

Proving the potential impact of data sharing
among actors in the port call process through
data analyses and discrete event simulation

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Delft University of Technology
MSc. Thesis

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Proving the potential impact of data sharing among actors in the port call process through data analyses and discrete event simulation

By

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Before you lies the master thesis proving the potential of data sharing during port calls in container shipping with Rotterdam as use case. This thesis is the final requirement in the master's degree in Engineering and Policy Analysis, a master's degree lasting 2 years and consisting out of 120 ects.

After seeing a broad number of subjects in my academic career this thesis, with port logistics at its beating heart will form the conclusion of my academic career. With previous experience in aviation, aerospace, process optimisation, and finance, port logistics where quite a new concept. It took a couple of weeks to get at least the basics of operations. As time passed information about operations and facts and figures about nautical processes really started to fascinate me. Perhaps one of the most memorable and motivating experiences was attending an actual port call. Accompanying a pilot on a 400-meter leaving vessel was amazing and gave an extra dimensions to all prior knowledge acquired with regard to port calls.

I would like to express my sincere appreciation towards the port of Rotterdam, for their hospitality and the opportunity for having me. With special thanks towards my direct company supervisor for his endless help and positive attitude towards my thesis. I would also like to express my gratitude towards my supervisors at the TU Delft, for the excellent supervision and providing me with the opportunity to do this thesis in the first place.

I hope you will enjoy reading,

Rotterdam, July 31, 2018

D. Wijma

DISCLAIMER

Before the writing of thesis a confidentiality agreement has been signed by the writer and all involved due to the sometimes sensitive data provided by the Port of Rotterdam. It is therefore that two versions have been created, one for the port and supervisors and one for publication in the TU Delft repository. In this version, the public version, some information might therefore be concealed as it could harm the port or the reputation of the port in any way.

EXECUTIVE SUMMARY

About 85 percent of all volume trade goes by marine traffic nowadays which is not expected to get any less soon. In marine operations there are different operations with each having their own characteristic. Different trades for example include containers, tankers, bulk, or passenger vessels. But in the end, all of them have to enter a port, this is the place where many actors come together to service a vessel. Due to the many actors involved in the port call, which could run up to around ten actors, planning a vessel stay can get very tedious. Planning the port call can get especially hard if sequential services are not aligned with each other or if relevant information appears to be inaccurate or even missing.

Major complications in port calls are therefore the lack of information sharing. Often parties have a very poor insight in when a vessel is arriving or departing. In general actors in the port environment have been striving to optimise their own processes not including others affected. Very few research has been done in port operations to see what the effects are of data sharing and collaboration among actors. The question is therefore how information sharing among actors in a port call can affect the situation and to what extent. And in particular what information should be shared and with what interval.

To quantify the effects of data sharing three major components are included in the research approach with the port of Rotterdam as use case. The first part of the research focusses on qualitative aspects exploring actors and the port call event. Through this part of the research a better understanding of the port call process is gained which will be useful for the next steps. Also understanding which actors have a dominant role, benefit, or have a lot of power is important for further steps in the research. After a clear overview of the port call and most important actors a combination of data analysis and modelling is done. In this research a discrete simulation model is used to make an abstraction of the real world and use this for testing. Through a simulation parts of the port call process can be tested under different circumstances or inputs of interest. Outputs will then give an indication how the system will respond to particular changes. To get the model correctly running data from the Port of Rotterdam will be used for a correct parameterisation. Parameters would include statistics of port operations such as the number of vessels, handling time, and speed of the vessel.

After going through the previous mentioned steps results show that vessels can reduce their waiting time at anchorage by 35% and therefore their fuel consumption as well. One of the biggest gains would be realised if captains and terminals would start sharing information with each other about arrival and departure times. Ideally this would be done on an interval smaller than 2 hours. When vessels are aware of delays in the berth they can slow down to arrive just in time at the anchorage, or perhaps they can sail straight to the terminal. This information towards the captain is crucial as it can be used to adjust speed and thereby realise fuel savings. In the most optimal case the waiting time at anchorage could be reduced by 35%. Furthermore throughout the whole process more accurate information is required which will support actors in making a more robust planning and be able to plan farther ahead.

Two things need to be done from here, one is further research to consolidate these outcomes and see effects in other operations such as bulk or on more microscopic level such as inland shipping. Also research with regard to the implementation will be required to get everyone on board such as actors with fewer gains that are required to make this a success. the second is to get stakeholders together and make them realise that cooperation and sharing of data will have tremendous implications not only for the waiting times but also for CO2 emissions and robustness of operations.

INDEX

| | |
|--|------|
| Acknowledgements | iv |
| Executive summary | vi |
| List of figures | x |
| List of tables | xiii |
| List of abbreviations | xiv |
| 1. Introduction..... | 1 |
| 1.1. Problem statement..... | 1 |
| 1.2. Scientific and societal relevance | 1 |
| 1.3. Link with EPA programme | 2 |
| 1.4. Research structure | 2 |
| 1.5. Literature review | 2 |
| 1.6. Knowledge gap | 8 |
| 1.7. Formulation of research question..... | 9 |
| 2. Research approach..... | 10 |
| 2.1. Answering the main research question..... | 10 |
| 2.2. Modelling software and justification | 10 |
| 2.3. Modelling approach | 10 |
| 2.4. Model structure..... | 12 |
| 2.5. Sub questions | 13 |
| 2.6. Preliminary Thesis outline And scope | 14 |
| 3. Port call and actor analysis..... | 16 |
| 3.1. Actors involved in port call..... | 16 |
| 3.2. Events in a port call | 21 |
| 3.3. Communication among port call stakeholders | 25 |
| 3.3.1. List of information among actors | 25 |
| 3.3.2. Information and their possible consequences | 29 |
| 3.3.3. Key performance indicators and levers..... | 30 |
| 3.3.4. Contracts between actors | 31 |
| 3.3.5. Chosen actors for simulation..... | 33 |
| 4. Model structure and requirements..... | 34 |
| 4.1. Requirements of the model | 34 |
| 4.2. Scenarios | 34 |
| 4.2.1. Different model inputs | 34 |
| 4.2.2. Available scenarios | 37 |
| 4.2.3. Chosen scenario | 38 |

| | | |
|--------|--|----|
| 4.3. | Constraints and assumptions | 38 |
| 4.4. | Key performance indicators | 40 |
| 4.5. | Modelling actors in the port call | 41 |
| 5. | Data sources, distributions and correlations | 42 |
| 5.1. | Data exploration | 42 |
| 5.1.1. | Pronto initiative | 42 |
| 5.1.2. | Data exploration | 42 |
| 5.2. | Event analysis | 43 |
| 5.2.1. | Vessel arrival | 44 |
| 5.2.2. | Journey length | 50 |
| 5.2.3. | Terminal operations | 55 |
| 5.2.4. | Pilotage distribution | 57 |
| 5.2.5. | Bunker parameters | 60 |
| 5.3. | Distributions | 61 |
| 6. | Model creation, boundaries and assumptions | 63 |
| 6.1. | Vessel | 63 |
| 6.1.1. | Vessels entering the scope of the model | 63 |
| 6.1.2. | Assigning a berth to the vessel | 64 |
| 6.1.3. | Updating of vessel speed | 64 |
| 6.2. | Terminal | 65 |
| 6.2.1. | Updating speed of assigned vessels | 65 |
| 6.2.2. | Arrival at the berth | 66 |
| 6.2.3. | Update on cargo operations | 66 |
| 6.3. | Piloting | 66 |
| 6.4. | Bunkering | 66 |
| 6.5. | Uncertainty of information | 67 |
| 7. | Verification and Validation | 68 |
| 7.1. | Verification | 68 |
| 7.1.1. | Simplified model | 68 |
| 7.1.2. | Animation | 68 |
| 7.1.3. | Stress testing | 69 |
| 7.2. | Validation | 69 |
| 8. | Experiment set up | 71 |
| 8.1. | Controls and responses | 71 |
| 8.2. | Defined scenarios | 72 |
| 8.3. | Run settings | 74 |

| | | |
|--------|--|-----|
| 8.4. | Continuation model..... | 75 |
| 9. | Results | 76 |
| 9.1. | Methods used for analysis of results..... | 76 |
| 9.1.1. | Statistics used | 76 |
| 9.2. | Tested scenarios | 77 |
| 9.3. | Sensitivity of parameters..... | 83 |
| 9.4. | Summary on results..... | 100 |
| 10. | Implications of the quantitative and qualitative | 105 |
| 10.1. | Dimensions in this research | 105 |
| 10.2. | Interests of actors in the levers and outcomes | 106 |
| 11. | Discussion | 109 |
| 11.1. | Events and actors during the port call..... | 109 |
| 11.2. | Information availability | 109 |
| 11.3. | Event distribution for port calls..... | 110 |
| 11.4. | Characteristics of Rotterdam..... | 111 |
| 11.5. | Scenarios to be tested and sensitive policies | 112 |
| 11.6. | Effects and constraints of data sharing | 112 |
| 11.7. | The potential impact of data sharing in the port of Rotterdam..... | 113 |
| 12. | Conclusion | 114 |
| 12.1. | Recommendations and further work | 114 |
| 12.2. | Relevance and reproducibility..... | 115 |
| 12.3. | Limitations | 116 |
| 12.4. | Reflection..... | 116 |
| | Bibliography..... | 117 |
| | Appendices | 122 |
| | Appendix I..... | 123 |
| | Appendix II..... | 125 |
| | Appendix III..... | 126 |
| | Appendix IV | 127 |
| | Appendix V | 128 |
| | Appendix VI | 129 |
| | Appendix VII | 133 |
| | Appendix VIII | 136 |
| | Appendix IX..... | 137 |
| | Appendix IX..... | 139 |
| | Appendix X..... | 152 |

LIST OF FIGURES

| | |
|--|----|
| Figure 1: Low versus High Connectivity and Willingness (Fawcett, 2007) | 7 |
| Figure 2: aggregate steps in model | 12 |
| Figure 3: Thesis outline..... | 14 |
| Figure 4 Lind (2015) process of port call | 22 |
| Figure 5 Rotterdam (2017) business process port call..... | 23 |
| Figure 6: information and system relations for port calls part 1 | 23 |
| Figure 7: information and system relations for port calls part 2 | 24 |
| Figure 8: Process map for nautical services | 25 |
| Figure 9: Information lines in the port | 30 |
| Figure 10: stowage plan for bulk ports and container terminals (Umang, 2014) | 35 |
| Figure 11: different data sources from Pronto | 36 |
| Figure 12: different port scenarios..... | 37 |
| Figure 13: operational levels in port calls | 39 |
| Figure 14: Histogram of vessel lengths in 50 meter bins | 46 |
| Figure 15: Number of container moves carried out by the terminal and the number of vessels falling in these classes..... | 46 |
| Figure 16: Correlation of the vessel length and the number of containers shipped | 47 |
| Figure 17: Distribution for the number of containers shipped by vessels longer than 350 meter..... | 47 |
| Figure 18: Percentage of vessels with a particular number of berth visits | 48 |
| Figure 19: Histogram of time that vessels have remained at the berth | 49 |
| Figure 20: Histogram on the number of vessel and their waiting time | 50 |
| Figure 21: Histogram on time of first event before arrival | 51 |
| Figure 22: interpolation for vessel displacement equation | 52 |
| Figure 23: Approximation of fuel consumption under different speeds | 53 |
| Figure 24: accuracy of estimated arrival and actual arrival | 54 |
| Figure 25: Smaller time window on the accuracy of estimated time of arrival | 55 |
| Figure 26: inaccuracy of estimates when closer to actual arrival | 55 |
| Figure 27: Correlation number of containers and berthing time HaMIS data | 57 |
| Figure 28: Correlation number of containers and berthing time prediction algorithm..... | 57 |
| Figure 29: Total scope of delay in pilot arrival | 58 |
| Figure 30: Delay of pilots on arriving vessels | 59 |
| Figure 31: Delay of pilots on departing vessels..... | 59 |
| Figure 32: Histogram on the number of hours bunkerering was done before departure of the vessel | 60 |
| Figure 33: Representation of the model used..... | 63 |
| Figure 34: approach to data analysis and tests | 77 |
| Figure 35: Different elements of SMORE-plot..... | 77 |
| Figure 36: Average waiting time at the pilot boarding place | 78 |
| Figure 37: Average time in system | 79 |
| Figure 38: Amount of fuel saved per vessel | 79 |
| Figure 39: Distributions of the predefined cases with regard to average waiting time | 81 |
| Figure 40: Distributions of the predefined cases with regard to fuel consumption per vessel..... | 81 |
| Figure 41: Percentage of berth utility in the three predefined cases | 82 |
| Figure 42: Average waiting time PBP for different communication intervals..... | 84 |
| Figure 43: Fuel saved per vessel for different communication intervals | 84 |
| Figure 44: Average waiting time at anchorage | 86 |

| | |
|---|-----|
| Figure 45: Average fuel savings per vessel..... | 86 |
| Figure 46: Average waiting time at PBP for different cargo delay updates..... | 88 |
| Figure 47: Fuel saved per vessel for different cargo delay update intervals..... | 88 |
| Figure 48: Average waiting PBP for increased probability of cargo delays..... | 90 |
| Figure 49: Average extra fuel consumption for increased probability of cargo delays..... | 90 |
| Figure 50: Average waiting time PBP for different bunker probabilities..... | 92 |
| Figure 51: Fuel consumption for scenarios with different probability of bunkering..... | 93 |
| Figure 52: Waiting time for scenarios with different bunker delays and bunker updates..... | 95 |
| Figure 53: Fuel saved per vessel for different bunker delays with and without sharing..... | 95 |
| Figure 54: Average waiting time at anchorage for scenarios with different information accuracies... | 97 |
| Figure 55: Average fuel saved with different information accuracies..... | 97 |
| Figure 56: average waiting time at PBP for different green steam intervals..... | 99 |
| Figure 57: Average fuel consumption per vessel for different green steam communication intervals | 99 |
| Figure 58: Average vessel consumption at anchorage..... | 104 |
| Figure 59: Average fuel saved during trip..... | 104 |
| Figure 60: Pairplot of vessel characteristics..... | 127 |
| Figure 61: Linear regression lines of berth lay times..... | 127 |
| Figure 62: Creation of vessel beginning of the simulation..... | 129 |
| Figure 63: Assignment logic for berths..... | 129 |
| Figure 64: Speed update logic for vessels before assignment berth..... | 130 |
| Figure 65: logic speed update from the berth..... | 130 |
| Figure 66: Berth entering logic..... | 131 |
| Figure 67: Pilot reservation logic..... | 131 |
| Figure 68: Bunkering logic..... | 131 |
| Figure 69: burn in period for 0 days..... | 133 |
| Figure 70: burn in period for 2 days..... | 133 |
| Figure 71: burn in period for 10 days..... | 134 |
| Figure 72: Total fuel consumption under different repetitions..... | 134 |
| Figure 73: Average waiting time at pilot boarding place..... | 135 |
| Figure 74: Average waiting time at anchorage for different simulation lengths..... | 135 |
| Figure 75: Average number of tonnes saved per vessel..... | 135 |
| Figure 76: Total fuel consumption..... | 137 |
| Figure 77: Number of vessels handled..... | 137 |
| Figure 78: Berth 1 entered..... | 138 |
| Figure 79: Berth 2 entered..... | 138 |
| Figure 80: Percentage lower consumption..... | 138 |
| Figure 81: Communication interval high total fuel consumption..... | 139 |
| Figure 82: Communication interval high total vessel time..... | 139 |
| Figure 83: Communication interval high average consumption anchorage..... | 140 |
| Figure 84: Communication interval low total fuel consumption..... | 140 |
| Figure 85: Communication interval low total vessel time..... | 141 |
| Figure 86: Communication interval low average consumption anchorage..... | 141 |
| Figure 87: Delay update interval total fuel consumption..... | 142 |
| Figure 88: Delay update interval total vessel time..... | 142 |
| Figure 89: Delay update interval average consumption anchorage..... | 143 |
| Figure 90: Probability of delay total fuel consumption..... | 143 |
| Figure 91: Probability of delay total vessel time..... | 144 |
| Figure 92: Probability of delay average consumption anchorage..... | 144 |

Figure 93: Probability of bunkering total fuel consumption 145

Figure 94: Probability of bunkering total vessel time 145

Figure 95: Probability of bunkering average consumption anchorage 146

Figure 96: Average bunker delay total fuel consumption 146

Figure 97: Average bunker delay total vessel time 147

Figure 98: : Average bunker delay average consumption anchorage 147

Figure 99: Accuracy of information total fuel consumption 148

Figure 100: Accuracy of information total vessel time 148

Figure 101: Accuracy of information average consumption anchorage 149

Figure 102: green steaming and communication interval total fuel consumption 149

Figure 103: green steaming and communication interval total vessel time 150

Figure 104: green steaming and communication interval average time at anchorage 150

Figure 105: fuel consumption at anchorage with equally spaced scenarios 151

Figure 106: Bonus simulation run with a single berth 152

LIST OF TABLES

| | |
|---|-----|
| Table 1: desired information with respective actions and results per actor | 29 |
| Table 2: Data contributors to Pronto initiative | 42 |
| Table 3: port call event data available | 43 |
| Table 4: container terminals port of Rotterdam and specifics | 44 |
| Table 5: Shore side name, dtype: int64, Port of Rotterdam data | 45 |
| Table 6: Vessel length classification and distribution of containers | 48 |
| Table 7: Constants and units for equations of displacement and fuel consumption | 51 |
| Table 8: Variables for the function of displacement in Simio | 52 |
| Table 9: Variables for the berth time function in simio | 56 |
| Table 10: parameters for calculating delays | 58 |
| Table 11: Summary of parameters and functions for the model | 62 |
| Table 12: variables used for calculation of vessel speeds | 65 |
| Table 13: Controls in the simulation model and their meaning | 71 |
| Table 14: Responses of the simulation model and their meaning | 72 |
| Table 15: Parameterisation of current case for further comparison | 73 |
| Table 16: Range of parameters that will be tested | 74 |
| Table 17: Explanation with SMORE plot elements | 78 |
| Table 18: Normality test fir wirst, normal and best scenario parameters | 80 |
| Table 19: Significance test for parameters compared to current case | 80 |
| Table 20: Extremes and means of the responses | 83 |
| Table 21: Normality tests for communication interval scenarios | 85 |
| Table 22: Significance tests for communication interval scenarios | 85 |
| Table 23: Test for normality communication interval 2 | 87 |
| Table 24: Test for significance communication interval 2 | 87 |
| Table 25: test of normality on cargo update scenarios | 89 |
| Table 26: Test for significance for scenarios cargo update delay | 89 |
| Table 27: results of normality analysis for delay probability | 91 |
| Table 28: Significance analysis on different probabilities of delay | 92 |
| Table 29: Normality analysis on scenarios with different bunkering probability | 93 |
| Table 30: Test of significance for scenrios with different probabilities of bunkering | 94 |
| Table 31: Normality tests for average bunker delay scenarios | 96 |
| Table 32: Significance tests for average bunker delay Scenarios | 96 |
| Table 33: Normality tests for information accuracy scenarios | 98 |
| Table 34: Significance tests of information accuracy scenarios | 98 |
| Table 35: Normality tests for green steam scenarios | 100 |
| Table 36: Significance tests for green steam scenarios | 100 |
| Table 37: Results of lever sensitivity analysis | 102 |
| Table 38: Fuel and CO2 savings in tonnes per vessel and per year | 104 |
| Table 39: Scores on levers and responses | 108 |
| Table 40: Left side Rotterdam business process | 123 |
| Table 41: Right side Rotterredam business process | 124 |
| Table 42: All parameters from port dataset | 126 |

LIST OF ABBREVIATIONS

| <i>Abbreviation</i> | <i>Abbreviated</i> |
|---------------------|---|
| <i>JIT</i> | Just In Time |
| <i>ETA</i> | Estimated Time of Arrival |
| <i>ETD</i> | Estimated Time of Departure |
| <i>PBP</i> | Pilot Boarding Place |
| <i>STM</i> | Sea Traffic Management |
| <i>ICA</i> | Iterative Combinatorial Auction |
| <i>BAP</i> | Berth Allocation Problem |
| <i>DES</i> | Discrete event Simulation |
| <i>OR</i> | Operational Research |
| <i>VTS</i> | Vessel Traffic Service |
| <i>ISPS</i> | International Ship and Port Security Code |
| <i>PC</i> | Port Captain |
| <i>CR</i> | Captains Room |
| <i>BIMCO</i> | Baltic and International Maritime Council |
| <i>DSS</i> | Deep Sea Shipping |
| <i>SSS</i> | Short Sea Shipping |
| <i>TEU</i> | Twenty foot equivalent Unit |
| <i>SMORE</i> | Simio Measure Of Risk and Error |
| <i>HPD</i> | Highest Posterior Density |
| <i>ROPE</i> | Region of Practical Equivalence |

1. INTRODUCTION

In this chapter an introduction will be given towards the problem, and what topics touch upon this subject. Furthermore a literature study will be presented which leads up to an initial research question.

1.1. PROBLEM STATEMENT

A port call is a complex process in harbours in which many different parties work together and are mutually dependent from the moment a vessel approaches the port until it leaves the port. Actors that are involved in this process include terminals, shipping companies, captain of the vessel, local guides, tug boats, linesmen and refuelling ships, and others. For long these actors have been competing in a self-organising ecosystem creating an environment where actors are keen on keeping their data covert to prohibit other competitors from making better informed operational and strategic decisions (Lind, et al., 2018) (Lind, Haraldson, Karlsson, & Watson, 2015). This deep rooted competition and reluctance regarding multi actor optimisation can be seen as one of the causes for many inefficiencies in maritime and port operations. Other characteristics of the maritime industry include long event times, since vessels can take on large dimensions making them less manoeuvrable. In the case of reluctant data sharing among actors consequences can affect the vessels and terminals in the form of long delays. Desired effects and opportunities in port call optimisation are reduction of waiting time, fast turnaround for vessels, green steaming, just in time operations, optimal resource utilisation, and an high degree of predictability (GS1, 2016). With higher predictability it is possible to exploit the opportunities of green steaming on a larger scale (GS1, 2016). Green steaming is the reduction in speed for vessels to arrive just in time (JIT) with approximately 2% savings in fuel costs per 1% speed reduction above 14 knots (Watson, Holm, & Lind, 2015). However Watson (2015) are not the only one emphasizing the importance of slow steaming for unnecessary fuel consumption and lower gas emissions (Gusti & Semin, 2016) (TijdelijkeAanduiding1) (Notteboom, 2006).

The problem is therefore that in the nautical environment too few reliable data is being shared, causing many inefficiencies in a port. Often inefficiencies or problems of one actor will have a cascading effect therefore also affecting consecutive actors utilising shared resources. This research should therefore focus on the consequences of data sharing among port call actors and how this would affect efficiency. Data sharing will be in the form of event times, such as the planned or actual departure time of a vessel.

1.2. SCIENTIFIC AND SOCIETAL RELEVANCE

Due to the competitive nature of ports there has been little emphasis on the optimisation of processes spanning multiple actors such as port calls. Actors have focussed more on improving their own processes. However in times of economic growth and increased competitiveness amongst ports the relevance of operation optimisation becomes more apparent. Because Rotterdam as harbour holds 37.7% of European transloading activity (Rotterdam, 2017) an improvement in sustainability can affect a large share of the European economy.

Of all worldwide trade approximately 80% is done through maritime transportation (Zanne, Počuča, & Bajec, 2013) (Budipriyanto, Wirdodirdjo, Pujawan, & Gurning, 2017) (GE, 2018) (Mulder & Dekker, 2016). Because of this large share in international trade any improvement in sustainability would have a tremendous impact around the world. Predictability of time schedules and operation would therefore allow green steaming for vessels. This green steaming already showed fuel and emission savings of 4.1% and another saving potential of 34% in the port of Gothenburg (Watson, Holm, & Lind,

2015). Noted here by Watson (2015) is that the potential for savings varies per port and tends to increase with increased traffic, anchoring and waiting times.

1.3.LINK WITH EPA PROGRAMME

This research will bring together a lot of EPA related competences ranging from actor analysis to simulation and data analysis. Because of the complex nature of interactions *“Maritime ports are complex operational systems with many different types of stakeholders, for example shipping lines, terminal operators, harbour masters, resident firms who store or process cargoes, port users, local residents, transport firms and logistics service providers.”* (Shaw, Grainger, & Achuthan, 2017) an actor analysis and simulation can be considered very useful. The goal of the research is to determine the impact of information sharing between actors on the effectivity of the port call process. Positive results of the simulation experiments and data analysis should eventually foster the road towards sustainable operations in order to reduce CO2 emissions. As long as these improvements have not been made, services at the end of the supply chain will also remain at the same price. As long as companies are not aware of the benefits they will not start sharing critical information, the current competitive nature will remain the same and resources continue to get wasted. Apart from the technical issue of sharing data another issue to touch upon would be the policy to get everyone in the process involved which is highly policy oriented.

1.4.RESEARCH STRUCTURE

In the following sections the research question is given and the literature on which this question is based. After the research question a research approach will be suggested including the different approaches for research and sub questions that should aid in answering the main research question. After the research approach I will give a research flow diagram and fit research methods accordingly to each of the earlier defined sub questions. Finally the fifth chapter concludes with the thesis outline and a detailed planning. The thesis outline should function as skeleton for my final thesis report and serve as demarcation as what to include in the thesis and what not. The planning includes all mentioned activities, meetings with supervisors and end date of the thesis.

1.5.LITERATURE REVIEW

Fighting inefficiencies in ports by sharing data and information among actors has received some attention over the years, but often with a different focus. For optimisation port call actors often look at their own processes and how these could be improved. Furthermore the amount of multi actor research with regard to port operation is often limited to competition between shipping lines, inter port operation, or for terminals the berth allocation process. Information sharing is recognised as having a positive influence on operational efficiency. But given the high competition many actors have their reasons for not sharing information. Aforementioned findings and research are discussed more elaborate in the next section.

