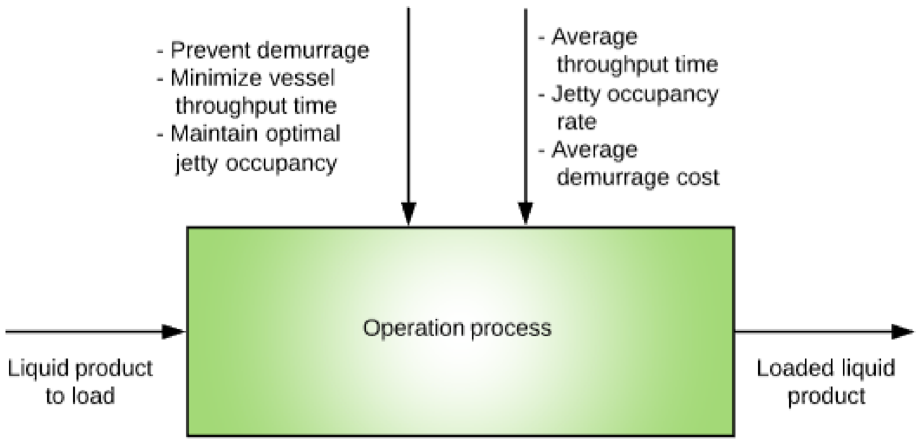

Figure 3.11: Operation process model

Departure

The last part of the process, departure, transforms a vessel waiting to depart into a departed vessel, as can be seen in Figure 3.12. This process is of influence on two KPIs. As mentioned earlier, the turnaround time of a vessel ends when the vessel has departed. As the turnaround time affects the jetty occupancy rate, the departure process is also of influence on the jetty occupancy KPI.

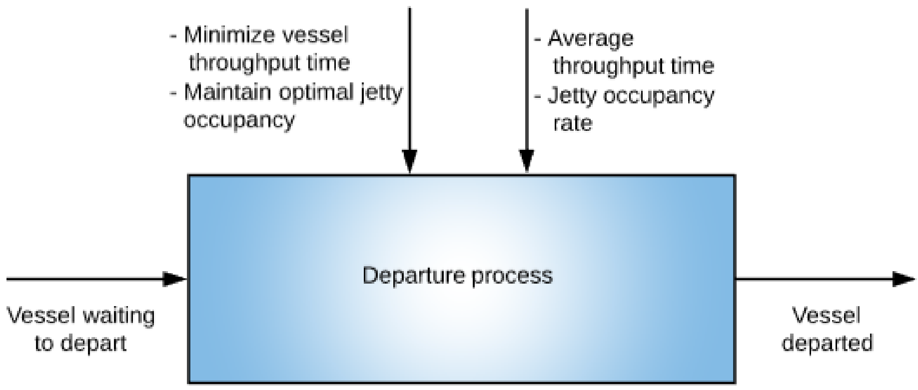

Figure 3.12: Departure process model

This chapter has thus far mentioned four KPIs to measure the performance of VTAW and has also zoomed in on the different aspects of the vessel handling process to explain where these KPIs are measured exactly. According to the outcomes of these performance measurements, the problems within the process at VTAW should become clear. The following subsections will measure each of the KPIs to ultimately formulate the goal for the remainder of the project.

3.3.1. Jetty occupancy

The jetty occupancy rate of an oil terminal is an important KPI to measure because it gives an indication as to how effectively the terminal is running. The formula for the jetty occupancy rate is as follows:

$$\text{Jetty occupancy} = \frac{\text{Total amount of time a jetty is occupied in a year}}{\text{Total amount of serviceable hours in a year}}$$

According to the Major Ports Development Plan by the Port of Rotterdam, an average jetty occupancy of 60-70 % is optimal for major tank terminals [CAG,2009]. A higher occupancy rate indicates congestion and long waiting times, whereas a lower occupancy would mean the terminal capacity is too large for the current demand. In the case of a Vopak tank terminal, operations run 24 hours a day so the denominator in the fraction above is simply one year. The total amount of berthed hours in a year is recorded per jetty in the VTAW data. The jetty occupancy rate for both seagoing vessel jetties are given in the table below along with the average.

Thus the average jetty occupancy at VTAW is about 80%. This is well above the suggested optimal rate and indicates congestion at VTAW. The results of the waiting times at VTAW should give more clarity whether this is a legitimate claim.

Table 3.1: VTAW jetty occupancy in 2016

	Jetty 1	**Jetty 2**
Berthed hours	6842,73	7168,17
Hours in a year	8760	8760
Jetty occupancy	78,11%	81,83%

3.3.2. Waiting time

The waiting time at at tank terminal is a crucial KPI for numerous reasons. Oil is a fast changing market, meaning that prices can change for better or worse during waiting time. As VTAW is not a suitable terminal for oil traders this is not necessarily a problem, however, waiting time may also count, partially, for the laytime causing demurrage. This is further explained in a later section, but the bottom line is the customer costs will increase and the customer satisfaction will decrease with increasing waiting times. Thus, waiting times must be minimized, whilst accounting for terminal efficiency. This compromise between efficiency and waiting time leads to the above mentioned optimal jetty occupancy of about 60-70 %. The average waiting time of seagoing vessels at VTAW is calculated using the Vopak Agencies data. Agents record the pre-arrival process of the vessel. As is explained in a later section, the first 6 hours after the NOR has been tendered is usually not counted as laytime to account for the arrival and berthing process of the vessel. Thus, the waiting time of a vessel will be assumed to be the time between "all fast" and "NOR tendered" minus 6 hours. If a vessel is berthed under 6 hours, the waiting time is assumed to be zero. Taking all this information into account, the average waiting time at VTAW for seagoing vessels is:

$$\text{Average Waiting Time} = 34 \text{ hours}$$

This result confirms the previous claim that the current jetty occupation rate is too high and leads to congestion.

3.3.3. Turnaround time

The turnaround time is the actual berthing time of the vessel. The turnaround time is an important KPI for the terminal as it gives insight into the efficiency of seaside operations. An increase in operational efficiency is a way to decrease the turnaround time of a vessel and in turn decrease the jetty occupancy rate, considering a stagnant demand. Within every sector, companies strive to minimize the turnaround time of a product or service and this is no different in the oil industry. This was also one of the goals of Rienstra's research, which was previously explained in Chapter 2, namely to find the reasons for idle time within the processes during which the vessel is berthed and find possible solutions to take this away. Aside from the minimization of the turnaround time, control of the turnaround time is equally important. To control the turnaround time means to standardize the process and decrease the variance to achieve the same quality and speed for each vessel. From the 2016 data at VTAW, the average turnaround time for seagoing vessels can be determined. The vessels are sorted into two categories, namely, vessels and coasters. Vessels are seagoing ships larger than 150 meters, whereas coasters are less than 150 meters. The reason for this categorization is that it is also done when negotiating the demurrage terms. Vessels are allowed a longer laytime than coasters. The average turnaround times can be seen in the table below:

Table 3.2: Average turnaround times for vessels and coasters at VTAW in 2016

	Average turnaround Time
Coasters	24,42 hours
Vessels	55,41 hours

3.3.4. Laytime and demurrage

Laytime and demurrage are difficult to standardize as these concepts are different for each vessel and each operation. It is agreed upon by the vessel charterer and the captain of the vessel. To quantify and get a sense of the scale of the total demurrage costs at VTAW, a number of assumptions will be made as to the calculation of laytime and demurrage. These assumptions are based on actual contractual demurrage agreements:

- Laytime shall commence 6 hours after acceptance of the Notice of Readiness or once the vessel has been declared ”all fast”. These 6 hours account for time steaming from anchorage to berth, commencing from pilot on board and ceasing when hoses connected.
- 48 running hours shall be allowed as Laytime for cargo size up to 130,000 tons for discharging and up to 60,000 tons for loading. For vessels loading more than 60,000 tons, a further 12 hours Laytime shall be allowed.
- Laytime shall cease when hoses are disconnected upon completion of discharge or loading.
- The demurrage rate is set at 800 dollars per hour.

Using the assumptions above, the following equation can be generated to calculate the laytime and the demurrage of each of the vessels registered in the 2016 data of the terminal:

$$Laytime = max(WaitingTime - 6, 0) + (HosesDisconnected - AllFast)$$
$$Demurrage = (Laytime - RunningHours) * 800$$

The average results for the laytime and demurrage of vessels at VTAW are as follows:

$$\text{Average Laytime per Vessel} = 79,39 \text{ hours}$$
$$\text{Average Demurrage Cost per Vessel} = 27700 \text{ dollars}$$

3.4. Terminal Seaside Performance

The KPIs above each give a small insight into the performance of the terminal. However, by looking at the KPIs individually, no accurate representation of the overall seaside terminal performance can be sketched. Thus, to be able to get an accurate idea of terminal performance in current and future states, and to be able to compare these states, a mathematical equation will be formulated, that combines the KPIs, to calculate the Terminal Seaside Performance (TSP).

3.4.1. Vopak Performance

The first component of the TSP is the Vopak performance. The goal of the terminal is maximizing profit. There are three main ways for Vopak to earn a profit:

1 Tank storage: Customer rent tank space for certain periods of time.

2 Throughputs: Sometimes a certain amount of throughputs is negotiated in the contract, however, usually a fee is paid by the customer per throughput of product.

3 Services: Extra services such as blending.

The profit gained from tank space rental has little to do with the actual vessel handling process. However, the amount of throughputs and additional services are impacted by the seaside process. More handled vessels means more product throughputs and possibly more additional services. Hence, Vopak performance is determined by the jetty occupancy and the turnaround time. The Vopak performance increases if the jetty occupancy increases or if the turnaround time decreases. This is, of course not always the case, for example if the jetty occupancy increases due to the fact that the turnaround time increases. However, this would not lead to an increase in terminal performance because the negative change in turnaround time would cancel out the positive change of the jetty occupancy. The turnaround time will be assumed optimal, if the amount of interrupt time within the total turnaround time is 0. The two KPIs are quantified within the equation as follows:

$$\text{Jetty Occupancy Rate (JOR)} = \frac{\text{Time jetty is occupied}}{\text{Total time passed}} \qquad 0\% \leq JOR \leq 100\%$$

$$\text{Interrupt Ratio (IR)} = \frac{\text{Total interrupt time}}{\text{Total turnaround time}} \qquad 0\% \leq IR \leq 100\%$$

This gives the following equation for the Vopak performance:

$$\text{Vopak Performance} = \frac{JOR + (1 - IR)}{2}$$

In the equation above, the jetty occupancy and the turnaround time are given the same weight. With the help from Vopak planners, who are part of this process on a daily basis, weights were given to these KPIs.

A jetty is one of the largest investments a terminal can make, and thus the terminal wants it to be used. However, the jetty occupancy is partly influenced by the market, and thus not completely controllable by the terminal. The terminal has more influence on the turnaround time and decreasing the amount of interrupts in the process. Decreasing interrupts also increases the amount of useful time the jetty is occupied. Hence, the turnaround time was overall considered a more important KPI regarding terminal performance. This led to the following equation for the Vopak performance component of the TSP:

$$\text{Vopak Performance} = \frac{1}{3} * JOR + \frac{2}{3} * (1 - IR)$$

3.4.2. Customer Satisfaction Performance

The second component of the TSP is the customer satisfaction performance. Vopak is a service-based company and thus customer satisfaction is equally important to operational performance. The latter two KPIs, the waiting time and the laytime & demurrage, are used to quantify the customer satisfaction at a tank storage terminal. Waiting time is an important component for customer satisfaction in any industry for obvious reasons and should therefore try to be minimized. The waiting time performance will be assumed to be 0 once the waiting time has reached the charter time of the vessel, which was set at 60 hours. Demurrage is a cost to the customer and hence should also be minimized to increase customer satisfaction. As the customer expects the vessel to be handled within the charter time, the customer satisfaction will be assumed to be 0% in the case of demurrage and 100% in the case of no demurrage. The two KPIs are quantified below:

$$\text{Waiting Time Ratio (WTR)} = \frac{\text{Total waiting time}}{\text{Total vessel charter time}} \qquad 0\% \leq WTR \leq 100\%$$

$$\text{Demurrage Ratio (DR)} = \frac{\text{Amount of vessels without demurrage}}{\text{Total amount of vessels handled}} \qquad 0\% \leq DR \leq 100\%$$

This gives the following equation for the customer satisfaction performance:

$$\text{Customer Satisfaction Performance} = \frac{DR + (1 - WTR)}{2}$$

As was done with the Vopak performance component, this equation was also weighted with the help of the planners at VTAW, as they are in contact with the customer every day. Although demurrage is an actual cost for the customer, the waiting time is still deemed a more important KPI. The reasoning for this is that the customer cares less about costs than about delaying their operations. Another reason is the fact that demurrage could have multiple causes, that are not always caused by Vopak. For example, the customer is sometimes the cause for the demurrage due to last minute deviations in the order. Hence, the customer satisfaction performance equation becomes:

$$\text{Customer Satisfaction Performance} = \frac{1}{3} * DR + \frac{2}{3} * (1 - WTR)$$

3.4.3. Seaside performance

The two components above combined make the terminal seaside performance. As Vopak is service-based, Vopak is nothing without its customers and vice versa. This is the reason that the above components will be weighted equally, such that if one of the components scores a 0, the terminal seaside performance would never get a sufficient result regardless of the score of the other component. The final equation for the Terminal Seaside Performance is as follows:

$$TSP = \frac{\text{Vopak Performance} + \text{Customer Satisfaction Performance}}{2} * 100$$

$$= \frac{(\frac{1}{3} * DR + \frac{2}{3} * (1 - WTR)) + (\frac{1}{3} * JOR + \frac{2}{3} * (1 - IR))}{2} * 100$$

3.4.4. Summary

In this chapter the problems at VTAW have been analyzed on the basis of the terminal model and KPI results. The terminal is essentially a means to decouple different modes of transport. This terminal function is realized through the order flow, product flow, and resource flow.

The work order is received from the client is transformed into a handled work order by loading or discharging the required product from the vessel to the tank or vice versa. This operation is done using the available resources at the terminal such as jetties, pumps, and operators.

The overall process is overseen by terminal control, which is subjected to certain requirements. These requirements are measured to see if they are met with the use of KPIs. The KPI results determine the performance rating of the terminal in the past year. These results also expose the areas of improvement.

The KPI results, as shown in the previous section, make clear that the jetty occupancy is currently to high at VTAW. This causes large waiting times for vessels, which in turn cause high demurrage costs for the customers.

The next chapter will recapitulate on the problem statement that was mentioned in the first chapter of this report. It will take the previously made analysis to check whether the research objective is still the best way forward to improve the overall terminal performance.

4

Problem Recapitulation

The previous chapter exposed current problems regarding the vessel handling process at VTAW. The performance measurements gave new insights as to the exact nature of the problem creating a cause for recapitulation of the previously stated research question and KPIs in this report. This chapter will reformulate the research question and objective based on the acquired information in the analysis.

4.1. Research objective

The research objective formulated at the start of this project is stated in Chapter 1 as: *"Improve the vessel handling supply chain at Vopak Terminal Amsterdam Westpoort to contribute to the aim of a more efficient overall process and a better terminal performance"*. Thus the problem, as seen from Vopak's point of view, is too much inefficiency in the process at the expense of terminal performance. The analysis in the previous chapter has funneled this rather broad claim to a few specific problems. The main issues that came to light were the following:

- High amount of idle time
- Little or inefficient collaboration
- High jetty occupancy
- High waiting times
- High customer demurrage costs

4.1.1. Problem statement

Vopak is a service-based company and the goal of service-based companies is to please the clients to whom you offer your services. In the case of a tank terminal, the customer satisfaction seems to be largely based on the following two factors:

1 Demurrage

2 Flexibility

Demurrage, as previously explained, is the cost of using a vessel for a longer time than it has been chartered. Flexibility, in this case, is the freedom to change loading plans and quantities at the last moment and during operation. Ironically, these two factors are adversative. More flexibility usually accounts for a longer throughput time, which in turn leads to more demurrage. Thus the terminal must attempt to achieve an optimal compromise between the two.

Currently, VTAW is leaning towards high flexibility to please the customers. This takes its toll on operations as it requires a reactive and high maintenance planning mentality. Vessels are handled on an FCFS basis and are only planned and scheduled once they have arrived at Ijmuiden and tendered an NOR. The negative result of this mentality consists of two factors:

1 The client does not know the amount of congestion at the terminal.

2 vessels aim to get to the terminal as fast as possible, and thus at full speed, to claim a spot in the FCFS queue.

Hence, the reactive planning mentality at VTAW makes it impossible for clients and vessels to properly plan their operations at a time that suits all parties. This, along with the high jetty occupancy, could be a large cause for the long waiting times, as seen in the previous chapter.

The reactive mentality also creates a second problem. Due to the fact that a planning schedule is made, and often changed, shortly before operations this causes many interrupts. The three most frequent interrupts that are most probably caused, partially, by this planning mentality are the following:

1 Waiting for the pilot to board the vessel and enter the lock. Due to the late planning, pilots are often busy at the time Vopak is ready to accommodate a vessel. Also, the lock schedule might be full.

2 Waiting for the surveyor to arrive and take samples of the product. Due to the reactive mentality, a surveyor is often ordered once the vessel has berthed causing idle time.

3 Changes in the loading plan. Allowing clients the flexibility of last minute changes in the loading plan causes delays due to time needed for changes to land-side equipment.

Thus, the reactive planning strategy is also the cause of idle time during the vessel handling process.

4.1.2. Revised objective

The previous subsection laid out the problems of the current reactive planning strategy of vessels, namely, that it causes, among other things, long waiting times as well as idle time within the process. Switching to a proactive mentality and planning strategy could potentially exonerate the terminal congestion and shorten the throughput time of vessels by collaborating with the other parties within the process. Taking this into account, the revised objective of this research should strive to calculate the effect of a proactive planning strategy on terminal performance.

Hence the revised objective of this graduation project is stated as follows:

- *Assess the impact of the implementation of a proactive planning strategy at Vopak Terminal Amsterdam Westpoort with respect to the operational performance.*

4.2. Modeling Approach

Multiple approaches are possible when analyzing a system such as a tank storage terminal. An overview of these approaches can be seen in Figure 4.1, which shows Daniluk and Chisu's methods for system analysis.

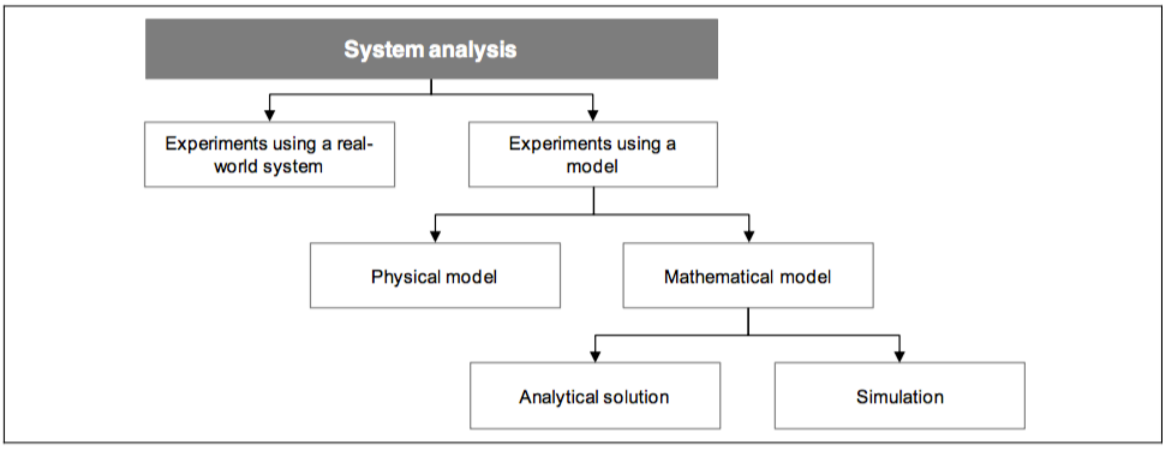

Figure 4.1: Methods for system analysis [Daniluk,2010]

The most realistic approach would be to run experiments using a real-world system. Obviously, this is not an option due to the time it would take and the risks for the customers. Thus, the terminal must be modeled. A mathematical model is the logical choice considering the size and complexity of the terminal. Hence, the only choice that must be made is whether to analyze the terminal performance analytically or using a simulation. The main advantage of an analytical model is that exact information is obtained on questions of interest. However, most real-world systems are too complex to allow realistic models to be evaluated analytically, and these models must be studied by means of simulation. In a simulation we use a computer to evaluate a model numerically, and data are gathered in order to estimate the desired true characteristics of the model [Law,1991]. Another advantage of a simulation over an analytical approach is the ability to model stochasticity, or irregularities such as peaks in the inter arrival times of vessels. Thus, a simulation will be used to model the terminal and calculate the impact of various scenarios on the operational performance of the terminal.

4.3. Research question

Now that the objective has changed, the research question is changed as well. Also, new goals have to be formulated to help guide the project in the right direction. The research objective above can be reformulated to acquire the main research question for this project:

- *What is the impact of a proactive planning strategy at Vopak Terminal Amsterdam Westpoort on Terminal Seaside Performance?*

The following steps will be taken to help answer the research question above:

i Create a simulation that models the current state of the terminal

ii Create different scenarios that are linked to a proactive planning strategy

iii Test the different scenarios using the simulation model iv Calculate the effect on the terminal performance for each scenario

v Compare the results of the different scenarios and the current state

4.4. Summary

The research objective that was formulated in the first chapter put the focus of the project on the terminal efficiency and performance. The goal of this chapter was to funnel the objective into a more specific direction with the help of the analysis in the previous chapter.

Process inefficiency is indeed a problem at VTAW and takes its toll on the overall terminal performance. These inefficiencies cause multiple problems within the process, however, the core cause of these inefficiencies seem to be the current terminal planning mentality and strategy. The terminal is currently offering flexibility to the customer at the cost of efficient terminal operations. The FCFS strategy results in reactive planning, which in turn causes more idle time and larger waiting times for vessels. This eventually leads to more demurrage costs for the customer. The hypothesis is that a more proactive planning strategy would relieve the congestion at the terminal and allow for a more efficient overall process and decrease the demurrage costs for the customer.

Thus, the revised research objective for this graduation project is stated as follows:

- *Assess the impact of the implementation of a proactive planning strategy at Vopak Terminal Amsterdam Westpoort with respect to the Terminal Seaside Performance.*

This objective will be achieved by modeling the terminal using a simulation. A simulation is used because it allows the modelling of complex real-world systems and irregularities within the system.

The next chapter will provide a more comprehensive formulation of the problem and look into possible methodologies to solve the objective and answer the research question. It will explain how the terminal is simulated and the different scenarios that will be tested using this model.

5

Conceptual Planning Model

The previous chapter recapitulated on the research objective formulated in the first chapter. After analysis of the terminal, the objective has been revised and will now focus on a proactive planning strategy compared to the current reactive mentality. This chapter will further formulate the problems of this reactive planning strategy and provide a new proactive planning model for the terminal.

5.1. Reactive Planning

As previously stated, VTAW uses a reactive planning strategy when handling vessels. The reason this strategy is used is to give the customer maximum flexibility. Due to rapid price fluctuations in the oil market, the customer often changes the exact quantity and blend of the product to be loaded at the very last moment or even during loading. Although flexibility is without a doubt an important factor to VTAW's customers, as Steve Jobs once famously quoted: "Customers don't know what they want until we've shown them". Customers often don't see the effects of some of the demands they make. In this section, the effects of reactive planning on the vessel handling process at VTAW will be analyzed.

VTAW works with a FCFS system, which is the main cause for the reactive strategy that is applied. FCFS means that the first vessel to tender a Notice of Readiness, of which an example can be seen in Figure 5.1, will be the first vessel to be handled. The Notice of Readiness is a document that tells the terminal that the respective vessel is, in all aspects, ready for loading or discharging. The NOR may only be tendered if the vessel has reached Ijmuiden. NORs that are tendered during voyage are rejected. This system gives the customer flexibility as the vessel is not bound to a schedule until it tenders an NOR. However, this way of working has multiple disadvantages as well.

NOTICE OF READINESS

Name of Vessel:	Port:	Voyage Number:

To: ____

I herewith tender you this vessel, of which I am the Master, as being ready in all respect to **LOAD** her cargo of : **xxx** **MT of** **xxxxx**.

The notice is tendered this **8th** day of **JAN 2017** at **16:30** hours **(LT)**, subject to the terms, conditions and exceptions of the charterparty.

____

Master

Date Acknowledged: __________

Time Acknowledged: __________

(Signature)
Name in Print: __________
(with block letters)

Representing: __________
(with block letters)

Figure 5.1: Example of an NOR

5.1.1. Uncontrolled arrival distribution

The order nomination is the first piece of information a terminal receives of an incoming vessel. A nomination contains information such as the vessel name, product, and ETA. The nomination can be received a week in advance or as short as one day in advance. Because of the FCFS rule, the nomination is not used for planning, and the terminal waits until it receives an NOR. This means the terminal has some idea, but ultimately does not know how many vessels will arrive on a specific day. This is what is meant by an uncontrolled arrival distribution. The arrival distribution is an important factor to take into account when looking at waiting times and jetty occupancy. As stated earlier in this report, the ideal jetty occupancy for a tank storage terminal is between 60-70%. This percentage is based on multiple factors such as time lost in between two vessels and also an arrival distribution that is not constant. A constant arrival distribution would mean that each the time in between two vessel arrivals is always the same. Considering this were to be the case, the jetty occupancy could be increased to 90% without increasing the waiting times, not taking into account maintenance. However, this is a theoretical case and in practice inter arrival times are never constant. Although, it can be controlled. An example of controlling inter arrival times is slot booking. Vessels that have booked a specific time slot will most likely not arrive long before their slot. A more controlled arrival distribution, as opposed to the current situation, could potentially increase terminal efficiency.

5.1.2. Information sharing

Another result of last minute vessel planning is the lack of information that can be shared with other parties. First of all, the customer has no way of knowing the congestion at the terminal and thus will charter a vessel as soon as a loading or discharging operation is necessary. Meanwhile, the vessel has no benefit in knowing the congestion as a large waiting time is beneficial due to the high demurrage rates. The result is that the vessel will cruise to the terminal at full speed to be able to tender an NOR as soon as possible and start the official laytime. From an environmental perspective, as well as the perspective of the terminal and the customer, it would be more beneficial if the vessel were to travel at a more fuel efficient speed and reach the terminal once congestion has decreased. Second is the pilot, who is also responsible for reserving a time slot for the lock. Due to the accuracy and small amount of information the terminal is able to provide regarding arrival and departure time of vessels, the pilot is not able to rely on this knowledge. The consequence is that the pilot has decided to adopt the same reactive mentality, meaning that the pilot will only act on an order once the arrival of a vessel has been confirmed. This potentially creates a problem regarding the lock reservation as the lock is often congested as well and thus the vessel must wait for a time slot. The same reasoning can be applied to the surveyor actions. The surveyor only acts on an order once the readiness of a vessel is confirmed and so, as was proven in Rienstra's research, vessels often spend time waiting on the surveyor to arrive.