EXISTING BODY OF LITERATURE REGARDING PORT CALLS AND INFORMATION SHARING BETWEEN PARTIES DURING PORT CALL

A port call can be defined as:

“the activities performed prior, during, and after the (physical) turn-around process, Fig. 3. A port call process is initiated when the port is informed for the first time about a vessel steaming to the port.” - Lind et al (2015)

When referring to a port call the main interest is therefore on the turn-around of a ship and how this can be optimised. Lind et al (2015) also emphasise that optimisation of this process will increase port efficiency, reduce fuel consumption, and lower emissions. In this growing competitive industry actors

start to realise that more collaboration is essential in serving their customers. This does, however, mean that actors will have to move away from their traditional operation of not sharing data (Lind, et al., 2018). During a port call data of interest mainly regards event data on who is where and when. Lind et al (2018) highlight that better coordination would lead to a more optimal performance for actors and that collaboration also includes the sharing of data. Lind et al (2018) are not the only ones to realise that collaboration and data sharing will improve operations (Vieira, Kliemann Neto, & Ribeiro, 2015). In a report focussing on the competitiveness of the port call process Norén and Ekström found a couple of potential improvements.

“The first proposal is to start collecting data and measure estimated time for departure and actual time for departure in a structured way. Second, the stakeholder relationship should be evaluated. Third, increasing the level of collaboration between stakeholders through establishing quality meetings. Fourth, establish clear routines for communication and information sharing. Lastly, in order for the other suggestions to be successful there is a need to strive towards higher transparency.” (Norén & Ekström, 2015)

Since the article of Norén and Ekström there has actually been an initiative to standardise data regarding arrival and departure (GS1, 2016). With the general consensus that data sharing and transparency will increase port operation and efficiency a few initiatives have already been launched. Applications for data sharing work towards more transparency and higher operational efficiency, however initiatives presented so far focus on different methods of data sharing. In the first category information regarding the dimensions of the port and vessels are the focus whereas the second category is more operations data centred. These two categories are called master data and event data respectively (Scherpenzeel B. v., 2015). In the first category many stakeholders have worked together to reach a common understanding of standardised information (Association, 2017). This standard information will ease the first step of communication between ports and vessels to identify restraints in early berth planning, such as depth of the canals and vessel for example. In the second category the interactions between different actors in the port are included. Operational data includes for example the departure time of a vessel at a berth place to inform the following vessel it can be tugged in for unloading and loading, or delays such that successive vessels can act accordingly.

A few of these initiatives are the Sea Traffic Management (STM) with Port Collaborative Decision Making (PortCDM), Single Window, Port Control Systems, and Port community Systems, Avanti, Pronto and Port Optimizer. STM aims to create an information hub where actors can decide to whom their input is available where the port authority is used as hub (Lind, et al., 2018) this information is rather administrative, for example information about goods. With the implementation of PortCDM a good step towards information sharing is made, however, this application does not go so far as to share data with all involved actors. Single Window is a resource mainly used by the maritime and aviation sector to transmit information regarding customs, cargo and pax. The Avanti initiative was launched after many large parties realised different standards were used. For example the event of vessel arrival was unclear, for different actors this could refer to arrival at the berth, where the first mooring line was thrown out, all mooring lines were connected, or the gangway was lowered. Avanti strives to set a single standard for the marine industry such that communicating parties refer to the exact same event. At the Port of Rotterdam Pronto is currently developed to display event data through a combination of online data, machine predictions, and data from participating actors. Port Optimizer looks quite similar to Pronto but in a more advanced stadium and having more focus on the complete supply chain. It is however also aimed at stimulating data flow among actors to effectively service vessels, improve predictability and reliability, and enhance supply chain performance (Campanelli, 2017).

Initiatives in the aforementioned section are mainly focussed on the gathering of data in a rather administrative way. Data is put into some data structure that is rigid and does not change a lot over time, also there is few data going out. What is missing is some sort of platform where stakeholders can upload data on certain events and subscribe to other events. It is however hard to create such a platform where stakeholders upload reliable data that is not intended to mislead other actors on strategic grounds. Such a platform would also create a dynamic data flow where event times keep coming in and can be subject to inaccuracy for example estimated time updates.

Although there are many parties with different interests that prioritise their own processes leading to silos of information (Mongelluzzo, 2017) it appears that actors in the harbour can be motivated to work together, for this is underpinned by the following statement: *“The most important driver of the willingness of members of the port community to work together is the existence of external threats.”* (Heaver, 2009). Together with the efforts of the companies visiting the port overall costs of operations in the port can be reduced, making it more attractive for shipping companies. In this case the port would therefore reduce threats of shipping lines preferring other ports while at the same time shipping lines can reduce fuel costs and operational surprises. Heaver (2009) also realises that cooperation among all the actors in the harbour suffer multiple problems ranging from a shared investment

“first condition is the probable unequal distribution of the costs and benefits of investments to improve co-ordination such that benefits may not adequately compensate some actors”

to the interaction including the competitive element:

“Third, co-ordination may be impeded in a highly competitive market by the reluctance of actors to undertake initiatives that would also benefit competitors. Fourth, firms that are risk averse or have a very short-term focus may be unwilling to invest in co-ordination efforts the results of which are uncertain or are long term.” Heaver (2009).

However, Heaver does not really propose actions or methods to overcome the issues he presented. Grainger and Shaw (2017) did propose some solutions of data sharing in disaster situations namely *“a centralised method of information sharing that is used in a decentralised way”* and *“using stakeholders’ subjective needs for more information to motivate participation. Helping stakeholders to access the information they need helps them to work more effectively themselves and with other system stakeholders.”* (Shaw, Grainger, & Achuthan, 2017). Also Mongelluzzo (2017) mentions developments where carriers call on more efficient terminals which will include sharing of data. But this framework for data sharing might still apply outside of disaster situations when only shared to relevant stakeholders.

Because of the many actors involved in this competitive nature where cooperation could yield higher gains for most parties it could be interesting to approach this problem from a game theory perspective. Aside from the game theoretical approach an actor analysis could also provide useful insights. Up till now several studies have been conducted regarding maritime operations, but as with the data sharing these studies had different focuses. Studies include for example the current aspects and possibilities for cooperation, competition and co-opetition between ports and shipping lines instead of focussing more on the intra port (Asgari, Farahani, & Goh, 2013) (Huo, Zhang, & Chen, 2018) (Yoshitani, 2018). With regard to game theory many opportunities exist to analyse operations in marine operations as suggested by the article of Shi and Voss (2011) however most of their suggestions are link or transport related rather than information sharing wise. The closest research with regard to this information sharing is on a master bay plan problem which focusses on the optimisation of terminal planning (Parthibaraj, Palaniappan, Gunasekaran, & Subramanian, 2017). Optimisation of this planning is done through an Iterative Combinatorial Auction (ICA) which is used to bid for multiple items and intended

to reduce costly preference elicitation (Rastegari, 2005). More research focusses on optimal berth and terminal operation (Gudelj, Krcum, & Twrdy, 2009) (Park & Dragovic, 2009) (Dohmen, 2016) (De Léon, Lalla-Ruiz, Melián-Batista, & Moreno-Vega, 2017) (Ribeiro, Mauri, Beluco, Lorena, & Laport, 2016) (Pratap, Nayak, Cheikhrouhou, & Tiwari, 2015). Although the Berth Allocation Problem (BAP) is a significant part of the port call process it is terminal focussed. Optimisation of the BAP problem is done in order to improve operations of the terminal rather than improving efficiency among more actors in the port. Due to the more extensive research into the BAP results could be used for modelling but focus should remain on the bigger picture where interaction among the whole chain is being optimised instead of the actor 'silos'.

Since all ports have different sizes, ownership structures, policies and a different focus with regard to industry there is no single right actor analysis, however there is a general framework of actors and their interests (Meersman, Van de Voorde, & Vanelslender, 2010). Meersman (2010) acknowledges the fact that there is a substantial part of intra port competition with large players such as shipping lines, terminal operating companies, and the port authority. However the research of Meersman (2010) lacks the desired detail how different parties relate to each other and how this affects information sharing. In the article of Coppens (2007) an elaborate dependency is presented for actors in the port of Antwerp, though this does not directly apply to other ports because of differences in magnitude and operations although the actors are more or less the same. Within the port the following actors are identified: agents, customs brokers, forwarders, hinterland transport companies, shipbuilding and repair, dredging, fuel trade, other trade, supporting activities, shipping companies, and terminal operating companies (Coppens, et al., 2007). Furthermore Coppens (2007) elaborates on the relations among the actors in terms of financial and operational dependencies but does not quantify communication lines and topics.

Furthermore it is important to realise the difference in operations between types of vessel operations. Container shipping and bulk shipping differ in multiple ways starting with the BAP (Umang, 2014), as well as the planning. Bulk shipping often referred to as tramp shipping heavily relies on contracts (Plomaritou, 2014) between different parties making operation less predictable compared to container liner shipping that have scheduled routes and ports they visit (Clarkson, 2004). These contracts often also include agreements for delays and laytime (Alderton, 2008) expressed in daily compensation for virtual lost income. In some cases these agreements incentivise the shipowner to steam as fast as possible to the destination port and gain demurrage when incurring laytime (Clarkson, 2004). Behaviour of these actors is highly dependent on the contracts, if shipowners can earn more money when reaching the next port no matter berth availability they will do it.

Suggestions given in the previous paragraphs emphasize the effect of sharing data with parties. Potential gains from sharing data are not uncommon especially with game theory in mind where the sharing of data can have strategic implications. In the literature a great emphasis is set on sharing data through a supply chain, a myriad of articles with respect to information sharing in supply chains is enumerated and reviewed by Sahin (2002). A distinction is made between partial and full information sharing and no system coordination (Sahin & Robinson, 2002). One of the perks mentioned by Huang (2014) is the competitive advantage it grants within the supply chain:

"The more and better the information sharing with a firm, the greater the competitive advantage it acquire. Thus, if high quality information sharing characterizes an inter-organizational relationship, the competitive advantage of the supply chain as a whole will be enhanced." (Huang, Chuang, & Huang, 2014) (Holland, 1995)

Although concepts of data sharing through a supply chain have proven to increase efficiency it is not so trivial to frame this around marine operations. Or as Fawcett (2007) puts it: *“Information sharing is at the core of collaborative, supply-chain based business models. Think Dell and Wal-Mart, two companies that depend on information exchange to help diverse members of a supply chain to work together efficiently and effectively”*. It is obvious that information sharing would improve efficiency and reduce uncertainty, but these are the burdens and benefits that come with sharing. If any inequalities exist between benefits and burdens for receiving and disclosing parties they will be tempted to distort this information flow (Simatupang & Sridharan, 2001). A suggestion given by Simatupang (2001) is to employ one of the following procedures: side payments, subsidies, penalties, auctions, and willingness to pay for information.

In a supply chain there is higher dependency among actors whereas is the port call many actors still fight for shared resources. A shared resource for example could be berthing space and time at a particular terminal. Literature does expand on data sharing in a shared resource pool. Research regarding information sharing in a fishing context might not be applicable in a one to one situation, however, some of the conclusion and remarks made seem very fruitful. A distinction is made between short and long term data sharing, information sharing through a broker, and trust towards other parties (Barnes, Shawn, Kalberg, & Leung, 2016). For marine operations short term information sharing is probably more important as this concerns operational information that could for example affect fuel consumption. Shared resources for shipping lines are cast as berthing windows with a certain performance guarantee. Opposed to fishing resources these berthing windows are limited in the sense that one has to book in advance or decide to go to another terminal. In turn terminals are in competition with each other to handle as much containers as possible.

While Barnes (2016) mentioned the hostility among actors to share information, willingness and capability have been identified as major enablers for information sharing (Fawcett, Osterhaus, Magnan, Brau, & McCarter, 2007). For fruitful sharing of data the right infrastructure should be in place, this would enable the actors to safely share data. Besides being able to share data actors should also be willing to share the data, if sharing truly improves processes then actors should convince themselves and their company to steer towards a data sharing culture. In Figure 1: Low versus High Connectivity and Willingness (Fawcett, 2007) four scenarios are shown with their typical characteristics.

| | | | |
|---------------------|-------------|--|--|
| | High | <p>II</p> <ul style="list-style-type: none"> • While closer relationship exists, partners resist open information sharing for fear of opportunistic behavior. • Technology links are in place to enhance coordination, but the information shared is incomplete or insufficient to support collaboration. • Order and inventory information is shared; however, partners hold closely more sensitive information including new product development plans, technology roadmaps, and market entry objectives. • Opportunities for high levels of unique collaboration are overlooked. | <p>IV</p> <ul style="list-style-type: none"> • Relationship is strategic, built on high levels of trust and shared information. • Technology integration has been a high priority in the relationship, enabling high levels of connectivity. • All relevant decision-making information is shared on a frequent and timely basis. Information is accurate, honest, and open. • Opportunities for high levels of unique collaboration are identified and leveraged via a strong information-sharing capability. |
| Connectivity | Low | <p>I</p> <ul style="list-style-type: none"> • Relationship is arm's length, lacks trust, and share's information reactively. • Insufficient resources are available or dedicated to information technology. • History of opportunistic behavior limits the willingness to share more information than is necessary. • Minimal information is shared, leading to missed opportunities to improve efficiencies and collaboration. | <p>III</p> <ul style="list-style-type: none"> • Strategic relationship is desired, trust has been established, but information sharing does not yet support relationship goals. • Insufficient resources are available to create adequate technology linkages. • An effort is made to share information, however, information is often processed and communicated slowly and may be inaccurate. Decision makers may have difficulty making sense of the shared information. • Opportunities for high levels of unique collaboration are not readily identifiable and are not fully supported by the needed information. |
| | | Low | High |
| | | Willingness | |

FIGURE 1: LOW VERSUS HIGH CONNECTIVITY AND WILLINGNESS (FAWCETT, 2007)

Willingness for information sharing can thus be expressed in disclosing information or not, but in Bâlâu (2017) takes it a step further that parties under certain circumstances might only disclose unimportant and less private data concealing or even lying about the valuable data. Other aspects include the ability to share information, means for sharing, pull or push system, and sharing of information under time pressure. It appears that actual time pressure is detrimental for sharing of information and that a push systems increases sharing of valuable information (Bâlâu & Utz, 2017).

As suggested by Simatupang (2001) actors can be incentivised in either positive or negative ways to start sharing data but also through auctions. An auction can be seen as an allocation method which falls in the realm of mechanism design which focusses on the allocation of goods or services under different situations (Prize Committee of the Royal Swedish Academy of Sciences, 2007).

To see whether auction methods are applicable to terminal operations it is necessary to have a basic understanding of terminal operations. While terminals have berths and quay crane capacity available for vessels to bid on at the same time there are other terminals that also want to handle container vessels. Therefore this situation with multiple terminals and vessels does not easily resemble classic

auctions methods such as the Dutch, English, first price, and second price where there is only one actor offering the good. Also the bidders have different demands, there is not one perfect cut berth window to bid for.

Focus and operation can change per container terminal, in general there are five distinct sorts of terminals which will be briefly explained (Singh, 2016). Singh (2016) defines the following types of terminals: Public or state run terminals run on a first come first serve basis, with resources and processes such as tariff rates, loading processes, and berths shared equally among costumers unless agreed upon discounted rates.

Carrier-Lease dedicated terminals have contracts between the port authority that will lease the terminal for a prolonged period of time. In this time the carriers that have invested in the terminal will get exclusive excess to the terminal.

Terminals building and operation is a type of terminal where the terminal operator has a separate contract with the port authority for lease.

Carrier – built and operation terminals type of terminal is similar to the previous terminal but instead of a terminal owing the asset, a carrier or joint venture of carriers invest in the terminal by making a deposit to the port authority or funding the construction.

Joint venturing of the carriers and terminal operators is a type of terminal where shipping lines and the terminal operators have a common agreement and thereby establish a company. Parties will make direct investments and in return gain priority in container handling operations.

It appears that there has been very little research regarding auction methods especially with regard to the berth allocation. However in the paper of Shi and Voss (2011) the possibility exists that this situation could be researched as a two persons zero-sum game. As the reduced slot allocation of one player after bargaining comprises the added slots that the other player would achieve based on the negotiation (Shi & Voss, 2011). However, this auction is more designed for vessel routing allocation and under the assumption that only two players are involved.

In the following paragraph as short summary will be given on the available literature and what limitations previous research has with regard to the problem statement. Comparing current research to the problem statement will indicate what information is missing and is considered to be worthwhile researching. This last part will be presented in the research question in 1.7.

1.6.KNOWLEDGE GAP

Research in the maritime industry with a focus on port processes has steadily increased over the last few decades. With regard to logistics and cooperation many articles focus on the interaction of ports to hinterlands (Van der Horst & De Langen, 2008). Or articles have a higher scope of research, such as general causes of delay or policy that could hamper operational optimisation (Gigado, 2015) (Schepler, Balev, Michel, & Sanlaville, 2017), only identify information sharing as problem (Vieira, Kliemann Neto, & Ribeiro, 2015), or in disruptive events that do not only affect port operations (Shaw, Grainger, & Achuthan, 2017) (Asadabadi & Miller-Hooks, 2018), or the inter port level rather than intra port level (Huo, Zhang, & Chen, 2018), or focus on particular problems in the whole chain such as the BAP (Budipriyanto, Wirdodirdjo, Pujawan, & Gurning, 2017) (De León, Lalla-Ruiz, Melián-Batista, & Moreno-Vega, 2017) (Dohmen, 2016) (Ribeiro, Mauri, Beluco, Lorena, & Laport, 2016). Data sharing is recognised a suitable mean for improvement of operations (Heaver, 2009) (Huang, Chuang, & Huang, 2014) (Sahin & Robinson, 2002) however different reasons impede successfulness. Therefore classifying data and putting relevant mechanisms in place that tackle the different reasons for reduced

sharing are required (Vieira, Kliemann Neto, & Ribeiro, 2015) (Norén & Ekström, 2015) (Barnes, Shawn, Kalberg, & Leung, 2016) (Simatupang & Sridharan, 2001) (Shaw, Grainger, & Achuthan, 2017). The knowledge gap for this research is thus the shortcoming of actionable information sharing within the port call process and how this is expressed in the sense of gained time and reduction in waste. Besides explicitly mentioning consequences of information sharing in the port limited data is available on implementation. Propositions for different implementations are made but not tested.

As seen before the nature of operation in ports is very competitive among the actors and the absence of a hierarchy does not foster quick change and implementation. This competition and way of doing business is mentioned as cause for higher fuel consumptions and reduced efficiency. Multiple articles have identified data sharing as solution and method to achieve higher efficiency in both operations and emissions (Lind, et al., 2018) (Norén & Ekström, 2015). Urgency for data sharing is slowly creeping to ports leading to the development of data sharing environments. Some of these initiatives have already been mentioned and one of these initiatives, Pronto, is led by the Port of Rotterdam. However, the Port of Rotterdam is convinced of the potential benefits that the sharing of actionable information between parties in the port call process will bring and is therefore interested in quantifying the impact under different scenarios.

This research will therefore include a case study in the port of Rotterdam to quantify the potential impact of data sharing. Rotterdam would serve as a suitable case study because of its size and wide diversity of actors and goods that are handled in the port. In further research case studies on similar and smaller ports could be performed to generalise the effect of data sharing in such an environment. The advantage of doing the research in the port of Rotterdam is also the availability of data. Through multiple databases within the port it is easier to gain better insight compared to research with open data.

1.7. FORMULATION OF RESEARCH QUESTION

In the literature review in previous paragraphs few research has been done on the multi actor aspect of data sharing in ports. However the need for sharing information has been identified and concluded from research. Minimal research has been done to actually see the effects of information sharing and validating earlier conclusions. It would therefore be interesting to see how data sharing in a multi actor environment would affect operations and how large the gains in operations would be. By using a simulation model different scenarios could be tested, by changing certain levers the effects of data sharing over smaller time intervals could therefore be tested.

With the previous literature review and knowledge gap in mind the following research question is aimed to validate the effects of data sharing. And to see if improvement can be quantified.

What is the potential impact on the port call process when involved actors start sharing information with each other, quantified through data analysis and discrete event simulation with the port of Rotterdam as case study?

This research question will try to address the question of what happens if parties in the port of Rotterdam would share information with each other. Despite the fact that many actors compete with each other there is a potential for all actors to gain in cooperation. Since there are many sources of information in the research different situations can be assessed to see how certain information lines might affect the process. To test different situations a simulation model could prove very useful, as this method can easily test different situations of interest in a short time frame without huge costs. But before any model is made an exploration of actors and operations have to be done together with a data analysis to justify model inputs. The approach will be elaborated in the next chapter.

2. RESEARCH APPROACH

In this chapter more will be told about the research approach, specifically how the problem is to be modelled and what will be required to model this.

2.1.ANSWERING THE MAIN RESEARCH QUESTION

The combination of a logistical problem in a highly competitive environment with the lack of research on intra port optimisation can be seen as a suitable case to apply modelling techniques. Other methods could be pure numerical, continuous modelling or even agent based modelling. However so far no discrete models have been used to tackle this problem whereas the visual presentation of such an approach can be really useful in both validation and supporting policies. The next section argues more elaborately why a discrete model is used in this research.

2.2.MODELLING SOFTWARE AND JUSTIFICATION

There are many different methods of modelling a system all depending on the characteristics of the system. The final model should be a representation of a part of the process in the port of Rotterdam, especially the port call operation. Results should show the interaction between multiple parties and how this affects the operations.

Since these operations are very time bound, that means they have a particular starting time and end time where delays are important, and therefore it is better to use a dynamic simulation model. Dynamic models with respect to static models do include the effects of time and do not represent the system at one particular moment i.e. a snapshot.

Furthermore the actions and events that happen during a port call process are of a discrete nature rather than continuous. States change discretely, for example the entities in the system have certain arrival and departure times at terminals, either the ship is at the berth or not. Other events include a boarded pilot, occupied tug boats, or the availability of a berth.

Finally the operations of the parties in the harbour tend to have a certain pattern but are not known precisely. This means we will not be using a deterministic model which represent a system with fixed input variables that are non-random. More suitable is a stochastic approach where certain actions can be represented with distributions to call from.

Combined the aforementioned characteristics make it very logical to use a discrete model for this research. For building this model there are different software packages available such as, but not limited to: Arena, Anylogic, Enterprise Dynamics, ExtendSim, FlexSim, Simio, and VisualSim. For this research Simio will be used because of its availability through the Technical University of Delft, previous experience with this programme, compatibility with Excel and Python, ability to run multiple experiments at the same time, and user friendly interface.

2.3.MODELLING APPROACH

For answering the main research question a Discrete Event Simulation (DES) will be used. Advantages of answering this question through a DES in Simio are the use of graphics, since these will serve as a good validation to see the effect of data sharing. DES is also considered to be a good solution because of the process structure and knowledge about events in the process chain. Showing a visualisation in either 2D or 3D will be more convincing towards the actors, in a policy this could therefore have a supportive role in convincing parties to start sharing information. When the model is operational, part of the validation can be done with employees of the port of Rotterdam.

The DES model itself should model part of the Rotterdam harbour, and for this research the focus will be on deep-sea shipping, specifically on container shipping and neglect the inland vessels where possible. Over the span of one year the port of Rotterdam receives close to 30,000 deep-sea ships (Rotterdam, 2017). Some of the fundamental differences are in size and routing. Deep-sea ships tend to be larger than inland ships, have longer travel times, and often only visit a single terminal per port visit. Also due to their sheer size deep sea vessels have a cascading effect down the supply chain and on other actors' planning. Focus will therefore be kept on deep sea container vessels that only make one berth in the port of Rotterdam.

To correctly model the part of the port of Rotterdam that will be of interest, data from the port is used regarding which parts of the port are of relevance and what terminals operate in these parts. Aside from the operational data such as the handling of parties the infrastructure is an important counterpart. Infrastructure includes the dimensions and waterways to see where the ship can go, as some routes might not be available for large vessels at the same time, whereas they are for smaller vessels. Furthermore, to correctly model operations, historical data will be used on vessel visits and terminal operational performance. To eventually test the effects of data sharing it is also important to have an overview of the information that is both available and shared among parties. Data is available to the port authority although one thing should be noted, it seems that standard definitions can differ widely between data owners, hence the attempt to standardise in the maritime sector (GS1, 2016). It is therefore crucial to assess data quality (Huang Y. , 2013) and see if semantics for a specific event are the same for multiple actors. In the maritime sector the Estimated Time of Arrival (ETA) of a vessel can have many different meanings, some actors use ETA for the arrival of the vessel at the berth whereas others define this as either first mooring line secured, last mooring secured, gangway down, or gangway down plus secured. In light of standardisation, attempts have been made to give a standard representation of a port call, and these are defined in the process mapped by the Port of Rotterdam (2017), and Lind (2015).

Data is available through a few sources, one of these is Pronto, the application currently developed by the port of Rotterdam. Pronto includes a lot of event related data such as event times, but also all event estimations before actual completion. Data that is provided by the terminals, shipping lines, and other actors is also included in this application. As port authority Port of Rotterdam also tracks data regarding number of containers loaded. For vessel related data most information is open source such as dimensions and actual position. Since the information used is coming from the port of Rotterdam or an actor operating within this port the data will have a certain amount of bias in it, i.e. it is likely to be subject to the port's capacity and operations and will therefore be different in other ports.

After answering all the sub questions that will be proposed in the next section, an input for the modelling part is given. Given the information and relations among actors a model will be made in Simio. After the model has been made it should be subjected to some verification and validation tests to ascertain if the modelled assumptions are correctly implemented and whether these are reasonable in the real system. For verification and validation a myriad of methods can be used such as one step analysis, deterministic model, simplified model, tracing, animation, continuity testing, degeneracy testing, consistency testing, expert intuition, real system measurements, and theoretical results analysis (Hillston, 2003).

After successful model development, verification and validation, the scenario development can be done followed by a series of experiment runs. For the experiment it is important to know what information is currently being shared and what information is not. Different scenarios of data sharing should give better insights in how the performance improves. Before testing different schemas of communication lines three different scenarios will be modelled. The most basic scenario represents

operations with absolutely no data sharing, representing the bare minimum which can be held as benchmark against the actual situation. In the second scenario the actual case will be modelled such as it is now. And in the final case the a fully optimised scenario is analysed. This last scenario represents the operations when complete knowledge is available. After these scenarios a comparison can be made as to how much can be improved and how much has already been done. Furthermore, scenarios can be based on communication schemas, where schemas allow complete data sharing among all actors down to virtually no sharing. Also the speed and interval of sharing could be of interest to see how sensitive some information is. A more detailed planning of the experiments is still dependent on the results of the sub questions and the data available. For the information schemas that are available a full factorial design could be used. Since operations in the port represent a non-terminating system, other choices have to be made regarding simulation length, use of initial transient period, and replications (Barton, 2010).