5.2. Proactive planning model

The problems mentioned above regarding the current reactive planning model can potentially be solved by forward planning. A common forward planning model is slot booking. Slot booking consists of a start time and end time with a certain tolerance range, as shown in Figure 5.2. Slot booking requires

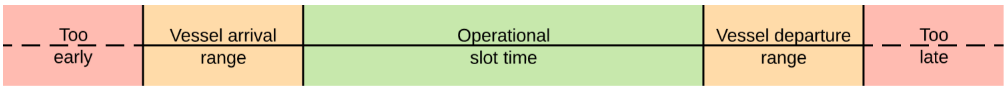

Figure 5.2: How slot booking works

a certain amount of predictability regarding arrival times and vessel handling times. As mentioned previously in this report, uncertainties are one of the main problems in the handling of vessels at tank storage terminals. These uncertainties within the process would mean one of two outcomes upon implementation of this model:

1 A majority of vessels do not finish within the registered slot time causing congestion and decreasing customer satisfaction

2 A large safety margin and hence long operational slot time is chosen causing vessels to finish long before the next vessel arrives, which decreases terminal efficiency.

From the above situations, the conclusion can be made that, with the current level of predictability, an end time can not be guaranteed. Thus, slot booking is not a realistic option in the near future for tank storage terminals. However, by taking the end time out of the equation, a more plausible forward planning model could be designed.

5.3. First Order First Serve

The conceptual planning model explained in this section was designed with the input of planners at VTAW, with the goal to limit the amount of changes in operations for the customer and the vessel. The planning model enforces a First Order First Serve rule. The model works as follows:

1 A fixed X days (or later at risk of congestion) before vessel ETA, the order nomination must be

sent by the customer to VTAW. If the order nomination is sent earlier than the set amount of days, the vessel will still only be planned X days before its expected arrival.

2 When the vessel is planned it is given an arrival time range no earlier than the ETA on the order nomination. This arrival time is based on the congestion prediction at that moment. Hence, no guarantee is given that the vessel will be handled immediately upon arrival. This is due to the unpredictable handling times.

3 If the vessel arrives later than the assigned arrival time range, it runs the risk of losing its place. This depends on the planning at that moment and the vessel's successor and predecessor.

4 Once the vessel is called-in, operations are the same as in the current state of the terminal.

This new model could greatly reduce waiting times at the terminal by sharing future congestion information with the customer and the vessel. The FOFS planning model is subjected to 2 important variables regarding planning.

Time of Planning

The first variable is the time of planning. This variable indicates how long, prior to the expected vessel arrival, vessels will be scheduled. Thus, in the current state of the terminal, this variable would be equal to zero because vessels are scheduled only when they have tendered an NOR, which means the vessel has already arrived. If the time of planning would be equal to, for example, 3 days then customers would be obliged to send an order nomination at least 3 days in advance of the planned operation. The vessel would then be given an arrival time at which the terminal expects a vacant jetty. This is not to be mistaken by a time slot. The vessel is given a time at which it must arrive at Ijmuiden to claim its planned spot in the FOFS line, however, the terminal does not guarantee immediate service. Essentially, the ability to claim a spot at the end of the FCFS line has been moved from NOR tendered to 3 days in advance.

Maximum customer delay

The second variable is the maximum customer delay. This means the maximum amount of time the terminal may delay the expected arrival time of the customer's vessel upon receiving the order nomination. This is an important part of forward planning because if, for example, the arrival time can not be delayed at all, it does not matter whether the terminal plans ahead as it will not change the arrival distribution of vessels. In the current situation, the value of this variable is 0% as there is no time to delay the vessel due to the time of planning value of 0. There are essentially two ways to interpret this variable:

- The customer sends an order nomination before chartering a vessel, thus giving the terminal maximum flexibility to delay the customer. If the terminal is too busy at that moment, the customer will simply choose to use another terminal or to delay the operations to a later time.

- The customer has already chartered a vessel upon sending the order nomination. This vessel could slow down to a minimum of 50% of its speed, if necessary, to delay its arrival at the terminal. This is called slow steaming and is nowadays a common way for vessels to lower costs by reducing fuel consumption. This, however, gives the terminal a limited customer delay, which increases as the time of planning variable increases.

Thus, the maximum customer delay and the time of planning, together influence the arrival distribution of vessels and the amount of planning flexibility for VTAW, which could lead to a more efficient terminal operation.

A third and last should also be taken into account when implementing the new conceptual model: the interrupts. The new FOFS planning model enforces forward planning, meaning that through information sharing and collaboration, certain or potentially most interrupts could be prevented, positively influencing the terminal performance.

Interrupts

Interrupts are essentially the factor that makes the accurate berth planning of vessels so difficult. The total average interrupt time for vessels is 11-13 hours, which leaves a lot of time to be saved. It is unrealistic to think that all interrupts can be permanently solved in the near future, however solving just a few re-occurring problems could potentially have a large positive effect on the terminal operations. Rienstra's research has looked into the distribution of the different interrupt codes and the result can be seen in Figure 5.3. This figure shows that just the interrupt codes WASU, Waiting for Surveyor Activities, and WASA, Waiting for Surveyor Arrival, make up 52% of the total interrupt time within the process. Thus, assuming these interrupts can be prevented, this could potentially influence terminal efficiency.

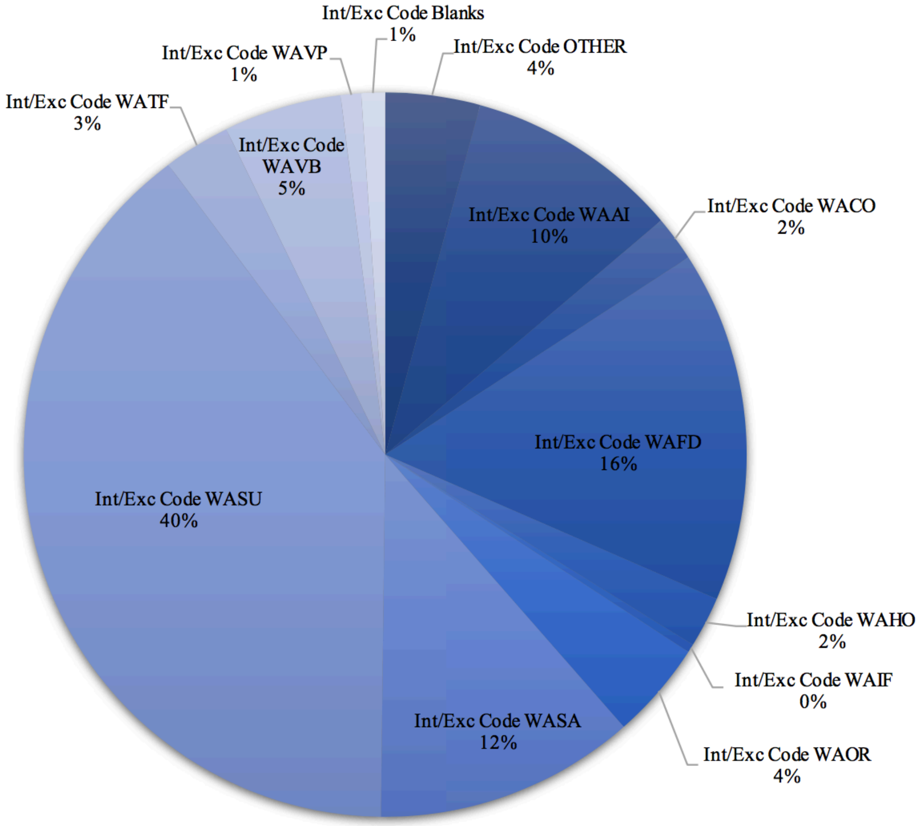

Figure 5.3: Results from the test simulation run

5.4. Summary

VTAW currently uses a reactive planning strategy when scheduling vessels to offer maximum flexibility to the customer. Two disadvantages of a reactive strategy are the following:

- Uncontrolled arrival distribution
- Lack of information sharing

Forward planning could potentially solve these problems and increase terminal performance. A common forward planning method is slot booking. Unfortunately, the low level of predictability makes this approach implausible. Hence, a new conceptual planning model is designed in cooperation with planners at VTAW. This model enforces a First Come First Order rule. The model is subjected to two variables: time of planning and maximum customer delay. These variables influence the arrival distribution of vessels and the amount of flexibility VTAW is given within the planning process. A third variable, the interrupts, could be influenced by the new forward planning strategy and should therefore also be taken into account when testing the model.

The next chapter will explain how the implementation of this conceptual planning model is tested.

6

Model Implementation

The previous chapter explained the disadvantages of using a reactive planning approach. It introduced a new proactive planning approach that enforces a First Order First Serve rule. The model is subjected to two variables, namely, the 'time of planning' and the 'maximum customer delay'. This chapter will provide an extensive explanation of how the model implementation will be tested.

6.1. Proactive planning model

To study the effect of a proactive planning mentality, a model of the current state of the terminal will be made. The current state simulation will be compared to the proactive strategy simulation, in which multiple scenarios will be tested. The simulation model is made using Lazarus and Tomas. Lazarus is a programming environment using the Pascal language. Tomas is a discrete simulation package for logistical modeling and simulation design to be used within this environment. Some more information as to these programs will be given below. After this, the current state model of the terminal will be explained as it is programmed. Lastly, the proactive model will be introduced along with various scenarios to be simulated.

6.1.1. Background programming information

As mentioned above, the terminal will be modeled using discrete event simulation. Below, some more information will be given into backgrounds on computer programming, and in particular programming in Lazarus/Tomas.

Lazarus/Tomas programming

To find solutions for logistical problems such as the on described in this report, often computer simulations are used. A computer simulation makes use of a model, and runs this model a given number of times to calculate what will happen. As a model is a simplified representation of the real world, one should take great care in building the model. Some parameters can be left out, while others are of the utmost importance.

In this project, an object-orientated model is used, which implies that objects are defined in the system that have certain specifications and characteristics. In this case there is just one object, a vessel. However, each vessel is created with differences in specifications and characteristics, according distributions based on real data. The model works according to the following structure:

- **Classes:** These are defined as the actual elements in the model, and these can be both existing or non-existing. An example of an existing element is a vessel. A non-existing element would be a generator, which ”creates” vessels to enter the simulation. Both of these examples are classes.
- **Attributes:** These are the properties given to a class. For instance, a vessel may have a product quantity or a maximum flow rate as an attribute.
- **Processes:** A process is an actual action of a certain class, if that is an ability of that class. The action of the lock for instance, is to transport vessels from the North Sea outside Ijmuiden to the North Sea Canal. The vessel itself is not active within such a process and thus a vessel does not ”have” an action.
- **Queues:** An element is stored into a queue, until the next event occurs. The time of entering and leaving the queue are recorded so that the total time within the queue can be calculated. Queues are useful not only to simulate actual waiting queues but also operational processes. For example, a surveyor activity can be modeled by putting a vessel in a queue for the amount of time it takes a surveyor to complete the respective activity.

The time within a queue gives valuable information as to the average times of certain processes and, in this case, occupancy rates of jetties. It is able to give information every element in the system and the queues are therefore an important part of the model to get to a conclusion. All the commands above are valid for most programming languages. In this project Lazarus is used for writing the program and TOMAS is an additional package that makes it possible to trace step by step, what is happening in the simulation and also to create clear 2-D animations of model for visualization purposes.

6.1.2. Model Structure

The current state vessel handling process has been explained earlier in Chapters 2 and 3. The coming sections will explain how this process has been simplified into a model to accurately portray the current reality. The main focus of the simulation is the arrival process as this is the cause of the reactive mentality. However, the operational processes must also be modeled to be able to generate results regarding the effect of a new strategy on these processes.

Tomas elements are simply all parts that contribute to the simulation model of the terminal. These elements include classes, processes, and queues. The different elements form the structure of the model. This model structure is summarized in table 6.1.

Table 6.1: Model structure of the simulation

Classes	**Attributes**	**Description**
Vessel	OperationType	Loading or discharging operation
	TransShip	If the vessel also plans a transshipment operation
	ProductQuantity	The amount of product to be loaded or discharged
	FlowRate	The maximum allowable flow rate of the vessel
	OrderLines	The amount of orderlines
	AllFast	The jetty arrival time of the vessel
	Depart	The departure time of the vessel
	LayTime	The amount of handling time used to calculate demurrage
	PredictedLaytime	The predicted amount of laytime for a vessel
	ArrivalTime	The arrival time assigned to the vessel by the terminal
	ETA	The planned arrival time on the order nomination
	SlowETA	The arrival time based on maximum accepted customer delay
	TransShipTime	The time taken to handle the transshipment order
	OrderLineTime	The time taken between each order line
Queues		
JettyNomination		Contains vessels of which order nominations have been received
JettyWait		Contains vessels that have arrived and are waiting
LockTravelQueue		Vessels that are traveling to the lock
LockQueue		Vessels that are currently in the lock
OutOfLock		Vessels that have cleared the lock
JettyArrival		Vessels that are traveling from the lock to a jetty
JettyPrePump		Vessels undergoing pre-pump operations
JettyPump		Vessels undergoing pumping operations
JettyPostPump		Vessels undergoing post-pump operations
JettyInterrupts		Vessels undergoing possible interrupts within the process
Processes		
VesselGenerator		Generates vessels as input to the simulation
JettyArrivalPlan		Regulates vessel arrivals according to the schedule
Lock		Simulates the lock at Ijmuiden
Jetty		Simulates the operational processes during berth

6.1.3. Processes

To understand how the simulation model works, a closer look will be taken at the individual processes. The processes define the model and use classes and queues to help achieve this goal. Below, each process is explained in more detail along with the Process Description Language (PDL) for the specific process. The actual written code can be found in Appendix B. All distributions mentioned in the processes below are cumulative distributions that fit the historical data to make the model as realistic as possible. The cumulative distribution charts, based on the data, can be found in Appendix C.

Vessel Generator

The vessel generator creates vessels according to a given arrival distribution. Created vessels have the attributes as seen in table 6.1. However, most attributes are given a value of 0 upon creation. Depending on attributes such as the operation type, the correct distribution is chosen to assign values to the remainder of the attributes. This is because loading vessels have different attribute distributions than discharging vessels. Two of the vessel attributes are binary, meaning these have a value of either 0 or 1. These two attributes are the operation type and the transshipment attribute. A value of 0 means loading or no transshipment respectively, as for 1 means discharging or transshipment respectively. The last attribute to be assigned is the arrival time, which in the current state is immediately as no forward planning takes place. Once all attributes have been assigned a value, the vessel is put into one of two nomination queues depending on the jetty it has been assigned to.

VesselGenerator.Process

```
Repeat
    NewShip = Vessel.Create
    If NewShip.OperationType = Loading then
        Begin
            NewShip.ProductQuantity = LoadQuantity.Sample
            NewShip.FlowRate = ProductQuantity * LoadConstant
            NewShip.OrderLines = LoadOrderLines.Sample
            NewShip.PredictedLaytime = Sum(Predicted process times)
        End
    Else
        Begin
            NewShip.ProductQuantity = DischargeQuantity.Sample
            NewShip.FlowRate = ProductQuantity * DischargeConstant
            NewShip.OrderLines = DischargeOrderLines.Sample
            NewShip.PredictedLaytime = Sum(Predicted process times)
        End

    If NewShip.TransShip = 1
        Begin
            NewShip.TransShipTime = TransShipTime.Sample
            NewShip.PredictedLaytime = NewShip.PredictedLaytime + Predicted TransShipTime
        End
```

```
NewShip.ETA = TNow + AmountOfForwardPlanDays
NewShip.SlowETA = TNow + NewShip.ETA + MaximumVesselDelay

    If NewShip.ETA < PredictedTimeToJettyAvailable
        NewShip.ArrivalTime = min(NewShip.SlowETA, PredictedTimeToJettyAvailable)
    Else
        NewShip.ArrivalTime = NewShip.ETA
    TimeBetweenVessels = NewShip.ArrivalTime - PredictedTimeToJettyAvailable
    PredictedTimeToJettyAvailable = PredictedTimeToJetty1Available +
    Max(TimeBetweenVessels, 0) + NewShip.PredictedLaytime
    JettyNomination.AddToTail(NewShip)
```

Arrival Plan

The function of the arrival plan process is to be able to simulate proactive forward planning. As seen in the PDL above, the arrival time of a vessel is already given in the vessel generator process. Thus, the only thing left to do in this process is to hold until the next vessel arrives and put the respective vessel through to the waiting queue.

ArrivalPlan.Process

```
Repeat
    While JettyNomination.Length = 0 do Standby
    myShip = JettyNomination.FirstElement
    Hold(myShip.ArrivalTime - TNow)
    myShip.LeaveQueue(JettyNomination)
    myShip.EnterQueue(JettyWait)
```

Lock

The lock process simulates the vessels traveling to and clearing the lock at Ijmuiden. If a vessel is waiting and one of the jetties is vacant, the lock process calls in a vessel. The travel time to the lock and the time in the lock has been determined according to the historical data and is simulated as a constant. The lock process holds a vessel in the respective queues for the given amount of time and lastly puts them in the OutOfLock queue. This makes the vessel available to the jetty processes.

Lock.Process

```
Repeat
    While JettyWait.Length = 0 or JettiesOccupied = 2 do Standby
    myShip = JettyWait.FirstElement
    myShip.LeaveQueue(JettyWait)
    myShip.EnterQueue(LockTravelQueue)
    Hold(TravelTimeConstant)
    myShip.LeaveQueue(LockTravelQueue)
    myShip.EnterQueue(LockQueue)
    Hold(LockTimeConstant)
    myShip.LeaveQueue(LockQueue)
```

```
    myShip.EnterQueue(OutOfLock)
```

Jetty

The model contains two jetties and thus two jetty processes. The only difference between the two processes is that Jetty 1 has priority over Jetty 2, which means that if both jetties are vacant, the vessel will berth at jetty 1. The jetty process contains 5 queues that simulate the different sub-processes within the vessel handling procedure. These sub-processes are the travel time to the jetty, the pre-pump process, the pumping process, the post-pump process, and the interrupts. The interrupts are simulated as a separate sub-process because the data does not indicate where in the vessel handling process the interrupt took place. After a vessel has passed through all queues, the vessel leaves the simulation and is destroyed. Once a vessel has been destroyed, the jetty becomes vacant again.

Jetty.Process

```
Repeat
    While OutOfLock.Length = 0 do Standby
    myShip = OutOfLock.FirstElement
    myShip.LeaveQueue(OutOfLock)
    myShip.EnterQueue(JettyArrival)
    Hold(JettyTravelTimeConstant)

    myShip.LeaveQueue(JettyArrival)
    myShip.EnterQueue(JettyPrePump)
    myShip.AllFast = TNow
    If myShip.OperationType = Loading
        Hold(LoadPrePumpTimeConstant)
    Else
        Hold(DischargePrePumpTimeConstant)

    myShip.LeaveQueue(JettyPrePump)
    myShip.EnterQueue(JettyPump)
    Hold(OperationTime + OrderLineTime + TransShipTime)

    myShip.LeaveQueue(JettyPump)
    myShip.EnterQueue(JettyInterrupts)
    If myShip.OperationType = Loading
        Hold(LoadInterrupt.Samples)
    Else
        Hold(DischargeInterrupt.Samples)

    myShip.LeaveQueue(JettyInterrupts)
    myShip.EnterQueue(JettyPostPump)
    If myShip.OperationType = Loading
        Hold(LoadPostPumpTimeConstant)
    Else
```

```
    Hold(DischargePostPumpTimeConstant)

myShip.LeaveQueue(JettyPostPump)
myShip.Destroy
```

6.1.4. Output

The output of the model is generated in a Lazarus form during simulation. Output is generated for two reasons:

- To obtain the necessary results needed for the research
- To check whether the model is doing what it is supposed to be doing

Both these reasons will further be dealt with in later chapters. This section will explain how the output form is structured and what information is obtained for the results. The form containing the output of this model can be seen in Figure 6.1. The form is divided into three parts:

1 *Vessel Handling Process:* Generates information regarding all steps within the vessel handling process. It generates both individual time values for each vessel as well as the overall average.

2 *Individual Jetty Results:* Generates the wanted results for this research project per individual jetty.

3 *KPI Results:* Generates the overall wanted results for this research project, averaging the individual jetty results. This is the part of the output that will be used as the result when testing different scenarios.

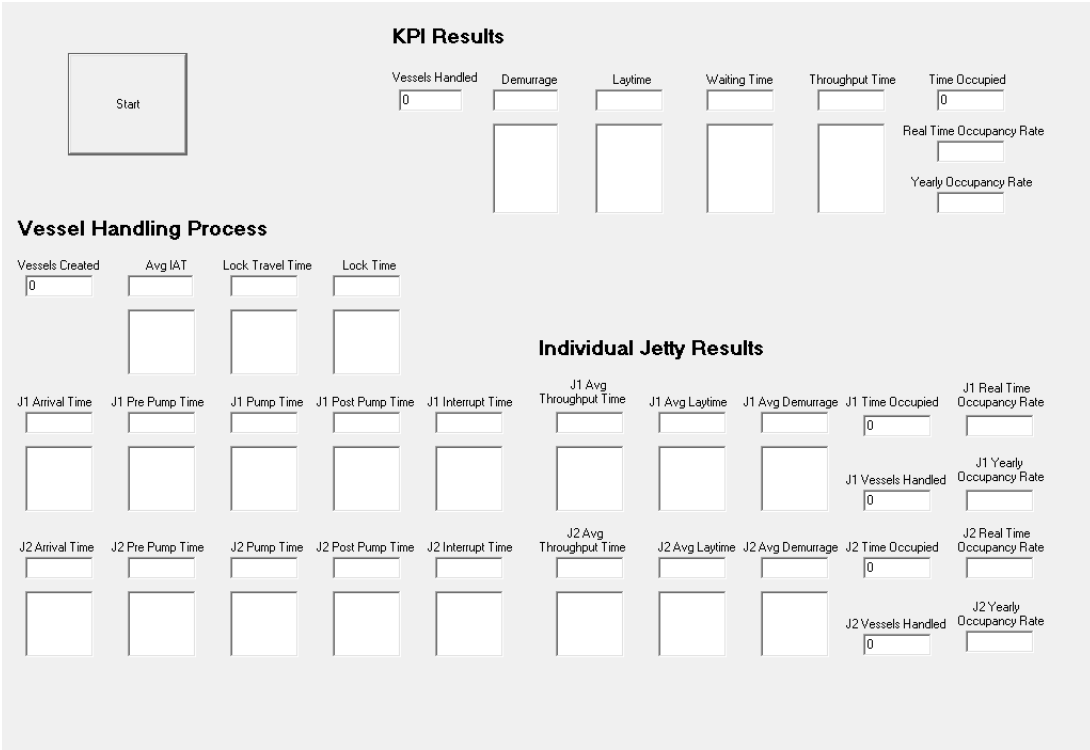

Figure 6.1: Output form containing simulation results

The start button in the form obviously starts the simulation. The rest of the individual output values generated within each of the categories will be briefly explained below:

Vessel Handling Process:

Vessels Created = Total number of vessels that have entered the simulation
Avg IAT = Individual and average values of the inter arrival times between vessels
Lock Travel Time = Individual and average values of the travel time to the lock
Lock Time = Individual and average values of the time within the lock
J1/J2 Arrival Time = Individual and average values of the travel time from the lock to the jetty
J1/J2 Pre Pump Time = Individual and average values of the time between berthing and pumping
J1/J2 Pump Time = Individual and average values of the pumping times of vessels
J1/J2 Post Pump Time = Individual and average values of the time between pumping and departure
J1/J2 Interrupt Time = Individual and average values of the interrupt times within the process

Individual Jetty Results:

J1/J2 Avg Throughput Time = Individual and average values of the time between berthing and departure
J1/J2 Avg Laytime = Individual and average values of the time counting for demurrage of vessels
J1/J2 Avg Demurrage = Individual and average values of the demurrage paid to vessels
J1/J2 Time Occupied = Total time that the jetty has been occupied by vessels
J1/J2 Vessels Handled = Total amount of vessels that have been handled by the jetty
J1/J2 Real Time Occupancy Rate = The real time rate between the time a jetty has been occupied and the total time passed
J1/J2 Yearly Occupancy Rate = The rate between the time a jetty has been occupied and the total time in one year

KPI Results:

Vessels Handled = Total amount of vessels handled in the simulation
Demurrage = Individual and average values of the demurrage paid to vessels
Laytime = Individual and average values of the laytime of vessels
Waiting Time = Individual and average values of the waiting time of vessels
Throughput Time = Individual and average values of the throughput time of vessels
Time Occupied = Total time that the jetties have been occupied by vessels
Real Time Occupancy Rate = The real time rate between the time the jetties have been occupied and the total time passed
Yearly Occupancy Rate = The rate between the time the jetties have been occupied and the total time in one year

6.2. Summary

To study the effect of switching to a proactive planning strategy, a model has been created to simulate the results of such a strategy. The model has been made using Lazarus and the Tomas add-on package for logistical modeling and simulation design.

The model uses classes, processes, and queues to simulate the various processes within the vessel handling system. The output is generated in a form, which can be seen in Figure 6.1. The outputs are categorized into individual process results, to help determine the correct working of the program, and overall results, used to study the effect of a proactive planning approach.

The next chapter will introduce the different scenarios or experiments that will be done using this model and validate the model to ensure the obtained results are the correct ones.

7

Model Validation and Verification

The previous chapter introduced the proactive planning model created with Lazarus and Tomas. This chapter will run some simulations to test the simulation model. This serves to verify and validate the model to ensure that the model is correct and does what it is intended to do.

7.1. Verification

Model verification is important to avoid unknowingly getting incorrect results due to the fact that the simulation does not run as it should. it is intended to ensure that the model does what it is intended to do. There are multiple techniques for model verification, but in this case tracing will be used. Tracing is part of the Tomas add-on package and it describes the key events within the simulation in text. This makes it easy to check whether the model is doing what it's supposed to do. If a certain event is not registered by the trace, it can be manually added in the code to appear in the trace field output to ensure the event has actually happened.

7.1.1. Prognosis

To verify the model, a test simulation setup will be used. In the test setup the hold values, which define length of the different process steps, will be changed to a known constant value as opposed to a distribution sample. Knowing these constants, the results can be calculated by hand before running the simulation. If the simulation results and events match the hypothesis, the model is verified. The following events will be key focus points when testing the simulation:

- The vessel generator should successfully place a newly created vessel into the correct JettyNomination queue, thus the queue with the least predicted waiting time.
- The vessel is placed into the JettyWait queue at the time of its arrival.
- Only once the jetty is vacant and the lock is not in use, the vessel may enter the lock process.
- Once a vessel has been handled, it must be destroyed and the next vessel in the waiting queue may enter the process.
- A maximum of one vessel may be present in each of the jetty processes at all times

To make the calculation easy, all hold values will be multiples of 5 time units. The hold values for the different queues are given in Table 7.1. The test simulation will be run for 45 time units to ensure that all key events take place. The prognosis for the test simulation can be seen in Table 7.2.