2.4.MODEL STRUCTURE

For this research a generic model will be made first, which on a very aggregate level looks like figure 1. The steps here have been derived from the process map by Port of Rotterdam (2017) which is included in appendix I. In the figure the most basic steps a vessel goes through are displayed, so this does not show all physical events and communicational activities that happen during the port call.



FIGURE 2: AGGREGATE STEPS IN MODEL

After answering the first sub questions a more detailed process should be mapped. By ‘generic’ the basic process is meant, as this includes crucial events that would also apply to other ports. However, this is done based on data from the port of Rotterdam. As mentioned before usage of data from the port of Rotterdam could have its own characteristics with regard to different operating ports. Outcomes of this first model can thus be generalised up to a certain extent and potential differences in operations should be carefully discussed. After this generic model, part of the port of Rotterdam will be modelled. This model of the port of Rotterdam will then be a continuation from the generic port with port specific features included such as waterway limitations. Depending on the available and relevant data a choice will be made to model a part of the port of Rotterdam. Data availability depends on the communication between the port and terminals. Not all terminals have made a commitment towards the port of Rotterdam Pronto project yet, therefore it is better to limit the model to those terminals that have sufficient data available. Making this generic model more specific towards the port of Rotterdam will be done in a few ways. For example distances between parts of the port can be manually changed. This will also be done for other port parameters such as the arrival of vessels, handling time and average delays. These are manual inputs that are to be retrieved through a data analysis and are different for each port.

Furthermore, the model will be parametrised as accurately as possible. If operational data on certain parameters are not available this can be covered by asking experts opinion, deducing through data manipulation or assimilation, or making a guestimate and including this in the assumptions.

Regarding operations, the model fully focuses on the seaside of the operation, and this means that as little as possible attention will be given to operations of the hinterland. All other important actors in the port are being modelled, and up till now this includes the vessel, pilot, tug boats, terminal, port authority, agent, bunker, and services.

2.5.SUB QUESTIONS

Before the research question can be answered some preliminary research has to be done. This research is done through answering a series of sub questions that will lead up to the research question.

Depending on the goal of the sub question different methods might be required for the desired results. In the following section methods and tools per sub question will be discussed.

1. What are the events performed during a port call in the harbour of Rotterdam and what actors are involved during this process?

To get a better view of the complete process in the port and understanding of all events that are required multiple interviews will be done besides an exploratory research. Before conducting the exploratory research the literature should give a basic understanding of port calls to grasp the bigger picture before going into more detail. After the exploratory research multiple interviews with experts should yield more detail about exact procedures performed in the port of Rotterdam.

2. What information do the different actors use in the port call and what are the relationships between the actors involved in the port call process?

In Pronto the new data sharing initiative by the Port of Rotterdam actors are already sharing data to a certain extent. It is important to look at the data that is already being shared and it is even more important to look at the data that is not being shared. For the latter interviews would be the most suitable method, talk with representatives of the different actors to see what information they share and why not all information is being shared at the moment.

3. What are the distributions for the different events in a port call?

With only fixed or average values for the simulation model it is only possible to create a deterministic model. Therefore some data analysis should yield distributions regarding event times. These event times can also be dependent on vessel characteristics if this is deemed to be significant. Analysis of this data will be done by means of statistical packages in either Python or R.

4. How do characteristics of the port of Rotterdam affect the port call process?

First of all a blueprint will be made for a highly simplified and general model for the operations in a port call. From that moment on port characteristics can be included to see how these affect the port call process in Rotterdam. These specifics could include the distance from terminals to anchoring place, or the amount of tug boats available.

5. What scenarios should be tested to see the effects of data sharing among port call actors?

KPIs that are being used in the port to measure performance are to be included in the model, these are in place to measure performance of the defined scenarios. KPIs could change per actor, but by means of a scoreboard or a total sum of the KPIs a score can be given to each experiment. Furthermore the design of the experiments can be based on some predetermined scenarios that are of interest. The rest of the scenarios can be designed by making all possible combinations of information lines such that all possibilities of information sharing are used. Experiments with different values for a particular

parameter should also be included by doing this the sensitivity of some of the parameters will also be tested.

6. What are the effects and constraints of data sharing and optimisation in the port call process?

After analysing the effect of data sharing it is important to take into account the constraints that come along with the results. Results of the model are subject to constraints of the model, things that have not been included, and degrees of freedoms that have been limited. It is therefore important to see how real world operation would change including not certain constraints.

2.6. PRELIMINARY THESIS OUTLINE AND SCOPE

In the first part of the thesis a lot of research will be done regarding the operations in the port of Rotterdam. Based on this research the outline will be sharpened, and depending on the size of the operations and the complexity the scope can be reduced.

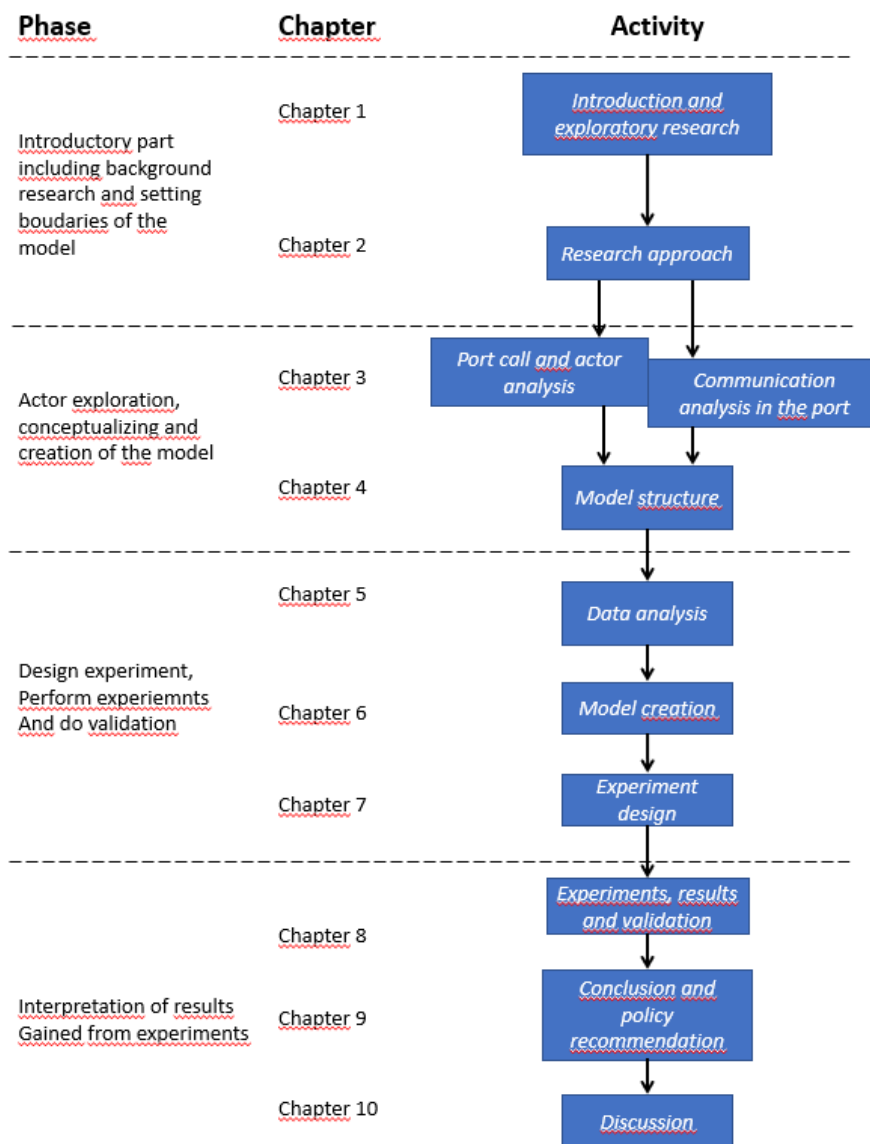


FIGURE 3: THESIS OUTLINE

So far the model will only focus on the deep sea ships and not the inland ships. Although there is a difference in the deep sea ships with regard to shipment where the main shipments are containers, breakbulk, wet bulk, and dry bulk. From the deep sea shipping only containers are taken into account. The difference between container and bulk shipping, for example, is the sensitivity of information, as container vessels are to follow a certain schedule with routes and ports making it more predictable. Bulk shipping in turn does not have fixed routes for shipping its cargo. Besides the variable routes operations are largely dominated by contracts often valid for only a single journey. Bulk shipping is also sensitive to market information, for example the market price of the bulk could change during the journey which could eventually affect destination and time of entering a port. This is because entering a port while the market price is very low would lead to losses for the seller.

With regard to the impact of data sharing a few parameters will be taken. A simulation run will then be made with different settings to see how the parameters then change over time. Some of the initial KPIs include waiting time at the anchorage place and fuel consumption.

NEXT STEPS TO BE TAKEN

Next steps in the research will mainly follow the outline in figure 3. However as mentioned before the actual activities of the research might deviate a bit from the initial plan depending on outcomes. If for example specific information or operations have not been mentioned some parts will be revisited, also the scope can be reduced in case of too complex operations.

For now the next step will be the actor and operation exploration, in this third chapter involved actors of the port call will be reviewed. Next the operation itself will be considered with regard to the steps and crucial information lines. With actors and operations in mind a conclusion will follow on what actors are considered to be most important and their respective KPIs. Following chapters will then focus more on the model, what structure it should have, how to be modelled and the data analysis. Bases on chapter three different information sharing mechanisms will be implemented taking into consideration the most important. Data analysis will return the specific values entered in the model making it more port specific. In the end an actor and operation exploration together with the data analysis and a functioning model specific to Rotterdam should answer the main research question on the impact of data sharing.

3. PORT CALL AND ACTOR ANALYSIS

The port call is a complex process that involves many different actors that have to cooperate to make a port call happen. In this chapter all relevant actors for this research will be presented, furthermore the port call process itself will be explained, and finally a comprehensive stakeholder analysis is presented to visualise communication lines among the involved actors.

3.1. ACTORS INVOLVED IN PORT CALL

In port and marine operations many actors are involved this applies especially to port calls, where in a relatively short period of time many actors mutually interdependent. In the following section short introductions will be given to the most important actors in a port call. Not all of the presented actors will be considered in the eventual model but only the most relevant ones with higher impact on the process and higher availability of data.

CONSIGNOR

In the contract for transport as either containerized shipping or bulk shipping the consignor is part of the contract as seller or shipper. The other side of the contract is held by the consignee, the buyer or receiver of the goods.

CONSIGNEE

The consignor's antagonist is the consignee, the party that buys the shipment and in some cases also the recipient of the shipment. Distinguishing between consignor and consignee is important contract wise. Contracts can affect operations depending on the clauses, especially in tramp shipping where operations are not always just in time. For the port call process the contracts can shape operations but belong mainly to the preparations established before planning the journey to the next port. Depending on the shipment either the consignor or the consignee is also the charterer.

CHARTERER

In literature and many manuals the term charter is mentioned as either the consignee or consignor ordering a vessel. Often in tramp shipping either the buying or selling party is also responsible for the shipment of the goods, and this is called the charterer. Therefore a charterer could refer to consignor, consignee, or even a shipping line that is utilising a vessel they do not own themselves.

SHIPPING LINE

In container shipping many companies have fixed routes that they operate with a few vessels. Routing and port selection is done on a more tactical level, which comes before creating contracts with other actors in the port. With regard to the port call, shipping lines are more involved in the planning phase where the selection is done of port, terminal, bunker, and other service providers. During the actual execution of port call the shipping agent will act as representative of the company and take responsibility.

With regard to the port call the shipping line has less contact with others parties as he relies upon the agent as his representative. However if the shipping line were to be informed further in advance about any delays or other relevant operational constraints he could act differently. When knowledgeable about deviating operations the shipping line can decide to alter the schedule and change the order of the port call or go to another port instead and tranship the container to another vessel going to the initial planned port. Containers that should have been picked up can then be taken by the next ship in the same rotation. This is to retain schedule integrity over the full route and save costs.

In maritime shipping there is a very wide range of actors that serve different routes. However the capabilities and assets change rapidly per firm. Although there are many shipping lines active in

container transport many of these parties own only a few vessels or even a single one. This stands in stark contrast with the few large shipping lines that own up to multiple hundreds of vessels. To make matters a bit more complicated these larger shipping lines often own or have high interests in terminal companies giving them the power to influence both shipping and terminal operations. The higher amount of vessels available also increases the freedom to reach many destinations through different routing options.

TERMINAL OPERATOR

Larger ports often have different terminals with different operations, these terminals can be classified as for example container, bulk, or passengers terminals. For this research the main emphasis will be on container terminals.

Container terminals have an existential relationship with the container vessel and vice versa. In maritime trade the terminal operates as the gateway between land and sea, or between vessels as transshipment terminal. Ports either import or export goods or handle transshipment, in either way the terminal has to do the unloading and loading of the vessel. Regardless of the specific nature of the terminal some challenges and characteristics will always remain in the terminal. Furthermore for this research focus is on deep sea shipping rather than short sea, barges, feeders and other services as this will simplify operations, since including feeders and multiple berth visit vessels would tremendously increase complexity.

Deep sea vessels are characterised by their larger size and pre scheduled operation. Many deep sea vessel have a fixed route and number of ports they will call on, which in a sense increases predictability of the vessel. Furthermore, due to the size and amount of containers to be moved they tend to stay longer at the berth than other vessels, and also only one berth per port is called upon. Due to its complexity, diverse operations, and competitive nature, research has already been done with regard to terminal operations. Most of the research is Operational Research (OR) which considers the following problems: stowage planning, berth allocation, quay-crane split, horizontal transport, and container stacking (Kemme, 2013). Eventually all of these problems can affect the time required to operate the ship.

Stowage planning is the manner in which containers are loaded on the ship, subject to certain restraints, such as weight and positioning for consecutive ports. Berth allocation is the planning of ships along sections of the quay, taking into account dimensions, services and consecutive ships. Quay crane split concerns the allocation of cranes for operation, since not all cranes can work at the same vessel, and sometimes capacity has to be divided over multiple vessels. Horizontal transport reviews the moves of the container from the stacking cranes towards their storage stacks. Finally the problem of container stacking is deciding where to exactly put the container.

According to the expert (Koggel, 2018), larger established and routinized terminals have higher predictability and lower variance in operation time. However the general perception is the closer the operations get to the quay the higher their impact is on the turnaround time. So in this sense the quay crane split will have a higher effect on the turnaround time than terminal operations further away from the quay.

In general, terminal productivity can be influenced by many factors, a few of the most important ones are weather, technical, and human factors (Bruggeling, 2011). Weather can influence terminal productivity in multiple ways, for strong winds can prohibit crane operations as stability of the crane or containers are jeopardised. But seasonal effects such as ice might hamper productivity as personnel will take extra safety precautions. Some consider the weather to be a relatively predictable factor (Bac, 2018). Other factors such as human factors are less predictable. A majority of the terminal operations

still rely on human input such as the crane usage, since more skilled crane handlers can move more container per hour. Besides cranes there are also other human actions that play an important role in the productivity, for example workers might purposely sabotage tools as part of a strike or get a break while others perform maintenance (Bruggeling, 2011).

PORT AUTHORITY

In Rotterdam the port authority is separated in two parts: one is the Vessel Traffic Service (VTS) and the second part is the Port Coordination Centre, in Dutch abbreviated to HCC. The major difference between these two parties is that the VTS has direct contact with captains as soon as they come into range. The HCC is more concerned with planning and has contact with other parties in the port. In the port of Rotterdam the port authority will cooperate with pilots, tugs, and linesmen also known as nautical services to get vessels safe in and out of the port. HCC is responsible for waterway planning and monitoring furthermore it will make an estimate for the amount of tug boats required based on the vessel and weather conditions. Information will then be forwarded to nautical services, and together a window will be created to service the vessel.

Depending on the port size, structure and operations, these departments perform slightly different operations or could be merged completely.

In general there is not one set of activities and obligations port authorities have to live by. Depending on the operations in a port and the structure of it, i.e. commercial or private, activities may change per port. Also in Alderson (2008) there is not a conclusive answer about the responsibilities of the port authority, also indicating the difference between ports. Only very few activities are done by all the ports. For example in private ports where port authorities have more power over terminal operations and nautical services, implementation of new policies might be easier.

Based on the initial vessel submission done far in advance by the agent, the HCC will make an entry to see if it's possible for the vessel to enter the port based on safe port information. When the vessel is close to the port an update will be done about the ETA and this information is then transferred to VTS which will have contact with the vessel about draught and other information as soon as it comes into the VHF range, which is approximately 30 miles or 3 hours from the port entry.

HYDROGRAPHIC OFFICE

Geospatial and hydrographic data are required for the planning of travel routes. Hydrographical offices therefore collect and supply data that can be used for the routes between ports. However, data about depths and other characteristic of a port are provided by local authorities. Local infrastructure is the responsibility of different actors depending on the structure of the port, be it private or commercial. Many contracts are maintained in the port environment, and contracts relate to exploitation of specific parts of the port, operations, and maintenance such as dredging.

CAPTAIN

In charge of and responsible for the vessel is the captain, and even during port call operations the pilot has to propose actions and ask for permission to the captain. For all other vessel services, including bunkering, permission has to be given as well, to come on board or to start the service. Depending on the contracts these service providers often have a lot of freedom to decide when to execute the services, and this makes operations for the captain unpredictable. Because he does not know what comes first, he cannot really adapt his operations.

Overall the operation of captains can change per shipping type and contract type. For some operations the shippers are responsible for their own bunker, in other contracts this is arranged by the shipping

line, the same yields for the vessel services. Therefore it is possible that agreements are made between the agent and service providers leaving the captain out of the process.

In terms of time the captain knows almost exactly when he arrives at the port, that is if no disruptive events occur, and these times are also communicated towards the agent. However, it is often the lack of information to the captain that hinders operation. The captain sails the route according to the given terminal window and a prescribed speed but he is often contacted late about probable delays. Especially in the case of Rotterdam, as soon as the vessel comes in, the VHF range port authority will notify the captain about any delays due to planning, insufficient nautical services, or previous delays. But as soon as the vessel entered the VHF range the potential for fuel or time savings becomes very limited.

Although the terminal has the most influence on the schedule integrity in the sense that they decide the amount of cranes per vessel and therefore influence productivity, the captain has a few actions at his disposal. The Captain is first of all responsible to arrive at the terminal in time and provide all the relevant information. Next the captain is to give clearance for all services and departure of the vessel, for only on his command and consent can the vessel actually depart.

BUNKERS

Bunkering is the maritime term for fuelling a vessel. Because of the large quantities big container vessels require, the fuel is delivered by bunker vessels. The process of bunkering can take up to multiple hours and even multiple bunker parties, depending on the required quantity or substance. In the port two categories of bunkering can be distinguished for container shipping: these are the low sulphur and high sulphur fuels. High sulphur bunkers often only service one vessel at the time due to the large quantities. High sulphur bunkers therefore move between ship and terminal, making it more predictable. Low sulphur bunkers often load less because it is more expensive and only required on certain routes. Low sulphur bunkers therefore service multiple vessels with one load making it harder to plan more vessels which do not always share their data.

VESSEL SERVICES

Apart from bunkering the ship other vessel services are also required, and there is a very wide range of services that can be performed. Some of the services come by land, and this could include food, medicines and other supplies, but other services come over water to collect for example waste water, do repairs or wash the vessel. Especially for the wet side inter party coordination can be crucial as not all parties can offer their services at the same time.

All services require clearance from the captain which goes in combination with the International Ship and Port facility Security Code (ISPS). For clearance of the services that come by land additional contact is therefore required with the terminal.

SHIPPING AGENT

Local representatives of a vessel or shipping are called shipping agents. As vessels steam along many different ports, arranging services in every port would therefore be a very burdening activity (Network, 2016), apart from language and cultural differences. Therefore shipping agents act as representatives in the port being responsible for necessary paperwork, arranging all required services and functioning as information hub among the different parties. Information from the captain often goes via the agent and information from other parties goes to the captain through the agent. In a sense the agent functions as information hub and contact towards the captain.

Unlike the name suggests a shipping agent often represents a group performing different tasks. In the region of Europe there are many different agencies with different ways of operation. The following

operation is an example of an agency that works in the port of Rotterdam. For this agency there are different roles, in the beginning of the process the Port Captain (PC) will do activities of an administrative nature. This includes forwarding information to a central system about the vessel, cargo, and planning. A PC will continue to update the planning for the port when the ship is expected to arrive within 14 days. Potential changes then include delays it could incur, and information about the move count. For planning the berth window move count is an important factor as this determines how many containers are to be shipped, this could therefore cause delays or other inconveniences if information appears to be incorrect. As the vessel comes closer to the port call the planning will become more accurate. Accuracy can be subject to a wide variety of disruptive events, ranging from broken quay cranes at other ports to later barges, in compliance to deliver something on time. The PC is also responsible for the berth window, in negotiations with the terminal the time, crews and crane split will be determined.

Besides the PC the Captains' Room (CR) is in contact with the captain on the vessel. In an ongoing dialogue the CR will get the ETA anchorage but at the same time also inform the captain about potential delays if he is aware of those. If the CR is aware of a vessel leaving later or even earlier and the exact time, he can communicate this to the incoming vessel. Often this is only possible if the two vessels are from the same agent and for agents with fewer vessels per week this is harder to do. Those agents could always call in to the terminal and ask about the operations but this is very labour intensive and not very common.

Contact between agents and bunkers differs quite per shipping line. Some of the shipping lines have better contract or arrangements with bunkering parties. However, operations in Rotterdam often require two different bunker operations, low sulphur due to environmental restrictions in north western Europe and high sulphur elsewhere. Combining these operations can be tricky as they cannot always bunker at the same time. Especially the low sulphur bunker is more complicated as they have to service multiple vessels in the port.

PILOT

For ports with more complex infrastructure in combination with large vessels usage of local pilots is often made mandatory. In the port of Rotterdam, apart from exceptions or certified captains, all vessels above 75 meter require a pilot, which boils down to all deep sea shipping.

Main objective for the pilot is to get the vessel safe to the berth and after operations back to sea. To do this the pilot is in continuous contact with the linesmen and tug boat as well as the VTS. Depending on the port there is a certain time limit in which incoming or leaving vessels have to order their nautical services, in Rotterdam a two hour heads up is required to get all the nautical services ready. Once an agent ordered the pilot and tug boats overall availability among nautical services will be checked, if there are not enough tug boats available the pilot does not have to bother going aboard the vessel. However once the pilot is on board he first assesses the situation the vessel is in. If for some reason the pilot needs an extra tug boat he then has to ask for that, this could be the case when the vessel has incurred damage or has reduced operability. Once the pilot is on board and able to start operations he will send a text about his exact arrival. Until the ship has arrived safely in the berth the pilot is in continuous contact with the other nautical services, VTS, and the terminal if something is not right with the berth.

One of the challenges for pilots is having the right personnel at the right time since not every pilot is able to board every vessel or at any place in the port because of their certifications. Depending on the type of vessel and the location in the port different pilots are required. If informed far in advance pilots can plan accordingly making planning more efficient and reducing costs. Pilots have different

qualifications for different parts of the port and different vessels, when information about delays or other operational events are known the pilot can increase reliability and predictability.

TUG BOAT

In many large ports large vessels require some extra help to safely reach and leave the berth. This is done through the help of tug boats. With regard to operations tug boats have contracts with shipping lines to operate them, these contracts sometimes complicate operation in the port of Rotterdam. Since not all tug companies service all incoming shipping companies this can lead to restrictions due to multiple incoming vessels to be serviced by the same company in combination with tug boat capacity. Only a few hours before arrival tug boats are booked. With regard to information sharing tug boats want to know the required capacity for a vessel, this can change due to weather conditions but also if the captain of an incoming vessel reports damage to the vessel.

LINESMEN

At the berth linesmen are responsible to secure the vessel to the bollard how this is done can also differ per port. For example in the port of Rotterdam linesman will already come to the vessel just before berthing to collect the lines by boat. In other port this might still be done through linesmen with trucks or other equipment on the shore.

After considering most actors in the port call a better understanding has been created with respect to the involvement of actors. This means that some actors have a higher influence on the port call, or execute activities that have a different impact on the port call. Together with a process analysis in the following paragraph the number of actors will be scoped down only considering the most important ones in the model, reducing unnecessary complexity.

3.2. EVENTS IN A PORT CALL

In the previous section the different actors have been summed and introduced, in the next section relations between these actors will be explored. This will be done through some process maps, and interviews and better depicts the relations between the actors.

For classification of performed events a combination of the process maps by Lind (2015), Port of Rotterdam (2017), and Berenschot/Port of Rotterdam (2016) is taken. In the first map by Lind focus is on the specific events that happen during the port call figure 2. In figure 3 the map made by the Port of Rotterdam the process is mapped on a higher level distinguishing more between phases. In the process map by Berenschot and Port of Rotterdam high level of attention is paid on the events and information lines specifically for the port of Rotterdam, in this case the port call is divided in three phases, one preparatory, one about three hours before port arrival, and one on entering the port. These different maps are made to make parts of the port call better understandable, including insight in the events and how these follow each other, but also how different information systems and information flows are in the port.

A good understanding of the process forms the critical structure for a model. Before modelling it is important to know what the relations are between actors but also the events. Most certainly in a discrete event model it is important to know what events will be performed as well as the sequence of these events. Some events or actions cannot be fulfilled if previously required events or actions have not been completed. Take for example the berthing space, as long as vessel A is still berthed vessel B cannot berth or start operations.