Table 7.1: Hold values for the test simulation

Event	Time Units
Vessel IAT	5
Travel to Lock	5
Lock	10
Travel to Jetty	5
Pre Pump	5
Pump	5
Post Pump	5
Interrupt	5

Table 7.2: Prognosis for test simulation

W1 = Waiting queue for jetty 1
W2 = Waiting queue for jetty 2
L = Lock process
J1 = Jetty 1 process
J2 = Jetty 2 process
D = Destroyed

	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
Vessel 1	L	L	L	J1	J1	J1	J1	J1	D	-
Vessel 2	-	W2	W2	L	L	L	J2	J2	J2	J2
Vessel 3	-	-	W1	W1	W1	W1	W1	W1	L	L
Vessel 4	-	-	-	W2	W2	W2	W2	W2	W2	W2
Vessel 5	-	-	-	-	W1	W1	W1	W1	W1	W1
Vessel 6	-	-	-	-	-	W2	W2	W2	W2	W2
Vessel 7	-	-	-	-	-	-	W1	W1	W1	W1
Vessel 8	-	-	-	-	-	-	-	W2	W2	W2
Vessel 9	-	-	-	-	-	-	-	-	W1	W1
Vessel 10	-	-	-	-	-	-	-	-	-	W2

The prognosis in the table above incorporates all the key events mentioned before:

- The vessel generator places each vessel into the queue with the shortest waiting time. In this case, this means alternating between jetty 1 and jetty 2 because all processing times are constant and equal for all vessels.
- The test simulation uses the current state of the terminal, meaning no forward planning, and thus immediately puts the vessels into the waiting queue because the time of creation is equal to the time of arrival.
- Vessel 2 is ready and jetty 2 is vacant, however, vessel 2 waits until vessel 1 has cleared the lock before entering the lock process.
- Once vessel 1 has left finished the post-pump process it is destroyed and vessel 3 is immediately put into the lock process.
- The rest of the created vessels are in the waiting queues as only one vessel may be present in each jetty process at any one time.

7.1.2. Simulation results

Using the Tomas form, the key events mentioned earlier can be traced. The key events and the respective part of the trace text have been summarized in Figure 7.4.

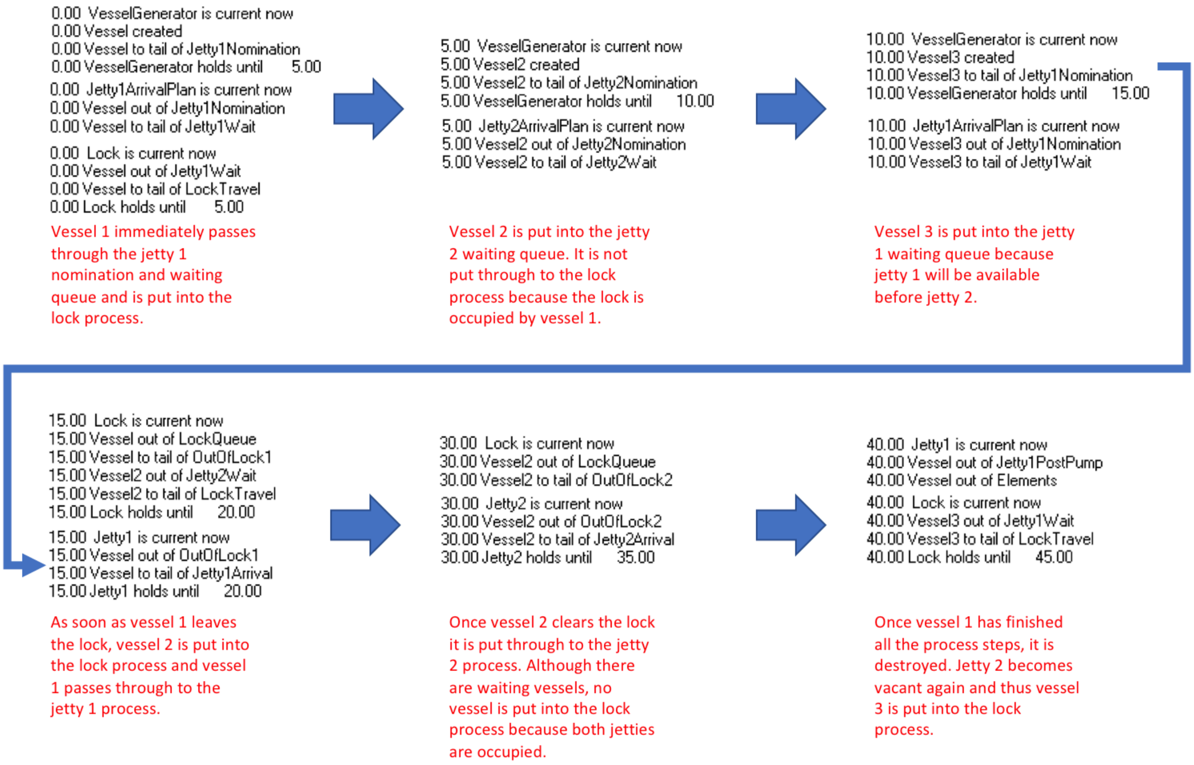

Figure 7.1: Results from the test simulation run

As can be seen in the figure, the results from the test simulation match the prognosis. Thus, the conclusion can be made that the model works as expected and has been verified.

7.2. Variables

To ensure that the simulation works correctly when testing the conceptual FOFS planning strategy, each variable must be tested with a simulation to ensure that the simulation model interprets it correctly.

7.2.1. Planning variables

The time of planning and maximum customer delay variables can be verified simultaneously. For this test simulation the following inputs will be given:

- **Time of planning:** 3 days
- **Maximum customer delay:** 100%

If the model works as it should then the following two events should be seen in the simulation's trace:

- The first two vessels arrive 3 days after they are created by the vessel generator. As the simulation is in minutes this means 4320 minutes.

- The third vessel should be delayed as the first two vessels occupy the jetties. The vessel should be delayed no more than 100%, or 3 days.

Figure 7.2 shows the relevant pieces of text found in the trace file regarding the first 3 vessels. The trace show that the vessels arrive 3 days after they are created unless the jetties are occupied. In this case, the vessel is delayed until the jetties are predicted to be available again.

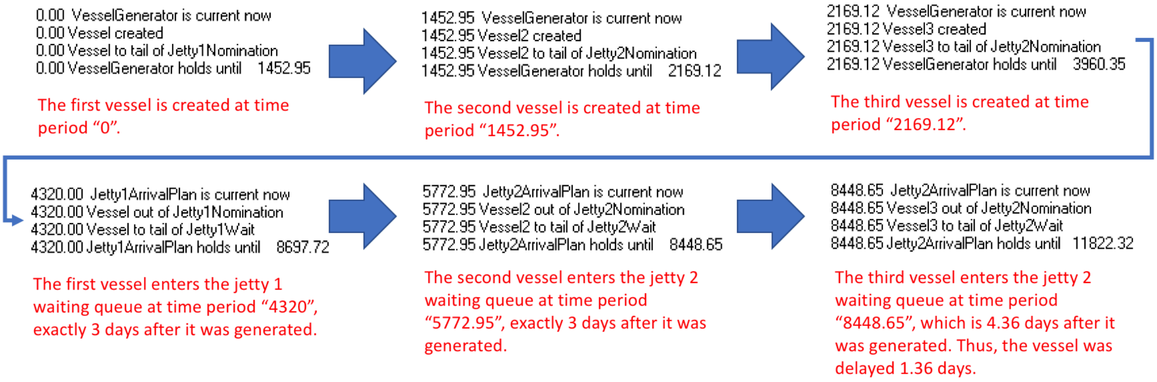

Figure 7.2: Verification of the first two variables

7.2.2. Interrupt variable

The interrupt variable can be tested by running a single simulation. In this simulation, the interrupts will be taken out of the model for jetty 1, but will remain for jetty 2. If the model works as it should, the following two results should be seen in the output window:

1 The interrupt edit box for jetty 1 shows 0 exactly.

2 The interrupt edit box for jetty 2 gives a result higher than 0.

Figure 7.3 shows the output window for this simulation. The two relevant edit boxes showing the jetty 1 and jetty 2 interrupts have been outlined. As can be seen from the figure, jetty 1 shows an interrupt time of 0, whereas the interrupt time of jetty 2 is much higher. The results are as expected and thus the model is verified.

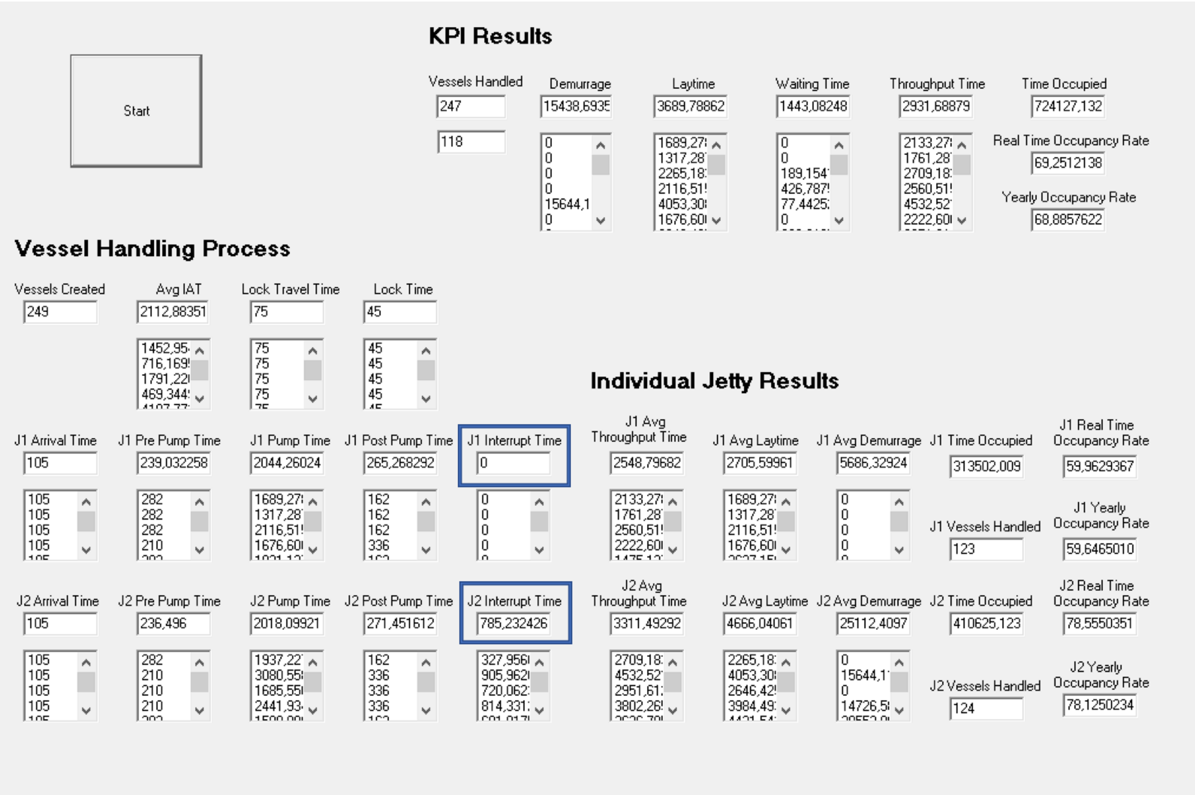

Figure 7.3: Verification of the third variable

7.3. Validation

Model validation ensures that the model gives realistic results. To validate a model, the results must be compared to actual findings and any differences between the two should have a valid reason. As all the data distributions used in the simulation model are closely based on actual data, the expectation is that the results should closely reflect the actual findings.

The actual KPI results were analyzed and given in Chapter 3. An overview of these results can be found below in Table 7.3.

Table 7.3: Actual 2016 KPI results

KPI	Yearly Average Result
Vessels	247
Jetty Occupancy Rate	79,97%
Waiting Time	34 Hours
Turnaround Time	55,41 Hours
Laytime	79,39 Hours
Demurrage	27700 Dollars

To obtain an accurate average representation of the simulation results, the simulation will be run 10 separate times, each for a period of 1 year, and the results of all 10 runs will be averaged. The final result is shown in Table 7.4.

As can be seen from the two tables, the results are quite similar, indicating that the simulation gives a realistic representation of the terminal. The few hours difference between some of the values are negligible, however there is one finding that is quite interesting:

Table 7.4: Test simulation results

KPI	Yearly Average Result
Vessels	247,4
Jetty Occupancy Rate	79,18%
Waiting Time	38,26 Hours
Turnaround Time	56,1 Hours
Laytime	82,2 Hours
Demurrage	28700 Dollars

- The average turnaround time and amount of vessels is slightly larger in the simulation, but the jetty occupancy rate is lower.

The most probable explanation for this finding, seeing as the rest of the values are quite similar, is that the simulation has a time variance in the process that is slightly higher than the actual process. This could, for example, mean that the average turnaround time of vessels in a simulation is just a bit lower than in reality, but due to a few outliers the average is raised to just above the actual value. The same reasoning, along with an average longer waiting time, accounts for the higher average laytime. Overall, the simulation results do seem to accurately represent the actual values, and thus the model has been validated.

7.3.1. Amount of simulation runs

To validate the model and get significant average KPI results, the simulation in the previous section was run 10 times for a period of 1 year. This gives a total simulation time of 10 years, which is quite a large default simulation time. This will be used as the default run to test how many simulation runs are needed to get significant results for the coming research experiments regarding terminal seaside performance. This is done using a 95% t-test. The 95% is chosen to give a certain level of confidence whilst not requiring an extremely high amount of simulations. The amount of runs can be calculated using the following formula:

$$R \geq \left(\frac{t_{1-\frac{\alpha}{2}} * S_0}{\epsilon * \bar{x}_0}\right)^2$$

$$R = \text{amount of runs}$$

$$t = \text{t-distribution}$$

$$\alpha = \text{level of uncertainty}$$

$$S_0 = \text{variance of null hypothesis}$$

$$\epsilon = \text{error percentage}$$

$$\bar{x_0} = \text{average of null hypothesis}$$

The value for t can be found in the t-distribution table in Appendix D along with the 10 results for the terminal seaside performance in the null hypothesis. α is the level of uncertainty, so in this case for a 95% confidence interval this would be 0.05, which also goes for ϵ. This gives the following result:

$$R \geq \frac{1.81 * 0.019}{0.05 * 0.54}^2 = 1,62$$

To ensure significant results, a safety factor of 2 will be applied. Rounded up to a whole number, this gives 4 runs. Thus 4 runs are needed for each experiment to achieve significant results.

7.4. Summary

Model verification and model validation are often mistaken for one another. Model verification is used to ensure that the model does exactly what it is supposed to do and works according to your expectations. Model validation ensures the model gives a good representation of reality.

The simulation model has been verified using the tracing method, which is part of the Tomas package. Tracing records the key events in the simulation. This makes it easy to track what the simulation is doing at certain times. This is useful for finding errors or unexpected events in the simulation. The variables within the simulation were also verified to ensure the simulation works to test the new conceptual FOFS planning strategy as well.

After verification of the model, it was validated by comparing the simulation results to the actual findings. The results were overall quite similar. One interesting finding was the fact that the jetty occupancy rate was lower even though the amount of vessels and average turnaround times were the same. This is probably due to more outliers within the simulation model, which push the average upwards.

Lastly, the amount of simulation runs for the experiments was calculated using a t-test with a 95% confidence interval. The result of this test concluded 4 runs per experiment are needed.

8

FOFS Simulation Experiments

The previous chapter both verified and validated the model by running some simulations and checking whether the model worked as it was supposed to and whether the outcomes were similar to the actual values. This chapter will introduce the experiments that will be simulated to test the effectiveness of the FOFS strategy.

8.1. Experiment inputs

The impact of forward planning on VTAW will be studied based on various experiments that will be used as input for the simulation model. The inputs are based on the three variables mentioned earlier: time of planning, maximum customer delay, and interrupts. The goal of the experiments is to find the optimal forward planning strategy that will give the highest increase in terminal seaside performance. The different inputs for each variable will be given and substantiated in the following sections of the report.

8.1.1. Time of Planning

Currently, the time of planning of the terminal is 0 due to the FCFS rule. When changing to a forward planning strategy it is important to take into account the customer and how much the customer is willing to change and plan ahead operations. Currently, the average time, according to the planners at VTAW, that order nominations are received is 3-5 days in advance. Hence, 5 days will be taken as the maximum possible time of planning. To find the optimal time of planning, all values between the current state of 0 and 5 should be tested, giving the input values for the time of planning shown in Table 8.1.

Table 8.1: Input values for the time of planning variable

Time of Planning
Input values
1 day
2 days
3 days
4 days
5 days

8.1.2. Maximum Customer Delay

Currently, the maximum customer delay at the terminal is 0. This is due to the fact that it is impossible to delay a vessel if the time of planning is 0. If the time of planning were larger, it would be possible to share congestion information with the vessel, such that the vessel can change its speed accordingly to save fuel. As it is extremely time consuming to test each individual percentage of delay from 0% to 100%, well known speed settings in the shipping industry will be used: slow steaming and super slow steaming. slow steaming and super slow steaming mean lowering the speed of a vessel with the goal to save fuel. slow steaming is when the vessel travels at about 25% of its maximum speed, whereas super slow steaming is when the vessel travels at about 50% of its maximum speed. Hence, the values, also shown below in Table 8.2, will be tested for the maximum customer delay. Keep in mind that the percentages are based on delay in terms of time to arrival, and not in terms of speed.

Table 8.2: Input values for the maximum customer delay

Maximum Customer Delay
Input values
50%
100%

8.1.3. Interrupts

As mentioned before, forward planning could impact the amount of interrupts in a positive manner. This variable is tested to see whether it has an effect on the optimal planning approach regarding the previous two variables. This could impact the strategy chosen once certain interrupts are prevented or solved. The current state of the terminal takes into account all current interrupts. Furthermore, VTAW is looking into the most time consuming interrupts. These are the surveyor interrupts, as was shown in Chapter of this report. Hence, the terminal seaside performance will also be tested considering no surveyor interrupts. Finally, the performance will also be tested considering a possible future state of no interrupts at all. The input values for this variable can be seen in Table 8.3.

Table 8.3: Input values for the interrupts variable

Interrupts
Input values
All interrupts
No surveyor interrupts
No interrupts

8.1.4. Input combinations

To find the optimal planning strategy for all terminal interrupt states, each variables input values must be combined and tested. This gives the following total number of experiments to be tested using the simulation model:

Table 8.4: Number of input values per variable

Variable	Amount of input values
Time of planning	5
Maximum customer delay	2
Interrupts	3

$$\text{Amount of experiments} = 5 * 2 * 3 = 30\ experiments$$

The specific input combinations can be found in Table 8.5:

Table 8.5: All experiments and input combinations

Experiment	Time of Planning	Maximum Customer Delay	Interrupts
Current State	*0 days*	*0%*	*All*
1	1 day	25%	All
2	1 day	50%	All
3	1 day	25%	No surveyor
4	1 day	50%	No surveyor
5	1 day	25%	None
6	1 day	50%	None
7	2 days	25%	All
8	2 days	50%	All
9	2 days	25%	No surveyor
10	2 days	50%	No surveyor
11	2 days	25%	None
12	2 days	50%	None
13	3 days	25%	All
14	3 days	50%	All
15	3 days	25%	No surveyor
16	3 days	50%	No surveyor
17	3 days	25%	None
18	3 days	50%	None
19	4 days	25%	All
20	4 days	50%	All
21	4 days	25%	No surveyor
22	4 days	50%	No surveyor
23	4 days	25%	None
24	4 days	50%	None
25	5 days	25%	All
26	5 days	50%	All
27	5 days	25%	No surveyor
28	5 days	50%	No surveyor
29	5 days	25%	None
30	5 days	50%	None

8.2. Summary

To study the impact of forward planning, combinations of three variables will be tested using the simulation model. Two of the variables, time of planning and maximum customer delay, determine the planning time and flexibility. The third variable is the interrupts. This variable is included to take into account future states of the terminal, as forward planning could decrease the amount of interrupts in the process.

The time of planning counts five input values, 1 day to 5 days ahead. The maximum customer delay counts just two inputs, which are based on well-known vessel speed settings. The interrupts consist of 3 inputs. Hence, a total of 30 experiments will be done to find the strategy that gives the best overall terminal performance. The 30 experiments can be seen in Table8.5.

The next chapter will publish the results of the different scenarios. The results will be analyzed and the impact of the planning strategies on the terminal will be determined.

9

Results

The previous chapter introduced 3 variables. two variables define the forward planning strategy of the terminal, whereas the third variable defines current and future states of the interrupts at the the terminal. The various inputs for each variable account for a total of 30 experiments to be simulated by the model. This chapter will publish the results of these experiments by showing the impact of each simulation on the KPIs of the terminal.

The goal of the simulation experiments is to find the best forward planning strategy for the terminal regarding time of planning and maximum customer delay. However, the best strategy might differ for future states of the terminal when, for example some or all interrupts are prevented. Thus, the results will be categorized according to the third variable inputs. This will allow for a better and more distinct recommendations in the remainder of this report.

9.1. All interrupts

The first simulation input regarding interrupts is the current situation, namely all interrupts are taken into account. The inputs for these ten experiments can be seen in Table 9.1.

Table 9.1: Experiments taking into account all interrupts

Experiment	Time of Planning	Maximum Customer Delay	Interrupts
Current State	*0 days*	*0%*	*All*
1	1 day	25%	All
2	1 day	50%	All
7	2 days	25%	All
8	2 days	50%	All
13	3 days	25%	All
14	3 days	50%	All
19	4 days	25%	All
20	4 days	50%	All
25	5 days	25%	All
26	5 days	50%	All

9.1.1. KPI results

The results for each of the KPIs, defined in Chapter 3, will be shown in the remainder of this section.

Figure 9.1 shows the results for the jetty occupancy rate. The jetty occupancy rate shows no difference for any of the ten cases relative to the current state. This is due to the fact that forward planning does not affect the amount of vessels that visit the terminal. Forward planning is, in fact, a strategy to cope with a high jetty occupancy rate and thus the jetty occupancy rate remains constant.

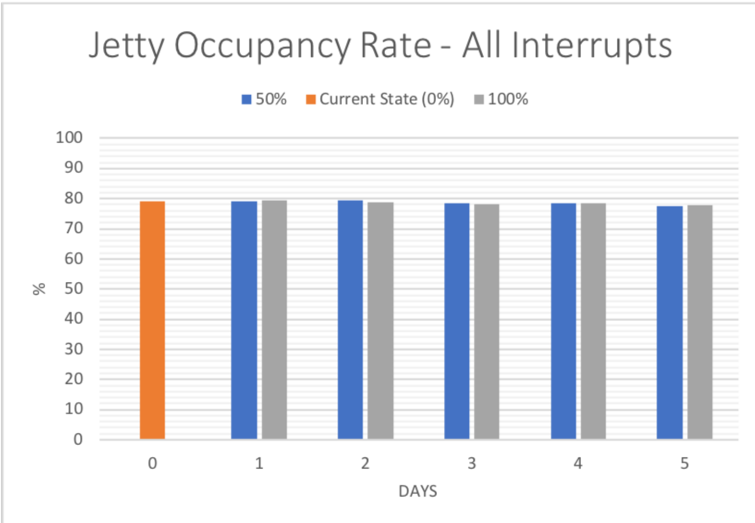

Figure 9.1: Jetty occupancy rate results for the experiments taking into account all interrupts

Figure 9.2 shows the waiting time results. The waiting time shows a large and continuing decrease as the time of planning increases. The decrease in waiting time is larger for the 100% customer delay. It seems that, for the 100% maximum customer delay, a longer time of planning after about 3 days has little effect on the waiting time and it has reached a lower limit. The reason the waiting time is not able to decrease to 0 is the fact that the interrupts make it impossible to 100% accurately plan the vessels.

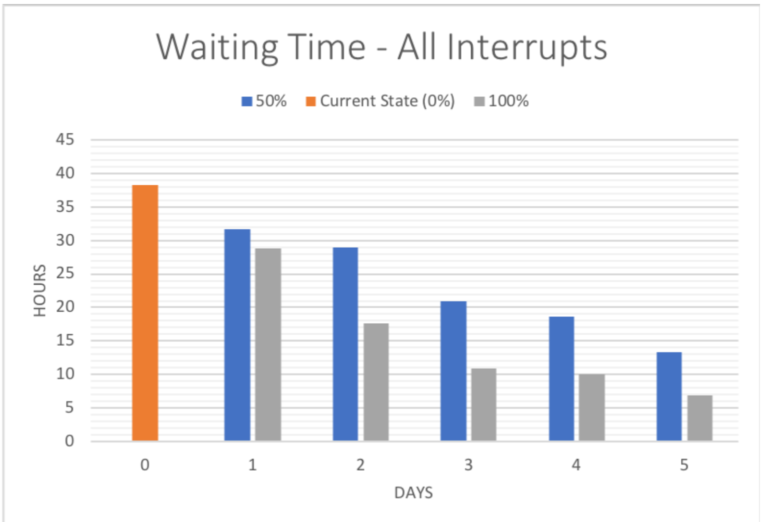

Figure 9.2: Waiting time results for the experiments taking into account all interrupts

Figure 9.3 shows the throughput time results. As all interrupts are taken into account in this simulation, the throughput time remains constant throughout the experiments.

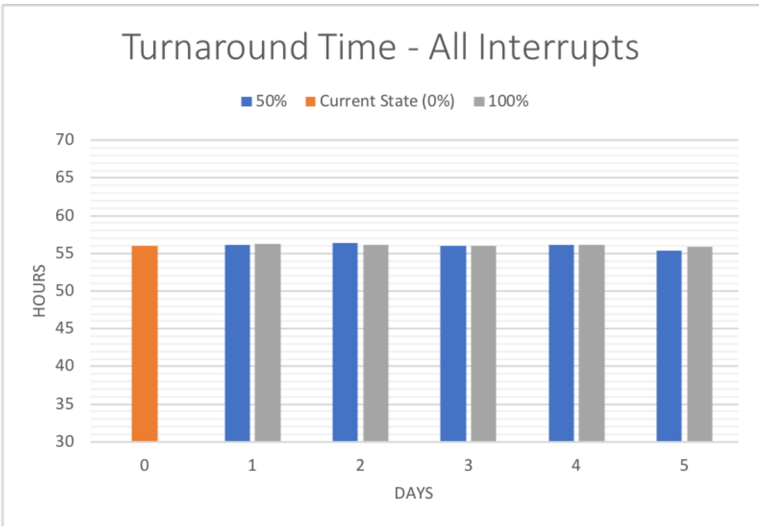

Figure 9.3: Turnaround time results for the experiments taking into account all interrupts

Figures 9.4 and 9.5 show the laytime and demurrage results. These KPIs are directly correlated and thus show a similar trend. However, the demurrage does show a steeper decrease than the laytime. This is due to more vessels being handled within the contractual laytime, which has a large effect on the average demurrage costs.