In the figure below all the events of the actual port call are mapped. This process map gives a good idea of the sequence of events that every actor perform and when they come together. However what is missing is the shipping agent. Some of the tasks that are currently put as activities of the vessel can

be seen as responsibility of the shipping agent. Whereas this map shows a detailed timeline of events for every actor it does not really distinguish between actual actions and communication. Nor is it really clear how actions of different actors relate to each other in time when they are not aligned. For example it is not really clear where on the vessel timeline the terminal does the “confirm ready to receive vessel”. And finally the map only includes about three hours before entering the port and two hours of exiting the port.

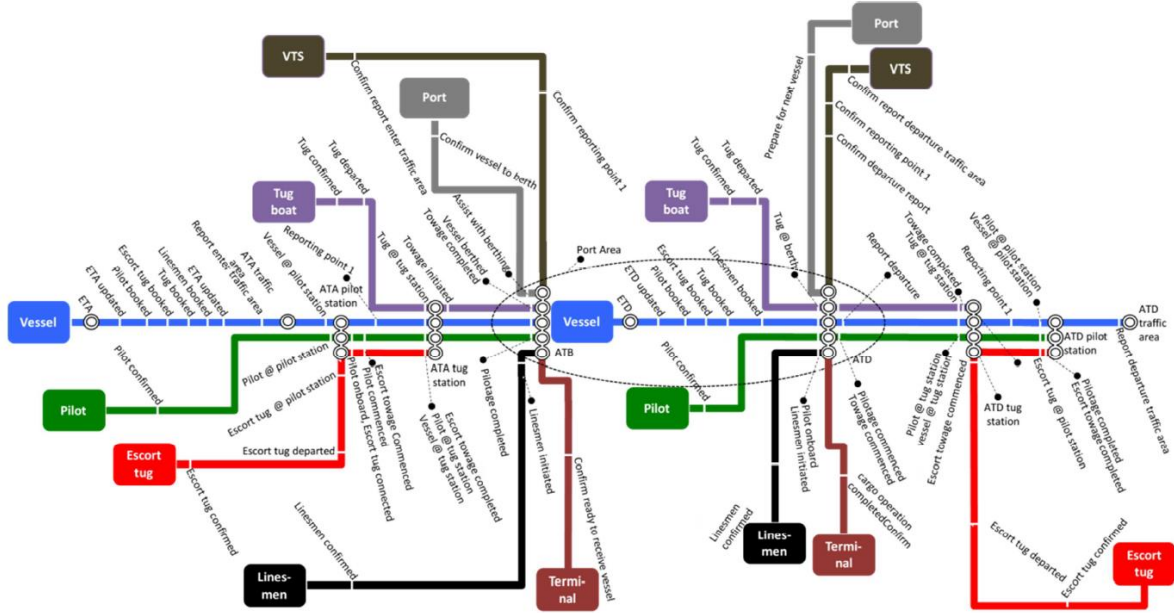


FIGURE 4 LIND (2015) PROCESS OF PORT CALL

In the following figure the process map of the port of Rotterdam is given, this map covers more of the activities done before the actual port call than described by Lind. Preparations for a port call are captured in the first four phases. This part is not very elaborate in terms of communication, it seems that the terminal only provides safe berth information during the contracting phase. Safe berth information is there to match berth prospects and vessel characteristics, these include for example the draught of vessels, height of cranes, and other features that could potentially jeopardize safety of the vessel at the berth. Furthermore estimated berth and pilot boarding area times are proposed by the captain which in turn are confirmed by respectively the terminal and port authority. Also in this process map just like the one from Lind, actions by the captain and shipping agent are aggregated into one. Overall as business map, it is not very detailed in terms of communication and events. Also the map focusses more on estimated, planned, and actual times.

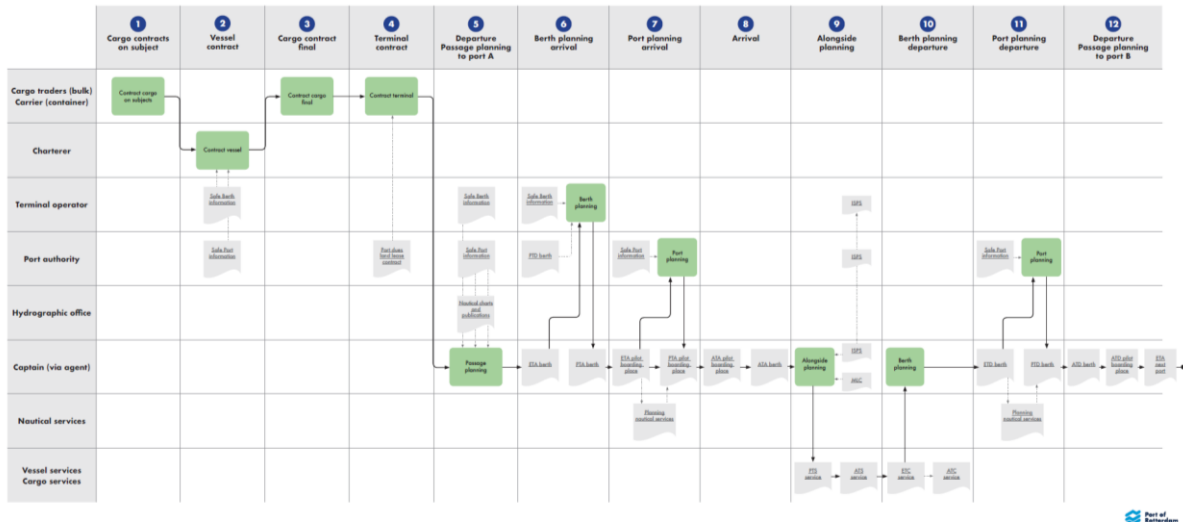


FIGURE 5 ROTTERDAM (2017) BUSINESS PROCESS PORT CALL

The two figures below are the result from a project between the Port of Rotterdam, Berenschot, and FERM Rotterdam Port Cyber Resilience and represent the process when the vessel is three hours away from the port and the part where the vessel reaches the port entrance until completion of mooring. This map gives an indication of the involved actors and communication systems for different parts of the port call therefore being a good illustration of the complexity involved in this operation. Purpose of this was to see the consequences when one or multiple communication channels would fail. Compared to the two aforementioned process maps the following map is very detailed in terms of events, decisions, and communication lines. However the map is very port specific mainly due to the mentioned software in the right columns which might be different for other ports. Also the left columns do not mention the agent which is included in the administrative process, this would suggest that the agent plays an insignificant role just before and during the actual port call.

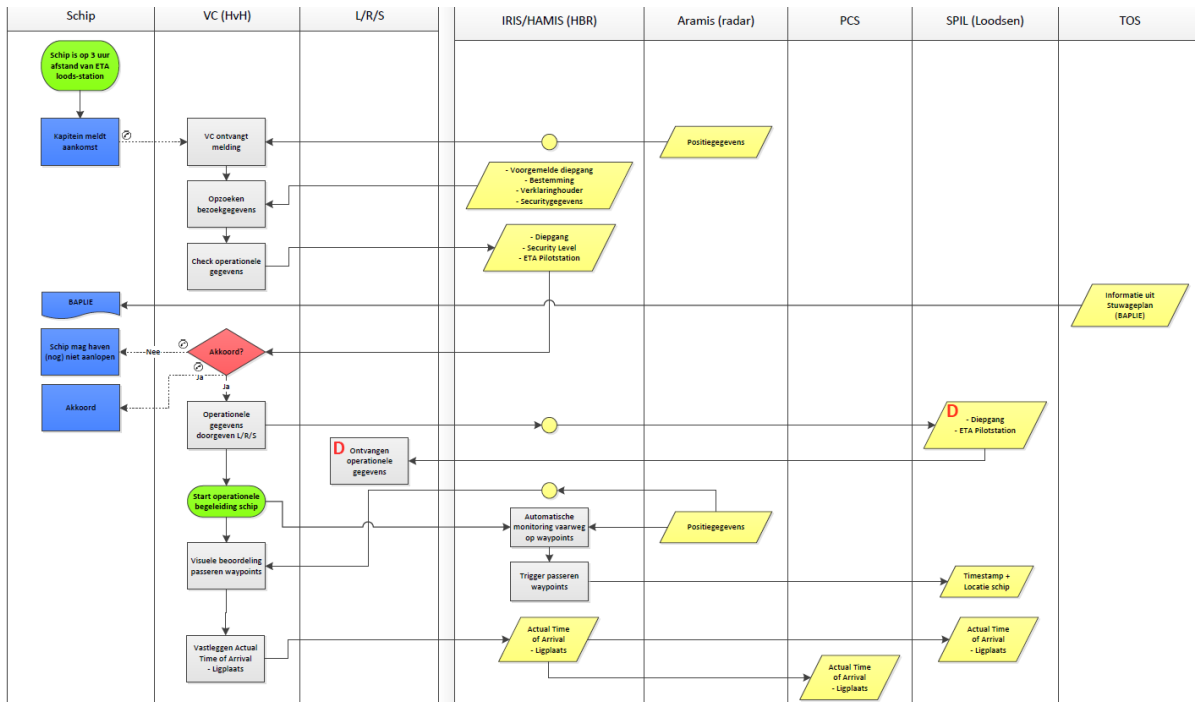


FIGURE 6: INFORMATION AND SYSTEM RELATIONS FOR PORT CALLS PART 1

In Figure 6 it can be seen that during the pre-port call process, just before the ship arrives already five different systems are being utilised to get information to all important parties. Systems are displayed to the right of the grey bar in the middle, on the left are the involved actors. This means there must be a lot of contact between the actors to get all the information in all the different systems. Next only few activities are captured in this process event wise, basically the captain forwards his ETA which is checked by the VC who then gives clearance to continue.

After the vessel has really arrived at the port the following process map applies to the situation. In this process is mainly about the berthing of the ship, as soon as the ship reaches the port entrance different parties have to match availability of resources, most important are the waterway, pilot, and tug boats in the case of Rotterdam. Often tug boats appear to be the limiting factor especially if the suggested number of boats deviate from the actual and a shortage of capacity is encountered. In the scheme a very detailed overview of the sequence of actions is presented showing the particular order of contact and decisions in the port call itself.

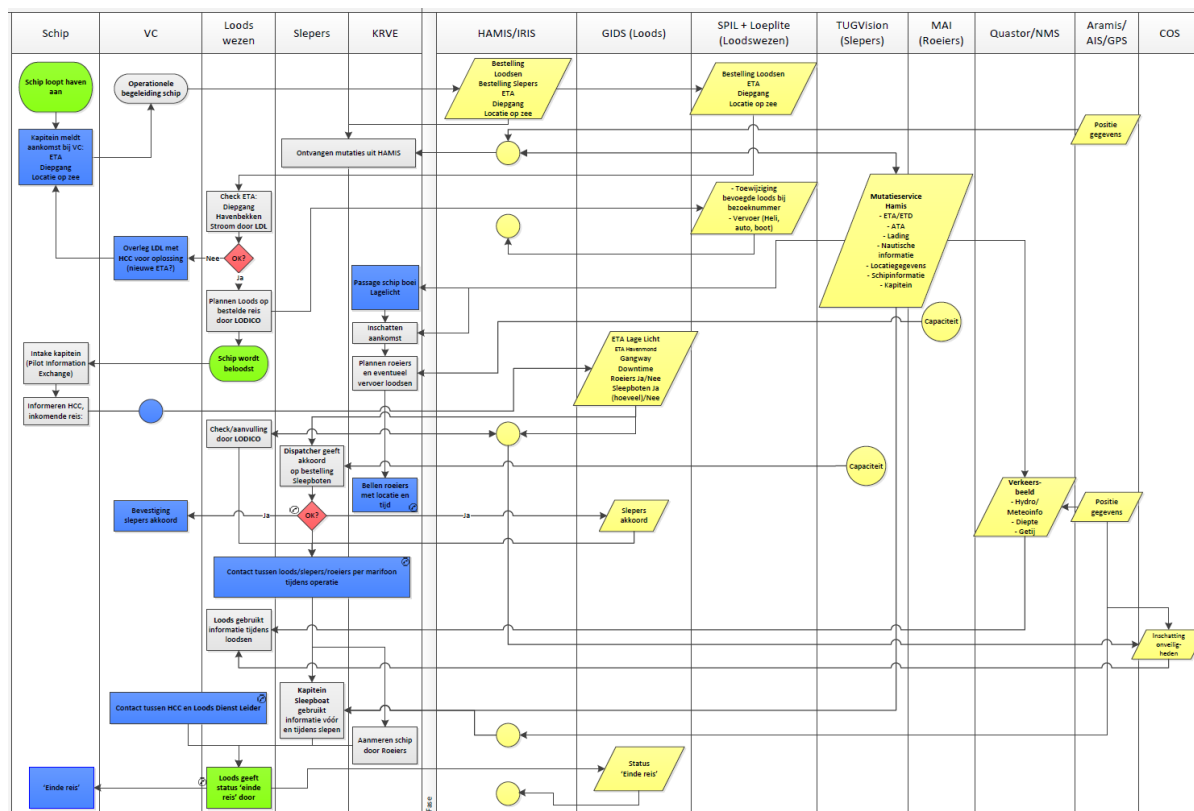


FIGURE 7: INFORMATION AND SYSTEM RELATIONS FOR PORT CALLS PART 2

The following map is made specifically for nautical services and the Port Authority. In the process map there is a slightly larger emphasis in communication between the actors compared to the actual events. A good impression is given how agent, pilot, tugs, and port authority interact with each other and what databases or communication lines are used for this. Since this map is on a more macroscopic level than microscopic, it does not show interaction during operations. And because of its specific focus on nautical services, it does not show interactions with terminals, shipping lines, or other services in the port.

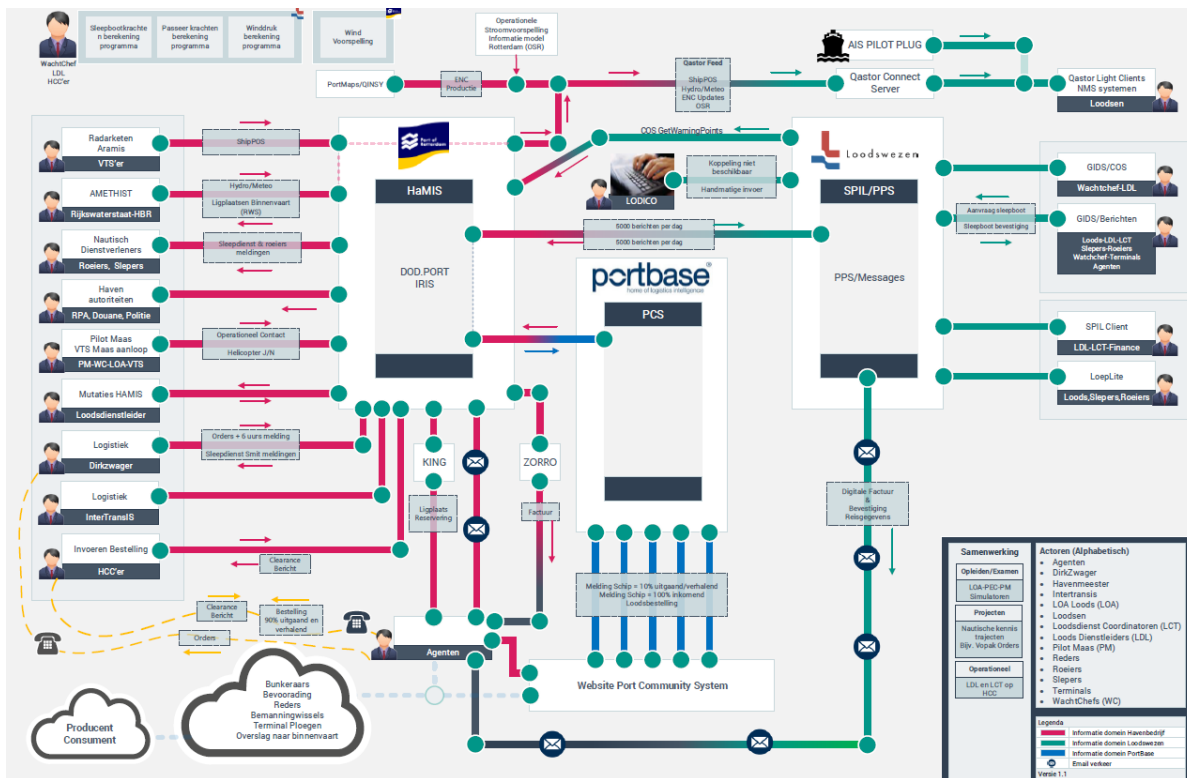


FIGURE 8: PROCESS MAP FOR NAUTICAL SERVICES

3.3.COMMUNICATION AMONG PORT CALL STAKEHOLDERS

This paragraph will focus on the information sharing in port call events, to get a better insight in what information everyone is getting, and what some actors would like to receive. For port operations information is crucial, without communication between actors there would be complete anarchy as actors depend on each other's operations. Some actors are required in exactly the same time frame for the arrival and departure of a vessel, other actors can only fulfil their services when the vessel is in the berth. But the vessel cannot leave before all crucial actions and services have been completed. Therefore actors in the port require accurate information to reduce uncertainty for themselves as well as other actors and improve operations.

3.3.1. LIST OF INFORMATION AMONG ACTORS

Information in the summations below is a combination of interviews with experts in the Port of Rotterdam combined with literature with regard to the port call process (Mulder & Dekker, 2016). Some of the information given might be specific for Rotterdam and deviate in other ports, and this will also be mentioned. Important is to know who shares information with whom before and during a port call in order to create a valid model. The table includes four distinct columns, the first indicating the actor, the second indicates the information available to the actor, the third column is what information actors would like to receive based on literature, interviews and process logic, and in the final column is the actual information the actors receives. It should be mentioned that the last two columns are sometimes subject to situation, actors do not always get the information they need or want. This table does however not include the interval of data sharing, the quantity and the quality of the data as this can vary across the actors. Variances in the quantity, quality and interval of data sharing can be used as input for model levers. Appendix II includes an excel sheet with on the column axis parties giving information and on the row axis the actors receiving information.

SHIPPING LINE

Has information about the following:

- Has information about the shipping rotation, what ports will be visited.
- In every port the shipping line has contracts with agents.
- Information about the vessel or fleet. In case of chartering information by shipping owner.
- Productivity contract with terminals, including laytime and number of visits.
- Depending on the shipping line contract with bunker parties otherwise often by agent of captain.
- For safe operations the shipping line gets information from the port authority, information could be used to match vessel and infrastructure size.

Wants information about the following:

- Berth planning mainly with regard to schedule integrity and estimated departure.
- Estimate of bunker price.

Gets information about the following:

- Will eventually get operational delays when they occur, however not immediately.
- Terminal planning, including the berth planning, cargo planning and the stowage planning.
- Contract with bunkering party. Will receive a bunker delivery note.

TERMINAL

Has information about the following:

- Berth schedule.
- Information about delays and estimated time of completion of cargo operations.
- Productivity rates, due to operational management such as quay crane allocation.
- Stowage planning.
- Bollard information where vessels are planned during their stay.

Wants information about the following:

- More reliable information in advance about the number of container moves.
- More accurate arrival times of incoming vessels.
- Departure time of departing vessel. They have completion times but are still dependent on the vessel actually leaving with a pilot.

Get information about the following:

- Get estimated time of arrival and departure from the agent, this will be input to berth window planning.
- Has contract with shipping line for handling vessels and operational service.
- Information from the agent regarding bunkering and other services.
- Amount of containers to be moved, input to stowage planning as well.

AGENT

Has information about the following:

- Contracts and services required per shipping line or vessel owner.
- Incoming vessel information and terminal contract for berth window negotiations.
- Depending on the agency and terminal, information about operational delays.

- Berthing window of the vessel.
- Ship dimensions, cargo specifications and other notifications and declarations.

Wants information about the following:

- More accurate move count depending on previous ports or delivery at the terminal.
- Estimate times for arrival of the vessel.
- Estimate departure from the terminal.
- Availability of nautical services for arrival and departure.

Get information about the following:

- Get the schedule from shipping lines and has to plan berth visits accordingly.
- Vessel planning from the captain, including ETA PBP, ATA PBP.
- Cargo operations planning and updates on PTD of vessel at least 2 hours before departure.
- PTA PBP from PA, this is after consensus of nautical services.

PORT AUTHORITY

Has information about the following:

- Port dimensions, waterway utilisation, draught, and other port information.
- Moment of start bunkering as the notification for start and amount is obligated.
- Agreement on planned time of arrival with other nautical services. Port authority has the overview on waterway usage and other vessels that either want to enter or leave the port.

Wants information about the following:

- Reliable information about terminal bollards planning.
- ETDs for departing ships.
- Depth of vessels.

Get information about the following:

- Registration of new port call. Until the port call regular updates from the agent.
- Vessel information, declarations, notifications, port dues and other administrative information from the agent.

CAPTAIN

Has information about the following:

- Malfunctions and damages on the vessel potentially limiting operation.
- ETA vessel at anchorage or PBP.
- Shipping contract with clauses such as speed and performance or even green steaming.
- Vessel services required and coming especially the ones requiring the captains approval.
- Stowage planning and special cargo such as reefers.

Wants information about the following:

- Berth and operations availability at the port including ETD vessel planned berth.
- Arrival of services with regard to required ISPS clearance for preparation.
- Information on previous delays to adjust operations.
- More accurate information about keel clearance.

Get information about the following:

- Berth window from agent and an estimate time to arrive at the port.
- Terminal rules and berth prospects.
- Operational information from bunkering and other services.

BUNKERING

Has information about the following:

- Has information about the type of fuel and quantity from the ordering party.
- Bunkers are often given a berthing window when vessels are at the terminal and ready for operations. However updating this information would help bunkering in their planning.
- Will send a notification to the port authority when operations start and how much will be loaded.

Bunkering wants more accurate information about arrival times from vessels.¹

Furthermore getting information about the ETA of a vessel bunker parties can better plan.

PILOT

Has information about the following things

- Before boarding the pilot already has operational information about the vessel, but on board the captain might tell extra information regarding operational constraints.
- Pilot estimates the arrival time at the berth or departure time from the berth.
- Together with other nautical services and the port authority an agreement is made on operations. This could for example be the tide a ship is coming in or the amount of tugs required.

For incoming vessels the pilots wants to know if there is anything wrong with the vessel which could impact nautical operations and tugging into the port. Furthermore pilots receive the PTA PBP of the vessel and departure time from the agent.

TUG BOATS

Has information about the following things

- Contractual information about whom to serve.
- The number of available tug boats or the tug boat planning.

Tug boats want more accurate information about the number of required tugs, which might change for damaged vessels, bad weather, or less experienced pilots². Just like the pilots tug boats receive information about arrival at PBP and the PTD of the vessel.

LINESMEN

Has information about the following things

- Linesmen availability across the port. In the port of Rotterdam securing the vessel to bollards for example is not their only task. In an agreement with the piloting station all pilots are brought and picked up by linesmen.

¹ No interviews have been conducted with bunkering parties. Information has been distilled from literature and other interviews.

² No interviews have been conducted with tug actors. Information has been distilled from literature and other interviews.

With more accurate arrival and departure estimates linesmen could improve their planning. Furthermore linesmen get the PTA and PTD of vessels.

3.3.2. INFORMATION AND THEIR POSSIBLE CONSEQUENCES

The following table is a summary of how certain information will influence the operation of actors. Actors can perform different types of actions per information type which in turn will lead to different results. In the model information can then be used as lever where information is not being shared or shared on a higher interval.

| Actor | Information | Action | Result |
|----------------|--|--|--|
| Terminal | Container move count | <ul style="list-style-type: none"> - Create more accurate planning - Adjust berthing window | <ul style="list-style-type: none"> - More predictable terminal planning - Higher berth efficiency |
| | Departure of the vessel depending on the nautical services | <ul style="list-style-type: none"> - Inform next vessel when to come in | <ul style="list-style-type: none"> - Higher berth utilisation - Tighter terminal planning |
| Agent | Arrival time vessel and departure time vessel | <ul style="list-style-type: none"> - Book nautical services further in advance | <ul style="list-style-type: none"> - Will increase availability of the services. When ordering later availability will decrease. |
| | Estimate time arrival and departure | <ul style="list-style-type: none"> - With more accurate estimates agent can book nautical services and tighter berth window . | <ul style="list-style-type: none"> - Higher availability of nautical services. - Berthing window could meet arrival time better. |
| Port Authority | Departure time vessel | <ul style="list-style-type: none"> - Better planning waterway utilisation | <ul style="list-style-type: none"> - Better planning and less delays due to waterway occupation. |
| Captain | More accurate information about terminal operations. | <ul style="list-style-type: none"> - Slow down or speed up to meet ETA. - Divert to another port | <ul style="list-style-type: none"> - Safe fuel - Reduce waiting time at anchorage. |
| | Arrival times from bunker and other vessel services | <ul style="list-style-type: none"> - Prepare arrival - Take into account services times. | <ul style="list-style-type: none"> - Better prepared and better knowledge of possible delays. - More accurate ETD |
| Bunkering | Arrival and cargo times at terminal | <ul style="list-style-type: none"> - Adjust planning accordingly | <ul style="list-style-type: none"> - More predictable operations and less delays. |
| Pilot | More information about vessel status | <ul style="list-style-type: none"> - Order right amount of tug boats | <ul style="list-style-type: none"> - Reduce delays and have safer operation. |
| Tug boats | Better estimate on number of tug boats | <ul style="list-style-type: none"> - Send right amount of tug boats | <ul style="list-style-type: none"> - More efficient usage tug boats. |

TABLE 1: DESIRED INFORMATION WITH RESPECTIVE ACTIONS AND RESULTS PER ACTOR

A visual summary of the above results have been visualised in Figure 9. This figure is however not exhaustive and is merely there to see what information is important to more than one actor. Also some information lines have not been included to keep the figure readable. For example tug boats also want information about the arrival, but they plan an operation together with pilots, port authority and linesmen, once the pilot is on board he will make contact with tug boats. And in some cases stakeholders have information about an event but would like to have more accurate information.

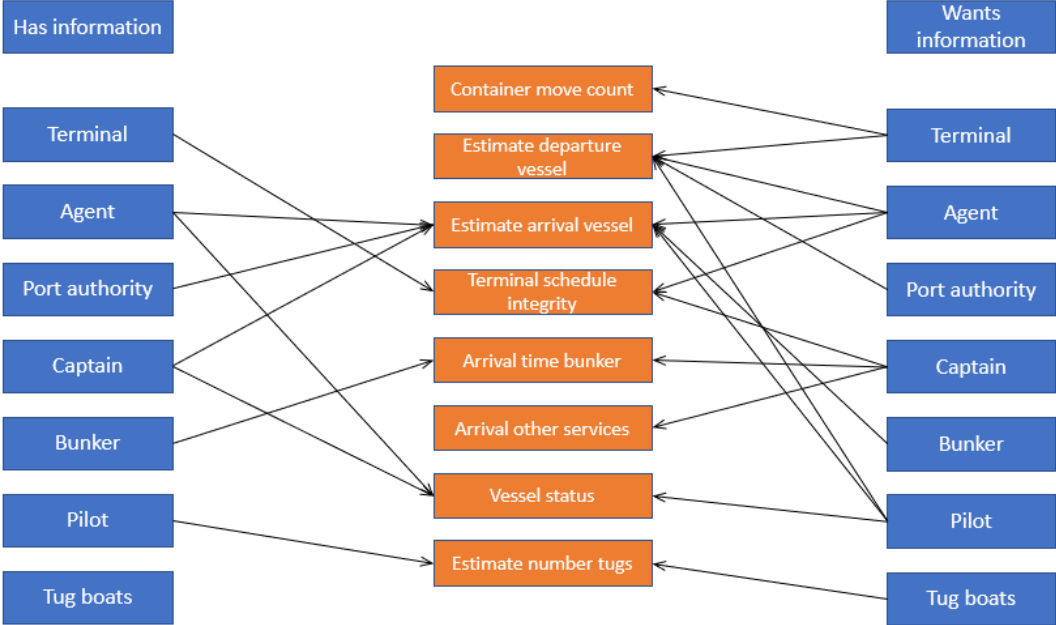


FIGURE 9: INFORMATION LINES IN THE PORT

3.3.3. KEY PERFORMANCE INDICATORS AND LEVERS

In the previous table information, actions, and results were presented. This information serves as another brick in the model, with definitions that explain the actions on information and the consequences for the system. In the following summation the most important KPIs are given. The Chosen KPIs are a combination of KPIs uses in the port or that were frequently used in the literature.

- Berth utility
 - This could be defined as the amount of containers being handled per berth or per crane. Other metrics could be the number of vessels visiting the berth, the utility indicating how efficient quay usage is.
- Fuel consumption
 - This is a metric that would be depended on vessel dimensions and speed reduction or acceleration.
- Waiting time at anchorage place
 - If the planned berth is not available for the proposed time the vessel will start incurring waiting time at the anchorage place. This will mean extra costs due to delays and fuel utilisation because of idle running engines.
- Asset utilisation of nautical services
 - With higher predictability of incoming ships pilots and tug boats can be planned more efficiently. Under uncertainty many pilots have to work on standby shifts.

Levers used to analyse these KPIs include:

- Accuracy of information
 - More accurate information will increase the quality of planning and predictions. In this case services can be better planned ahead. Accuracy of information can be changed by altering the normal distributions of events.
 - Another leverage would be to reduce the amount of uncertainty in some events such as the move count.
- Information sharing
 - There are different degrees of information sharing, rock bottom would be no data sharing whereas full data sharing would be all the information with everyone real time. Depending on the actors and events this changes. Therefore this could be a good lever for changing the level of data sharing between actors on different events. Especially for sharing estimates between the terminal and vessel would be interesting as the vessel could actually act by changing his speed and therefore influence its KPI. Information sharing comes in two dimensions, first is the information and whether it is shared or not and second is the interval in which sharing takes place.

These KPIs have been selected as a combination of literature (Clausen, Kaffka, & Meier, 2012) and the experience from people working in the industry that have been interviewed. Interviewees mentioned more KPIs during the interviews, however some of the KPIs are harder to measure and model in this research. It is therefore that these KPIs have been chosen since they are generally accepted and useable in the model.

3.3.4. CONTRACTS BETWEEN ACTORS

Actor actions and interactions are to a large part dictated and determined by the contracts different parties have with each other. In this paragraph a comprehensive review will be given on the involved contracts for deep sea shipping, the focus of this research.

TERMINAL OPERATIONS

Briefly mentioned in the literature study are the different types of terminals that exist. This means that different terminals will also have different interests and therefore different contracts. These five types are in turn often reduced to carrier owned or operated terminals and private terminals. In the port of Rotterdam the three large container terminals are: a joint venture, a privately owned terminal, and carrier owned.

This means that two terminals in the port of Rotterdam have different contracts with different shipping lines and will therefore prioritise those shipping lines that have a stake in the terminal. Due to the sheer size some shipping lines can exert more power during negotiations (Kim & Lee, 2015). Often these larger shipping lines have contracts for prolonged periods of time for vessels that are to be serviced on a certain interval or rotation. Besides these returning vessels there are also the vessels that have contracts per visit.

In these contracts shipping lines and terminals negotiate container lift charges which are also dependent on the weight of the container and whether it is destined for transshipment (European Commission Competition, 2009). Furthermore, the terminal handling charges seem to be a negotiable item for larger shipping lines, especially those with larger volume and longer contracts. These contracts in turn guarantee shipping lines time at the quay and a particular numbers of moves per hour.

But it appears quite hard, as an outsider, to get a deeper insight in the specifics of contracts between terminals and shipping lines. Causes for this could be the sensitive information included in these

contracts such as amounts to be paid and productivity of terminals. If other terminals would have insight in the costs and productivity of competition they could use this to their advantage by counter propositions to container vessels or shipping lines. Current performance of terminals can be derived from available data with regard to the number of containers and length of berth visits.

SHIPPING LINES

Whereas bulk shipping is characterised by its tramp shipping and contracts, this is to a lesser extent applicable to the liner shipping. For large liners in container transport up to 50% of the vessels are owned by the company itself, these vessels and crews will then also have standard contracts with their shipping line. Though contracts for owned vessels may change per shipping line, some shipping lines give the captain a certain budget to arrange services and husbandry while ashore and other shipping lines arrange this themselves (Scherpenzeel B. , 2018). For the other vessels under the operation of shipping lines three main contracts are available namely: bareboat charter which is an empty vessel without a crew, voyage charter which is chartered for a particular journey, and a time charter which is chartered for a particular time. In the last two instances the crew is often included and under employment of the vessel owner (Chernoshtan, 2016). Chernoshtan provides a clear insight in clauses and different contracts, since law is endlessly elaborate and covers a huge line of topics, but there are a few topics of interest for this research. Take for example the *speed and performance*, *slow steaming*, and *performance of voyages* clauses. These clauses cover liability about the performance of vessels in terms of speed and fuel consumption, often captains are contractually bound to steam at a predetermined speed, and in addition fuel consumption and weather are taken into account. This also means there is a separate clause for *slow steaming*, which is the act of lowering speed in order to steam more efficiently. These contracts regarding speed and performance can have a high impact on the freedom of captains to adjust their speed. Besides the speed and performance there a special clauses about bunkering, which is done by either the shipowner or charterer, the latter being the most common. Situations where the shipowner is responsible for the bunker, he might be more aware of fuel consumption and more interested in slow steaming to prevent unnecessary consumption.

In the port of Rotterdam the shipping lines make contracts with nautical services, predominantly the pilots and tug boats. As there is only one company in the Netherlands they have a monopoly on piloting, they are obligated to provide their services and cannot deny costumers. However they still have to negotiate piloting charges which are done with the shipping lines separately. As with the terminals larger shipping lines have more power here and can threaten to reroute their schedules to different ports. However with respect to tug boats there is more competition in the port of Rotterdam with three different service providers. It might therefore sometimes be that the preferred supplier of tug boats does not have enough capacity, for example when extra tugs are required due to bad weather. As it is quite hard to get insights in these contracts it is difficult to say if there are any agreements made on data sharing, and if in place what these agreements are.

AGENTS

Agents are the representative of a shipping company in the port of call, and depending on the vessel contract type agents can have changing responsibilities. There are multiple standardised contracts that can be used by agents and incoming vessels. For example a Baltic and International Maritime Council (BIMCO³) has a general agency agreement for liner services. This contract states the following: "*In consultation with the Principal to recommend and/or to appoint on the Principal's behalf and account, Stevedores, Watchmen, Tallymen, Terminal Operators, Hauliers and all kinds of suppliers if required.*"

³ BIMCO is the largest international organisation representing shipowners with the main objective to foster marine operations by providing information, advice, standardised documents and promote standardised operations.

(FONASBA, 1993). This means the agent has to arrange all the services for the vessel, referred to as principal, that are required. Execution of services should be to the best of the principals operation, taking into account productivity levels as well as schedule integrity.

Marine operations have always been very traditional and change has been slow. Many of the contracts that have been used years ago are still in place today. In some situations contracts can hinder the freedom of actors and limit the optimisation potential. Examples of these could be clauses on speed or charter parties with demurrage in tramp shipping. For further research these contracts and constraints will be kept in mind, but will however not explicitly be modelled. Further down the road this information will be recalled to see what the implications are on developments and potential in operation and how they impede with data sharing.

IMPACT OF CONTRACTS

Contracts may have a large impact on operations in the sense that certain actions are off limits or mandatory thereby reducing the degrees of freedom actors have. The aforementioned section mentions some of the contracts and clauses shipping lines may have, if one of those clauses would concern slow steaming this can have impact on the decision of the captain. In case the captain is to sail at a certain speed or performance he may not be able to change his speed in order to arrive just in time. Besides the slow steaming clause in a contract on the costs of bunkering might be a reason to take away the incentive of slow steaming if the captain is not directly paying for this. In conclusion contracts can have diminishing effects on data sharing. Under hypothesis that the last will enhance efficiency in a port. Later in this research, after the experiments the contracts will again be considered to see their implications on operations and what their effect would be on the outputs.

3.3.5. CHOSEN ACTORS FOR SIMULATION

As seen in part 3.3.1 there is a considerable number of actors that are involved into port calls. When modelling and simulating a port call, including extra actors will add complexity to the model. With an increasing number of actors the number of possible information flows will also increase in a nonlinear manner as will the complexity. Therefore only four main actors will be considered from now on: these are the terminal, nautical services as an aggregation of pilots, tugs, and linesmen, bunkering and the vessel which largely represents the shipping line, captain and agent. These four have been selected as they represent the most dominant actors in the process and are mentioned the most during interviews.

Aggregation of the actors has been done to simplify some of the processes and to focus on the data sharing mechanism rather than recreating the actual situation. For example the shipping line, agent and captain have contact with each other and a similar interest which is the vessel being on time. However information between these parties often takes time and uses different channels which would imply extra complications for the model.

Furthermore with regard to information and communication the two most important parameters are the arrival and departure of a vessel. Services of some actors are bound to the arrival and departure events, and will only increase if the estimates of these events improve. Other actors have to perform their services between arrival and departure therefore also highly interested in the timeframe they have for operations, and when it should be done. Due to the aforementioned the arrival and departure times of vessels have gained a priority over other events.

4. MODEL STRUCTURE AND REQUIREMENTS

In this chapter the emphasis is on what requirements the model has, what it should return and under what circumstances. Also what inputs can be used for the model and how particular inputs would affect the purpose of the model.

4.1. REQUIREMENTS OF THE MODEL

Goal of this research is to see what the effects are of data sharing among actors during a port call. To assess the effects a model will be made that should assess the effects of data sharing, therefore the model should satisfy the following purposes:

1. Assess the effect when certain data is available to actors involved in the port call process;
2. Test the influence of uncertainties in data;
3. Capture the effects when the interval of information sharing is changed;

4.2. SCENARIOS

There are many scenarios that can be modelled in ports, but for this thesis I will mainly refer to the operations within the port of Rotterdam. This paragraph will elaborate on the different operations in a port that can be modelled. In the first part an overview will be given of the different operations in a port.

4.2.1. DIFFERENT MODEL INPUTS

There is a myriad of parameters that can influence the operation in a port, and in this paragraph more attention is paid to how some of these parameters influence the operations.

VESSEL SIZE

Implication of larger vessels mainly affect operations at terminals, and due to the increase in ship size between 1970 and 2012 a growth of 700% in peak load at the berth has been measured (Martin, Martin, & Pettit, 2015). According to Martin et al (2015) with an increase of 700% of peak load, port time of the vessel has remained the same, which is quite remarkable considering only an increase of 87% in quay cranes. To keep port times constant terminal operation would therefore have to improve, this can be done through multiple means such as higher crane productivity. Since the purpose of this research is to quantify the effects of data sharing and among actors rather than optimisation of terminal performance little attention will be given to terminal operations.

Other implications deduced from interviews is that larger vessels face other problems such as tides windows or extra services. For the very large vessels, especially of the bulk types, tidal windows can play a role, which means that the vessel can only enter or leave the port under particular tidal conditions without running into sand banks. This problem is partly inherent to the large vessels and partly to ports. Port infrastructure is also very important as some ports are by nature accessible for very deep vessels whereas some ports are less easily accessible or require dredging.

TYPE OF FREIGHT TRANSPORTED BY THE VESSEL

Ports may specialise in different kind of operations which in turn affect the efficiency of operations. For example transshipment ports have more containers which require more moves at the quay than more dominant import or export ports. While importing a container only costs one move at the quay transshipment also requires the container to get back on a different vessel.

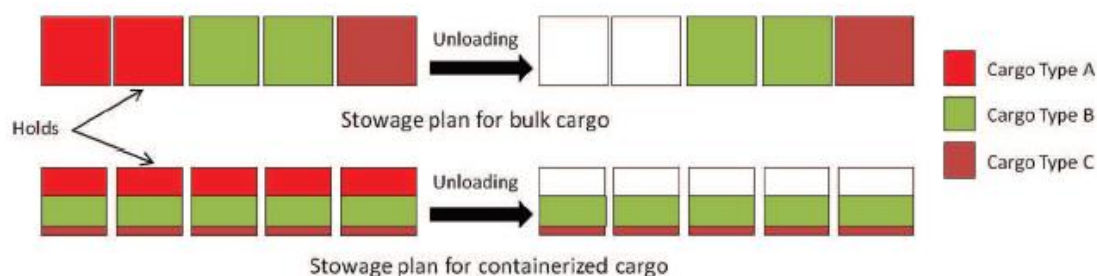


FIGURE 10: STOWAGE PLAN FOR BULK PORTS AND CONTAINER TERMINALS (UMANG, 2014)

Another difference is the stowage planning for different transport types, which is illustrated very well by Figure 10 (Umang, 2014). For vessels with different cargo types container vessels are more flexible in the sense that containers can be scattered over the vessel allowing more cranes to work simultaneously whereas this is not possible for bulk vessels with different cargo types. Small footnote here is that efficiency is reduced when the required containers are buried under other containers on the vessel.

There are about 6 distinct types of transport that occur in a port namely: cargo, Roll-on Roll-off (RoRo), tankers, passenger ships, fishing vessels, ferries, where the cargo division spans a large part with container and bulk shipping. In terms of operation there is a large difference between these two types. In Container shipping most of the times owned ships are used that will follow a predetermined route of ports. This makes operations for container shipping predictable up to a certain point. Furthermore the containers that are being shipped are not known to have fluctuating value over time or different owners. Bulk shipping, either wet or dry, is often only based on single trips through different contracts (Olesen, 2015).

ORIGIN OF VESSEL

Three main types of shipping can be distinguished, Deep Sea Shipping (DSS), Short Sea Shipping (SSS) and Inland shipping. DSS and SSS are respectively defined as follows:

“the maritime transport of goods on intercontinental routes, crossing ocean; as opposed to short sea shipping over relatively short distances.” (eurostat, 2015)

And

“the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports and ports situated in non-European countries having a coastline on the enclosed seas bordering Europe. Short-range maritime transport covers national and international maritime transport, as well as feeder services, along the coast and from/towards the islands, rivers and lakes” (CEC, 1999)

The main takeaway difference between DSS and SSS is therefore that DSS has longer steaming routes and hence more potential for green steaming than the vessels on shorter routes. Besides sea shipping there is also the inland shipping, these are the smaller vessels that can enter the canals to inland ports. Usually the smaller inland vessels sometimes called barges or feeders bring and take away smaller quantities of containers at the terminal. Due to the smaller quantity of these feeders they often have lower priority compared to DSS and SSS vessels at terminals but they are more flexible. Since smaller feeders have shorter quay times they can visit more terminals in a more flexible manner. The smaller

vessels are also not always obligated to have local pilots or tugs. This last part of flexibility reduces some of the information lines between actors and eases the process.

DATA AVAILABILITY

Through the Port of Rotterdam and its application more data is available than from the regular open sources. Aside from these restricted sources applications such as marine traffic are openly available, providing information about vessel whereabouts and dimensions.

Data obtained from the PoR includes transshipment data as terminals and vessels are required to forward the amount of goods they loaded and unloaded. This information therefore also includes the number of containers that have been moved. This is information that can be used to model characteristics of terminal and the arrival of vessels.

Pronto is an application by PoR and currently under development, but it does receive a lot of data from various parties Figure 11. In the next chapter a more elaborate description will be given on the contributing parties and data quality. Since the majority of terminals that have been sharing data focusses on containers it is also more logical to start working with this data.



FIGURE 11: DIFFERENT DATA SOURCES FROM PRONTO

PORT INFRASTRUCTURE AND ENVIRONMENT

Briefly mentioned before are the tide windows, which are part of the port infrastructure. Some features within a port can have operational effects and constraints on marine traffic. One of these constraints are tide windows, for ultra large crude carriers sometimes reach draughts of up to 24 meters deep. If the port and its waterways are not deep enough these vessel will get stuck on sandbanks. Another aspect of the port infrastructure is the width of waterways, for some waterways are one directional or cannot handle multiple large vessels side by side.

Aside from infrastructure the environment can also have a significant role on the operations in a port. In some parts of the world port calls might be harder during stormy seasons whereas this does not apply to other ports. In the PoR storm surge barriers are installed in case of higher water, but it is highly unusual that these have to be closed. Other weather circumstances, like hard wind, appear to be more

constraining as it can become too dangerous to pilot vessels inside the port. Also operations at terminals will get hampered. In general these situations are not very common in the PoR, however, a disruptive event like this can be acted upon as ports close down and many vessels would have to wait at anchorage.

4.2.2. AVAILABLE SCENARIOS

A combination of parameters in the previously mentioned paragraph could lead to different models. Due to the time of the research and the inherent complexity of all operations in a port, a specific set of parameters will be chosen.

Some of the major differences in the modelling of data sharing among actors can be seen in the following figure. Based on interviews and information, 4 different scenarios are identified with either small/inland vessels or large vessels, and either containers or bulk.

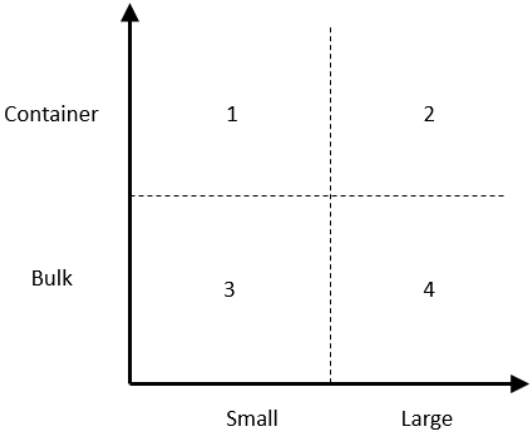


FIGURE 12: DIFFERENT PORT SCENARIOS

Characteristic for the first scenario with smaller container vessels is that operations are less predictable compared to the larger vessels. Especially the inland vessels have lower priority to DSS, also traveling times between port or even terminals in the same port is lower which affects the option of green steaming. However, depending on the degree of freedom vessels can decide to change berthing destinations inside or outside of the port.

Large container vessels have longer travelling times towards the port of call giving them more potential for altering steaming speed. Compared to the smaller vessels they also, on average, have longer quay times, single berth visits and less freedom in diverting to other terminals as containers to be loaded often get pre stacked on the yard. However as Van Ouden mentioned in an interview (Ouden, 2018) if vessels know far enough in advance that terminals are delayed they could change the order of port calls if the next port call is close enough and can accommodate the change in planning.

In scenario three smaller bulk vessels are considered. The first major difference is the irregularity compared to container shipping. Majority of bulk shipping goes under charter parties which are often limited to single trips. Cargo that is shipped is often traded on the spot market, and the value of the cargo can therefore change depending on supply and demand, so this is one of the reasons vessels do not always want to unload their cargo upon arrival. Bulk vessel sometimes wait from hours up to days for selling their cargo and actually asking for a berthing window and entering the port (Bac, 2018).

Major difference between the ultra large bulk vessels and smaller bulk vessels is that the first ones are often limited by their draught. Draught of ultra large vessels is sometimes so deep that they can only enter the port during certain tide windows. In the case of Rotterdam these vessels also get a planning priority over other vessels due to their long approach in the Europeul that has to be piloted.

Further parameters affecting port operations are often related to the type of cargo transported, take for example terminals layout, or they apply to both types of shipping, such as the infrastructure of the port.

4.2.3. CHOSEN SCENARIO

Paragraph 4.2.2 was aimed at giving an impression of all available dimensions that can have an influence on the operations. For this research assumptions will be made into what to include and what not. With regard to the sort of operations focus will be on container shipping. A choice has been made to focus on container shipping because of its considerable share in nautical operations. For example bulk shipping is also very big in terms of operations but follows a completely different process. Furthermore on the spectrum of vessel size only the larger vessel will be looked into, these are the vessels more inclined to visit a single berth whilst also travelling larger distances oversea. Especially the last is of higher interest, vessels that come from further have a bigger time window to act accordingly.

Of main interest is the responses and behaviour of the system when actors would share data with each other under different circumstances. For that reason weather and environmental influences have been left out, this means that exceptional weather situations will not be considered. Also port infrastructure such as depth and width of canals will not be considered, also because in Rotterdam there is no tidal window for container vessels.

4.3.CONSTRAINTS AND ASSUMPTIONS

Within the scope of this research it is not possible to model the whole operations of a port, therefore some assumptions are made and constraints added to the model. With regard to terminal simulations levels of fidelity are microscopic and macroscopic: *“models would aim the behaviour of vehicles and traffic control infrastructure in great detail, in an attempt to replicate the dynamics of a system. In contrast, macroscopic (strategic) models have a lower fidelity as they are based on aggregate information”* respectively (Angeloudis & Bell, 2011).



FIGURE 13: OPERATIONAL LEVELS IN PORT CALLS

For this research focus will be on the middle part, tactical operations. This means that terminals will be simplified in their operations. But this also means that high level strategy as what port to call upon is included, planning and operation are given and the effects of parameters on these will be tested.

Furthermore the research will be predominantly generic instead of focussed. This means that the model seeks to accommodate many different operations instead of focussing on detailed planning.

With the level of aggregation in mind the following assumptions are made:

1. Terminal

- Terminals often have a particular length of quay available with multiple bollards where vessels can be secured, for research this quay length can be separated in discrete berthing places having a fixed capacity, or into continuous places able to accommodate a variable number of vessels depended on their length (Burkhal, Zuuglian, Ropke, Larsen, & Lusby, 2011). For this research discrete berths will be used, as focus is on DSS it is often hard to fit another vessel at the quay that averages 300 meters. No difference will be made in loading and unloading of containers. A certain number of unloading and loading containers will be assumed and modelled as one handling time with a distribution depending on other parameters.
- Productivity of the crane with regard to the yard and hinterland will not be considered. As this research focusses on the wet side of port operations, the dry side is not taken into account model wise, however characteristic delays can be modelled through productivity distributions.
- A dynamic berth allocation will be used as opposed to the static allocation where only the vessels are considered that have already entered the port (Budipriyanto, Wirdodirdjo, Pujawan, & Gurning, 2017). Furthermore once a vessel has been allocated a certain berth it will not change anymore.
- For terminal operations a fitting distributions will be taken that resemble actual operations. Delays can be linked to certain parameters such as number of moves, to be determined by the data analysis part. However the vessel will enter the model with a certain time window since the service level agreement is already known.

2. Agent

- Agents will be left out as actor in the model. Agents act as representative for the captain/shipping line and will therefore affect the speed of information handling (Olesen, 2015) however they do not profit much nor get penalised by information sharing, for agents act as information window but can themselves not act on the data. However their actions will have consequences for other actors, and timely passing on of information will have a positive effect.

3. Captain

- In the model the captain is visualised as the vessel and it is assumed that he can act independently on received information. This means there will be no restrictions
- Captains are in charge of changing the vessel's speed. However there will be a minimum and maximum vessel speed that are not exceeded. Speeds outside of the operating boundary are not used as these are extremely inefficient or impossible to attain.

- the captain will enter the model with a “request time” for operation, this is a time which has been agreed upon by the agent and the terminal and is based on the contract of the shipping line with the terminal, the amount of moves, and terminal productivity. Vessels entering the model have therefore also skipped the contractual phases in the process map Figure 5 and are bound for a specific terminal.
 - Requested time can be changed if the number of containers to be moved changes as well.
4. Nautical services
- For this model pilots, tugs, and linesmen have been aggregated into one, under the assumption that linesmen will never be late and incoming vessels will always need a tugging vessel.
 - Also there will be no difference between the vessel to be handled, although larger vessels often require mover tug boats, especially with wind this is not taken into account.
5. Bunkering
- As Rotterdam is considered to be an important bunker port in combination with the travelled distance and travelling distance ahead, it is assumed that many vessels will do bunkering and that bunkering will not be aborted.
 - Bunker vessels have a certain travel distance to the vessel and a predetermined arrival delay which can be set before running.
 - Interaction between the bunker vessel and terminal is not taken into account. This means that bunker operations can commence without prior consent of the terminal, neither will the terminal operations be affected.

4.4. KEY PERFORMANCE INDICATORS

In chapter 3 a short summary of KPIs has already been given along with the reasons why these KPIs are important. In this Part a short recap will be given on these KPIs and their units used in the model. In the model the following performance measures will be used to see how actors will perform under different situations.