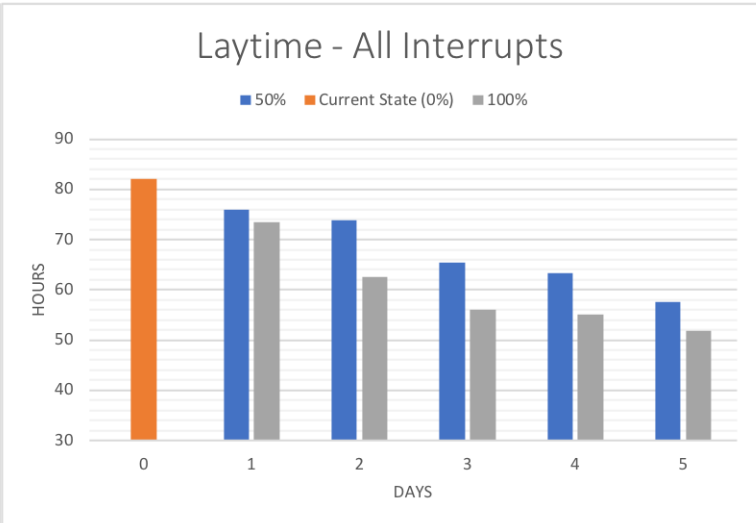

Figure 9.4: Laytime results for the experiments taking into account all interrupts

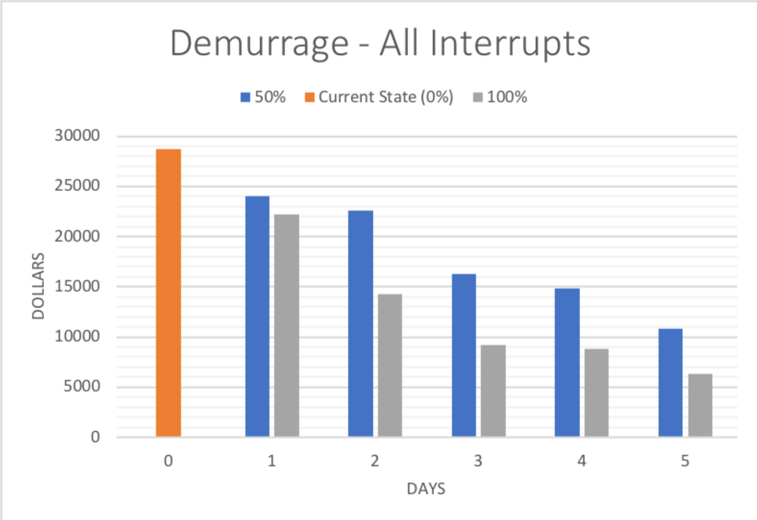

Figure 9.5: Demurrage results for the experiments taking into account all interrupts

9.2. No surveyor interrupts

The second simulation input regarding interrupts is no surveyor interrupts. Surveyor interrupts account for 52% of the total registered interrupt times. The inputs for these ten experiments can be seen in Table 9.2. To allow for a more realistic performance comparison of the forward planning strategy, the current state will assume to have no surveyor interrupts as well. Hence, any performance increases can be directly associated with forward planning.

Table 9.2: Experiments taking into account no surveyor interrupts

Experiment	Time of Planning	Maximum Customer Delay	Interrupts
Current State	*0 days*	*0%*	*No surveyor*
3	1 day	25%	No surveyor
4	1 day	50%	No surveyor
9	2 days	25%	No surveyor
10	2 days	50%	No surveyor
15	3 days	25%	No surveyor
16	3 days	50%	No surveyor
21	4 days	25%	No surveyor
22	4 days	50%	No surveyor
27	5 days	25%	No surveyor
28	5 days	50%	No surveyor

9.2.1. KPI results

The results for each of the KPIs regarding this situation without the surveyor will be shown in the remainder of this section.

Figure 9.6 shows the results for the jetty occupancy rate. For the same reason mentioned in the previous section, the jetty occupancy rate shows no difference for any of the ten cases relative to the assumed current state. However, the jetty occupancy rate is significantly lower due to the fact that the surveyor interrupts are taken out of the process. This gives a decrease in jetty occupancy rate of about 15% compared to the current situation with all interrupts.

Figure 9.7 shows the waiting time results. The waiting time already shows a large decrease by just

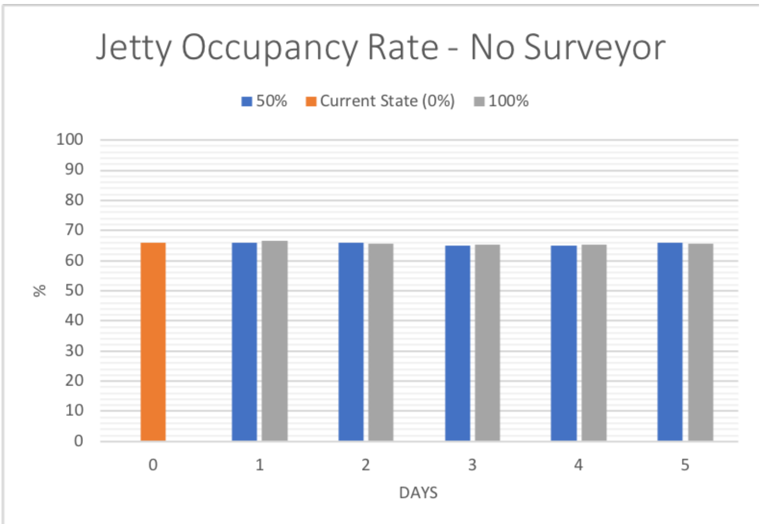

Figure 9.6: Jetty occupancy rate results for the experiments taking into account no surveyor interrupts

taking away the surveyor interrupts. Forward planning continues this trend. However, for both the 50% and 100% customer delay values, the decreasing trend stops at a time of planning of 4 days and 3 days respectively.

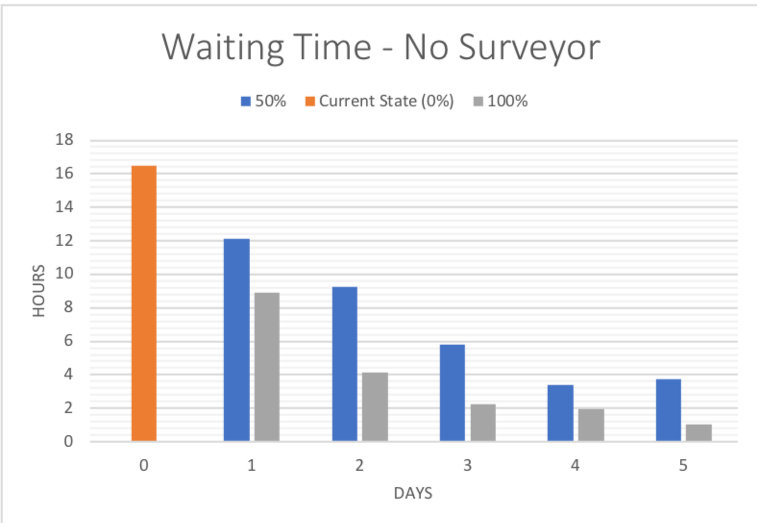

Figure 9.7: Waiting time results for the experiments taking into account no surveyor interrupts

Figure 9.8 shows the throughput time results. Just as in the previous case, the turnaround time remains constant as forward planning does not influence it. However, the average turnaround time has decreased by almost 10 hours compared to the situation with all interrupts. This is also the reason for the decrease in the jetty occupancy rate that was seen before.

Figures 9.9 and 9.10 show the laytime and demurrage results. Due to the decrease in turnaround time and the further decrease in waiting time, the laytime is positively affected. Both the laytime and demurrage show a decreasing trend that stops at a time of planning of 3-4 days.

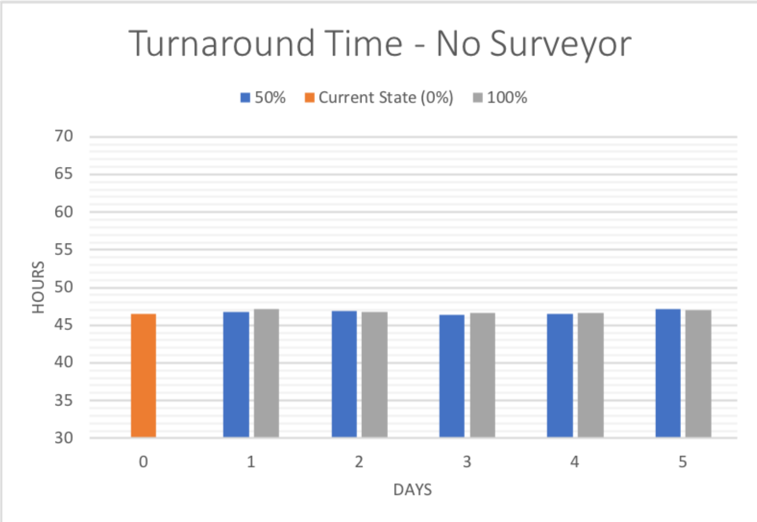

Figure 9.8: Turnaround time results for the experiments taking into account no surveyor interrupts

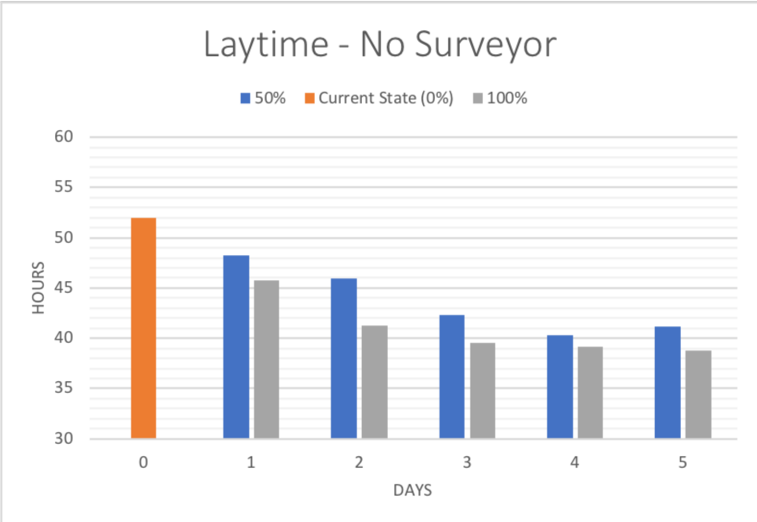

Figure 9.9: Laytime results for the experiments taking into account no surveyor interrupts

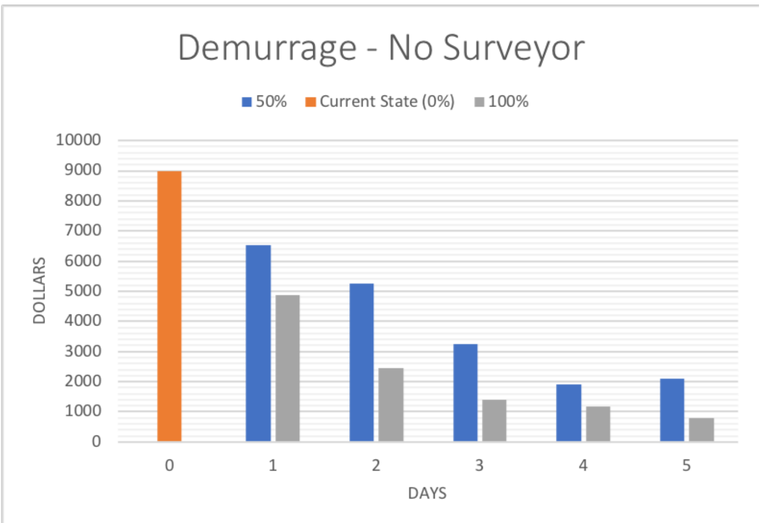

Figure 9.10: Demurrage results for the experiments taking into account no surveyor interrupts

9.3. No interrupts

The third and last simulation input regarding interrupts is no interrupts at all. This assumes that all interrupts at the terminal have been solved or prevented. The inputs for these ten experiments can be seen in Table 9.3. Once again, to allow for a more realistic performance comparison of the forward planning strategy, the current state will assume to have no interrupts as well. Hence, any performance increases can be directly associated with forward planning.

Table 9.3: Experiments taking into account no interrupts

Experiment	**Time of Planning**	**Maximum Customer Delay**	**Interrupts**
Current State	*0 days*	*0%*	*None*
5	1 day	50%	None
6	1 day	100%	None
11	2 days	50%	None
12	2 days	100%	None
17	3 days	50%	None
18	3 days	100%	None
23	4 days	50%	None
24	4 days	100%	None
29	5 days	50%	None
30	5 days	100%	None

9.3.1. KPI results

The results for each of the KPIs regarding this situation without the surveyor will be shown in the remainder of this section.

Figure 9.11 shows the results for the jetty occupancy rate. As explained in the previous two sections, the jetty occupancy rate shows no difference for any of the ten cases relative to the assumed current state. It has, however, decreased a further 5% approximately compared to the no surveyor situation due to the fact that the rest of the interrupts have been taken out of the process. This gives a total decrease in jetty occupancy rate of about 20% compared to the current situation with all interrupts.

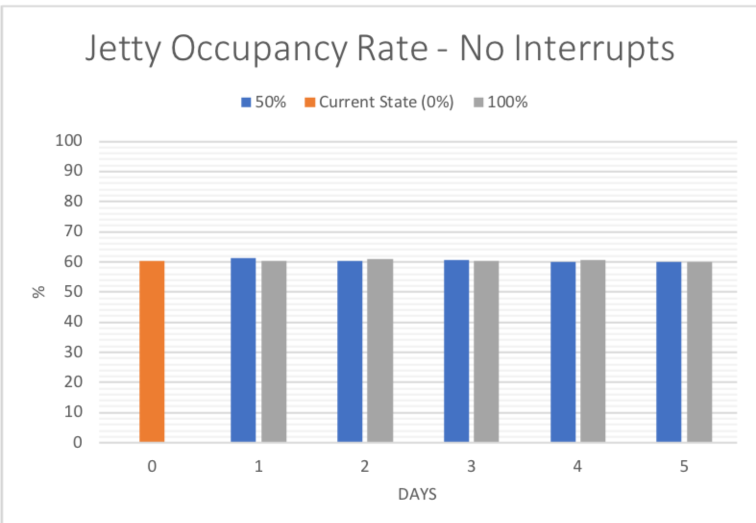

Figure 9.11: Jetty occupancy rate results for the experiments taking into account no interrupts

Figure 9.12 shows the waiting time results. The waiting time, once again, show an even larger decrease. With no interrupts in the system, the process becomes much more predictable. Hence, the waiting time is able to drop even further than in the previous situations. At a time of planning of 3 days and a customer delay of 100%, the trend seems to even out and the waiting time has diminished to almost 0.

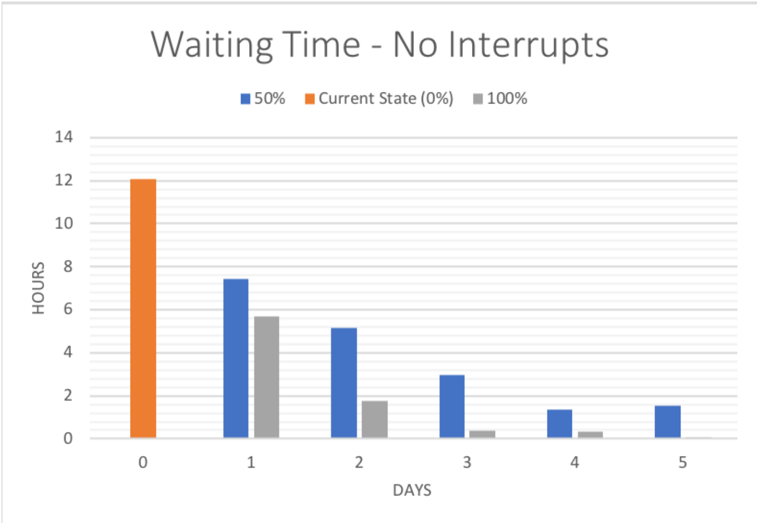

Figure 9.12: Waiting time results for the experiments taking into account no interrupts

Figure 9.13 shows the throughput time results. As in the previous two cases, the turnaround time remains constant as forward planning does not influence it. The turnaround time shows a lesser overall decrease compared to the no surveyor situation. Compared to the current situation considering all interrupts, the turnaround time has decreased a total of almost 15 hours, which shows in the large decrease of the jetty occupancy rate as well.

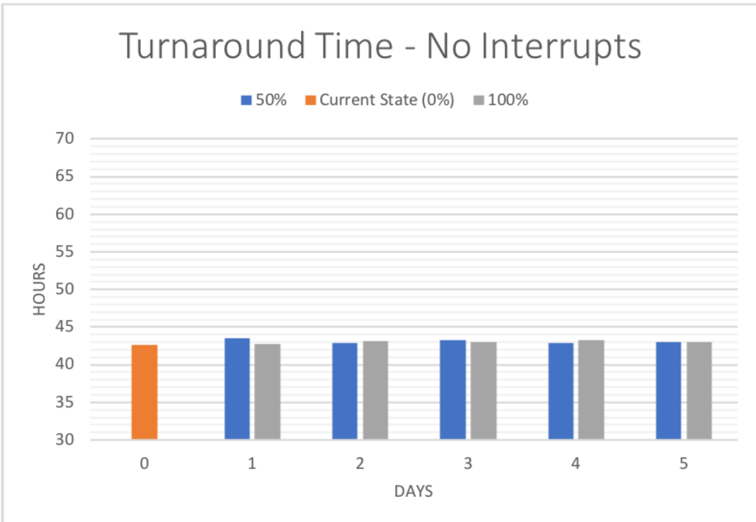

Figure 9.13: Turnaround time results for the experiments taking into account no interrupts

Figures 9.14 and 9.15 show the laytime and demurrage results. Due to the waiting time decreasing to almost 0 as the time of planning increases and the turnaround time decreasing, the same trend can be seen in the laytime. At a time of planning of 4 days, regardless of the maximum customer delay value, the demurrage costs have almost completely diminished. Apparently, the average laytime is now well below the contractual laytime, meaning almost no demurrage can be claimed in most cases.

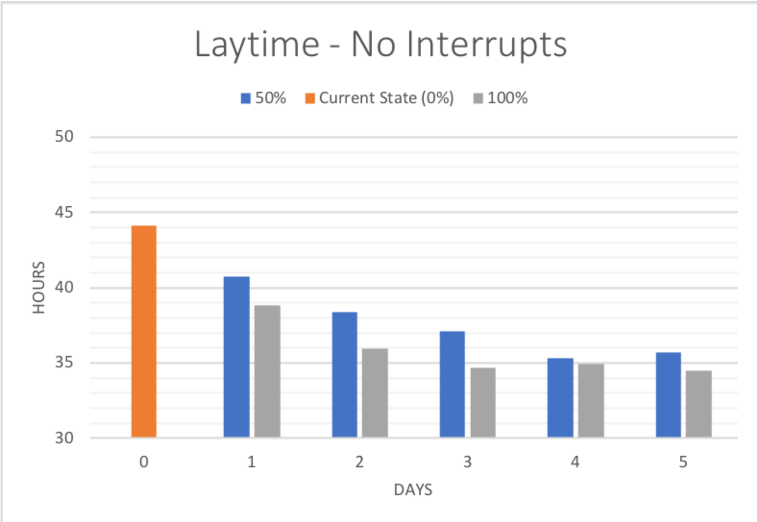

Figure 9.14: Laytime results for the experiments taking into account no interrupts

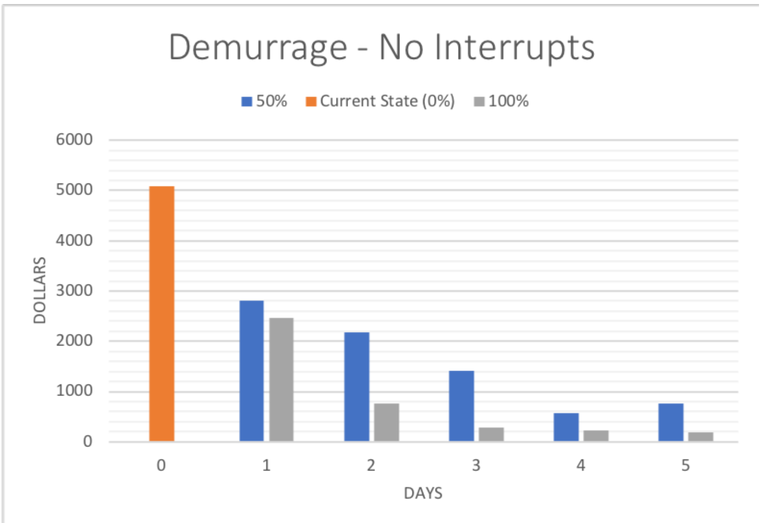

Figure 9.15: Demurrage results for the experiments taking into account no interrupts

9.4. Terminal seaside performance

In the previous section, the results of each KPI were shown for all three interrupt cases. These results give a good picture of the impact of the various experiments on the terminal. However, it is difficult to determine the best strategy on the basis of these results. This is why the "Terminal Seaside Performance" was introduced in Chapter 3, which is an equation to determine the overall performance of the terminal based on Vopak requirements and customer satisfaction. The TSP incorporates all the KPIs as seen in the previous section. Figure 9.16 shows the TSP for all 30 experiments tested in the simulation model. Note that the vertical axis lower limit is 50% to better visualize the differences in performance.

The impact of the prevention of interrupts is extremely clear from this figure. Regardless of the forward planning strategy, the prevention of surveyor interrupts has a larger effect on terminal seaside

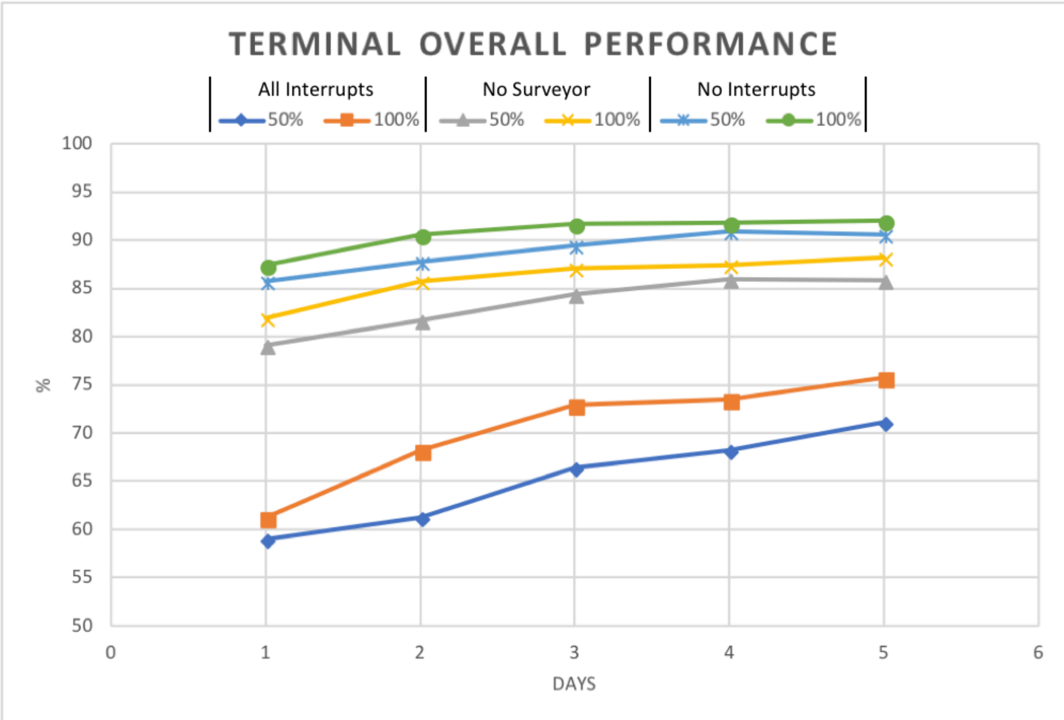

Figure 9.16: TSP results for all 30 experiments

performance. This impact is noticeably smaller when taking all interrupts out of the process, as opposed to just the surveyor interrupts. Although the impact of interrupt prevention is large, forward planning clearly also has a positive effect on terminal seaside performance. The level of impact decreases, however, as the level of interrupt prevention increases. This is explainable because the decrease in interrupts causes a decrease in turnaround time. This, in turn, causes a decrease in jetty occupancy, which decreases the need for forward planning. From the TSP results in Figure 9.16, it seems the experiment resulting in the best terminal seaside performance is the following:

- **Time of planning:** 3-5 days
- **Maximum customer delay:** 100%
- **Interrupts:** No Interrupts
- **Terminal seaside performance:** 92%

9.5. Summary

This chapter has published the results of the simulations. The results were categorized according to the state of the interrupts, which is the third variable in the experiment inputs.

Forward planning seems to have a positive impact on the terminal. The performance of most KPIs increase as the time of planning and the maximum customer delay increase. However, the interrupts have a larger impact on the terminal performance, as can be seen in Figure 9.16. The best result appears to derive from the following experimental inputs, giving a TSP of 92%:

- **Time of planning:** 3-5 days
- **Maximum customer delay:** 100%

- **Interrupts:** No Interrupts

The results from all 30 experiments can be seen in Table 9.4. The next chapter will further discuss these results, as well as recapitulate the results to the research question.

Table 9.4: Terminal seaside performance results for all 30 experiments

Experiment	Time of Planning	Maximum Customer Delay	Interrupts	TSP
Current State	*0 days*	*0%*	*All*	*55%*
1	1 day	50%	All	59%
2	1 day	100%	All	61%
3	1 day	50%	No surveyor	79%
4	1 day	100%	No surveyor	82%
5	1 day	50%	None	86%
6	1 day	100%	None	87%
7	2 days	50%	All	61%
8	2 days	100%	All	68%
9	2 days	50%	No surveyor	82%
10	2 days	100%	No surveyor	86%
11	2 days	50%	None	88%
12	2 days	100%	None	91%
13	3 days	50%	All	66%
14	3 days	100%	All	73%
15	3 days	50%	No surveyor	84%
16	3 days	100%	No surveyor	87%
17	3 days	50%	None	89%
18	3 days	100%	None	92%
19	4 days	50%	All	68%
20	4 days	100%	All	73%
21	4 days	50%	No surveyor	86%
22	4 days	100%	No surveyor	87%
23	4 days	50%	None	91%
24	4 days	100%	None	92%
25	5 days	50%	All	71%
26	5 days	100%	All	76%
27	5 days	50%	No surveyor	86%
28	5 days	100%	No surveyor	88%
29	5 days	50%	None	91%
30	5 days	100%	None	92%

10

Discussion

A case study was conducted at Vopak Terminal Amsterdam Westpoort regarding the implementation of forward planning. Chapter 9 revealed the results for this study. The research question for this project stated: "What is the impact of a proactive planning strategy at Vopak Terminal Amsterdam Westpoort on the Terminal Seaside Performance?". In this chapter the results to this question will be discussed. First, the main findings related to the case study will be discussed. These results will then be related to the issues raised in the introduction of the report. This is then followed by a discussion about the current market and the feasibility of implementing the experiments for this terminal.

10.1. Results

The results are published in Chapter 9 of this report, categorized by the inputs of the interrupt variable. To gain a more comprehensible overview of the impact of the various cases on the terminal seaside performance, the impact on each of the KPIs and the TSR will be further discussed.

10.1.1. Turnaround time

The average turnaround time at VTAW is currently quite high at 56 hours. Forward planning does not directly influence this value as can be seen in Figures 9.3, 9.8, and 9.13. However it could cause an impact indirectly. To achieve a successful forward planning strategy, collaboration and insight into the vessel handling process must increase. This implies gathering accurate data regarding the unexpected and unpredictable aspects within the process, the interrupts. Solving or preventing these interrupts from happening increases planning accuracy and, most probably, decreases the turnaround time. Hence, forward planning performance and turnaround time are somewhat correlated. This can be seen when comparing the turnaround times in the different interrupt states of the terminal. Information that has been gathered regarding the interrupts show that more than 50% of interrupts are associated with the surveyor. Taking care of the surveyor interrupt codes could potentially decrease the turnaround time by more than 15%, which is a considerable performance increase. Interestingly, the rest of the interrupts have a considerably lesser effect, decreasing the turnaround time a further 8%. This is due to the fact that the surveyor interrupts occur 100% of the time on every vessel, whereas the remainder of the interrupts do not always occur, and thus have less of an impact on the average turnaround time.