1. Terminal
 - Berth utility [%] will be used as the main parameter for terminal utilisation. This indicates how good the occupancy rate of the quay is.
 - Number of ships serviced [real] will be the second KPI for the terminal. It is hypothesized that will more information sharing and optimal arrival of vessels more vessels can be handled at the berth.
2. Captain
 - Fuel consumption [Liters] will be used as one of the parameters. Fuel would be a function of speed and vessel size in this case. In the model the total fuel consumption is represented by the integral over the speed throughout the journey.
 - Fuel consumption at anchorage [Liters] will be used to see how much fuel is used before entering the port. Compared to the overall fuel consumption this could be more interesting as the emission take place just before the Dutch coast.
 - Waiting time at anchorage place [hours] is the second performance indicator as vessels will continue to use fuel when waiting to enter the port.
3. Bunker

- For the bunker no KPI will be used, this actor is mainly included to assess the effect of delayed bunker operations and how this would change if delays were to be shared with other actors in the chain.

4.5. MODELLING ACTORS IN THE PORT CALL

In the aforementioned sections the most important actors for the model are being discussed with their most important features and limitations. These will eventually be input for the model, limitations will put constraints on the behaviour of the actors KPIs will be in place to measure the performance of actors.

Aside from the actors a wider perspective with regard to the port is considered. Ports vary from each other in operation where every operation has its own taste and effect on modelling outcomes. When modelling a port these dimensions have to be considered to retain validity. Since these dimensions and characteristics can have a repercussions for the model and its purpose they have been reviewed in this section. For example tidal effects in conjunction with rising sea levels could give meaningful conclusions about infrastructure. However for this research tidal effects would affect planning and short term communication rather than long term. Furthermore constraints are presented to limit the degree of freedom of actors, this will in turn simplify the model. With less degrees of freedom fewer variation exists in results which could make them more suitable for testing particular policies without creating too much noise.

In the following chapter the data analysis will be performed which will return the parameters that will feed model parameters, such as average journey length to Rotterdam, berthing windows and so forth. Consecutively chapter 6 will discuss the model implemented in the chosen software and how the different actors are modelled including the logic they follow.

5. DATA SOURCES, DISTRIBUTIONS AND CORRELATIONS

Before modelling port call in the port of Rotterdam data is required. Most of the data is provided by the port of Rotterdam, part of this data comes from the port authority of Rotterdam that supervises all operations in the port. Much of the other data is available through the Pronto application currently under development in the Port of Rotterdam. In this chapter an introduction will be given to the data that has been used in 5.1. Under this paragraph a more elaborate explanation will be given towards the Pronto initiative. Consequently the data analysis will be done under part 5.2. For different types of data different methods will be applied, whichever seems most suitable at the moment. These methods will be directly discussed together with the analysis. In section 5.3 a summary will be given on the found results that will be implemented into the model.

5.1. DATA EXPLORATION

For the data analysis part multiple data sets will be used. One of the data sets contains information about all events that have been registered in Pronto. First this Pronto initiative will be discussed before exploring available data.

5.1.1. PRONTO INITIATIVE

Pronto is the data sharing initiative that has been set up by the port of Rotterdam. Pronto is currently developed as sharing platform for different actors during port operations. Due to the pilot and participating parties in the port of Rotterdam a lot of data is available. Since 2016 the Port of Rotterdam has been working on this application which receives their information from different actors and applications that have been cooperating since the start or joined later on. In Table 2 an overview is given of the different information sources and their role in the port call:

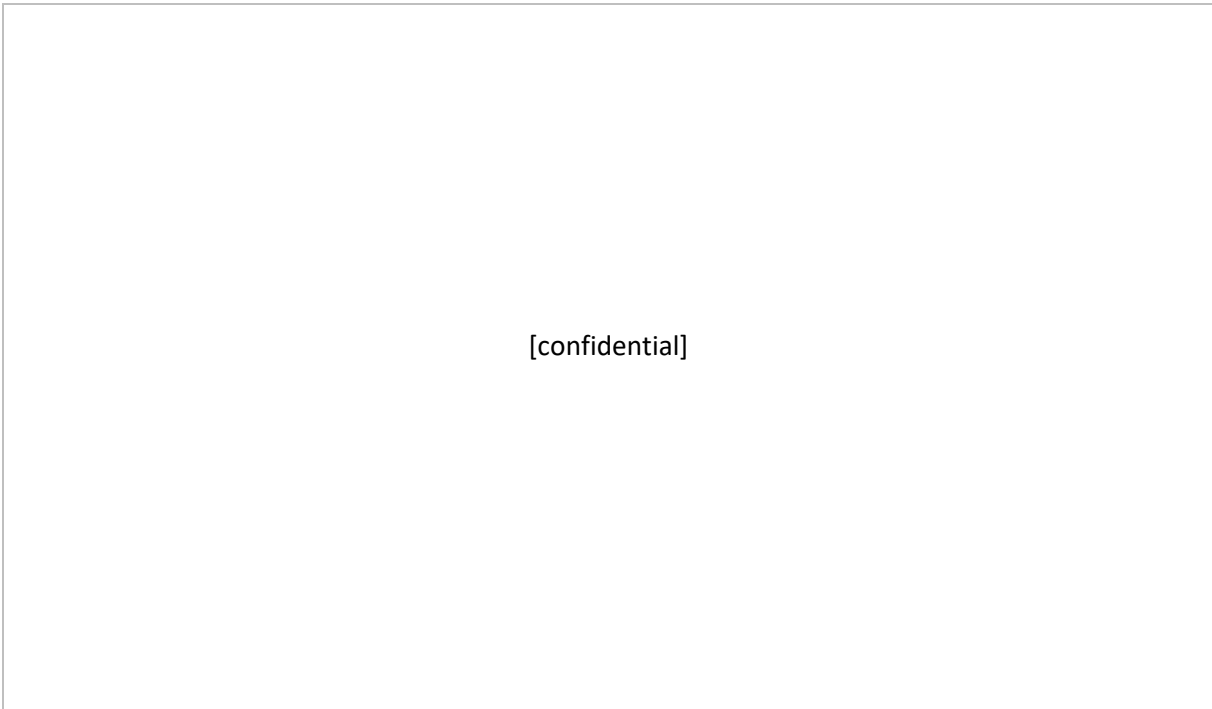


TABLE 2: DATA CONTRIBUTORS TO PRONTO INITIATIVE

5.1.2. DATA EXPLORATION

Before and in parallel with the modelling process the data analysis will be done, through the port authority different datasets are available. In the following sections short introductions will be given on the different available datasets.

PRONTO EVENTS

The following table gives the structure of an event in the database created by Pronto. In the third column the values of a random row are selected as an example. This represents the structure of an event, however within this structure there are a lot of different sources, the ones mentioned in the Pronto initiative, and a myriad of event types in the port call. Event types can roughly be classified into three groups, actual times, estimate times, and planned times. Actual times are filled in afterwards or determined through complex algorithms that measure vessel movement. Estimate times cover a wider spectrum including estimates of arrival two weeks up front until a couple of hours before the actual event, and estimates also include different predictions by algorithms. Planned times are submitted by actors and indicate an expected occurrence of the event.

| Column name | Data type | Example |
|----------------|-----------|---------|
| [confidential] | | |

TABLE 3: PORT CALL EVENT DATA AVAILABLE

PORT OF ROTTERDAM TRANSHIPMENT DATA

Additionally a confidential dataset has been taken from the Port of Rotterdam over the span of one year from January first 2017 until 2018 not including January first of 2018. The port registers a lot of information regarding visits, number of containers, location of berth, and other parameters to measure the performance of the port and charges to be paid to the port authority. For example the number of containers have to be submitted to the port authority as a tax has to be paid for every container transhipped. In appendix III a complete overview is given of the parameters available and their datatype.

For this research the most important parameters measure the location of the vessel, the number of containers, visit related timestamps, vessel information, and port call ids. Through the location of the vessel performance and visits per terminal can be determined. The number of containers can be related to the visit times from Pronto events, and for the analysis of service times this could prove useful. Timestamps of the visits could be used for time series analysis, in the modelling this argues for a uniform distribution of arrivals or changing arrivals per time interval. Vessel information includes IMO numbers which can be used as key for coupling different data tables, especially between Pronto and the port data. Other vessel information such as size influences the amount of cranes that can be employed as longer vessels can be handled by more cranes.

5.2. EVENT ANALYSIS

In modelling a port call there are a few essential events where good parametrisation will be crucial. In the next paragraphs these events will be considered, through the usage of the different data available events can be analysed on their characteristics. Results of this paragraph will eventually be input for the model and necessary for running experiments. Furthermore this paragraph has been divided into

four groups, first of is the created of vessels for the model, their quantity and size. Second is the length of the journey also including fuel consumption. Third are de terminal operations which will have a closer look at the time at berth. Fourth are nautical services including the timeliness of pilots. And finally attention will be given to the bunkering aspect.

Through data provided by the port some things can directly be calculated, for example the number of vessels for a particular time are given in the port its administration. The number of containers are also included in this dataset, which could therefore be used for the productivity of the terminals. However other events are not directly clear, for example the inaccuracy of information should be retrieved by comparing the estimates with the eventual time. From the previous chapter it became apparent that arrival and departure times are very important to many actors. Therefore the accuracy of these events can be calculated. In a discrete event model actions of actors, or events, will have a particular logic as well as probability. The probability could be related to a particular event actually happening, or the distribution of time required for an event. By means of data analysis these probabilities are to be found and implemented in the model. Having more realistic probabilities and numbers in the model will enhance model behaviour and improve outcomes.

Depending on the function in the model different forms of data are required. While doing the data analysis modelling will be done in parallel to better understand what parameters are required. At the end of this chapter all inputs will therefore be summarised, from probabilities and distributions to functions obtained by interpolation. For most variables simple distributions and probabilities will be used, so parameters are dependent on one probability and to a lesser extent on a joint distribution probability. In case of functions utilised it could be possible that values are a function of more than one parameter, which could be the case with fuel consumption.

5.2.1. VESSEL ARRIVAL

As mentioned before there are three large container terminals that operate in the Maasvlakte and handle large deep sea vessels. When querying these large terminals the events database for berth name, harbour name, length and width the following results from Table 4 show up.

| terminalId | berthName | harbourName | length | width |
|----------------|-----------|-------------|--------|-------|
| [confidential] | | | | |

TABLE 4: CONTAINER TERMINALS PORT OF ROTTERDAM AND SPECIFICS

From the table it becomes clear that there are a few places in the port where all the large vessels berth for operation. Three harbour places are noticeably larger than the rest. Compared to the other berthing places there, harbours have widths of 60 meter, dimensions which are crucial for DSS. These harbours also match with data from the transshipment, and when looking at the number of mentions the aforementioned harbours have the most visits on the Maasvlakte. For further analyses the other harbours will not be included anymore.

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| [confidential] |
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TABLE 5: SHORE SIDE NAME, DTYPE: INT64, PORT OF ROTTERDAM DATA

For further analyses three different tables have been merged into one and some filter operations have been performed. The tables have the following information:

- Berth visits in the port of Rotterdam, including the number of berths;
- Transshipment data, including the number of containers being loaded in the Port of Rotterdam and the lengths of the vessels;
- Event data on the estimates and actuals with their corresponding record times⁴;

Through some additional slicing values that have no values, such as “Not an Number” NaN values and negative values were impossible and have been filtered out. For example some vessels have a negative container count. Furthermore this is only done for the vessels that only visit one berth in the port as these vessels are assumed to be DSS.

VESSEL LENGTH AND THEIR IMPLICATIONS ON THE NUMBER OF MOVES

Figure 13 contains a distribution of the length of vessels. Vessel length itself is quite a discrete parameter with some gaps. This is because the length is often bound to certain constraints. Say the Vessel is supposed to pass a certain straight or canal such as Panama canal the vessels are designed such that they just fit in. For the old ship locks in Panama this was just below 300 meters whereas the new locks can handle vessels up to 366 meter, the same yields for the Malacca canal where vessels have a maximum length of 400 meters (Connector, 2018). It is therefore that some lengths will be concentrated around a particular value nevertheless length does have a large implication on the number of containers it can transport.

⁴ Event times specify when the event has actually taken place, the record time specifies when the event time has been created.

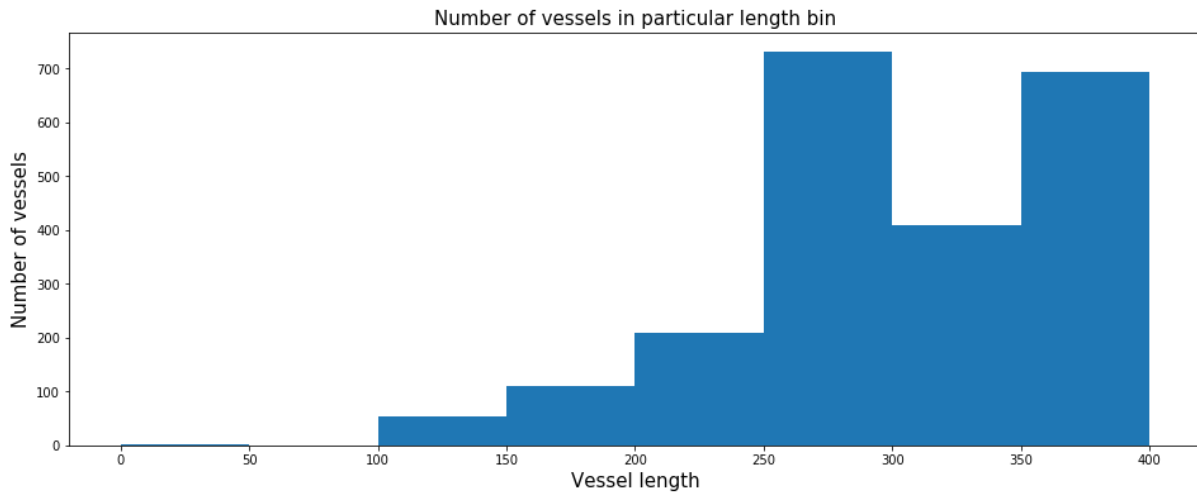


FIGURE 14: HISTOGRAM OF VESSEL LENGTHS IN 50 METER BINS

From the taken dataset it appears that 60% of the vessels are more than 300 meters long. And in total 93% of the vessels have a length of 200 meters or more. Therefore in the modelling vessels of 200 meter and longer will be considered which only yields an error margin of 7%.

When looking at the number of containers that have to be moved⁵ by the terminal, irrespective of the length of the vessel it is most likely that around 1000 moves will have to be performed (Figure 15). Intuitively this seems logical since larger vessel can always move fewer containers but smaller vessels will never be able to exceed their limits.

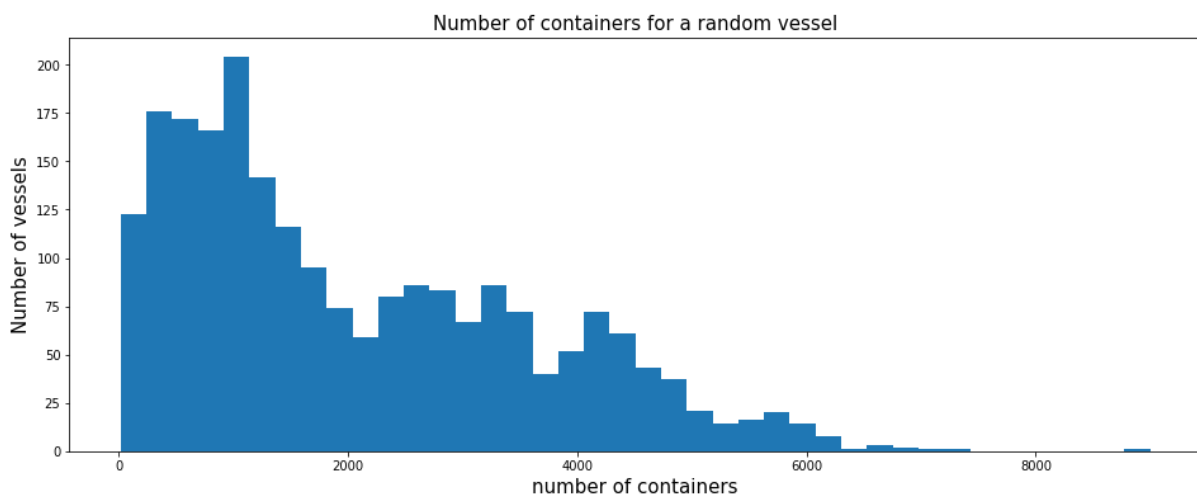


FIGURE 15: NUMBER OF CONTAINER MOVES CARRIED OUT BY THE TERMINAL AND THE NUMBER OF VESSELS FALLING IN THESE CLASSES

In Figure 15 is the number of containers to be moved for a random vessel, however to get the ultimate model better parameterised a correlation between the number of containers and vessel would be required. In Figure 16 the number of containers have be plotted against the length of the vessel. This therefore indicate the relation between the number of containers and the length of the vessel. Some of the things mentioned before become more clear through this figure. First the discrete length categories can be distinguished as some vessels approach the Neomax limit of 366 meters next vessels

⁵ Moves are here defined as the effort to get either unload or load a container. Unloading one container and loading another implies two moves.

no be much longer than the Malacca max of 400 meters. Second is the spread in the number of containers. Larger vessels are able to ship more containers but almost never load their full capacity at a port. Finally the figure has a lower alpha to better see if more vessels are clustered in one place, if they are the colour gets darker.

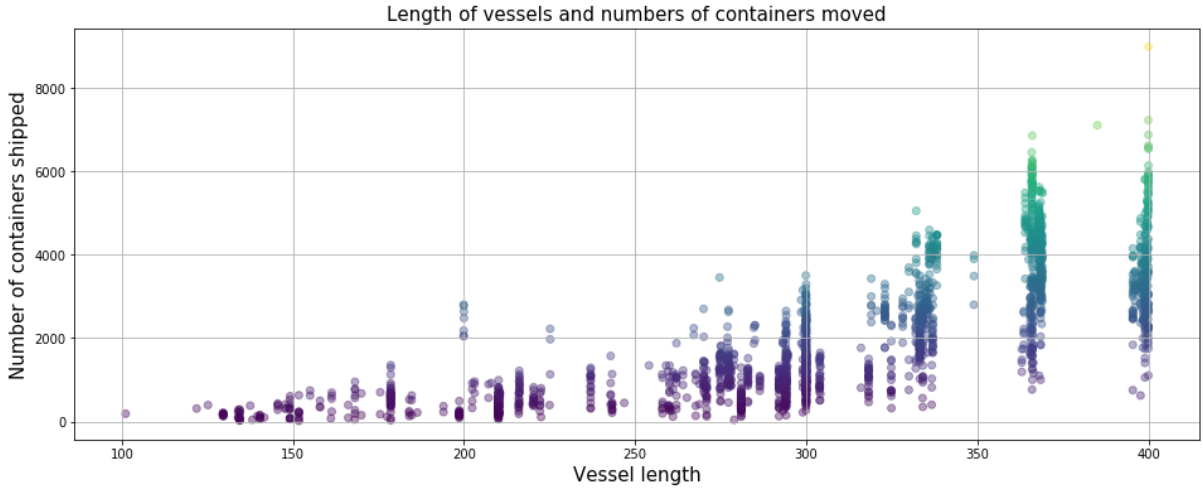


FIGURE 16: CORRELATION OF THE VESSEL LENGTH AND THE NUMBER OF CONTAINERS SHIPPED

With regard to Figure 15 when zooming in on a particular vessel length and its corresponding number of containers gathers more around an average. In Figure 17 the moves for vessels with a length above 350 meters is taken. For vessels above 350 meters it is most likely that the number of moves is somewhere around 4000, but this could also go down to 1000 moves or even up to 7000 moves with on outlier somewhere around 9000.

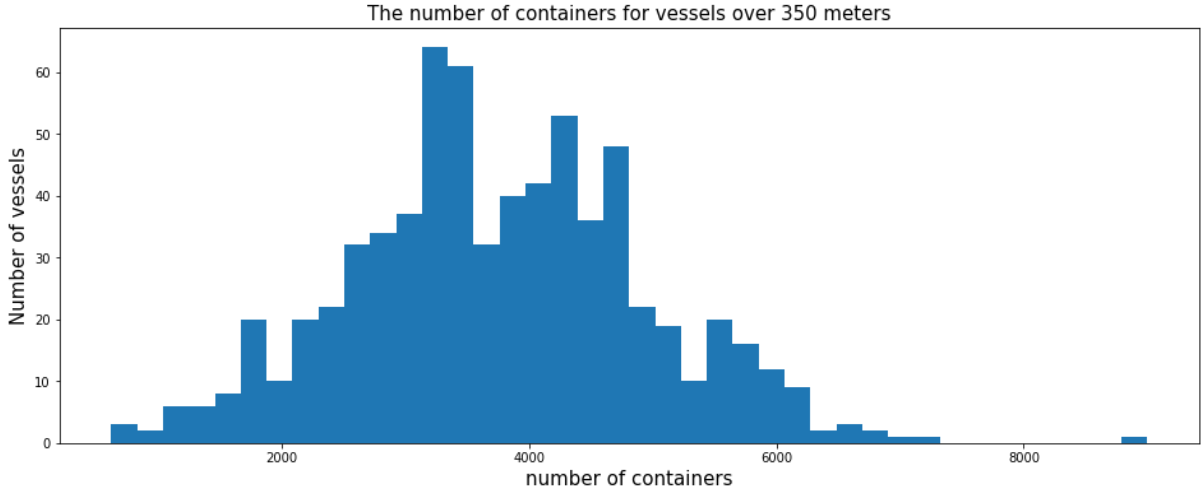


FIGURE 17: DISTRIBUTION FOR THE NUMBER OF CONTAINERS SHIPPED BY VESSELS LONGER THAN 350 METER

Due to operational constraints discussed before vessels often cluster around a particular length causing gaps in the data. These gaps are especially good visible for the larger vessels. For the model to approximate the number of containers four groups have been made, see Table 6. Every 'bin' of vessel lengths will have an average and standard deviation that will be used in the model. Bins have been chosen to preserve the randomness of the data, another option would have been fitting the data with a negative binomial distribution. However fitting this data could take away the randomness and might return rather invalid results as the data has some inconsistencies and has a rather high variance around some vessel lengths.

| Vessel group in meters | Members in this group | Average number containers moved | Standard deviation |
|------------------------|-----------------------|---------------------------------|--------------------|
| 200 – 249 | 208 | 528 | 324 |
| 250 – 299 | 750 | 1167 | 611 |
| 300 – 349 | 391 | 2293 | 1051 |
| > 350 | 694 | 3756 | 1190 |

TABLE 6: VESSEL LENGTH CLASSIFICATION AND DISTRIBUTION OF CONTAINERS

VALIDATING THE ASSUMPTION OF SINGLE BERTH VISITS.

For this research the assumption is made that only container vessels will be considered that visit a single berth. In the following analysis this assumption will be tested. From the data environment there is a table that has all berth visits that were recorded in the port of Rotterdam. For the following analysis this table will be used, however since this is data from the partners of the Pronto project there might be a certain amount of bias in it, since these are only the deep sea terminals.

When looking at the data in Figure 18 it seems that more than half of the vessels that come to a terminal will only visit one berth before setting sail to the next port. The Assumption for single berth visits will therefore still cover more than half of all visits. Other research could focus more on the implications when multiple berth visits are taken into account.

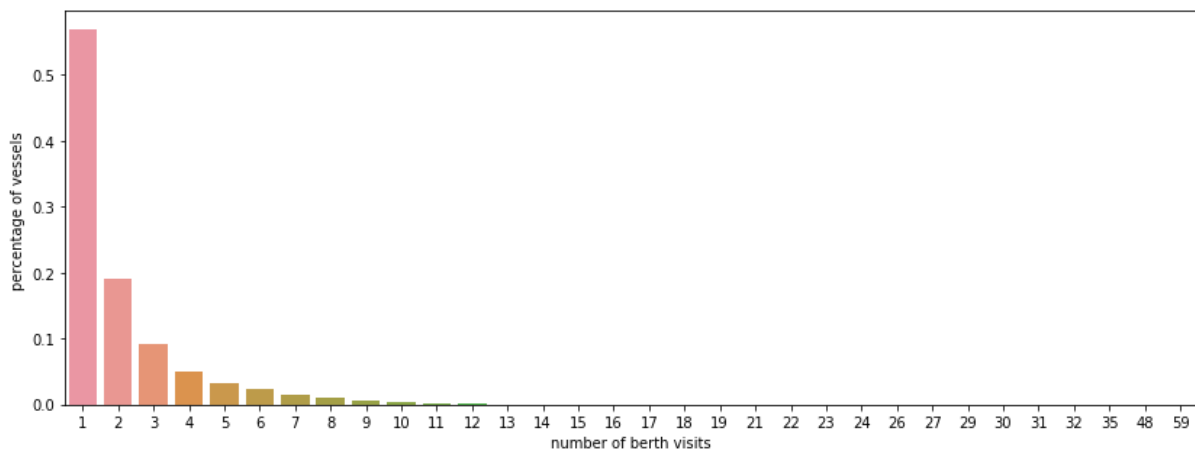


FIGURE 18: PERCENTAGE OF VESSELS WITH A PARTICULAR NUMBER OF BERTH VISITS

Aside from the number of visits this table also includes the port visit time. Port visit is the total time the vessel spent within the parameters of the port which is based on different sources. Within the table more than one source can indicate whether the vessel has arrived or not. Within the port of Rotterdam a logic has been made what source is the most accurate, for example in the absence of terminal data different sources will be used such as an arrival predictor or geographical data from AIS. In the last case a certain threshold will be used to check if the current location of the vessel is actually inside the port already. With this logic a “most accurate” event will be chosen, based on the source of the event. For the visits table used for the number of berth visits actual time of arrival and actual time of departure have been included. The following distribution in hours shows the elapsed time in the port sliced on vessels between 1 and 168 hours which is a full week and more than 98 percent of the vessels. These limits are chosen as it is rather unlikely that a vessel will remain in the port for longer than one week for operations. Also if a vessel were to stay longer than one week there could be other reasons, including structural damage to the vessel. In this case information sharing with regard to the journey would help to a lesser extent and will not be modelled.