10.1.2. Jetty occupancy rate

Likewise to the turnaround time, the jetty occupancy rate is only relevantly impacted by interrupt variable. The decrease in turnaround time due to the prevention of interrupts is also the direct cause for the lower jetty occupancy rate. This has two reasons:

1 The decrease in average turnaround time means that the amount of vessels the terminal can handle in a year increases. However, the amount of vessels arriving at the terminal does not necessarily increase. Thus, the same amount of vessels are handled in a shorter time, causing the total occupied berth time to decrease.

2 A shorter vessel turnaround time does not change the amount of time it takes to interchange vessels. For example, if the time between the berthing of a vessel and the departure of its predecessor is 7 hours on average, this does not decrease when the turnaround time decreases. Hence, the interchange time makes up a larger portion of the total arrival to departure time of the vessel decreasing the jetty occupancy rate.

The current average waiting time at the terminal suggests that the current jetty occupancy rate of 80% is much too high. That is, too high for the current level of planning. Interestingly, the results show two ways to handle this problem. The first is forward planning. Forward planning allows the terminal to control the arrival distribution of vessels, which keeps the other KPIs at a respectable level. The second is solving or preventing the interrupts that have the largest impact on the turnaround time. This second option, rather surprisingly, decreases the occupancy rate about 20%, seemingly taking away the need for forward planning. However, that statement may not be fully correct. Firstly, the respective case that was simulated already took into account a certain level of forward planning. Secondly, the large increase in terminal performance would most likely attract more vessels, which would once again increase the occupancy rate and the need for forward planning.

10.1.3. Waiting Time

The waiting time probably gives the best indication as to the effectiveness of the tested forward planning strategies. The current average waiting time is unusually large and is most likely caused by the high jetty occupancy rate. As mentioned in Chapter 8, planning is essentially a way to cope with a higher occupancy rate and the average waiting time determines how successful the terminal is in doing that. Once again, the interrupt variable has, overall, the largest impact on the waiting time, however, this is due to the decrease in turnaround time. The time of planning and maximum customer delay variables are more interesting when looking at the waiting time as these experiments show the direct effect of forward planning. From the results, the waiting times seem to be affected much more by an increase in maximum customer delay than an increase in time of planning. Thus, the amount of days prior to arrival that berth planning starts has less of an impact than the amount of delay time that is accepted by the customer. This is quite a logical result for VTAW but it is very terminal specific. VTAW has a modern infrastructure layout, meaning all jetties and tanks are interconnected, and VTAW handles almost solely petroleum products. Hence, relatively little can be gained by handling vessels in an order that optimizes the terminal's operational efficiency. A terminal with much more infrastructure planning possibilities might be better off with a longer planning period because more information is known about the types of vessels and products that will be arriving. The vessels could then be planned and handled in a specific order that optimizes the operational efficiency.

10.1.4. Laytime and demurrage

The laytime and demurrage are essentially an extension of the other KPIs. The laytime arises from the waiting time and the turnaround time. The demurrage cost, in turn, arises from the amount of laytime. Laytime and demurrage are difficult concepts as the terms are agreed upon by customer and vessel, without Vopak. Thus, as mentioned before, all demurrage costs calculated in the results are not based on actual data, however they do provide a ballpark. As a service-based company, Vopak must strive to minimize the demurrage cost and thus this is a relevant KPI to try to measure, regardless of the accuracy. The results show substantial savings in demurrage costs for the tested experiments. The question is whether the customer thinks this value is worth the loss of flexibility. Oil traders would probably under no circumstances want to give up their flexibility due to the rapid fluctuations in the oil market and the amount of money to be gained with the correct blend and product. However, VTAW has solely long-term contracts with customers and are not a terminal for traders. This means that demurrage savings could very well be interesting for them due to their ability to be more able to plan ahead. This topic will be further discussed later on in this chapter.

10.1.5. Terminal seaside performance

The terminal seaside performance shows a substantial increase in rating with the implementation of forward planning. In the best case, the performance increase would be 37%. Figure 9.16 in the previous chapter shows all the TSR results and from this figure, a number of interesting observations can be made:

- **The relation between the jetty occupancy rate and forward planning:** The figure shows that the more interrupts are prevented, decreasing the jetty occupancy, the lesser the effect of forward planning. The effect of forward planning can be seen by the steepness of the trend line. Hence, the trend line is much steeper when all interrupts are taken into account than when all interrupts are prevented. Thus, this proves the need for forward planning as the demand for the terminal and the jetty occupancy increase.

- **The maximum needed customer delay:** The maximum customer delay is an important factor in forward planning, as can be concluded from the fact that the experiments using a 100% delay show a better performance in almost all cases over the 50% delay. However, there comes a point where this is not the case as more possibility for delay would not be needed to improve the planning performance. This can be seen in the top four trend lines. Taking the green line for example, using a maximum customer delay of 100% and no interrupts, its performance does not increase after a time of planning of 3 days. Hence, in this case, the conclusion can be made that the maximum needed flexibility for the terminal regarding delaying the customer is 3 days.

- **The most promising experiment:** Lastly the most promising experiment can be seen in the figure. As mentioned earlier, the largest performance increase is gained in the following situation:

  - **Time of planning:** 3-5 days
  - **Maximum customer delay:** 100%
  - **Interrupts:** No Interrupts

  Hence, the best case would be to start planning 3 days ahead to grant the customer as much flexibility as possible. However the answer is not that simple. This performance increase is only realized once all interrupts have been solved or prevented. This is definitely a goal to strive towards, but it is most likely not possible in the near future. Thus, this could be a long term goal. In the short term, the terminal might benefit more by looking at just taking the surveyor out of the process, based on the large performance increase achieved by taking away just that specific interrupt. In that case, the best performance would be achieved at a time of planning of 4-5 days. Hence, the most promising experiment is up for some debate, however, there is no debate as to the long term goal, which is the experiment that gives a 37% overall performance increase.

10.2. Relationship with issues raised in introduction

The introduction of this report raised several problems with the current operation at VTAW and in the industry as a whole. This section will discuss the relationship between the forward planning strategy and these issues to argue whether it impacts or even resolves them.

10.2.1. Collaboration

The first problem that was mentioned is the low level of collaboration between VTAW and the other parties. Collaboration goes hand in hand with planning, especially at VTAW. Aside from the berth planning, the surveyors, pilots, and the lock must be planned. Forward planning could increase the collaboration with these different parties, but it greatly depends on the planning accuracy. For example, it would probably please the other parties if VTAW's schedule is shared 3 days in advance, however, the lock will not accept a reservation if there is a good chance the vessel might not arrive at the designated time. The same goes for the pilot and the surveyor, meaning that we would be back where we are now, which is a reactive strategy. Thus, forward planning relies heavily on close collaboration and will not be possible without it and without the sharing of accurate real time information.

10.2.2. Uncertainties

Another issue mentioned in the introduction was the high amount of uncertainty within the vessel handling process. A number of these uncertainties are mentioned below:

- Vessel ETAs often differ from actual arrival times.
- Vessels have different specifications, regulations and safety measures causing, for example, a lower than expected pump flow rate.

These uncertainties along with the interrupts are the cause of a low level of process predictability. This is also the reason that the forward planning strategy is not able to guarantee specific time slots. This will likely not change in the near future as the whole mentality of the market must change and all parties must take part in this. The forward planning strategy must therefore take into account these uncertainties and cope with them.

10.2.3. Flexibility

The last issue raised in the introduction was the amount of flexibility demanded by the customer. There is an incredible amount of last minute order deviations that are handled by VTAW. In the proposed forward planning cases, this is not disallowed, however the customer is encouraged to plan ahead operations. Last minute operations are still possible but with no guarantee as to the waiting time.

10.3. Implementation feasibility and limitations

The results show a great deal of promise. They show an alternative to building more infrastructure to accommodate the high demand. However, a valid question is the feasibility of the forward planning strategy within the current industry. Could this strategy be implemented at all? And if so, would this be possible on the short term or long term?

10.3.1. Current market

To understand the feasibility of forward planning at Vopak, it is important to understand the nature of the market and the mindset of the 3 main players: the terminal, the customer, and the vessel. Each of these players will be briefly discussed as well as what they have to lose or gain in case of the implementation of a forward planning strategy.

Terminal

The first question that must be answered regarding the terminal is what motive VTAW has to change the industry with a forward planning strategy. VTAW has two main sources of revenue:

- **Tanks:** Tank space is rented by customers to store and throughput their product.
- **Amount of throughput operations:** Customers with tank space at VTAW have a fixed number of operations included in the contract. For each extra operation, a fee is paid.

VTAW is currently running at above optimal capacity, which is good for business but takes a toll on customer satisfaction. So profitability is not necessarily a motive for VTAW to change to a forward planning strategy because, regardless of the strategy, the amount of vessels that use the terminal will not immediately change.

The clear motive for VTAW would be knowledge in the form of information and data. Planning ahead gives VTAW insight into the future congestion at the terminal. This information can be shared with customers, pilots, port authority, etc. It can also be used to optimize the amount of employees present at VTAW at any given time.

Customer

As mentioned before, VTAW is not in the oil trader business and thus only rents out tank space to long term customers. This is one of the reasons forward planning might be a possibility, because VTAW's customers must plan ahead as well.

For example, if company A sees that one of its petrol stations is running low, it will plan an operation in the coming days. Hence, customers usually send a first order nomination an average of 3 days in advance. The exact details of the order are subject to change up until the vessel has finished operation at the terminal. For the customers, the disadvantage of this new strategy could be seen as a loss of flexibility. This is somewhat true because the time at which a vessel can enter the back of the virtual serve queue shifts from arrival to 3 days in advance, to a FOFS system. This means that last minute operations have a good chance of extremely long waiting times. Then again, "normal" operations planned 3 days (or more) ahead are planned much more efficiently diminishing the waiting times.

Information as to future congestion at the terminal could also save the customer money. For example, if the customer is ready to charter a vessel, but the terminal information shows a high level of congestion, the customer might wait a few days before chartering the vessel.

In the case that a vessel is already chartered and on the way, forward planning gives no benefit from the customer's perspective because the possible demurrage must be paid regardless as the vessel has already been chartered for a certain period of time. This is sketched in the following scenario:

1 **Current situation**

   (a) Vessel arrives at Ijmuiden

   (b) Vessel tenders NOR

   (c) Vessel waits 24 hours

   (d) Vessel is called in and handled

2 **Forward planning**

   (a) Order nomination is received 3 days in advance

   (b) Vessel is told to arrive 24 hours later than the given ETA

   (c) Vessel lowers speed saving fuel

   (d) Vessel arrives and is immediately called in and handled

Thus, customers could benefit from information acquired from the terminal as to the congestion, however, this is only relevant in specific situations. As for the flexibility, it is less of an infringement as one might first expect. Changes in the order can still be made up until operations have finished. The only difference is the first order nomination must be given a few days in advance.

Vessel

Vessels are chartered by customers for a certain period of time. Every hour exceeding the agreed charter time is at a demurrage rate, which is much higher than the normal hourly charter rate. As explained earlier in this report, demurrage is quite a difficult concept to understand, especially in the oil industry. Due to the large amount of uncertainty within the vessel handling process and the waiting times at terminals, an operation is rarely without demurrage claims. You could almost argue that it is somewhat of a fixed income of varying magnitude for vessels. Considering the amount of money that could potentially be saved regarding demurrage in the simulation, vessels have a lot to lose in that respect. But this is also part of the problem within the industry. Vessels benefit from a slower process or operation. The more time is "wasted" during loading or discharging, the more demurrage a vessel can claim, unless of course the cause of the time wasting can be tracked back to the vessel. Thus, vessels stand to lose the most in the case of the implementation of a forward planning strategy because the amount of demurrage costs will likely decrease significantly.

Limitations

The current situation regarding the industry and the process at VTAW provides some setbacks and limitations for the feasibility of implementing a proactive planning strategy at VTAW. The main limitations mentioned in the discussion above, are summarized below:

- **Collaboration pilots, surveyors, port authority:** To make forward planning work efficiently, all parties must adjust their plan to one another. The pilots, surveyors and port authority will most likely not comply with this plan unless a certain level of planning accuracy can be demonstrated.
- **Customer flexibility:** a proactive planning strategy forces the customers to also plan ahead. It is unknown if the customers will accept this and see the long term benefit.

- **Demurrage decrease vessels:** A proactive planning strategy would most likely decrease the demurrage income for the vessels. The vessels will most likely not accept this change if there is no benefit in it for them.

10.3.2. Future view

Although there are some serious limitations regarding the feasibility of a proactive planning strategy at VTAW, these limitations are not insurmountable. It would require a large amount of collaboration, confidence, and trust between the relevant parties in the industry.

The most important thing is to get the customers and the vessels aboard with the new strategy. Ideally, all three parties would work together to make the whole process as efficient as possible such that they all benefit. Unfortunately, this is rarely the case in any industry. The problem is that the key to the customer, which, in the best case, is a zero demurrage guarantee, is the vessel's downfall. However, this does not have to be the case in my opinion. As all parties must change and adjust their strategies to one another, the profit that is gained should be fairly split among them. This is where the industry mentality must really change. If this change were to be realized, each party could reap their own benefits:

- **Terminal**
  - More information into future congestion at the terminal
  - More efficient employee planning
  - Possibly share in the customer demurrage savings (pay for performance)
- **Customer**
  - Demurrage savings
  - More information as to the terminal congestion, which could help improve own planning
- **Vessel**
  - Possible fuel saving in the case terminal congestion is known en route
  - Possibly share in the customer demurrage savings (pay for performance)

The benefits and scenarios sketched above seem somewhat far-fetched, and they might well be just that, at least in the near future. However, I believe it is inevitable that a proactive planning mentality will become part of the future of this industry. Especially when comparing it with the extremely automated and accurate container industry. Thus, it might be a long term view for now and it will definitely be a slow and gradual transition. However, I am confident that the change will happen eventually and it is better to be a part of this innovation than to miss the boat.

11

Conclusions and Recommendations

The previous chapter discussed the results of the various experiments that were performed using the simulation. This chapter will finalize the report by concluding the project and giving recommendations to increase the overall terminal performance at VTAW.

11.1. Conclusion

The main objective of this research project consisted of assessing the impact of a proactive planning strategy at Vopak Terminal Amsterdam Westpoort on the terminal seaside seaside performance. This research project will be concluded by briefly summarizing the answers to the 6 sub-questions formulated in Chapter 1 and answered throughout this report.

1 ***How is the current vessel handling process organized?***

The vessel handling process at VTAW can be categorized into pre-arrival and arrival-to-departure. The pre-arrival process starts when the order nomination has been received and ends once the vessel has tendered an NOR. The arrival-to-departure process is further categorized into an arrival, operation, and departure process. Aside from Vopak, the vessel handling process is completed by the customer, vessel captain, port authority, agent, pilots, and an independent surveyor. The vessels are called in according to a FCFS strategy. Vessels enter the back of this virtual line once the tendered NOR has been accepted. No priorities are given within this process. This is also the reason that vessels berth schedules are only planned once the vessel has arrived at Ijmuiden.

2 ***What are the expectations and/or restrictions of the customer regarding the vessel handling process?***

Customers at VTAW are solely long term contract customers and are in the oil business. These customers have high expectations regarding the flexibility and the efficiency with which the vessel is handled. Flexibility is an important requirement from the customer. It means that the customer must be able to make last minute changes to the loading or discharging order, whether it concerns the quantity or the specific blend. At the same time, the customer wants the vessel to be handled within the vessel charter time. If this is not done, the customer must pay demurrage costs to the vessel. These costs often result in claims.

3 ***Where in the process does the most idle time and/or delays take place and what are the reasons for these delays?***

Idle time at VTAW is registered as an interrupt code. In total, there are 11 different interrupt codes. Unfortunately, the data does not reveal where or when in the process a specific interrupt took place. However, 52% of the registered interrupts have to do with surveyor activities, which almost always take place during or just before the operation process. The surveyor interrupts are categorized into "waiting for surveyor arrival" and "waiting for surveyor activities". The first is the amount of time it takes before the surveyor starts the activity from the moment the surveyor has been ordered. The second is the time it takes the surveyor to finish the activity, which is usually checking the quantity and quality of the loaded or discharged product.

4 ***What are the tasks of the personnel organization within Vopak and how is this organized?***

There are 3 teams that are directly involved in the vessel handling process at VTAW: control, customer service and planning, and operations. The operations team does the actual field work. They walk around the terminal servicing vessels. The control team is responsible for correctly controlling the operations team and their activities. The overall berth planning and scheduling is done by the customer service and planning team. They are also in contact with the customer and handle any last minute order changes.

5 ***What is required to improve the current state of the vessel handling process?***

The key problem found in the performance measurements of the terminal is the reactive planning process disallowing the terminal to cope with the high demand and jetty occupancy rate. This leads to long waiting times, which in turn leads to long laytimes and high demurrage costs. Thus, to improve the current state of the vessel handling process, either the jetty occupancy rate must decrease or the arrival distribution of vessels must be controlled to limit the terminal congestion. Both these goals can be accomplished by changing to a forward planning strategy. This could increase the amount of available real time information and the collaboration with the other parties involved. Sharing this information could prevent interrupts such as "waiting for surveyor arrival" because the surveyor can be ordered well before the surveyor activity should start. Information gained from forward planning could also be shared with customer and vessel to control the arrival distribution of vessels to avoid heavy congestion at the terminal.

6 ***What is the impact of the solutions on the process and on Vopak as a whole?***

The impact of the forward planning strategy depends on the experimental model that is implemented. This is also strongly dependent on the state of the interrupts at the terminal. The best results for each of the tested interrupt variable inputs are shown below:

- **All interrupts (current):**
  - *Time of planning:* 5 days
  - *Maximum customer delay:* 100%
- **No surveyor (possible short term goal):**
  - *Time of planning:* 5 days

  - *Maximum customer delay:* 100%

- **No interrupts (possible long term goal):**
  - *Time of planning:* 3 days
  - *Maximum customer delay:* 100%

In the last and best case above, The jetty occupancy rate could potentially be brought back from 80% to 60%. This almost diminishes the waiting times at the terminal. Due to this and a decrease in average throughput time, a strong decrease is achieved for the average laytimes and demurrage costs. However, it remains a long term goal as the prevention of all interrupts does not happen over night. In the long term this could positively impact Vopak as a whole. If accurate planning information can be given to customers, strongly decreasing their demurrage costs, the demand for Vopak terminals will increase and all parties can share the benefits of the increase in process efficiency.

11.2. Recommendations to VTAW

Based on the results of this research project, a number of recommendations can be formulated to increase the performance of the terminal. It is vital for the terminal that something is done about the long waiting times and planning inaccuracies. Building a new jetty is just a temporary fix of the problem and is also expensive, resulting in a moderate profit gain. The results in this report show that there are alternatives. The recommendations for VTAW have been stated below along with a brief description.

Interrupt prevention and data collection

The results in Chapter 7 show that the interrupts, especially surveyor interrupts, have a major impact on the operational performance of the terminal. Some interrupts, such as technical failures, are unpredictable and can't always be prevented, however, other interrupts, such as surveyor activities, are planned and not completely necessary. To map the specifics of these interrupts, it is important to start collecting and registering detailed data to obtain information as to the precise activities and interrupts that have taken place. This could provide insights that, when shared with the customer, could lead to a compromise to limit the amount of unnecessary activities. For example, if data can show that the product quantity measured by Vopak is in accordance with the surveyor at least 99% of the time, the customer might decide to save valuable time by trusting the Vopak measurement or using random samples to check Vopak credibility.

Incorporate a forward planning strategy

Chapter 9 showed that the amount of acceptable customer delay had a much larger impact on operational performance than the amount of planning days prior to arrival. This was a positive result as this solution is also less of an infringement on the customer flexibility. Although this is a long term goal as it will take time to persuade the customers and vessels to accept the new strategy, it is recommended that VTAW start testing this. If need be, VTAW could start with one customer that is willing to test this and see the results on their own performance. The big advantage to this planning strategy is that, besides the fact that customers must plan their operations in advance, not much changes in comparison to the current operation. The only change is that vessels are no longer unnecessarily waiting at Ijmuiden to be called in to the terminal. To further service the customer, information could be shared real time regarding terminal congestion. This could be incorporated into the vessel clearance tool and brought to the customer. In this way, the customer could check the 3 day congestion forecast before chartering a vessel.

11.3. Recommendations for further research

Lastly, some recommendations are given concerning possible future research topics that could complement this project or could be of interest to Vopak and the tank storage industry. These recommendations are stated below.

Customer research

In this research project, the operational performance of the terminal was analyzed. When analyzing the results and the future possibilities, some assumptions had to made as to the way of working and planning on the side of the customer and the customer requirements. It would be valuable to look at this research from a customer point of view. By analyzing the full process that the customer must go through, the forward planning model can be made more compatible for both parties and it would have a better chance of succeeding.

Data collection

The quality of the Vopak database is currently insufficient to make accurate statements based purely on data. This has to do with multiple factors:

- Not all relevant data is registered
- The registered data is often unreliable
- The registered data information is too general

A valuable future research project would be to identify all the relevant data timestamps that should be available to Vopak and design a platform where this data is acquired and shared by Vopak and the other parties involved in the vessel handling process. This could help decrease the amount of claims and help show the responsible party for a specific claim.

Berth scheduling

In this research project, the realization came that berth time scheduling for seagoing vessels is extremely difficult. It is currently not possible to accurately predict vessel laytime, regardless of whether the exact product amount to be loaded or discharged is known. The exact reasons for this unreliability are not known. One reason is the large variance of flow rates for different vessels. Mapping these reasons and increasing the berth time scheduling accuracy could greatly improve the overall planning of the terminal. Thus, a valuable future research topic, which is only possible when the relevant data is available, is to map the reasons for the inaccurate berth time predictions and possibly create a tool that can accurately predict vessel berthing times.

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Scientific Article

-Research paper can be found on the next page-

Simulation of a Proactive Planning Strategy at a Tank Storage Terminal

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Abstract

The growing pressure on tank storage terminals is pushing the terminals to find ways to accommodate more vessels by increasing the efficiency of the vessel handling process. This research looks at the possibility of implementing forward planning at such a terminal by simulating multiple strategies and testing the impact on the seaside performance of the terminal. The current process is a reactive one due to the first come first serve rule that is enforced. This causes an unpredictable arrival distribution of vessels and a low level of information and collaboration. The simulation results are promising and show that a proactive planning strategy could drastically increase terminal seaside performance by allowing the terminal to control vessel arrival distributions and preventing certain interrupts that often occur within the process. In the best case, the terminal seaside performance increased from the current state performance of 55% to 92%.

I. INTRODUCTION

The 2017 worldwide oil demand was over 2 million barrels per day [Gilchrist,2017]. Of all petroleum products in the world, 61% is transported by sea [TB&P,2017]. Tank storage companies such as Vopak offer the petroleum trade tank storage to use as both a buffer and a means of linking sea to land.

The high demand for tank storage often causes congestion at the terminals. As new infrastructure is expensive, terminals are looking for ways to handle vessels more efficiently to reduce or cope with the congestion.

This research focuses on the implementation of forward planning at a tank storage terminal by proposing a First Order First Serve strategy. This entails that the first order nomination received, up until a maximum amount of days in advance, is the first vessel to be planned. Currently, a First Come First Serve rule is maintained, giving the terminal little insight into future congestion and causing high peaks in the arrival distribution.

By implementing a forward planning strategy, the expectation is that the following main changes should positively impact the terminal performance:

- **Control vessel arrival distribution:** As the future congestion at the terminal is known, vessels and customers can be informed to delay their arrival or operations to avoid waiting times.
- **Higher level of collaboration:** More information should allow closer collaboration between the terminal, the port, and other relevant parties to reduce interrupts at the terminal.

This research aims to assess the impact of implementing a proactive planning strategy at Vopak Terminal Amsterdam Westpoort with respect to the Terminal Seaside Performance.

II. METHOD

The Delft Systems Approach (DSA) [Veeke,2008] was used to analyze the current vessel handling process at VTAW. DSA focuses primarily on bridging the gap between theory and practice. DSA starts with systems thinking, which is the art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of underlying structure [Richmond,1987]. The idea of systems thinking is to take any process and view it from a simple perspective of, possibly, multiple systems and subsystems. First the function of the terminal, decoupling of the mode of transport, was determined using the black box method. Then the terminal was modeled using a process performance model, or a PROPER model. The requirements and KPIs of the terminal were determined to be able to measure the seaside performance.

C. Performance measurement

The 4 KPIs that are used to determine the performance of the terminal are the following:

- Jetty occupancy rate
- Waiting time
- Turnaround time
- Laytime & demurrage

1) Jetty occupancy rate

The jetty occupancy rate of an oil terminal gives an indication as to how effectively the terminal is running. The formula for the jetty occupancy rate is as follows:

$$\text{Jetty occupancy} = \frac{\text{Total amount of time a jetty is occupied}}{\text{Total amount of serviceable hours}}$$

2) Waiting time

Waiting time is an important KPI as it affects customer satisfaction. Customer satisfaction will decrease with increasing waiting times. Hence, waiting times must be minimized The first 6 hours after the NOR has been tendered is usually not counted as laytime to account for the arrival and berthing process of the vessel. Thus, the waiting time of a vessel will be assumed to be the time between ”all fast” and ”NOR tendered” minus 6 hours. If a vessel is berthed under 6 hours, the waiting time is assumed to be zero.

3) Turnaround time

The turnaround time is the actual berthing time of the vessel. The turnaround time is an important KPI for the terminal as it gives insight into the efficiency of seaside operations. To calculate the turnaround time, the departure time of the vessel is subtracted from the arrival time. Interrupts are part of the turnaround time. The ratio of interrupt time within the process gives information regarding process efficiency.

4) Laytime & Demurrage

Laytime and demurrage are difficult to standardize as these concepts are different for each vessel and each operation. It is agreed upon by the vessel charterer and the captain of the vessel. The laytime consists partly of waiting time and partly of turnaround time. To quantify and get a sense of the scale of the total demurrage costs at VTAW, a number of assumptions have been made as to the calculation of laytime and demurrage, which are based on actual contractual demurrage agreements. The demurrage rate has been set at 800 dollars per hour.

D. Terminal seaside performance

The KPIs above each give a small insight into the performance of the terminal. However, by looking at the KPIs individually, no accurate representation of the overall seaside terminal performance can be sketched. Thus, to be able to get an accurate idea of terminal performance in current and future states, and to be able to compare these states, a mathematical equation will be formulated, that combines the KPIs, to calculate the Terminal Seaside Performance (TSP). Weights were added to each aspect of the TSP equation in accordance with Vopak planners. The TSP is formulated as follows:

$$TSR = \frac{(\frac{1}{3} * DR + \frac{2}{3} * (1 - WTR)) + (\frac{1}{3} * JOR + \frac{2}{3} * (1 - IR))}{2} * 100$$

$$\text{Waiting Time Ratio (WTR)} = \frac{\text{Total waiting time}}{\text{Total vessel charter time}}$$

$$\text{Demurrage Ratio (DR)} = \frac{\text{Amount of vessels without demurrage}}{\text{Total amount of vessels handled}}$$

$$\text{Jetty Occupancy Rate (JOR)} = \frac{\text{Time jetty is occupied}}{\text{Total time passed}}$$

$$\text{Interrupt Ratio (IR)} = \frac{\text{Total interrupt time}}{\text{Total turnaround time}}$$

E. Proactive planning model To test the performance of the terminal with the implementation of a proactive planning strategy, the terminal has been modeled in Lazarus and Tomas. A discrete event simulation will be used to test the various experiments. The conceptual proactive planning model uses forward planning to address two problems seen in the current process: an uncontrolled arrival distribution and a low level of information sharing. The model enforces a First Order First Serve rule. The model works as follows:

1 A fixed X days (or later at risk of congestion) before vessel ETA, the order nomination must be sent by the customer to VTAW. If the order nomination is sent earlier than the set amount of days, the vessel will still only be planned X days before its expected arrival.

2 When the vessel is planned it is given an arrival time range no earlier than the ETA on the order nomination. This arrival time is based on the congestion prediction at that moment. Hence, no guarantee is given that the vessel will be handled immediately upon arrival. This is due to the unpredictable handling times.

3 If the vessel arrives later than the assigned arrival time range, it runs the risk of losing its place. This depends on the planning at that moment and the vessel's successor and predecessor.

4 Once the vessel is called-in, operations are the same as in the current state of the terminal.

The forward planning model is subjected to 3 variables, for which different input values will be tested:

- **Time of planning:** How long, prior to the expected vessel arrival, vessels will be scheduled
- **Maximum customer delay:** maximum amount of time the terminal may delay the expected arrival time of the customer's vessel upon receiving the order nomination
- **Interrupts:** The state of the interrupts within the process

F. Experiments
To be able to assess the best possible planning strategy, all combinations of inputs for the above mentioned variables must be tested in the simulation. These inputs have been chosen based on realistic and plausible scenarios. This gives a total of thirty experiments using the following inputs for each variable:

Time of Planning	**Maximum Customer Delay**	**Interrupts**
1 day	50%	All interrupts
2 days	100%	No surveyor interrupts
3 days		No interrupts
4 days		
5 days		

III. RESULTS

The goal of the simulation experiments is to find the best forward planning strategy for the terminal regarding time of planning and maximum customer delay. However, the best strategy might differ for future states of the terminal when, for example some or all interrupts are prevented. Thus, the results will be categorized according to the third variable inputs and compared to the current state, of which the values are given in Figure A.1. This will allow for better and more distinct recommendations in the remainder of this paper.

KPI	Yearly Average Result
Vessels	247
Jetty Occupancy Rate	79,97%
Waiting Time	34 Hours
Turnaround Time	55,41 Hours
Laytime	79,39 Hours
Demurrage	27700 Dollars

Figure A.1: Current state KPI values

A. All interrupts

The first simulation input regarding interrupts is the current situation, namely all interrupts are taken into account. Figure A.2 shows the results for all KPIs for the experiments regarding all interrupts.

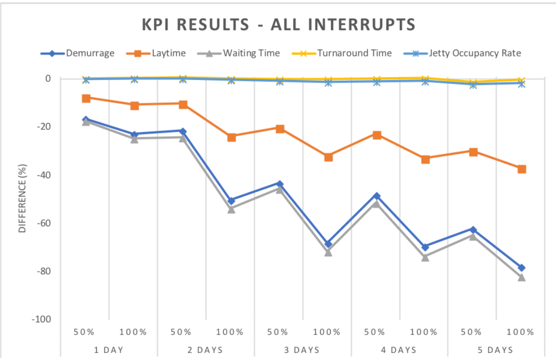

Figure A.2: Difference of each KPI relative to the current state

The jetty occupancy rate shows no difference for any of the ten cases relative to the current state. This is due to the fact that forward planning does not affect the amount of vessels that visit the terminal. Forward planning is, in fact, a strategy to cope with a high jetty occupancy rate and thus the jetty occupancy rate remains constant.

The waiting time shows a large and continuing decrease as the time of planning increases. The decrease in waiting time is larger for the 100% customer delay. It seems that, for the 100% maximum customer delay, a longer time of planning after about 3 days has little effect on the waiting time and it has reached a lower limit. The reason the waiting time is not able to decrease to 0 is the fact that the interrupts make it impossible to 100% accurately plan the vessels.

The throughput time remains constant throughout the simulation. This is because there is no change in the interrupts an thus the vessel handling processing times do not change.

The laytime and demurrage are directly correlated to one another and both decrease. However, the demurrage does show a steeper decrease than the laytime. This is due to more vessels being handled within the contractual laytime, which has a large effect on the average demurrage costs.

B. No surveyor interrupts

The second simulation input regarding interrupts is no surveyor interrupts. Surveyor interrupts account for 52% of the total registered interrupt times [**? ?**]. Figure A.3 shows the results for all KPIs for the experiments regarding no surveyor interrupts.

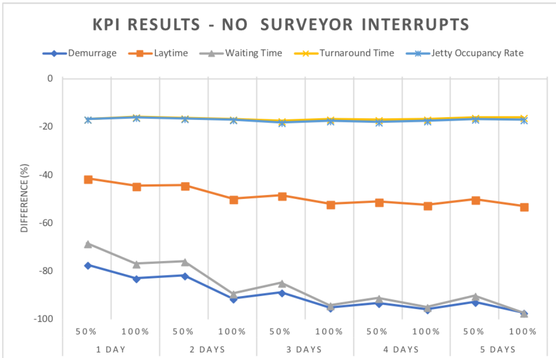

Figure A.3: Difference of each KPI relative to the current state

The jetty occupancy rate shows no difference for any of the ten cases relative to the assumed current state. However, the jetty occupancy rate is significantly lower due to the fact that the surveyor interrupts are taken out of the process. This gives a decrease in jetty occupancy rate of about 15% compared to the current situation with all interrupts.

Looking at the first node, the waiting time already shows a large decrease by just taking away the surveyor interrupts. Forward planning continues this trend. However, for both the 50% and 100% customer delay values, the decreasing trend stops at a time of planning of 4 days and 3 days respectively.

The turnaround time remains constant as forward planning does not influence it. However, the average turnaround time has decreased by about 15% compared to the situation with all interrupts. This is also the reason for the decrease in the jetty occupancy rate.

Due to the decrease in turnaround time and the further decrease in waiting time, the laytime is positively affected. Both the laytime and demurrage show a decreasing trend that stops at a time of planning of 3-4 days.

C. No interrupts

The third and last simulation input regarding interrupts is no interrupts at all. This assumes that all interrupts at the terminal have been solved or prevented. Figure A.4 shows the results for all KPIs for the experiments regarding no interrupts.

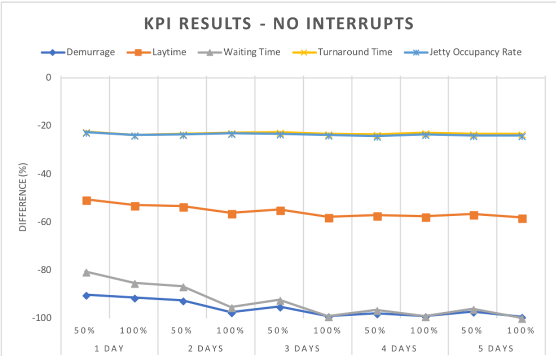

Figure A.4: Difference of each KPI relative to the current state

As explained in the previous two cases, the jetty occupancy rate shows no difference for any of the ten cases relative to the assumed current state. It has, however, decreased a further 5% approximately compared to the no surveyor situation due to the fact that the rest of the interrupts have been taken out of the process. This gives a total decrease in jetty occupancy rate of about 20% compared to the current situation with all interrupts.

The waiting time, once again, decreases even more. With no interrupts in the system, the process becomes much more predictable. Hence, the waiting time is able to drop even further than in the previous situations. At a time of planning of 3 days and a customer delay of 100%, the trend seems to even out and the waiting time has diminished to almost 0.

As in the previous two cases, the turnaround time remains constant as forward planning does not influence it. The turnaround time shows a lesser overall decrease compared to the no surveyor situation. Compared to the current situation considering all interrupts, the turnaround time has decreased a total of more than 20%.

Due to the waiting time decreasing to almost 0 as the time of planning increases and the turnaround time decreasing, the same trend can be seen in the laytime. At a time of planning of 4 days, regardless of the maximum customer delay value, the demurrage costs have almost completely diminished. Apparently, the average laytime is now well below the contractual laytime, meaning almost no demurrage can be claimed in most cases.

D. Terminal seaside performance

The results above give a good picture of the impact of the various experiments on the terminal. However, it is difficult to determine the best strategy on the basis of these results. This is why the "Terminal Seaside Performance" was introduced. The current state TSP is 55%. Figure A.5 shows the TSP for all 30 experiments tested in the simulation model.

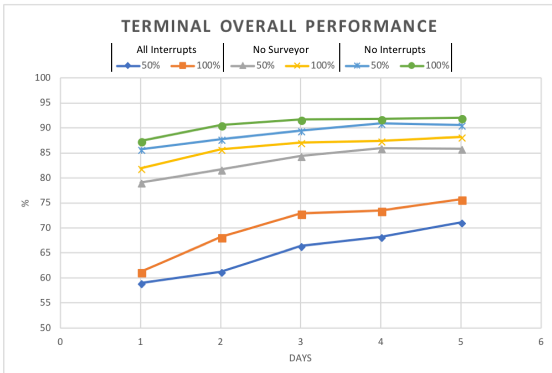

Figure A.5: TSP results for all 30 experiments

Note that the vertical axis lower limit is 50% to better visualize the differences in performance.

The impact of the prevention of interrupts is extremely clear from this figure. Regardless of the forward planning strategy, the prevention of surveyor interrupts has a larger effect on terminal seaside performance. This impact is noticeably smaller when taking all interrupts out of the process, as opposed to just the surveyor interrupts. Although the impact of interrupt prevention is large, forward planning clearly also has a positive effect on terminal seaside performance. The level of impact decreases, however, as the level of interrupt prevention increases. This is explainable because the decrease in interrupts causes a decrease in turnaround time. This, in turn, causes a decrease in jetty occupancy, which decreases the need for forward planning. From the TSP results in Figure A.5, it seems the experiment resulting in the best terminal seaside performance is the following:

- Time of planning: 3-5 days
- Maximum customer delay: 100%
- Interrupts: No Interrupts
- Terminal seaside performance: 92%

IV. DISCUSSION

The results show a great deal of promise. They show an alternative to building more infrastructure to accommodate the high demand. In the short term, the goal for the terminal should be to try to take the surveyor interrupts out of the process as this has a large effect on the terminal performance. In the long term, the terminal should focus on the implementation of forward planning in collaboration with the other parties in the industry. The best strategy for this has been determined in the results above. However, a valid question is the feasibility of the forward planning strategy within the current industry.

A. Challenges

To be able to implement the proactive planning strategy sketched in this paper, some challenges must be overcome. The current mentality in this industry would not allow such drastic changes in the vessel handling operation. The main limitations in the current industry regarding the implementation of forward planning are the following:

- **Collaboration pilots, surveyors, port authority:** To make forward planning work efficiently, all parties must adjust their plan to one another. The pilots, surveyors and port authority will most likely not comply with this plan unless a certain level of planning accuracy can be demonstrated. The current level of predictability within the process is too low to ensure the delivery of accurate information regarding arrival and process times.
- **Customer flexibility:** a proactive planning strategy forces the customers to also plan ahead. In the long term, this would increase customer flexibility as the customer knows to a certain extent when operations will take place, as opposed to the current situation with last minute operations and unknown waiting times. It is the question whether customers will accept this and see the long term benefit.
- **Demurrage decrease vessels:** A proactive planning strategy would decrease the demurrage income for the vessels. In the current situation, demurrage costs are almost a given in most operations, so vessels actually see it as part of the income. Hence, the vessels will most likely not accept this change if there is no benefit in it for them.

B. Future view

Although there are some serious limitations regarding the feasibility of a proactive planning strategy at VTAW, these limitations are not insurmountable. All parties must change and adjust their strategies to one another, and the profit that is gained should be fairly split among them. This is where the industry mentality must really change. If this change were to be realized, each party could reap their own benefits:

- **Terminal**
  - More information into future congestion at the terminal
  - More efficient employee planning
  - Possibly share in the customer demurrage savings (pay for performance)
- **Customer**
  - Demurrage savings
  - More information as to the terminal congestion, which could help improve own planning
- **Vessel**
  - Possible fuel saving in the case terminal congestion is known en route
  - Possibly share in the customer demurrage savings (pay for performance)

It might be a long term view for now and it will definitely be a slow and gradual transition. However, it is inevitable that the change to forward planning will happen and it is better to be a part of this innovation than to miss the boat.

V. REFERENCES

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B

Lazarus/Tomas Code

```
unit DogsUnit;

{$MODE Delphi}
{$M+}
interface

uses
  LCLIntf, LCLType, LMessages, Messages, SysUtils, Classes, Graphics,
      Controls, Forms, Dialogs,
  Tomas, StdCtrls, ExtCtrls, MATH;

type

  { TUserForm }

  TUserForm = class(TForm)
    Button1: TButton;
    Edit1: TEdit;
    Edit10: TEdit;
    Edit11: TEdit;
    Edit12: TEdit;
    Edit13: TEdit;
    Edit14: TEdit;
    Edit15: TEdit;
    Edit16: TEdit;
    Edit17: TEdit;
    Edit18: TEdit;
    Edit19: TEdit;
    Edit2: TEdit;
```

```
    Edit20: TEdit;
    Edit21: TEdit;
    Edit22: TEdit;
    Edit23: TEdit;
    Edit24: TEdit;
    Edit25: TEdit;
    Edit26: TEdit;
    Edit27: TEdit;
    Edit28: TEdit;
    Edit29: TEdit;
    Edit3: TEdit;
    Edit30: TEdit;
    Edit31: TEdit;
    Edit32: TEdit;
    Edit33: TEdit;
    Edit34: TEdit;
    Edit35: TEdit;
    Edit36: TEdit;
    Edit4: TEdit;
    Edit5: TEdit;
    Edit6: TEdit;
    Edit7: TEdit;
    Edit8: TEdit;
    Edit9: TEdit;
    Label1: TLabel;
    Label10: TLabel;
    Label11: TLabel;
    Label12: TLabel;
    Label13: TLabel;
    Label14: TLabel;
    Label15: TLabel;
    Label16: TLabel;
    Label17: TLabel;
    Label18: TLabel;
    Label19: TLabel;
    Label2: TLabel;
    Label20: TLabel;
    Label21: TLabel;
    Label22: TLabel;
    Label23: TLabel;
    Label24: TLabel;
    Label25: TLabel;
    Label26: TLabel;
    Label27: TLabel;
    Label28: TLabel;
```

```
    Label29: TLabel;
    Label3: TLabel;
    Label30: TLabel;
    Label31: TLabel;
    Label32: TLabel;
    Label33: TLabel;
    Label34: TLabel;
    Label35: TLabel;
    Label36: TLabel;
    Label37: TLabel;
    Label38: TLabel;
    Label39: TLabel;
    Label4: TLabel;
    Label5: TLabel;
    Label6: TLabel;
    Label7: TLabel;
    Label8: TLabel;
    Label9: TLabel;
    ListBox1: TListBox;
    ListBox10: TListBox;
    ListBox11: TListBox;
    ListBox12: TListBox;
    ListBox13: TListBox;
    ListBox14: TListBox;
    ListBox15: TListBox;
    ListBox16: TListBox;
    ListBox17: TListBox;
    ListBox18: TListBox;
    ListBox19: TListBox;
    ListBox2: TListBox;
    ListBox20: TListBox;
    ListBox21: TListBox;
    ListBox22: TListBox;
    ListBox23: TListBox;
    ListBox3: TListBox;
    ListBox4: TListBox;
    ListBox5: TListBox;
    ListBox6: TListBox;
    ListBox7: TListBox;
    ListBox8: TListBox;
    ListBox9: TListBox;
    procedure Button1Click(Sender: TObject);
  private
    { Private declarations }
  public
```

```
    { Public declarations }
  end;

  TLock = class(TomasElement)
    Published
      Procedure Process; override;
  end;

  TJetty1 = class(TomasElement)
    Published
      Procedure Process; override;
  end;

  TJetty2 = class(TomasElement)
    Published
      Procedure Process; override;
  end;

  TJetty1ArrivalPlan = class(TomasElement)
    Published
      Procedure Process; override;
  end;

  TJetty2ArrivalPlan = class(TomasElement)
    Published
      Procedure Process; override;
  end;

  TVessel = class(TomasElement)
    private
      Load1Dis0: Integer;
      TransShip: Integer;
      ProductQuantity: Double;
      FlowRate: Double;
      OrderLines: Integer;
      AllFast: Double;
      LayTime: Double;
      PredictedLaytime: Double;
      ArrivalTime: Double;
      ETA: Double;
      SlowETA: Double;
      TransShipTime: Double;
      OrderLineTime: Double;
      published
        Constructor Create(Nm: String; LD: Integer; TS: Integer; PQ:
```

```
            Double; FR: Double; OL: Integer; AF: Double; LT: Double; PL:
            Double; AT: Double; ETA: Double; SETA: Double; TST: Double; OLT
            : Double);
  end;

  TGenerator = class(TomasElement)
    private
      InterArrivalTimes: TTableDistribution;
      LoadProductQuantity: TTableDistribution;
      DisProductQuantity: TTableDistribution;
      LoadOrderLines: TNormalDistribution;
      DisOrderLines: TNormalDistribution;
      TransShipTime: TTableDistribution;
      OrderLineTime: TNormalDistribution;
      Published
        Constructor Create(Nm: String);
          Procedure Process; override;
  end;


var
  UserForm: TUserForm;
  VesselGenerator: TGenerator;
  Lock: TLock;
  Jetty1: TJetty1;
  Jetty2: TJetty2;
  Jetty1ArrivalPlan: TJetty1ArrivalPlan;
  Jetty2ArrivalPlan: TJetty2ArrivalPlan;
  LockQueue: TomasQueue;
  Jetty1Arrival: TomasQueue;
  Jetty1PrePump: TomasQueue;
  Jetty1Pump: TomasQueue;
  Jetty1PostPump: TomasQueue;
  Jetty2Arrival: TomasQueue;
  Jetty2PrePump: TomasQueue;
  Jetty2Pump: TomasQueue;
  Jetty2PostPump: TomasQueue;
  OutOfLock1: TomasQueue;
  OutOfLock2: TomasQueue;
  LockTravelQueue: TomasQueue;
  Jetty1Interrupts: TomasQueue;
  Jetty2Interrupts: TomasQueue;
  Jetty1Nomination: TomasQueue;
  Jetty2Nomination: TomasQueue;
  Jetty1Wait: TomasQueue;
```

```
  Jetty2Wait: TomasQueue;
  Jetty1Occupied: Integer;
  Jetty2Occupied: Integer;
  JettyPlan: Integer;
  PredictedJetty1Vacancy: Double;
  PredictedJetty2Vacancy: Double;

implementation

{$R *.lfm}

{ TDog }

{As soon as a jetty is free, the lock allows a vessel to enter. The lock
holds the vessel for the given lock time}
Procedure TLock.Process;
    Var
      myShip: TVessel;
      VesselQueueTime: Double;
      LockTravelTime: Double;
      LockTime: Double;
      Sum: Double;
      i: Integer;
    Begin
      While TRUE Do
        Begin
          While ((Jetty1Wait.Length = 0) or (Jetty1Occupied = 1)) and ((
              Jetty2Wait.Length = 0) or (Jetty2Occupied = 1)) Do
            Begin
              Standby;
            end;

          {Check if the vessel is meant for jetty 1 or jetty 2}
          If (Jetty1Wait.Length > 0) and (Jetty1Occupied = 0)  then
            Begin
              Jetty1Occupied:= 1;
              JettyPlan:= 1;
              myShip:= Jetty1Wait.FirstElement;

              {Write waiting times and average to form}
               VesselQueueTime:= TNow - myShip.QueueTime(Jetty1Wait);
               UserForm.ListBox1.Items.Add(FloatToStr(VesselQueueTime));
               If UserForm.ListBox1.Items.Count > 2 then
                 Begin
                   Sum:= 0;
```

```
         For i:= 0 to UserForm.ListBox1.Items.Count - 1 do
           Sum:= Sum + StrToFloat(UserForm.ListBox1.Items[i]);
       end;
     UserForm.Edit1.Text:= FloatToStr(Sum/UserForm.ListBox1.Items.Count);

     {Laytime commences 6 hours after NOR tendered}
     If VesselQueueTime > 360 then
       myShip.LayTime:= VesselQueueTime - 360;

     myShip.LeaveQueue(Jetty1Wait);
     myShip.EnterQueue(LockTravelQueue);
  end
Else
  Begin
    Jetty2Occupied:= 1;
    JettyPlan:= 2;
    myShip:= Jetty2Wait.FirstElement;

    {Write waiting times and average to form}
    VesselQueueTime:= TNow - myShip.QueueTime(Jetty2Wait);
    UserForm.ListBox1.Items.Add(FloatToStr(VesselQueueTime));
    If UserForm.ListBox1.Items.Count > 2 then
      Begin
        Sum:= 0;
        For i:= 0 to UserForm.ListBox1.Items.Count - 1 do
          Sum:= Sum + StrToFloat(UserForm.ListBox1.Items[i]);
      end;
     UserForm.Edit1.Text:= FloatToStr(Sum/UserForm.ListBox1.Items.Count);

     {Laytime commences 6 hours after NOR tendered}
     If VesselQueueTime > 360 then
       myShip.LayTime:= VesselQueueTime - 360;

     myShip.LeaveQueue(Jetty2Wait);
     myShip.EnterQueue(LockTravelQueue);
  end;

{Travel time from anchor place to lock}
Hold(75);

{Write lock travel times and average to form}
LockTravelTime:= TNow - myShip.QueueTime(LockTravelQueue);
UserForm.ListBox2.Items.Add(FloatToStr(LockTravelTime));
```

```
          If UserForm.ListBox2.Items.Count > 2 then
           Begin
             Sum:= 0;
             For i:= 0 to UserForm.ListBox2.Items.Count - 1 do
               Sum:= Sum + StrToFloat(UserForm.ListBox2.Items[i]);
           end;
          UserForm.Edit2.Text:= FloatToStr(Sum/UserForm.ListBox2.Items.Count);

          myShip.LeaveQueue(LockTravelQueue);
          myShip.EnterQueue(LockQueue);

          {Time to clear the lock}
          Hold(45);

          {Write lock times and average to form}
          LockTime:= TNow - myShip.QueueTime(LockQueue);
          UserForm.ListBox3.Items.Add(FloatToStr(LockTime));
          If UserForm.ListBox3.Items.Count > 2 then
           Begin
             Sum:= 0;
             For i:= 0 to UserForm.ListBox3.Items.Count - 1 do
               Sum:= Sum + StrToFloat(UserForm.ListBox3.Items[i]);
           end;
          UserForm.Edit3.Text:= FloatToStr(Sum/UserForm.ListBox3.Items.Count);

          {Moves the vessel to one of the jetties depending on the jettyplan}
          myShip.LeaveQueue(LockQueue);
          If JettyPlan = 1 then
            myShip.EnterQueue(OutOfLock1)
          Else
            myShip.EnterQueue(OutOfLock2);
        end;
      end;

{jetty 1 uses queues and hold time distributions to simulate the throughput
process of a vessel. The distributions are based on real data}
  Procedure TJetty1.Process;
    Var
      Demurrage: Double;
      J1LaytimeResume: Double;
      J1TimeOccupied: double;
```

```
    myShip1: TVessel;
    Jetty1ArrivalTime: Double;
    Jetty1PrePumpTime: Double;
    Jetty1PumpTime: Double;
    Jetty1PostPumpTime: Double;
    Jetty1InterruptsTime: Double;
    Jetty1ThroughputTime: Double;
    Sum: Double;
    i: Integer;
    LoadOther: TNormalDistribution;
    LoadWAAI: TNormalDistribution;
    LoadWACO: TNormalDistribution;
    LoadWAFD: TNormalDistribution;
    LoadWAHO: TNormalDistribution;
    LoadWAIF: TNormalDistribution;
    LoadWAOR: TNormalDistribution;
    LoadWASA: TNormalDistribution;
    LoadWASU: TNormalDistribution;
    LoadWATF: TNormalDistribution;
    LoadWAVB: TNormalDistribution;
    LoadWAVP: TNormalDistribution;
    LoadBlanks: TNormalDistribution;
    DisOther: TNormalDistribution;
    DisWAAI: TNormalDistribution;
    DisWACO: TNormalDistribution;
    DisWAFD: TNormalDistribution;
    DisWAHO: TNormalDistribution;
    DisWAIF: TNormalDistribution;
    DisWAOR: TNormalDistribution;
    DisWASA: TNormalDistribution;
    DisWASU: TNormalDistribution;
    DisWATF: TNormalDistribution;
    DisWAVB: TNormalDistribution;
    DisWAVP: TNormalDistribution;
    DisBlanks: TNormalDistribution;
  Begin
    Randomize;
    LoadOther:= TNormalDistribution.Create(530221,58,14);
    LoadWAAI:= TNormalDistribution.Create(530222,99,24);
    LoadWACO:= TNormalDistribution.Create(530223,38,9);
    LoadWAFD:= TNormalDistribution.Create(530224,202,50);
    LoadWAHO:= TNormalDistribution.Create(530225,18,4);
    LoadWAIF:= TNormalDistribution.Create(530226,7,1.5);
    LoadWAOR:= TNormalDistribution.Create(530227,89,22);
    LoadWASA:= TNormalDistribution.Create(530228,149,37);
```

```
    LoadWASU:= TNormalDistribution.Create(530229,538,134);
    LoadWATF:= TNormalDistribution.Create(530230,56,14);
    LoadWAVB:= TNormalDistribution.Create(530231,93,23);
    LoadWAVP:= TNormalDistribution.Create(530232,10,2.5);
    LoadBlanks:= TNormalDistribution.Create(530233,18,4);
    DisOther:= TNormalDistribution.Create(530221,27,6);
    DisWAAI:= TNormalDistribution.Create(530222,151,37);
    DisWACO:= TNormalDistribution.Create(530223,11,2.6);
    DisWAFD:= TNormalDistribution.Create(530224,108,27);
    DisWAHO:= TNormalDistribution.Create(530225,39,9);
    DisWAIF:= TNormalDistribution.Create(530226,1.9,0.4);
    DisWAOR:= TNormalDistribution.Create(530227,30,7);
    DisWASA:= TNormalDistribution.Create(530228,91,22);
    DisWASU:= TNormalDistribution.Create(530229,277,69);
    DisWATF:= TNormalDistribution.Create(530230,10,2.4);
    DisWAVB:= TNormalDistribution.Create(530231,47,11);
    DisWAVP:= TNormalDistribution.Create(530232,23,5);
    DisBlanks:= TNormalDistribution.Create(530233,2.3,0.5);
    While TRUE Do
      Begin
        While OutOfLock1.Length = 0 Do
          Begin
            Standby;
          end;
        myShip1:= OutOfLock1.FirstElement;
        myShip1.LeaveQueue(OutOfLock1);
        myShip1.EnterQueue(Jetty1Arrival);

        {Time to travel from lock to jetty}
        Hold(105);

        {Write lock to jetty travel times and average to form}
        Jetty1ArrivalTime:= TNow - myShip1.QueueTime(Jetty1Arrival);
        UserForm.ListBox4.Items.Add(FloatToStr(Jetty1ArrivalTime));
        If UserForm.ListBox4.Items.Count > 2 then
         Begin
           Sum:= 0;
           For i:= 0 to UserForm.ListBox4.Items.Count - 1 do
             Sum:= Sum + StrToFloat(UserForm.ListBox4.Items[i]);
         end;
        UserForm.Edit4.Text:= FloatToStr(Sum/UserForm.ListBox4.Items.Count);

        myShip1.LeaveQueue(Jetty1Arrival);
        myShip1.EnterQueue(Jetty1PrePump);
```

```
        myShip1.AllFast:= TNow;

        {Time needed for pre-pump operations depending on operation type }
        If myShip1.Load1Dis0 = 1 then
          Hold(210)
        Else
          Hold(282);

        {Write pre-pump times and average to form}
        Jetty1PrePumpTime:= TNow - myShip1.QueueTime(Jetty1PrePump);
        UserForm.ListBox5.Items.Add(FloatToStr(Jetty1PrePumpTime));
        If UserForm.ListBox5.Items.Count > 2 then
         Begin
           Sum:= 0;
           For i:= 0 to UserForm.ListBox5.Items.Count - 1 do
             Sum:= Sum + StrToFloat(UserForm.ListBox5.Items[i]);
         end;
        UserForm.Edit5.Text:= FloatToStr(Sum/UserForm.ListBox5.Items.Count);

        myShip1.LeaveQueue(Jetty1PrePump);

        {Laytime resumes at hoses connected}
        J1LaytimeResume:= TNow;
        myShip1.EnterQueue(Jetty1Pump);

        {Time needed for pumping operations}
        Hold(myShip1.ProductQuantity/myShip1.FlowRate*60+myShip1.OrderLines*myShip1.OrderLineTime+myShip1.TransShipTime);

        {Write pump times and average to form}
        Jetty1PumpTime:= TNow - myShip1.QueueTime(Jetty1Pump);
        UserForm.ListBox6.Items.Add(FloatToStr(Jetty1PumpTime));
        If UserForm.ListBox6.Items.Count > 2 then
         Begin
           Sum:= 0;
           For i:= 0 to UserForm.ListBox6.Items.Count - 1 do
             Sum:= Sum + StrToFloat(UserForm.ListBox6.Items[i]);
         end;
        UserForm.Edit6.Text:= FloatToStr(Sum/UserForm.ListBox6.Items.Count);

        myShip1.LeaveQueue(Jetty1Pump);
        myShip1.EnterQueue(Jetty1Interrupts);
```

```
        {Time spent on interrupts throughout vessel handling process}
        {The data does not specify where in the process it took place,
           thus modeled like this}
        //If myShip1.Load1Dis0 = 1 then
         //  Hold(Round(Random-0.30)*LoadOther.Sample+Round(Random-0.22)*
            LoadWAAI.Sample+Round(Random-0.41)*LoadWACO.Sample+Round(
            Random+0.19)*LoadWAFD.Sample+Round(Random-0.44)*LoadWAHO.
            Sample+Round(Random-0.44)*LoadWAIF.Sample+Round(Random-0.25)
            *LoadWAOR.Sample+Round(Random+0.48)*LoadWASA.Sample+LoadWASU
            .Sample+Round(Random-0.18)*LoadWATF.Sample+Round(Random
            -0.05)*LoadWAVB.Sample+Round(Random-0.38)*LoadWAVP.Sample+
            Round(Random-0.08)*LoadBlanks.Sample)
        //Else
        //   Hold(Round(Random-0.33)*DisOther.Sample+Round(Random-0.13)*
           DisWAAI.Sample+Round(Random-0.48)*DisWACO.Sample+Round(Random
           +0.07)*DisWAFD.Sample+Round(Random-0.34)*DisWAHO.Sample+Round
           (Random-0.42)*DisWAIF.Sample+Round(Random-0.38)*DisWAOR.
           Sample+Round(Random+0.43)*DisWASA.Sample+DisWASU.Sample+Round
           (Random-0.38)*DisWATF.Sample+Round(Random-0.18)*DisWAVB.
           Sample+Round(Random-0.41)*DisWAVP.Sample+Round(Random-0.27)*
           LoadBlanks.Sample);

        {Write interrupt times and average to form}
        Jetty1InterruptsTime:= TNow - myShip1.QueueTime(Jetty1Interrupts
           );
        UserForm.ListBox8.Items.Add(FloatToStr(Jetty1InterruptsTime));
        If UserForm.ListBox8.Items.Count > 2 then
         Begin
           Sum:= 0;
           For i:= 0 to UserForm.ListBox8.Items.Count - 1 do
             Sum:= Sum + StrToFloat(UserForm.ListBox8.Items[i]);
         end;
        UserForm.Edit8.Text:= FloatToStr(Sum/UserForm.ListBox8.Items.
           Count);

        myShip1.LeaveQueue(Jetty1Interrupts);

        {Write laytimes and average to form}
        {Laytime ends upon hoses disconnected}
        myShip1.LayTime:= myShip1.LayTime + (TNow - J1LaytimeResume);
        UserForm.ListBox17.Items.Add(FloatToStr(myShip1.LayTime));
        If UserForm.ListBox17.Items.Count > 2 then
         Begin
           Sum:= 0;
```

```
      For i:= 0 to UserForm.ListBox17.Items.Count - 1 do
        Sum:= Sum + StrToFloat(UserForm.ListBox17.Items[i]);
    end;
   UserForm.Edit21.Text:= FloatToStr(Sum/UserForm.ListBox17.Items.Count);

   {Write total laytimes and average of both jetties to form}
   UserForm.ListBox22.Items.Add(FloatToStr(myShip1.LayTime));
   If UserForm.ListBox22.Items.Count > 2 then
    Begin
      Sum:= 0;
      For i:= 0 to UserForm.ListBox22.Items.Count - 1 do
        Sum:= Sum + StrToFloat(UserForm.ListBox22.Items[i]);
    end;
   UserForm.Edit34.Text:= FloatToStr(Sum/UserForm.ListBox22.Items.Count);

   {Write demurrage and average to form}
   If myShip1.Load1Dis0 = 1 then
     If myShip1.ProductQuantity < 60000 then
       If myShip1.LayTime < (48*60) then
         Demurrage:= 0
       Else
         Demurrage:= 800 * ((myShip1.LayTime/60) - 48)
     Else
       If myShip1.LayTime < (60*60) then
         Demurrage:= 0
       Else
         Demurrage:= 800 * ((myShip1.LayTime/60) - 60)
   Else
     If myShip1.ProductQuantity < 130000 then
       If myShip1.LayTime < (48*60) then
         Demurrage:= 0
       Else
         Demurrage:= 800 * ((myShip1.LayTime/60) - 48)
     Else
       If myShip1.LayTime < (60*60) then
         Demurrage:= 0
       Else
         Demurrage:= 800 * ((myShip1.LayTime/60) - 60);

   UserForm.ListBox18.Items.Add(FloatToStr(Demurrage));
   If UserForm.ListBox18.Items.Count > 2 then
    Begin
      Sum:= 0;
```

```
      For i:= 0 to UserForm.ListBox18.Items.Count - 1 do
        Sum:= Sum + StrToFloat(UserForm.ListBox18.Items[i]);
   end;
  UserForm.Edit23.Text:= FloatToStr(Sum/UserForm.ListBox18.Items.Count);

  {Write total demurrage costs and average for both jetties to form}
  UserForm.ListBox23.Items.Add(FloatToStr(Demurrage));
  If UserForm.ListBox23.Items.Count > 2 then
   Begin
     Sum:= 0;
      For i:= 0 to UserForm.ListBox23.Items.Count - 1 do
        Sum:= Sum + StrToFloat(UserForm.ListBox23.Items[i]);
   end;
  UserForm.Edit35.Text:= FloatToStr(Sum/UserForm.ListBox23.Items.Count);

  myShip1.EnterQueue(Jetty1PostPump);

  {Time needed for post-pump operations depending on operation type}
  If myShip1.Load1Dis0 = 1 then
    Hold(336)
  Else
    Hold(162);

  {Write post-pump times and average to form}
  Jetty1PostPumpTime:= TNow - myShip1.QueueTime(Jetty1PostPump);
  UserForm.ListBox7.Items.Add(FloatToStr(Jetty1PostPumpTime));
  If UserForm.ListBox7.Items.Count > 2 then
   Begin
     Sum:= 0;
      For i:= 0 to UserForm.ListBox7.Items.Count - 1 do
        Sum:= Sum + StrToFloat(UserForm.ListBox7.Items[i]);
   end;
  UserForm.Edit7.Text:= FloatToStr(Sum/UserForm.ListBox7.Items.Count);

  myShip1.LeaveQueue(Jetty1PostPump);

  {Write throughput times and average to form}
  Jetty1ThroughputTime:= TNow - myShip1.AllFast;
  UserForm.ListBox14.Items.Add(FloatToStr(Jetty1ThroughputTime));
  If UserForm.ListBox14.Items.Count > 2 then
```

```
    Begin
      Sum:= 0;
      For i:= 0 to UserForm.ListBox14.Items.Count - 1 do
        Sum:= Sum + StrToFloat(UserForm.ListBox14.Items[i]);
    end;
   UserForm.Edit14.Text:= FloatToStr(Sum/UserForm.ListBox14.Items.Count);

   {Write total throughput times and average for both jetties to form}
   UserForm.ListBox21.Items.Add(FloatToStr(Jetty1ThroughputTime));
   If UserForm.ListBox21.Items.Count > 2 then
    Begin
      Sum:= 0;
      For i:= 0 to UserForm.ListBox21.Items.Count - 1 do
        Sum:= Sum + StrToFloat(UserForm.ListBox21.Items[i]);
    end;
   UserForm.Edit30.Text:= FloatToStr(Sum/UserForm.ListBox21.Items.Count);

   {Make jetty vacant}
   Jetty1Occupied:= 0;

   {Write berthing times and jetty occupancy rates to form}
   J1TimeOccupied:= TNow - myShip1.AllFast;
   UserForm.Edit20.Text:= FloatToStr(StrToFloat(UserForm.Edit20.Text) + J1TimeOccupied);
   UserForm.Edit24.Text:= FloatToStr(StrToFloat(UserForm.Edit20.Text)/TNow*100);
   UserForm.Edit25.Text:= FloatToStr(StrToFloat(UserForm.Edit20.Text)/525600*100);

   {Write total berthing times and jetty occupancy rates for both jetties to form}
   UserForm.Edit31.Text:= FloatToStr(StrToFloat(UserForm.Edit31.Text) + J1TimeOccupied);
   UserForm.Edit32.Text:= FloatToStr(StrToFloat(UserForm.Edit31.Text)/(TNow*2)*100);
   UserForm.Edit33.Text:= FloatToStr(StrToFloat(UserForm.Edit31.Text)/(525600*2)*100);

   {Take vessel out of simulation and write to form as handled vessel}
   myShip1.Destroy;
   UserForm.Edit16.Text:= FloatToStr(StrToFloat(UserForm.Edit16.
```

```
                Text)+1);
            UserForm.Edit36.Text:= FloatToStr(StrToFloat(UserForm.Edit36.
                Text)+1);
          end;
        end;

{When jetty 1 is occupied, jetty 2 is used and is essentially the same
    process
as jetty 1}
  Procedure TJetty2.Process;
    Var
      J2TimeOccupied: Double;
      Demurrage: Double;
      J2LaytimeResume: Double;
      myShip2: TVessel;
      Jetty2ArrivalTime: Double;
      Jetty2PrePumpTime: Double;
      Jetty2PumpTime: Double;
      Jetty2PostPumpTime: Double;
      Jetty2InterruptsTime: Double;
      Jetty2ThroughputTime: Double;
      Sum: Double;
      i: Integer;
      LoadOther: TNormalDistribution;
      LoadWAAI: TNormalDistribution;
      LoadWACO: TNormalDistribution;
      LoadWAFD: TNormalDistribution;
      LoadWAHO: TNormalDistribution;
      LoadWAIF: TNormalDistribution;
      LoadWAOR: TNormalDistribution;
      LoadWASA: TNormalDistribution;
      LoadWASU: TNormalDistribution;
      LoadWATF: TNormalDistribution;
      LoadWAVB: TNormalDistribution;
      LoadWAVP: TNormalDistribution;
      LoadBlanks: TNormalDistribution;
      DisOther: TNormalDistribution;
      DisWAAI: TNormalDistribution;
      DisWACO: TNormalDistribution;
      DisWAFD: TNormalDistribution;
      DisWAHO: TNormalDistribution;
      DisWAIF: TNormalDistribution;
      DisWAOR: TNormalDistribution;
      DisWASA: TNormalDistribution;
      DisWASU: TNormalDistribution;
```

```
      DisWATF: TNormalDistribution;
      DisWAVB: TNormalDistribution;
      DisWAVP: TNormalDistribution;
      DisBlanks: TNormalDistribution;
    Begin
      Randomize;
      LoadOther:= TNormalDistribution.Create(530221,58,14);
      LoadWAAI:= TNormalDistribution.Create(530222,99,24);
      LoadWACO:= TNormalDistribution.Create(530223,38,9);
      LoadWAFD:= TNormalDistribution.Create(530224,202,50);
      LoadWAHO:= TNormalDistribution.Create(530225,18,4);
      LoadWAIF:= TNormalDistribution.Create(530226,7,1.5);
      LoadWAOR:= TNormalDistribution.Create(530227,89,22);
      LoadWASA:= TNormalDistribution.Create(530228,149,37);
      LoadWASU:= TNormalDistribution.Create(530229,538,134);
      LoadWATF:= TNormalDistribution.Create(530230,56,14);
      LoadWAVB:= TNormalDistribution.Create(530231,93,23);
      LoadWAVP:= TNormalDistribution.Create(530232,10,2.5);
      LoadBlanks:= TNormalDistribution.Create(530233,18,4);
      DisOther:= TNormalDistribution.Create(530221,27,6);
      DisWAAI:= TNormalDistribution.Create(530222,151,37);
      DisWACO:= TNormalDistribution.Create(530223,11,2.6);
      DisWAFD:= TNormalDistribution.Create(530224,108,27);
      DisWAHO:= TNormalDistribution.Create(530225,39,9);
      DisWAIF:= TNormalDistribution.Create(530226,1.9,0.4);
      DisWAOR:= TNormalDistribution.Create(530227,30,7);
      DisWASA:= TNormalDistribution.Create(530228,91,22);
      DisWASU:= TNormalDistribution.Create(530229,277,69);
      DisWATF:= TNormalDistribution.Create(530230,10,2.4);
      DisWAVB:= TNormalDistribution.Create(530231,47,11);
      DisWAVP:= TNormalDistribution.Create(530232,23,5);
      DisBlanks:= TNormalDistribution.Create(530233,2.3,0.5);
      While TRUE Do
        Begin
          While OutOfLock2.Length = 0 Do
            Begin
              Standby;
            end;
          myShip2:= OutOfLock2.FirstElement;
          myShip2.LeaveQueue(OutOfLock2);
          myShip2.EnterQueue(Jetty2Arrival);

          {Time to travel from lock to jetty}
          Hold(105);