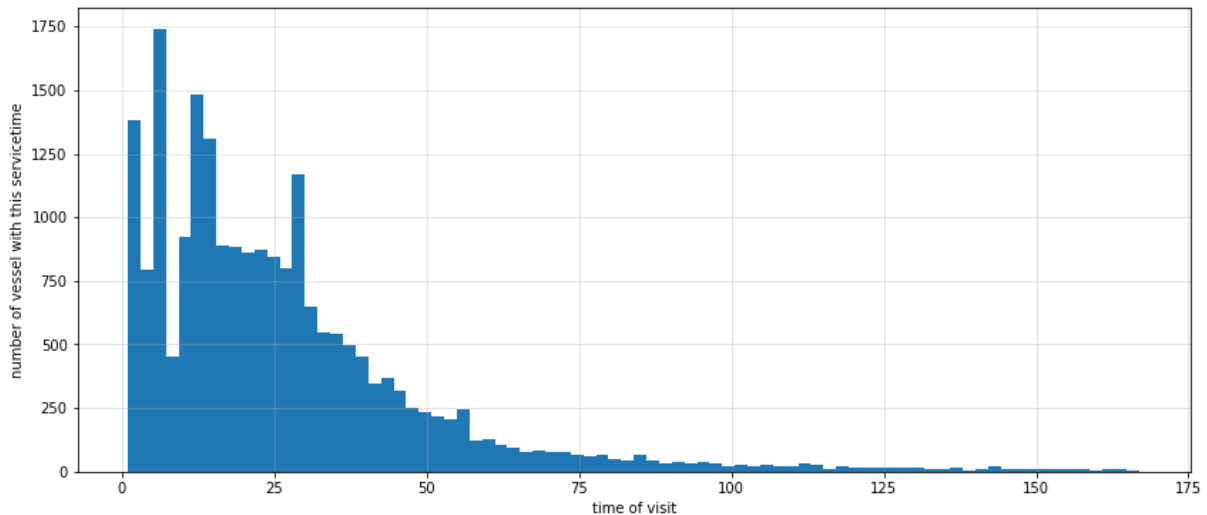


FIGURE 19: HISTOGRAM OF TIME THAT VESSELS HAVE REMAINED AT THE BERTH

In Figure 19 the distribution of time spent in the port has a very long tail. Close to 60% of these vessels will enter and leave the port within 24 hours, whereas by far most vessels will have a stay time of around 12 hours.

WAITING AT THE ANCHORAGE PLACE

As soon as a vessel enters the VHS range of the port but does not have clearance to go in to the port, it has to wait at the designated anchorage place. These events are however not actively timed or clocked by anyone. Within the Pronto application there is a geo fencing algorithm that indicates when a vessel has arrived at the anchorage area, as two events for this are recorded, namely the actual time of arrival and the actual time of departure. By a combination of geographical location and speed either the arrival or departure at the anchorage is determined.

Figure 19 gives an indication of the waiting times that vessels have in front of the port. For the waiting time the max values of the actual time of arrival and the max time of departure have been taken and then subtracted from each other. It should be mentioned that the predicting algorithm does have some flaws, for in some cases it will return up to three actual times for a single event. An explanation for this could be that for some speeds and locations it is not really clear whether the vessels have already arrived or departed. This can also be accounted for by the drifting before the port, when vessels remaining at anchorage usually do not shut down their engines but will start turning small circles where they currently are. In the figure the blue bars indicate the waiting times of vessels, calculated from all the anchorage events with negative values filtered out. The orange bars are the subset also used in in other analysis, as these are container vessels with only a single berth visit. For this last subset the average waiting time is about 15.6 hours whereas this is 17.4 for the whole set.

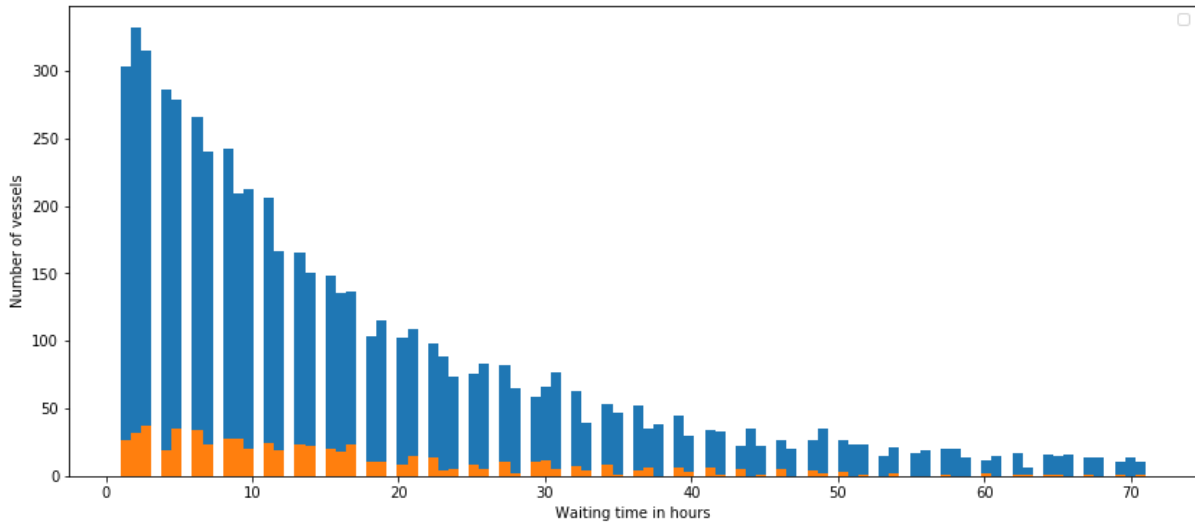


FIGURE 20: HISTOGRAM ON THE NUMBER OF VESSEL AND THEIR WAITING TIME

5.2.2. JOURNEY LENGTH

Through the given data it is slightly harder to determine how far vessels have sailed before they actually arrive at the port. This is an important parameter as the time to sail to a port has big implications on the potential to save fuel. When taking Rotterdam vessels leaving from Antwerp will have almost no time for slow steaming. Based on the expert opinion one in every five vessels has Rotterdam as first port of call. This means that sailing to Rotterdam will take more than a week and has therefore higher saving potential. This also means that the other four out of five ports are considered to be quite close to Rotterdam, for example large container ports such as Felixstowe, Antwerp, Goteborg, or Bremen.

The dataset has many events on the estimated time of arrival of the vessel at the port which could be used to get an indication of the time of journey. When comparing the first record time, the time this event was registered, of a vessel with the estimated time it will arrive an idea of the timeframe can be given. This means that if the record time is 20 days in advance both the terminal and vessel know the vessel will come, this could potentially be more time for slow steaming. Even though vessels visit other port in the vicinity of Rotterdam they could anticipate delays. For example travelling to Antwerp before Rotterdam and knowing that the terminal in Rotterdam will be delayed could be a reason to renegotiate a time window at Antwerp. In Figure 21 the difference between the first record time and event time are shown in days. The graph indicates that most of the vessels will have an estimated five days in advance whereas the average is close to nine days. When sailing for five days at 15 knots an overall distance of 1800 knots would be covered, which from Rotterdam would be somewhere on the edge of Europe. This last one is however the first estimate at the boarding place that can be made before departing from a port in the vicinity of Rotterdam.

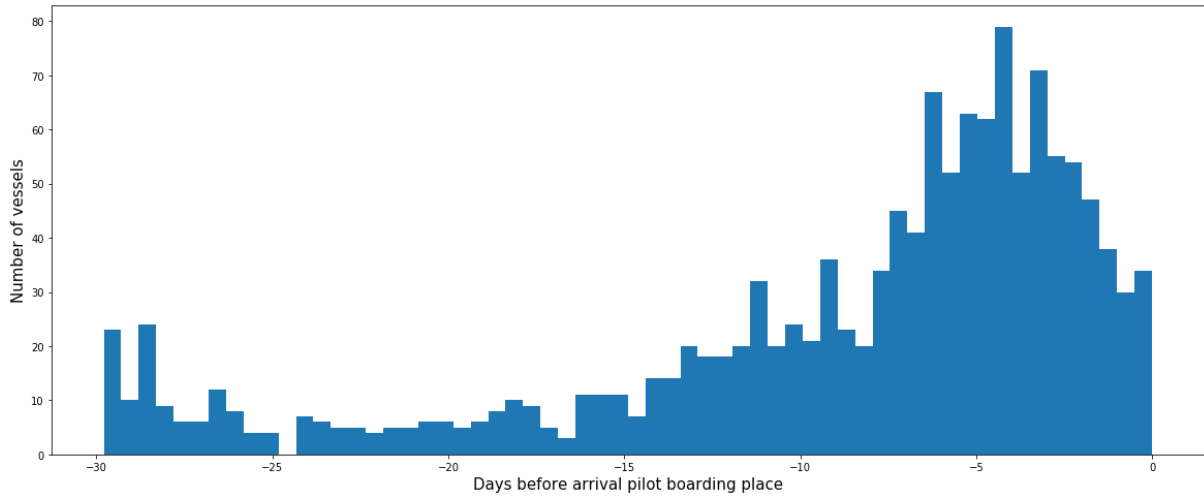


FIGURE 21: HISTOGRAM ON TIME OF FIRST EVENT BEFORE ARRIVAL

FUEL CONSUMPTION DURING THE JOURNEY

For this research a more simplistic approach for the fuel consumption will be used, since there are many variables that affect consumption. Consumption is a function of speed, the displacement, and engine. Classical marine information books have elaborate equations to calculate the specific fuel consumption which often depends on engine characteristics. An attempt is made (Mersin, Alkan, & Mısırlıoğlu, 2017) to estimate the fuel consumption in a more general way with the following formula:

$$\text{Let } \nabla(t) = \left[\sqrt[3]{\nabla(0)} - \frac{\lambda * v^3 * t}{3} \right]^3 \text{ be the displacement in tonnes}$$

$$\text{Let } F(v) = \lambda * v_{ij}^{\Omega} * \nabla^{\frac{2}{3}} \text{ be the fuel consumption in liters per hour}$$

| Parameter | Meaning |
|-------------|--|
| λ | Engine specific parameter |
| v | Speed in knots |
| ∇ | Displacement of the vessel |
| $\nabla(t)$ | Displacement as function of time, through fuel consumption this will decrease. |
| $\nabla(0)$ | Initial displacement of the vessel |
| Ω | Constant which is between 4 and 4.5 for medium to very large container vessels |
| t | Time elapsed in days |

TABLE 7: CONSTANTS AND UNITS FOR EQUATIONS OF DISPLACEMENT AND FUEL CONSUMPTION

Whereas the classical equation mentioned by Mersin et al (2017) is as follows:

$$\text{Let } F(t) = \frac{t}{24} * \lambda * v^3 * \nabla^{\frac{2}{3}} \text{ be the fuel consumption in liters per hour}$$

With fuel consumption as a function of time with time in hours and consumption in tons. For this research this rather simpler form will be used. Each vessel in the simulation will get an average displacement and lambda which will remain the same throughout the journey. In the data available

however there is no displacement available, and this means that an approximation for the displacement is required. When comparing the dimensions of the vessel with each other (Appendix IV) it becomes clear that capacity and dimensions do not have a linear correlation. When taking the upper right correlation from the pairplot in appendix IV a figure similar like the one in Figure 22 can be seen. The data and graph of the correlation between vessel length and vessel capacity in TEU will be used. In Figure 22 however, faulty vessels have been removed and in return vessels of around 400 meter long have been added. This data will be used as input to determine the displacement as a function of length.

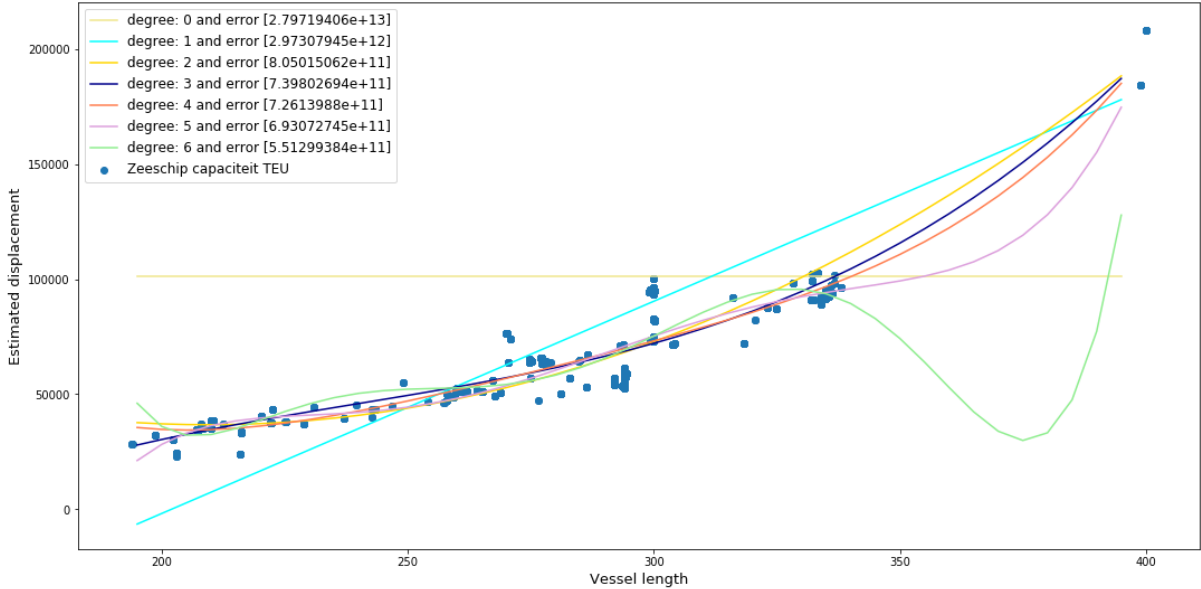


FIGURE 22: INTERPOLATION FOR VESSEL DISPLACEMENT EQUATION

Polynomial interpolation with different degrees will yield the lines shown in Figure 22. The error calculated is the sum of the square of each residuals. For the most extreme lines such as degree zero and seven the fit is very bad. With degree zero an approximation is tried with a horizontal line indicating the capacity would be constant. On the other extreme with degree six the line is heavenly overfitting the data especially between length 350 and 400 a very deep dip is observable, partly also because of faulty data⁶. For the modelling the dark blue line will be used, this one seems to fit the data well and only has a third order function. Intuitively a third order polynomial would also make sense as bigger ships are not only longer but also deeper and wider thus having effect in three dimensions. The function returned by this polynomial fit is as follows:

$$D(L) = 0.0232995669 * L^3 - 16.784636 * L^2 + 4383.22324 * L - 361315.98$$

| Parameter | Meaning |
|-----------|--------------------------------|
| D(L) | Displacement as function of L |
| L | Length of the vessel in meters |

TABLE 8: VARIABLES FOR THE FUNCTION OF DISPLACEMENT IN SIMIO

This function has been checked by random checking some variables, so the highest and lowest values have been compared to actual displacement of comparable real life containers vessels just like some

⁶ When verifying some of the vessels the length found from the port of Rotterdam data did not match that of the data from marine traffic.

other vessels. Besides different vessel designs and therefore varying displacement per length the approximation seems to be in bounds.

Putting all the functions together and integrating the displacement into the fuel consumption a performance map of speed versus fuel consumption can be made (Figure 23), this is however only the envelope for vessels between 200 and 400 meter. According to Notteboom (2009) there are four distinct speeds that are used in the marine industry:

- Normal: between 20 and 25 knots, the design of the hull in combination with engine performance will yield an optimal cruising speed.
- Slow steaming: between 18 and 20 knots, less fuel is burned but at the expense of longer travelling times. About 50% of the vessels were using this speed as of 2011
- Extra slow steaming or economical speed: between 15 and 18 knots for minimal fuel consumption while still delivering a decent commercial service.
- Minimal cost: between 12 and 15 knots, the lowest speed technically possible, reducing speed any further will only come at the cost of service.

The given speeds are therefore also used in the model, this means that the minimal speed will be 12 knots and the maximum speed 25 knots, which however comes at significantly higher fuel expenses. (Notteboom & Carriou, 2009)

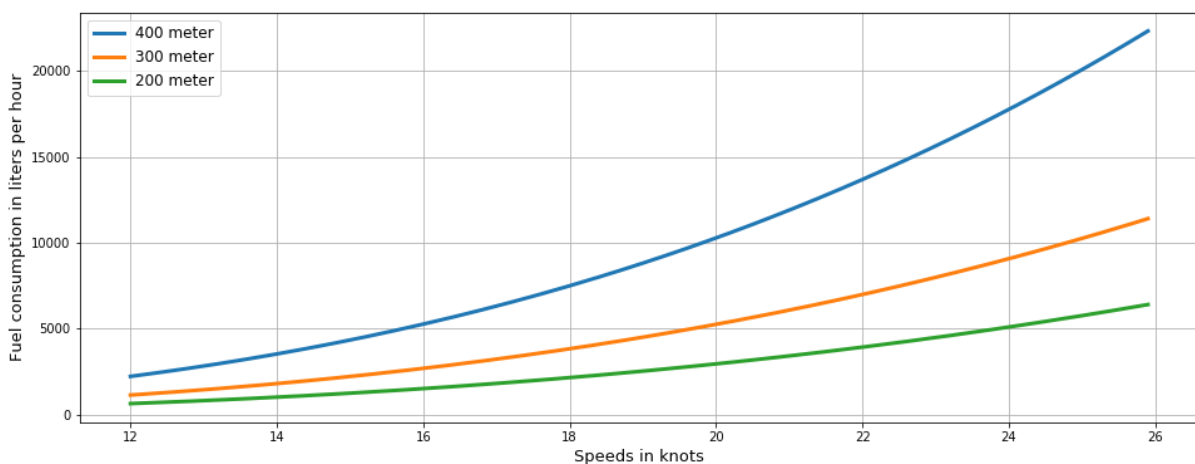


FIGURE 23: APPROXIMATION OF FUEL CONSUMPTION UNDER DIFFERENT SPEEDS

CURRENT ACCURACY OF ARRIVAL ESTIMATES

Implications of information sharing are twofold, at first sharing of data should be done, next the accuracy of the data should adhere to a certain standard. According to Bac (2018) many of the operations in the port are dependent on reliable data which is scarcely available. Due to the lack of accurate data it becomes harder and more strenuous to plan further in advance, therefore events can sometimes only be predicted accurately two hours in advance. Within the available data there is one terminal with a limited number of port calls that include both actual times of arrival and their estimate times of arrival. This data can be plotted to see how the estimates change over time with regard to the actual time of arrival (Figure 24). To calculate this the interval is defined as the difference between the actual time of arrival and the time the estimate has been made which is the record time of the estimate. The accuracy is then defined as the difference between the estimate time of arrival and the actual time of arrival. When the actual time is larger and subtracted from the estimate a negative time

will be returned indicating a delay. Furthermore the dots in the graph have been linked to the vessel size.

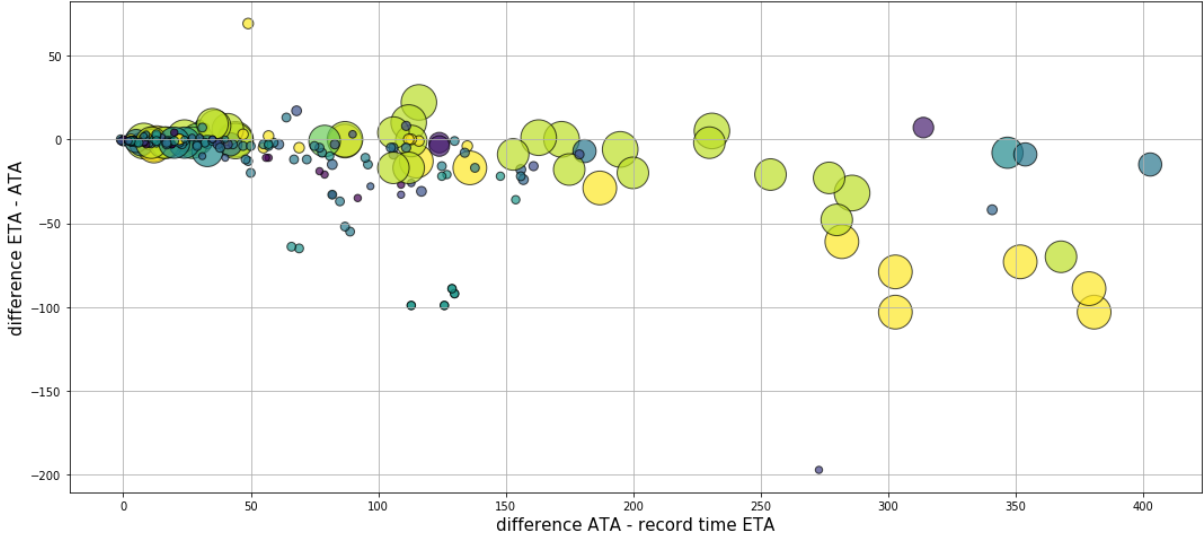


FIGURE 24: ACCURACY OF ESTIMATED ARRIVAL AND ACTUAL ARRIVAL

For this research the scope is reduced to a journey of 680 nautical miles which has a different time scope. When only considering the vessels within 48 hours from the port, which is the same as two days, Figure 24 can be reduced to the following Figure 25. These are the points on the far left that are closer to the port and therefore more accurate. In general the larger vessels plan farther ahead and slightly more accurate. The higher accuracy can be accounted for by the routine these vessels have whereas the smaller vessels have smaller time windows and more varying operations.

To include the effects of inaccurate information the accuracy of the vessels within 48 hours of the port has been divided by the time until berthing. This calculation yields the inaccuracy in percentages of the estimates depicted in Figure 26. One might expect that the accuracy will increase as the vessel comes closer to the port, and this is partly true, so the absolute error of the estimates will decline. However the relative error remains approximately the same, an hour difference close before the port will have an higher impact than an hour of difference 2 days before berthing. The average inaccuracy of all port call 2 days before berthing is 13%.

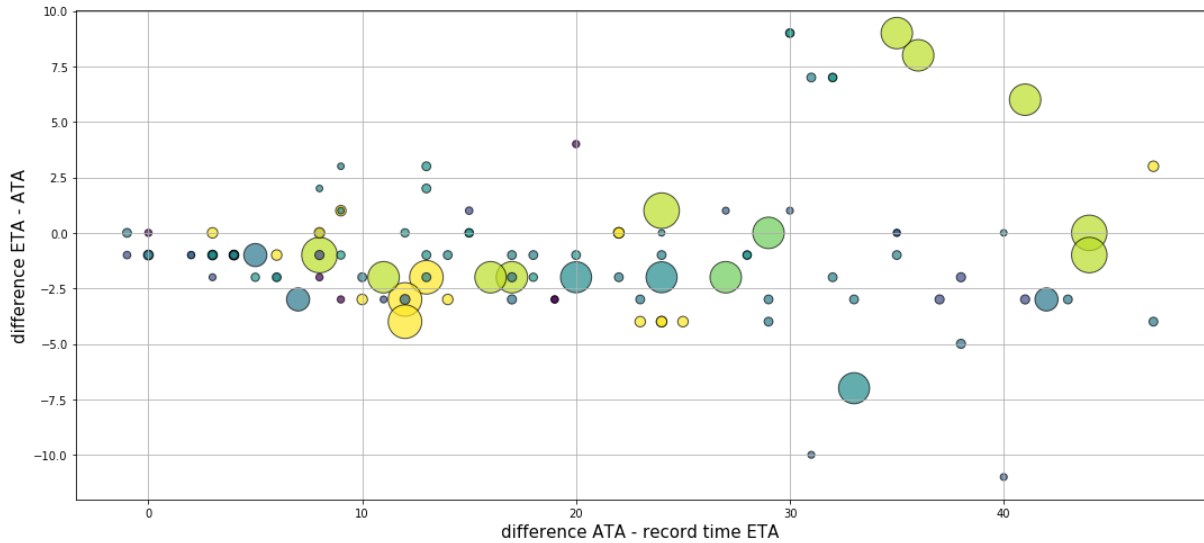


FIGURE 25: SMALLER TIME WINDOW ON THE ACCURACY OF ESTIMATED TIME OF ARRIVAL

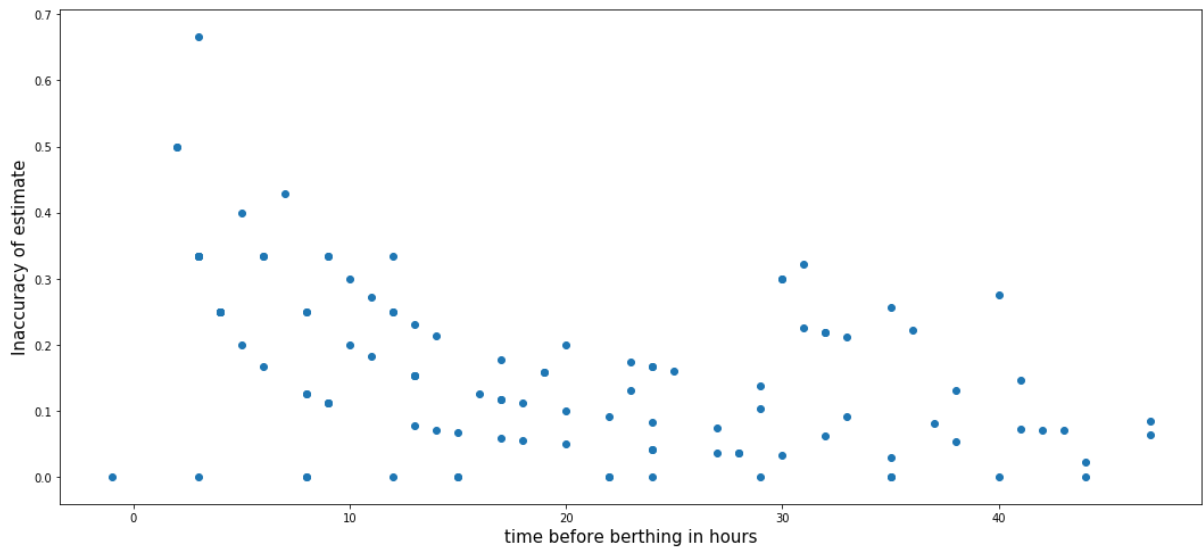


FIGURE 26: INACCURACY OF ESTIMATES WHEN CLOSER TO ACTUAL ARRIVAL

5.2.3. TERMINAL OPERATIONS

This research has a higher focus on the implications of data sharing among the different actors in the port call. This is why terminal operations are modelled quite simplistic. One of the assumptions made for the model is that vessels will enter the port with a contract for service already set up. This means that to a certain extent it is already known how much time will be required for the number of containers shipped by the vessel. To prevent complete randomness and invalid numbers a concise analysis has been done on the container terminal operations in the port of Rotterdam. In the data available there are multiple sources that provide the actual times of arrival and departure from the berth. The three main sources are a prediction algorithm, HaMIS, and the terminal itself, however because of the extremely low number of events provided by the terminals these events will not be used for the analysis. Only one terminal provided both ATA and ATD times, but only for about 60 visits. The number of complete visits by the prediction algorithm and Hamis however are respectively 3000 and 40500. In the two Figure 27 and Figure 28 the berths visits are plotted. Berth visits are calculated as the difference of departure minus the arrival of vessels taken in hours. To filter only the relevant

visits data about actual times has been merged with the single berth visits and container vessel visits. Furthermore data has been cleaned by dropping duplicate numbers and negative berthing times. To give the figure an extra dimension colours have been linked to the length of the vessel. What we can see here is that the variation with the number of containers is larger with longer vessels, probably due to their higher capacity that will not always be utilised.