```

```
{Write lock to jetty travel times and average to form}
Jetty2ArrivalTime:= TNow - myShip2.QueueTime(Jetty2Arrival);
UserForm.ListBox9.Items.Add(FloatToStr(Jetty2ArrivalTime));
If UserForm.ListBox9.Items.Count > 2 then
 Begin
   Sum:= 0;
   For i:= 0 to UserForm.ListBox9.Items.Count - 1 do
     Sum:= Sum + StrToFloat(UserForm.ListBox9.Items[i]);
 end;
UserForm.Edit9.Text:= FloatToStr(Sum/UserForm.ListBox9.Items.
    Count);

myShip2.LeaveQueue(Jetty2Arrival);
myShip2.EnterQueue(Jetty2PrePump);
myShip2.AllFast:= TNow;

{Time needed for pre-pump operations depending on operation type
    }
If myShip2.Load1Dis0 = 1 then
  Hold(210)
Else
  Hold(282);

{Write pre-pump times and average to form}
Jetty2PrePumpTime:= TNow - myShip2.QueueTime(Jetty2PrePump);
UserForm.ListBox10.Items.Add(FloatToStr(Jetty2PrePumpTime));
If UserForm.ListBox10.Items.Count > 2 then
 Begin
   Sum:= 0;
   For i:= 0 to UserForm.ListBox10.Items.Count - 1 do
     Sum:= Sum + StrToFloat(UserForm.ListBox10.Items[i]);
 end;
UserForm.Edit10.Text:= FloatToStr(Sum/UserForm.ListBox10.Items.
    Count);

myShip2.LeaveQueue(Jetty2PrePump);

{Laytime resumes at hoses connected}
J2LaytimeResume:= TNow;

myShip2.EnterQueue(Jetty2Pump);

{Time needed for pumping operations}
Hold(myShip2.ProductQuantity/myShip2.FlowRate*60+myShip2.
    OrderLines*myShip2.OrderLineTime+myShip2.TransShipTime);
```

```
        {Write pump times and average to form}
        Jetty2PumpTime:= TNow - myShip2.QueueTime(Jetty2Pump);
        UserForm.ListBox11.Items.Add(FloatToStr(Jetty2PumpTime));
        If UserForm.ListBox11.Items.Count > 2 then
         Begin
           Sum:= 0;
           For i:= 0 to UserForm.ListBox11.Items.Count - 1 do
             Sum:= Sum + StrToFloat(UserForm.ListBox11.Items[i]);
         end;
        UserForm.Edit11.Text:= FloatToStr(Sum/UserForm.ListBox11.Items.Count);

        myShip2.LeaveQueue(Jetty2Pump);
        myShip2.EnterQueue(Jetty2Interrupts);

        {Time spent on interrupts throughout vessel handling process}
        {The data does not specify where in the process it took place, thus modeled like this}
        //If myShip2.Load1Dis0 = 1 then
          //Hold(Round(Random-0.30)*LoadOther.Sample+Round(Random-0.22)*LoadWAAI.Sample+Round(Random-0.41)*LoadWACO.Sample+Round(Random+0.19)*LoadWAFD.Sample+Round(Random-0.44)*LoadWAHO.Sample+Round(Random-0.44)*LoadWAIF.Sample+Round(Random-0.25)*LoadWAOR.Sample+Round(Random+0.48)*LoadWASA.Sample+LoadWASU.Sample+Round(Random-0.18)*LoadWATF.Sample+Round(Random-0.05)*LoadWAVB.Sample+Round(Random-0.38)*LoadWAVP.Sample+Round(Random-0.08)*LoadBlanks.Sample)
        //Else
          //Hold(Round(Random-0.33)*DisOther.Sample+Round(Random-0.13)*DisWAAI.Sample+Round(Random-0.48)*DisWACO.Sample+Round(Random+0.07)*DisWAFD.Sample+Round(Random-0.34)*DisWAHO.Sample+Round(Random-0.42)*DisWAIF.Sample+Round(Random-0.38)*DisWAOR.Sample+Round(Random+0.43)*DisWASA.Sample+DisWASU.Sample+Round(Random-0.38)*DisWATF.Sample+Round(Random-0.18)*DisWAVB.Sample+Round(Random-0.41)*DisWAVP.Sample+Round(Random-0.27)*LoadBlanks.Sample);

        {Write interrupt times and average to form}
        Jetty2InterruptsTime:= TNow - myShip2.QueueTime(Jetty2Interrupts);
        UserForm.ListBox13.Items.Add(FloatToStr(Jetty2InterruptsTime));
        If UserForm.ListBox13.Items.Count > 2 then
         Begin
           Sum:= 0;
```

```
      For i:= 0 to UserForm.ListBox13.Items.Count - 1 do
        Sum:= Sum + StrToFloat(UserForm.ListBox13.Items[i]);
  end;
UserForm.Edit13.Text:= FloatToStr(Sum/UserForm.ListBox13.Items.Count);

myShip2.LeaveQueue(Jetty2Interrupts);

{Write laytimes and average to form}
{Laytime ends upon hoses disconnected}
myShip2.LayTime:= myShip2.LayTime + (TNow - J2LaytimeResume);
UserForm.ListBox19.Items.Add(FloatToStr(myShip2.LayTime));
If UserForm.ListBox19.Items.Count > 2 then
  Begin
    Sum:= 0;
      For i:= 0 to UserForm.ListBox19.Items.Count - 1 do
        Sum:= Sum + StrToFloat(UserForm.ListBox19.Items[i]);
  end;
UserForm.Edit28.Text:= FloatToStr(Sum/UserForm.ListBox19.Items.Count);

{Write total laytimes and average of both jetties to form}
UserForm.ListBox22.Items.Add(FloatToStr(myShip2.LayTime));
If UserForm.ListBox22.Items.Count > 2 then
  Begin
    Sum:= 0;
      For i:= 0 to UserForm.ListBox22.Items.Count - 1 do
        Sum:= Sum + StrToFloat(UserForm.ListBox22.Items[i]);
  end;
UserForm.Edit34.Text:= FloatToStr(Sum/UserForm.ListBox22.Items.Count);

{Write demurrage and average to form}
If myShip2.Load1Dis0 = 1 then
  If myShip2.ProductQuantity < 60000 then
    If myShip2.LayTime < (48*60) then
      Demurrage:= 0
    Else
      Demurrage:= 800 * ((myShip2.LayTime/60) - 48)
  Else
    If myShip2.LayTime < (60*60) then
      Demurrage:= 0
    Else
      Demurrage:= 800 * ((myShip2.LayTime/60) - 60)
Else
```

```
        If myShip2.ProductQuantity < 130000 then
          If myShip2.LayTime < (48*60) then
            Demurrage:= 0
          Else
            Demurrage:= 800 * ((myShip2.LayTime/60) - 48)
        Else
          If myShip2.LayTime < (60*60) then
            Demurrage:= 0
          Else
            Demurrage:= 800 * ((myShip2.LayTime/60) - 60);

      UserForm.ListBox20.Items.Add(FloatToStr(Demurrage));
      If UserForm.ListBox20.Items.Count > 2 then
       Begin
         Sum:= 0;
         For i:= 0 to UserForm.ListBox20.Items.Count - 1 do
           Sum:= Sum + StrToFloat(UserForm.ListBox20.Items[i]);
       end;
      UserForm.Edit29.Text:= FloatToStr(Sum/UserForm.ListBox20.Items.
          Count);

      {Write total demurrage costs and average for both jetties to
          form}
      UserForm.ListBox23.Items.Add(FloatToStr(Demurrage));
      If UserForm.ListBox23.Items.Count > 2 then
       Begin
         Sum:= 0;
         For i:= 0 to UserForm.ListBox23.Items.Count - 1 do
           Sum:= Sum + StrToFloat(UserForm.ListBox23.Items[i]);
       end;
      UserForm.Edit35.Text:= FloatToStr(Sum/UserForm.ListBox23.Items.
          Count);

      myShip2.EnterQueue(Jetty2PostPump);

      {Time needed for post-pump operations depending on operation
          type}
      If myShip2.Load1Dis0 = 1 then
        Hold(336)
      Else
        Hold(162);

      {Write post-pump times and average to form}
      Jetty2PostPumpTime:= TNow - myShip2.QueueTime(Jetty2PostPump);
      UserForm.ListBox12.Items.Add(FloatToStr(Jetty2PostPumpTime));
```

```
If UserForm.ListBox12.Items.Count > 2 then
 Begin
   Sum:= 0;
   For i:= 0 to UserForm.ListBox12.Items.Count - 1 do
     Sum:= Sum + StrToFloat(UserForm.ListBox12.Items[i]);
 end;
UserForm.Edit12.Text:= FloatToStr(Sum/UserForm.ListBox12.Items.
    Count);

myShip2.LeaveQueue(Jetty2PostPump);

{Write throughput times and average to form}
Jetty2ThroughputTime:= TNow - myShip2.AllFast;
UserForm.ListBox15.Items.Add(FloatToStr(Jetty2ThroughputTime));
If UserForm.ListBox15.Items.Count > 2 then
 Begin
   Sum:= 0;
   For i:= 0 to UserForm.ListBox15.Items.Count - 1 do
     Sum:= Sum + StrToFloat(UserForm.ListBox15.Items[i]);
 end;
UserForm.Edit15.Text:= FloatToStr(Sum/UserForm.ListBox15.Items.
    Count);

{Write total throughput times and average for both jetties to
    form}
UserForm.ListBox21.Items.Add(FloatToStr(Jetty2ThroughputTime));
If UserForm.ListBox21.Items.Count > 2 then
 Begin
   Sum:= 0;
   For i:= 0 to UserForm.ListBox21.Items.Count - 1 do
     Sum:= Sum + StrToFloat(UserForm.ListBox21.Items[i]);
 end;
UserForm.Edit30.Text:= FloatToStr(Sum/UserForm.ListBox21.Items.
    Count);

{Make jetty vacant}
Jetty2Occupied:= 0;

{Write berthing times and jetty occupancy rates to form}
J2TimeOccupied:= TNow - myShip2.AllFast;
UserForm.Edit19.Text:= FloatToStr(StrToFloat(UserForm.Edit19.
    Text) + J2TimeOccupied);
UserForm.Edit26.Text:= FloatToStr(StrToFloat(UserForm.Edit19.
    Text)/TNow*100);
UserForm.Edit27.Text:= FloatToStr(StrToFloat(UserForm.Edit19.
```

```
            Text)/525600*100);

        {Write total berthing times and jetty occupancy rates for both
            jetties to form}
        UserForm.Edit31.Text:= FloatToStr(StrToFloat(UserForm.Edit31.
            Text) + J2TimeOccupied);
        UserForm.Edit32.Text:= FloatToStr(StrToFloat(UserForm.Edit31.
            Text)/(TNow*2)*100);
        UserForm.Edit33.Text:= FloatToStr(StrToFloat(UserForm.Edit31.
            Text)/(525600*2)*100);

        {Take vessel out of simulation and write to form as handled
            vessel}
        myShip2.Destroy;
        UserForm.Edit17.Text:= FloatToStr(StrToFloat(UserForm.Edit17.
            Text)+1);
        UserForm.Edit36.Text:= FloatToStr(StrToFloat(UserForm.Edit36.
            Text)+1);
      end;
    end;

Constructor TVessel.Create(Nm: String; LD: Integer; TS: Integer; PQ:
    Double; FR: Double; OL: Integer; AF: Double; LT: Double; PL: Double;
    AT: Double; ETA: Double; SETA: Double; TST: Double; OLT: Double);
  Begin
    inherited Create(Nm);
    Load1Dis0:= LD;
    TransShip:= TS;
    ProductQuantity:= PQ;
    FlowRate:= FR;
    OrderLines:= OL;
    AllFast:= AF;
    LayTime:= LT;
    PredictedLaytime:= PL;
    ArrivalTime:= AT;
    ETA:= ETA;
    SlowETA:= SETA;
    TransShipTime:= TST;
    OrderLineTime:= OLT;
  end;

Constructor TGenerator.Create(Nm: String);
  Begin
    inherited Create(Nm);
    InterArrivalTimes:= TTableDistribution.Create(568903,cumulative);
```

```
        InterArrivalTimes.AddValue(0,0.00404858);
        InterArrivalTimes.AddValue(31,0.06882591);
        InterArrivalTimes.AddValue(307,0.11336032);
        InterArrivalTimes.AddValue(534,0.1902834);
        InterArrivalTimes.AddValue(1868,0.5708502);
        InterArrivalTimes.AddValue(3781,0.78947368);
        InterArrivalTimes.AddValue(4334,0.88259109);
        InterArrivalTimes.AddValue(5470,0.94331984);
        InterArrivalTimes.AddValue(6060,0.97975709);
        InterArrivalTimes.AddValue(9390,1);
        LoadProductQuantity:=TTableDistribution.Create(568234,cumulative);
        LoadProductQuantity.AddValue(7685,0.00833333);
        LoadProductQuantity.AddValue(24637,0.05833333);
        LoadProductQuantity.AddValue(32083,0.125);
        LoadProductQuantity.AddValue(35453,0.2);
        LoadProductQuantity.AddValue(43127,0.30833333);
        LoadProductQuantity.AddValue(46866,0.45833333);
        LoadProductQuantity.AddValue(52476,0.88333333);
        LoadProductQuantity.AddValue(62284,0.95);
        LoadProductQuantity.AddValue(83382,0.975);
        LoadProductQuantity.AddValue(116164,1);
        LoadOrderLines:=TNormalDistribution.Create(520623,4.37,1.09);
        DisProductQuantity:=TTableDistribution.Create(528134,cumulative);
        DisProductQuantity.AddValue(1240,0.01694915);
        DisProductQuantity.AddValue(8692,0.03389831);
        DisProductQuantity.AddValue(20860,0.13559322);
        DisProductQuantity.AddValue(24402,0.27118644);
        DisProductQuantity.AddValue(37778,0.47457627);
        DisProductQuantity.AddValue(42389,0.71186441);
        DisProductQuantity.AddValue(51601,0.81355932);
        DisProductQuantity.AddValue(52782,0.91525424);
        DisProductQuantity.AddValue(83774,0.96610169);
        DisProductQuantity.AddValue(102117,1);
        DisOrderLines:=TNormalDistribution.Create(520623,1.71,0.43);
        TransShipTime:=TTableDistribution.Create(528178,cumulative);
        TransShipTime.AddValue(2.61666667,0.01);
        TransShipTime.AddValue(7.36666667,0.11);
        TransShipTime.AddValue(17.2666667,1);
        OrderLineTime:= TNormalDistribution.Create(530267,120,30);
    end;

{the vessel generator generates vessels according to the inter arrival time
distribution, which is based on actual data}
  Procedure TGenerator.Process;
```

```
Var
  Seed: Integer;
  NewShip: TVessel;
  Sum: double;
  i: Integer;
  InterArrival: Double;
  CompareShip: TVessel;
  BetweenTime: Double;
  Jetty1PredAvailable: Double;
  Jetty2PredAvailable: Double;
Begin
  Randomize;
  Seed:=20746501;
  While TRUE Do
    Begin
      NewShip:= TVessel.Create('Vessel',Round(Random+0.14),Round(Random-0.08),0,0,0,0,0,0,0,0,0,0,0);
      NewShip.OrderLineTime:= OrderLineTime.Sample;

      {Vessel is given attributes depending on operation type}
      If NewShip.Load1Dis0 = 1 then
        Begin
          NewShip.ProductQuantity:= LoadProductQuantity.Sample;
          NewShip.FlowRate:= 39.785*(Power(NewShip.ProductQuantity,0.3565));
          NewShip.OrderLines:= Round(LoadOrderLines.Sample);
          NewShip.PredictedLaytime:= 75+45+105+210+(NewShip.ProductQuantity/NewShip.FlowRate*60)+NewShip.OrderLines*NewShip.OrderLineTime+336;//+788;
        end
      Else
        Begin
          NewShip.ProductQuantity:= DisProductQuantity.Sample;
          NewShip.FlowRate:= 9.4896*(Power(NewShip.ProductQuantity,0.504));
          NewShip.OrderLines:= Round(DisOrderLines.Sample);
          NewShip.PredictedLaytime:= 75+45+105+282+(NewShip.ProductQuantity/NewShip.FlowRate*60)+NewShip.OrderLines*NewShip.OrderLineTime+162;//+788;
        end;

      {Vessel is given transshipment time if relevant and predicted laytime is changed accordingly}
      If NewShip.TransShip = 1 then
        Begin
```

```
      NewShip.TransShipTime:= TransShipTime.Sample*60;
      NewShip.PredictedLaytime:= NewShip.PredictedLaytime +
         NewShip.TransShipTime;
    end;

  {The SlowETA defines how much a vessel can be delayed upon
     receiving the nomination}
  {A larger difference between ETA and SlowETA, the larger the
     time frame for an otimal planning strategy}
  {The amount of days before receiving a vessel's nomination can
     also be defined here}
  NewShip.ETA:= TNow + 3*24*60;
  NewShip.SlowETA:= TNow + 3*24*60*(4/3);

  {The vessel is given a jetty and an arrival time based on which
     jetty is available first according to the current plan}
  {The arrival time is the minimum number between the planned
     jetty availability time and the vessel's SlowETA}
  If Jetty1PredAvailable <= Jetty2PredAvailable then
    Begin
      If NewShip.ETA < Jetty1PredAvailable then
        NewShip.ArrivalTime:= min(NewShip.SlowETA,
           Jetty1PredAvailable)
      Else
        NewShip.ArrivalTime:= NewShip.ETA;
      BetweenTime:= NewShip.ArrivalTime - Jetty1PredAvailable;
      Jetty1PredAvailable:= Jetty1PredAvailable + Max(BetweenTime
         ,0) + NewShip.PredictedLaytime;
      Jetty1Nomination.AddToTail(NewShip);
    end
  Else
    Begin
      If NewShip.ETA < Jetty2PredAvailable then
        NewShip.ArrivalTime:= min(NewShip.SlowETA,
           Jetty2PredAvailable)
      Else
        NewShip.ArrivalTime:= NewShip.ETA;
      BetweenTime:= NewShip.ArrivalTime - Jetty2PredAvailable;
      Jetty2PredAvailable:= Jetty2PredAvailable + Max(BetweenTime
         ,0) + NewShip.PredictedLaytime;
      Jetty2Nomination.AddToTail(NewShip);
    end;

  {The amount of vessels created is updated and the process holds
     until the next vessel}
```

```
            UserForm.Edit18.Text:= FloatToStr(StrToFloat(UserForm.Edit18.
                Text)+1);
            InterArrival:= InterArrivalTimes.Sample;
            Hold(InterArrival);
            {Write inter arrival times and average to form}
            UserForm.ListBox16.Items.Add(FloatToStr(InterArrival));
            If UserForm.ListBox16.Items.Count > 2 then
             Begin
               Sum:= 0;
               For i:= 0 to UserForm.ListBox16.Items.Count - 1 do
                 Sum:= Sum + StrToFloat(UserForm.ListBox16.Items[i]);
             end;
            UserForm.Edit22.Text:= FloatToStr(Sum/UserForm.ListBox16.Items.
                Count);
          end;
      end;

  {The arrival plan process holds until the planned arrival time of the
      next vessel destined for jetty 1}
  Procedure TJetty1ArrivalPlan.Process;
    Var
      myShip: TVessel;
    Begin
      While TRUE Do
        Begin
          While Jetty1Nomination.Length = 0 Do
            Begin
              Standby;
            end;
          myShip:= Jetty1Nomination.FirstElement;
          Hold(myShip.ArrivalTime - TNow);
          myShip.LeaveQueue(Jetty1Nomination);
          myShip.EnterQueue(Jetty1Wait);
        end;
      end;

  {The arrival plan process holds until the planned arrival time of the
      next vessel destined for jetty 2}
  Procedure TJetty2ArrivalPlan.Process;
    Var
      myShip: TVessel;
    Begin
      While TRUE Do
        Begin
          While Jetty2Nomination.Length = 0 Do
```

```
                  Begin
                    Standby;
                  end;
                myShip:= Jetty2Nomination.FirstElement;
                Hold(myShip.ArrivalTime - TNow);
                myShip.LeaveQueue(Jetty2Nomination);
                myShip.EnterQueue(Jetty2Wait);
              end;
            end;

procedure TUserForm.Button1Click(Sender: TObject);
begin
  VesselGenerator:= TGenerator.Create('VesselGenerator');
  Lock:= TLock.Create('Lock');
  Jetty1:= TJetty1.Create('Jetty1');
  Jetty2:= TJetty2.Create('Jetty2');
  Jetty1ArrivalPlan:= TJetty1ArrivalPlan.Create('Jetty1ArrivalPlan');
  Jetty2ArrivalPlan:= TJetty2ArrivalPlan.Create('Jetty2ArrivalPlan');
  LockQueue:= TomasQueue.Create('LockQueue');
  Jetty1Arrival:= TomasQueue.Create('Jetty1Arrival');
  Jetty1PrePump:= TomasQueue.Create('Jetty1PrePump');
  Jetty1Pump:= TomasQueue.Create('Jetty1Pump');
  Jetty1PostPump:= TomasQueue.Create('Jetty1PostPump');
  Jetty2Arrival:= TomasQueue.Create('Jetty2Arrival');
  Jetty2PrePump:= TomasQueue.Create('Jetty2PrePump');
  Jetty2Pump:= TomasQueue.Create('Jetty2Pump');
  Jetty2PostPump:= TomasQueue.Create('Jetty2PostPump');
  OutOfLock1:= TomasQueue.Create('OutOfLock1');
  OutOfLock2:= TomasQueue.Create('OutOfLock2');
  LockTravelQueue:= TomasQueue.Create('LockTravel');
  Jetty1Interrupts:= TomasQueue.Create('Jetty1Interrupts');
  Jetty2Interrupts:= TomasQueue.Create('Jetty2Interrupts');
  Jetty1Nomination:= TomasQueue.Create('Jetty1Nomination');
  Jetty2Nomination:= TomasQueue.Create('Jetty2Nomination');
  Jetty1Wait:= TomasQueue.Create('Jetty1Wait');
  Jetty2Wait:= TomasQueue.Create('Jetty2Wait');
  VesselGenerator.Start(TNow);
  Lock.Start(TNow);
  Jetty1.Start(TNow);
  Jetty2.Start(TNow);
  Jetty1ArrivalPlan.Start(TNow);
  Jetty2ArrivalPlan.Start(TNow);
  StartSimulation;
end;
```

```
end.
```

C

Data Distributions

The times taken for the processes in the simulation are based on data distributions retrieved from the 2016 data. The data distributions are either constant, normal, or cumulative depending on the best fit. The only data set that does not belong to one of these categories is the flow rate, which is explained in the respective section. This appendix gives an overview of the data distributions for the various processes.

C.1. Cumulative Distributions

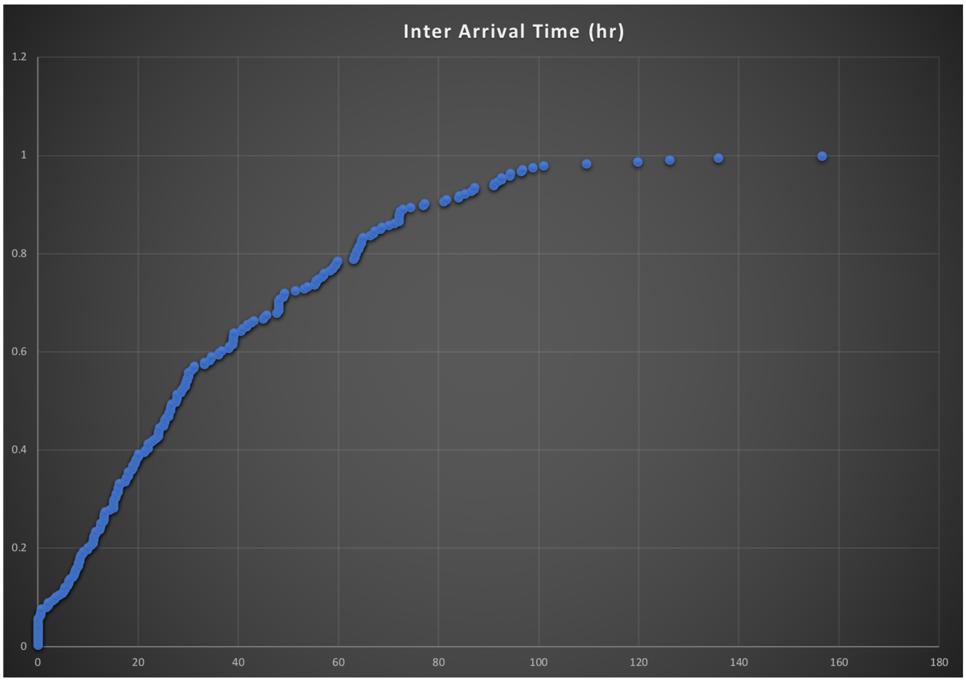

Figure C.1: Inter arrival time distribution

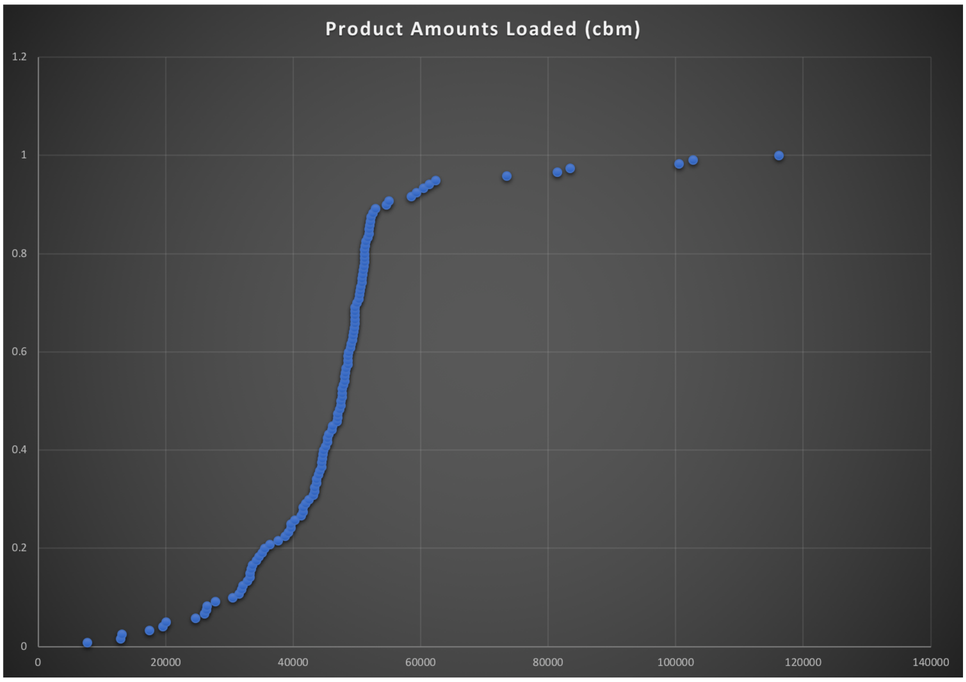

Figure C.2: Loading product quantity distribution

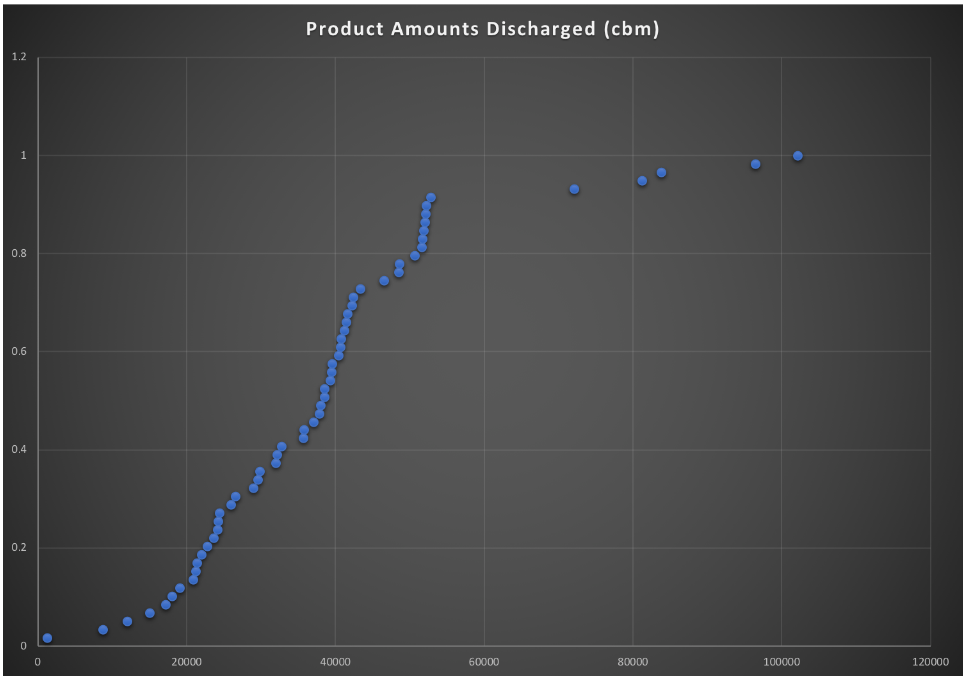

Figure C.3: Discharging product quantity distribution

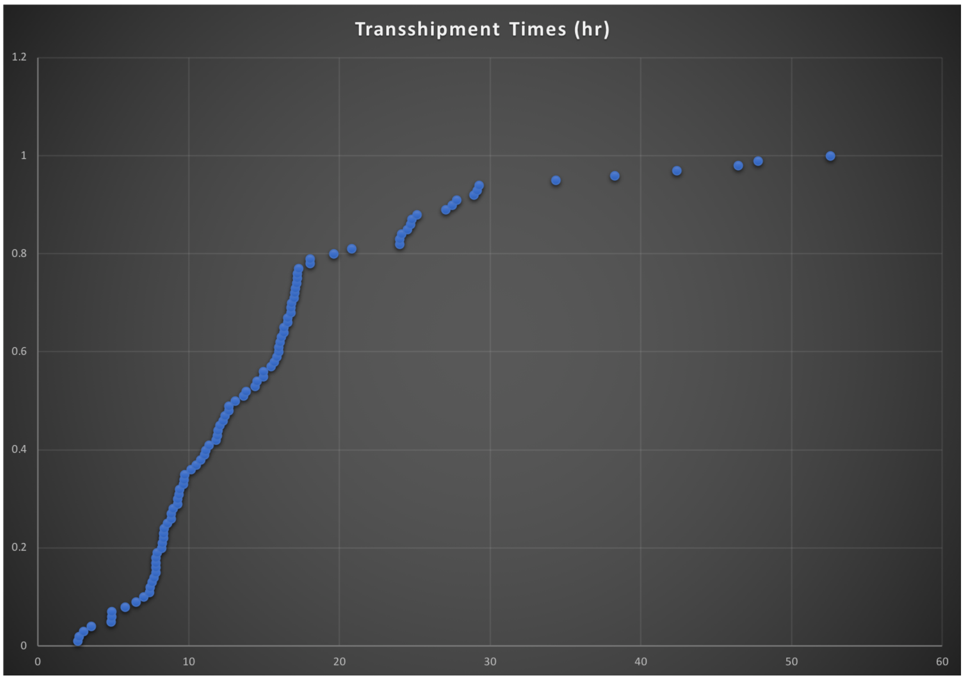

Figure C.4: Transshipment times distribution

C.2. Normal Distributions

Table C.1: Normal distributions

Process Step	Average	Standard Deviation
Amount of orderlines (Loading)	4,37	1,09
Amount of orderlines (Discharging)	1,71	0,43
Time between orderlines	120 min	30 min

C.3. Constant Distributions

Table C.2: Constant distributions

Process Step	Time (minutes)
Anchor to lock	75
Lock	45
Lock to jetty	105
Pre-pump operations (Loading)	210
Pre-pump operations (Discharging)	282
Post-pump operations (Loading)	336
Post-pump operations (Discharging)	162

C.4. Correlations

The flow rate is dependent on the product quantity. In principle, the flow rate is faster for a higher product quantity. This can be seen when the flow rate is plotted versus the product quantity. Thus the flow rate in the simulation is determined through the trend line formula in this plot, which can be seen below for both loading and discharging vessels.

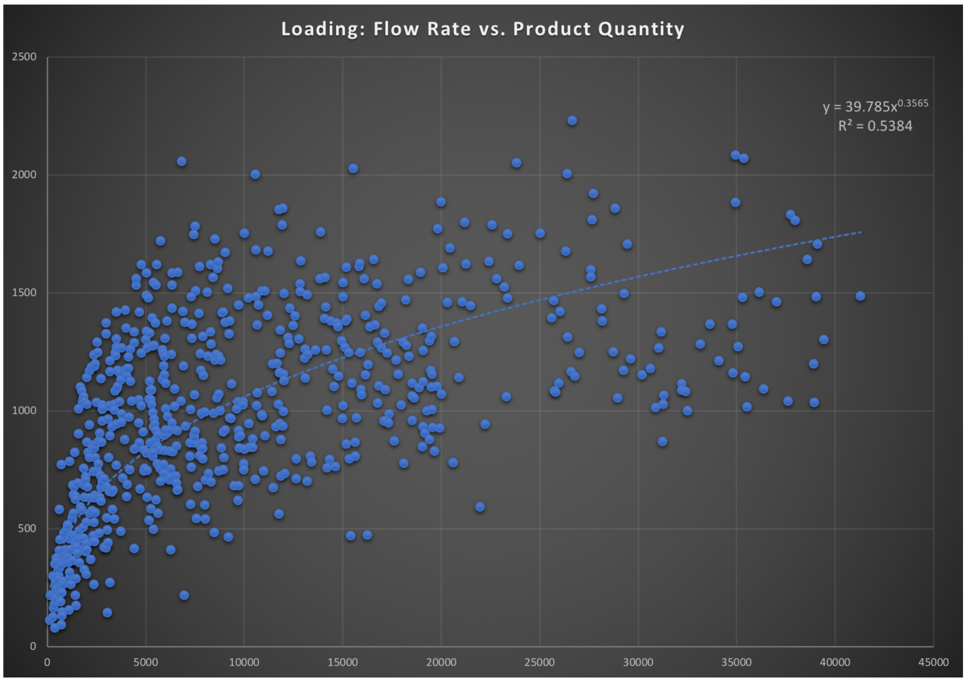

Figure C.5: Loading flow rate distribution and trend line

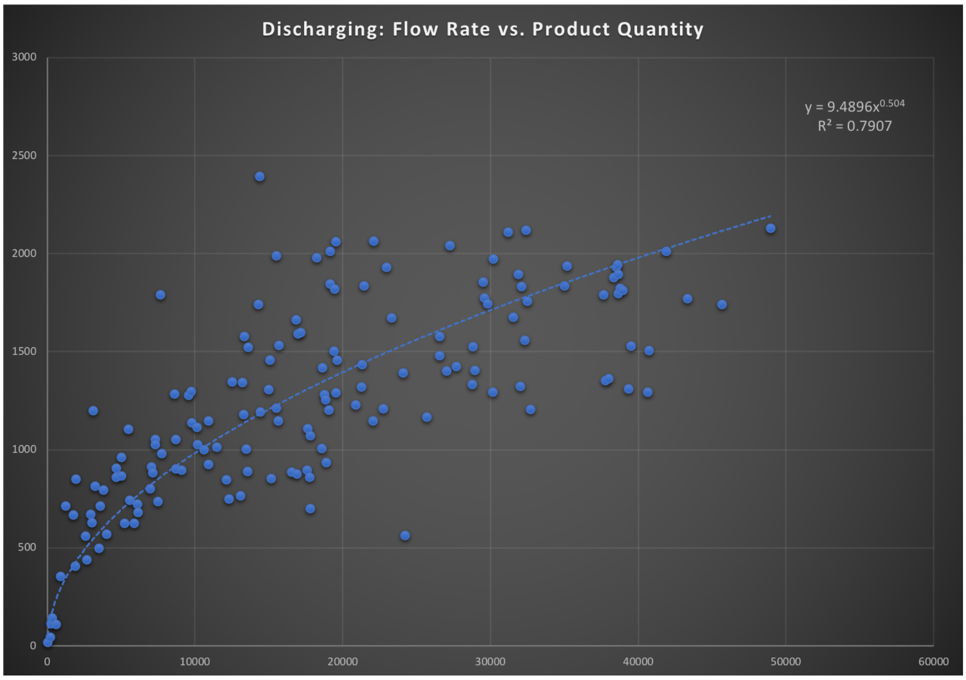

Figure C.6: discharging flow rate distribution and trend line

D

t-distribution

df/p	0.40	0.25	0.10	0.05	0.025	0.01	0.005	0.0005
1	0.324920	1.000000	3.077684	6.313752	12.70620	31.82052	63.65674	636.6192
2	0.288675	0.816497	1.885618	2.919986	4.30265	6.96456	9.92484	31.5991
3	0.276671	0.764892	1.637744	2.353363	3.18245	4.54070	5.84091	12.9240
4	0.270722	0.740697	1.533206	2.131847	2.77645	3.74695	4.60409	8.6103
5	0.267181	0.726687	1.475884	2.015048	2.57058	3.36493	4.03214	6.8688
6	0.264835	0.717558	1.439756	1.943180	2.44691	3.14267	3.70743	5.9588
7	0.263167	0.711142	1.414924	1.894579	2.36462	2.99795	3.49948	5.4079
8	0.261921	0.706387	1.396815	1.859548	2.30600	2.89646	3.35539	5.0413
9	0.260955	0.702722	1.383029	1.833113	2.26216	2.82144	3.24984	4.7809
10	0.260185	0.699812	1.372184	1.812461	2.22814	2.76377	3.16927	4.5869
11	0.259556	0.697445	1.363430	1.795885	2.20099	2.71808	3.10581	4.4370
12	0.259033	0.695483	1.356217	1.782288	2.17881	2.68100	3.05454	43178
13	0.258591	0.693829	1.350171	1.770933	2.16037	2.65031	3.01228	4.2208
14	0.258213	0.692417	1.345030	1.761310	2.14479	2.62449	2.97684	4.1405
15	0.257885	0.691197	1.340606	1.753050	2.13145	2.60248	2.94671	4.0728
16	0.257599	0.690132	1.336757	1.745884	2.11991	2.58349	2.92078	4.0150
17	0.257347	0.689195	1.333379	1.739607	2.10982	2.56693	2.89823	3.9651
18	0.257123	0.688364	1.330391	1.734064	2.10092	2.55238	2.87844	3.9216
19	0.256923	0.687621	1.327728	1.729133	2.09302	2.53948	2.86093	3.8834
20	0.256743	0.686954	1.325341	1.724718	2.08596	2.52798	2.84534	3.8495
21	0.256580	0.686352	1.323188	1.720743	2.07961	2.51765	2.83136	3.8193
22	0.256432	0.685805	1.321237	1.717144	2.07387	2.50832	2.81876	3.7921
23	0.256297	0.685306	1.319460	1.713872	2.06866	2.49987	2.80734	3.7676
24	0.256173	0.684850	1.317836	1.710882	2.06390	2.49216	2.79694	3.7454
25	0.256060	0.684430	1.316345	1.708141	2.05954	2.48511	2.78744	3.7251
26	0.255955	0.684043	1.314972	1.705618	2.05553	2.47863	2.77871	3.7066
27	0.255858	0.683685	1.313703	1.703288	2.05183	2.47266	2.77068	3.6896
28	0.255768	0.683353	1.312527	1.701131	2.04841	2.46714	2.76326	3.6739
29	0.255684	0.683044	1.311434	1.699127	2.04523	2.46202	2.75639	3.6594
30	0.255605	0.682756	1.310415	1.697261	2.04227	2.45726	2.75000	3.6460
z	0.253347	0.674490	1.281552	1.644854	1.95996	2.32635	2.57583	3.2905
CI	———	———	80%	90%	95%	98%	99%	99.9%

Figure D.1: t-distribution table

Escape special TeX symbols (Compress whitespace

Table D.1: Terminal seaside performance: null hypothesis

Simulation Run	Terminal Performance Value (%)
1	56,84
2	53,89
3	52,14
4	58,00
5	56,54
6	53,73
7	53,89
8	53,87
9	53,51
10	52,39