At first glance it seems that there is a certain correlation between the time at berth and the number of containers moved. When applying a linear regression to the Hamis data the following function is returned when taking 80% of the data points as training points:

$$\text{Let } B(N) = 0.00470523 * N + 10.50770892 \text{ be the berthtime in hours}$$

| Parameter | Meaning |
|-----------|----------------------|
| B | Berth time |
| N | Number of containers |

TABLE 9: VARIABLES FOR THE BERTH TIME FUNCTION IN SIMIO

This linear regression has a variance score of 65%, which is not extremely good compared to a perfect score of 100%. Also the Mean squared error of 71.74 seems a bit high which could be accounted for by high outliers. Taken together this does not perfectly resemble operations but does give a better insight in what is to be expected. For the model an extra variable or randomness could be introduced to create the variance in the berth time, either due to delays or service agreement.

However in a previous section vessels for this research have been placed in four categories having a certain distribution for the number of containers moved. Since the number of containers moved will not be higher than 4899 a different regression will be done. In the new formula the standard time at the berth is reduced with about 2 hours. With this new slice of data the average time at berth has also been reduced to 20.4 hours.

$$\text{Let } B(N) = 0.00621791 * N + 8.05667609 \text{ be the berthtime in hours}$$

For the linear regression data from the Hamis source was used because the graph from the prediction algorithm still shows some notable points. When looking at Figure 28 at some places on the graph it seems that a lot of vessels loaded an equal amount of containers with a very high frequency in the handling time. Since according to the data close to 7000 containers were moved in close to 0 hours at berth this data was not used for the linear regression. Explanations for these irregularities could be insufficient cleaning of the data, too much events for a single visit therefore including a single berth multiple times at different handling times, or irregularities in the prediction algorithm. In the last case vessels might still move while already moored which would mislead the algorithm in saying that is has not yet been moored.

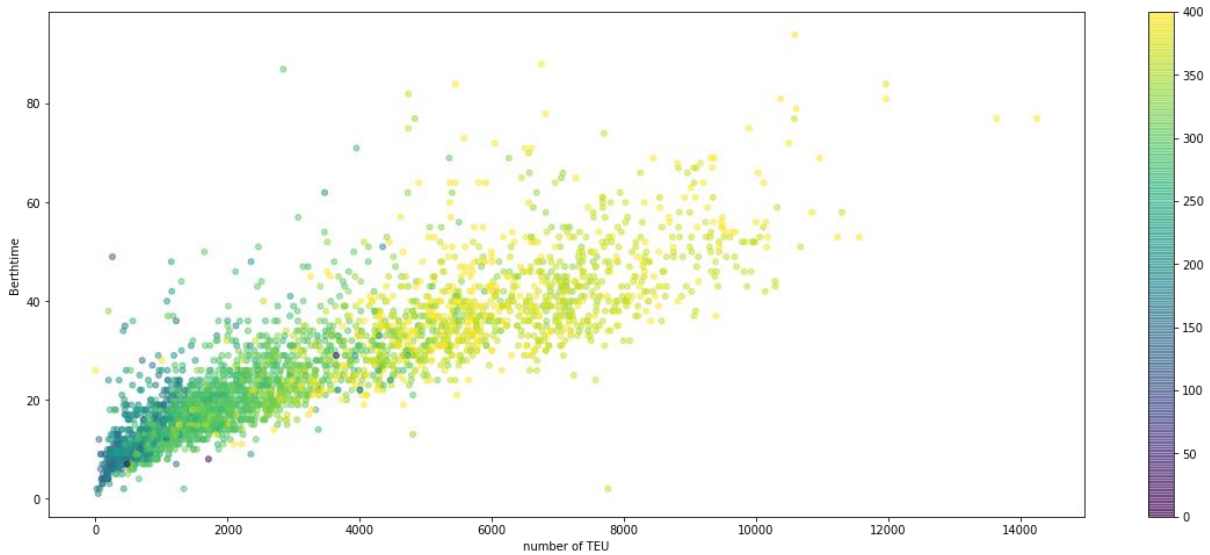


FIGURE 27: CORRELATION NUMBER OF CONTAINERS AND BERTHING TIME HAMIS DATA

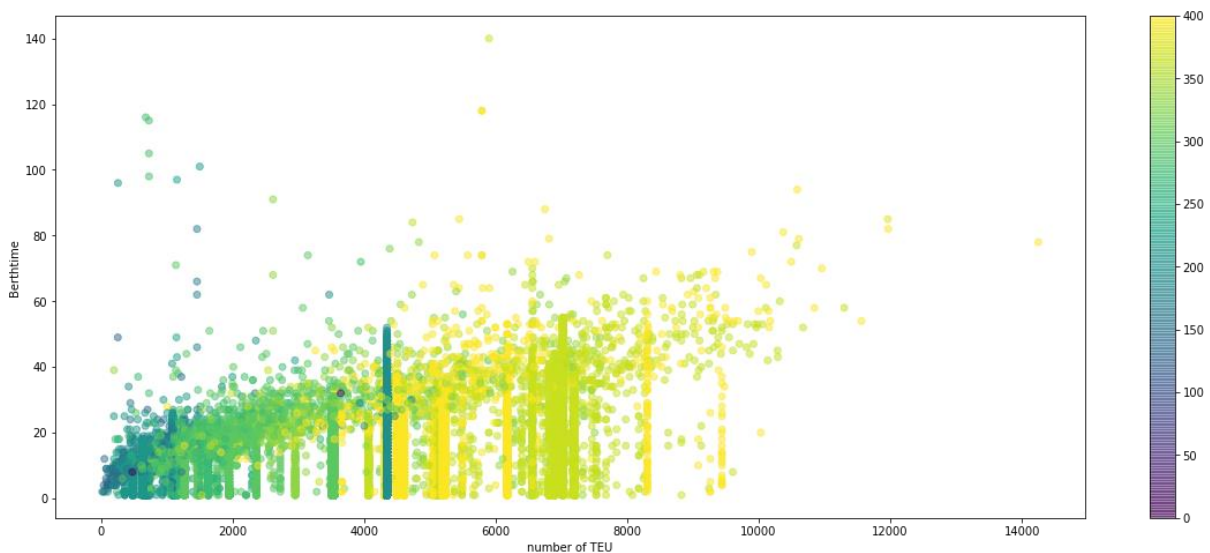


FIGURE 28: CORRELATION NUMBER OF CONTAINERS AND BERTHING TIME PREDICTION ALGORITHM

The high variance in berth time can be accounted for by multiple causes. For example some vessels might have been delayed by the cargo operations. As discussed before the number of cranes that work on the vessel has an immense impact on the handling time, and better contracts will therefore also generally yield shorter berth times. Another option would be that both the vessel and terminal are not in a hurry, either due to planning or reparations and other services on the vessels that require it to be at the quay for a longer time.

5.2.4. PILOTAGE DISTRIBUTION

For the distribution of pilotage the difference has been taken between the estimated time and the actual time of the pilot on board. This information is retrieved from the online data environment through the query listed in the appendix. These arrival times originally come from the Gids database used by pilots. Actual times are filled in by the pilot through an application installed on a mobile device. When filling in this data by hand some differences can emerge between pilots, for example one pilot submits the departed time when lines are loose, whereas another pilot might start when he gets on board and has all his instruments installed. Perhaps pilots could also forget to fill in the actual time and

in hindsight make a guess, all because it is administrative process that is not an operational necessity for berthing or unberthing a vessel. When plotting a histogram of the differences between the actual arrival and estimates arrival the outcome seems confusing (figure 28).

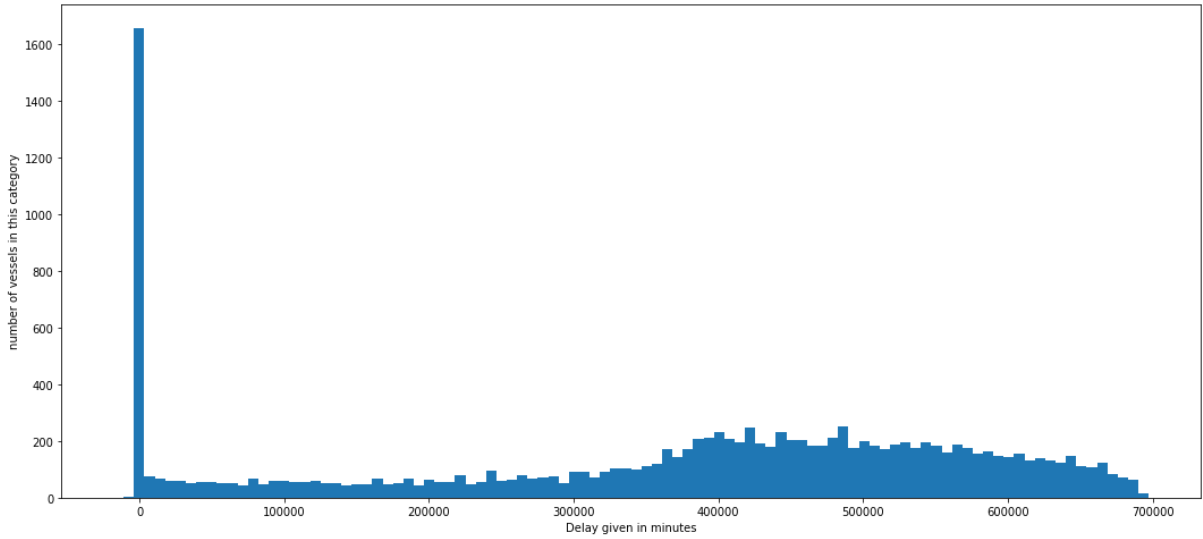


FIGURE 29: TOTAL SCOPE OF DELAY IN PILOT ARRIVAL

It appears that differences can reach inaccuracies of up to 700000 minutes which roughly translates to a delay of seven weeks. Therefore zooming in to a timeframe of 240 minutes, equivalent to 4 hours, will yield a completely different view (Figure 30). As pilots have the obligation to enter an incoming vessel within three hours before request, the timeframe of 4 hours seems fair. This actually returns an average of 1.4 minutes too early with a variation of 45 minutes. If the distribution were to be taken wider the variation would only increase due to some rare outliers. To arrive at these values the following formula has been used:

$$\text{Let } d = e - a \text{ be the difference in minutes}$$

| Parameter | Meaning |
|-----------|-----------------------------|
| d | Difference in time |
| e | Estimate of time of arrival |
| a | Actual time of arrival |

TABLE 10: PARAMETERS FOR CALCULATING DELAYS

This means that when the pilot is late the actual time will be larger and negative numbers indicate delays of the pilot. With the previous in min looking to the right, pilots being on time, it appears that some pilots can be at the vessel three hours before estimated.

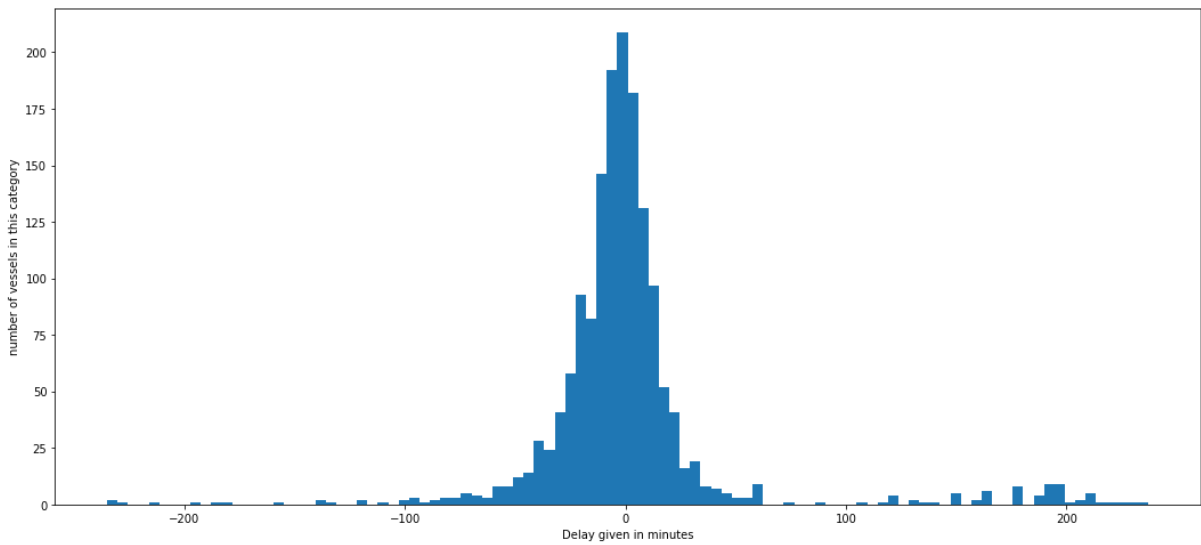


FIGURE 30: DELAY OF PILOTS ON ARRIVING VESSELS

In comparison to the arrival times the departure times are far less uncertain. In Figure 31 a very high difference density can be seen just beyond 0 minutes. This means that on many occasions the pilots are just in time. On average pilots leave 3.2 minutes before the estimated departure with a standard deviation of 11.7 minutes.

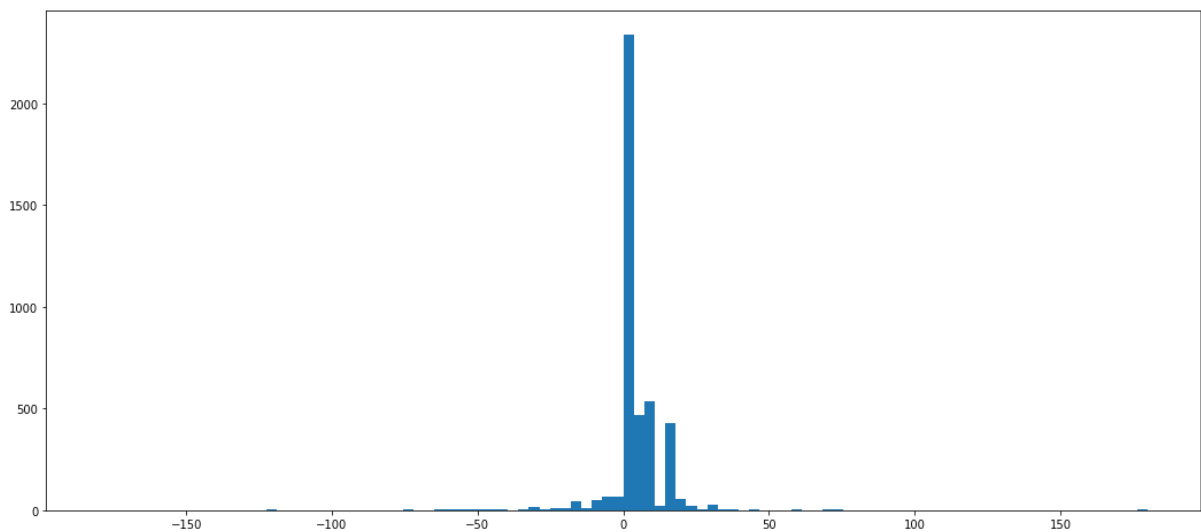


FIGURE 31: DELAY OF PILOTS ON DEPARTING VESSELS

When taking a look at the different pilot arrival differences it appears that in arriving vessels there is more variation and that pilots have a higher chance to be late. This seems quite odd and contradictory to what experts in the field say. Since arriving vessels are known far in advance and timely preparations can be met to get a pilot on board. Whereas terminal operations can sometimes be a bit less predictable due to delays, pilots do seem to be always on time here. Perhaps differences can be accounted for by other reasons. For example, departing vessels are of course in the port itself, closer to the main station where pilots wait, ready for operations. With arriving vessels pilots could also be delayed through delays in previous operation, for example a vessel that has not departed on time from the terminal or perhaps the availability of mobility to get pilots aboard of vessels to be piloted.

5.2.5. Bunker parameters

According to an expert opinion many of the bunkers arrive on arrival of the container vessel. This means that bunker operations could be ready to commence as soon as the container vessel is moored. However it might sometimes still happen that bunker barges are too late. Reasons for this can vary a lot, either by delayed operations somewhere or else of a last minute change in the bunker pickup if it is cheaper somewhere else (Bac, 2018). With the data available it is a bit harder to exactly determine how many of the bunker operations are too late. In the port it is mandatory for the bunker to communicate its arrival and start of bunker operations to the port authority. In case of an emergency or accident the port authority will immediately know if there are bunkering operations happening close by. But since departures or completion of bunker operation are not necessary to report to the port authority it is almost impossible to use the HaMIS data for determining bunker processes that have caused delays.

In determining the delays caused to late bunkering it would be best to compare the time of completion of the bunker with the planned or estimated time of departure of the vessel. Data of finished bunker operations are captured through a prediction algorithm that checks whether the bunker vessel is still aside the container vessel. Planned and estimated times are useful in this case as this is the time actors expect the vessel to leave and is made before actual bunkering. However good data regarding estimated or planned departures is quite scarce. For example one of the terminals has almost 200000 rows with estimated departure times but these remain useless without a portcall id. Portcall id's are necessary to couple data tables as these represent unique codes for every vessel visit in the port of Rotterdam. When trying to merge the data of all estimate/planned departure events with that of container vessels that visit a single berth only 12 unique portcall id's are returned which is too little to draw conclusions from.

Without further research the previous analysis might raise the idea that large container vessels do not bunker in the port of Rotterdam. This statement is however false since there are many more matches between the event data of actual departures and the completion of bunkering. In Figure 32 the difference is taken between the actual departure and completion of bunkering. As the actual time of departure has been subtracted from the bunker completion time the negative time in hours represents how many hours after completion the vessel departs.

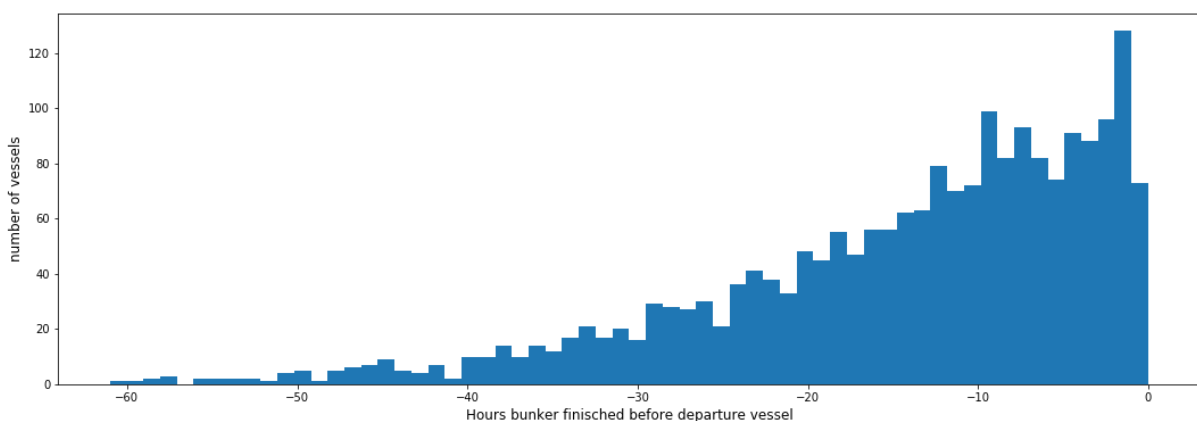


FIGURE 32: HISTOGRAM ON THE NUMBER OF HOURS BUNKERERING WAS DONE BEFORE DEPARTURE OF THE VESSEL

The Figure 32 tells that in many cases the bunker leaves the vessel often just before its departure. In this case it is not clear if the late bunkering is planned and just in time or whether it is a reason for delay at the terminal. However about 10% of the container vessels still have a bunker alongside 2 hours before departure. This could be taken as a proxy for the number of vessels that are delayed due to

bunker operations. Since this data does not reveal anything about the length of the delay this information is acquired from an expert. According to a former operations specialist at one of the terminals delay will often be around an hour and not exceed 1.5, but perhaps this is also dependent on the terminal, as mentioned before older and longer operating terminals have more routine and are therefore often less delayed.

5.3.DISTRIBUTIONS

With the data analysis in the previous sections the model can be fed with appropriate values for experiments. In the table presented below the different parts of the model and or journey are discussed and how these will be implemented in the model.

| Event | Implications for the model |
|-----------------------------------|--|
| Vessel arrival | <p>With a continuous quay length and variable vessel sizes the assumption of a discrete berth makes it slightly harder to assume one fixed value of vessel arrivals. However with an average berth time in Rotterdam of 20 hours this can be used as upper limit. That means an interarrival time higher than 10 hours for the operation of two berths.</p> <p>Variation in arrival will then come from the distribution in arrival times and the probability of vessel delays. In the model 50% of the vessel will have a delay of up to 5 hours.</p> |
| Vessel length | All vessels generated will be somewhere between 200 and 400 meters long. Exact generation will be done with a random triangular distribution where the average vessel equals 330 meters, this will be taken as the mode. |
| Moves per category of ship | <p>Vessels incoming to Rotterdam are divided in four equally wide baskets of 50 meter starting at 200. For every group there is a range of moves that can be made that is as follows:</p> <p>Group 1 is between 203 and 809 moves, group 2 is between 531 and 1731 moves. Group 3 is between 1089 and 3195 moves. And group 4 is between 2829 and 4899 moves.</p> |
| Waiting at anchorage | In the current situation the average waiting time at anchorage is 15.6 hours. This is an important parameter to tweak the model to the current situation as is. |
| Journey length | For the journey from entering the model to the berth 50 nautical miles are covered before the delay, 600 until the pilot boarding place and another 30 from the pilot boarding place to the berth totalling a journey distance of 680 nautical miles. |
| Fuel consumption | <p>For the fuel consumption a general simplified model will be used.</p> $F(t) = \frac{t}{24} * \lambda * v^3 * \nabla^{\frac{2}{3}}$ $\nabla = 0.0232995669 * L^3 - 16.784636 * L^2 + 4383.22324 * L - 361315.98$ <p>'t' here is taken as the time in hours. Furthermore the lambda coefficient is that of a steam engine⁷ thus not distinguishing between fuel types.</p> |

⁷ Note to self: Ask john for the source

| | |
|--------------------------------------|--|
| | At anchorage 15% fuel consumption of the initial speed is assumed. When vessels enter the model an initial speed of 17 knots is assumed. |
| Accuracy of arrival estimates | <p>In real life the estimates of arrival do get updated every now and then but often remain inaccurate. With more accurate information it would be easier to sail at the correct vessel speed. It is therefore that 'noise' will be added to the model. By multiplying the estimate time by a certain inaccuracy the effects of accurate information can be tested.</p> <p>The analysis found that the current inaccuracy of estimates is around 10 percent.</p> |
| Terminal operations | <p>For this research the main emphasis is on the mechanism and consequences of data sharing and it is for that reason that the terminal is modelled under many assumptions. For berthing time an analysis has been performed on data of large vessels in the port of Rotterdam. When linearly correlating the number of TEU units to be moved with the time at the berth the following function is found:</p> $B = 0.00621791 * N + 8.05667609$ <p>Furthermore the requested time will deviate according to a probability defined in the properties. Once the actual time window deviates from the requested one the vessel might be able to depart the berth after 90% of the requested time which means operations have finished early. Or operations finish at 115% of the requested time, which means the that the vessel will have a 15% delays with regard to the original requested time.</p> |
| Pilotage distribution | The combination of data analysis and the expert opinions give a slightly contradicting image of the piloting services. The hypothesis would be that departing vessels would have more delays than arriving vessels since the last category are known to arrive far in advance. However new vessels cannot berth when the previous vessel has not yet departed. In the data analysis almost none of the departing vessels have a delay, it is therefore that departing vessels will seize nautical services far in advance and arriving vessels can only seize nautical services that are available. |
| Bunkering | With the data given it is rather hard to determine the exact amount of vessels that is delayed due to later bunker operations. The same yields for the amount of delay. Through a combination of the actual time of completion of the bunkering and departure of the vessel a 10% chance for delays will be used. Also delays will not exceed two hours based on an expert opinion. |

TABLE 11: SUMMARY OF PARAMETERS AND FUNCTIONS FOR THE MODEL

In the beginning of this chapter it was mentioned the single parameter distributions would have the preference for implementation. However in the end this might not be completely true. In particular for the number of containers the distribution changes. For a given length of the vessel the distribution of number of containers will change. Making it more of a sequential distribution where first the length is assigned according to a probability and then given the length a number of containers is assigned to the vessel.

6. MODEL CREATION, BOUNDARIES AND ASSUMPTIONS

In chapter 4 the main outline was given of how the model would look like. This chapter will elaborate on the model made and what logic is used for each of the actors.

Below is a first glance of how the implemented model looks like. In the next paragraphs special parts of the bigger model will be highlighted. Furthermore this chapter focusses on the mechanisms designed in the model and not on the quantitative side of the model as the numbers for the parameters have already been discussed in the previous chapter.

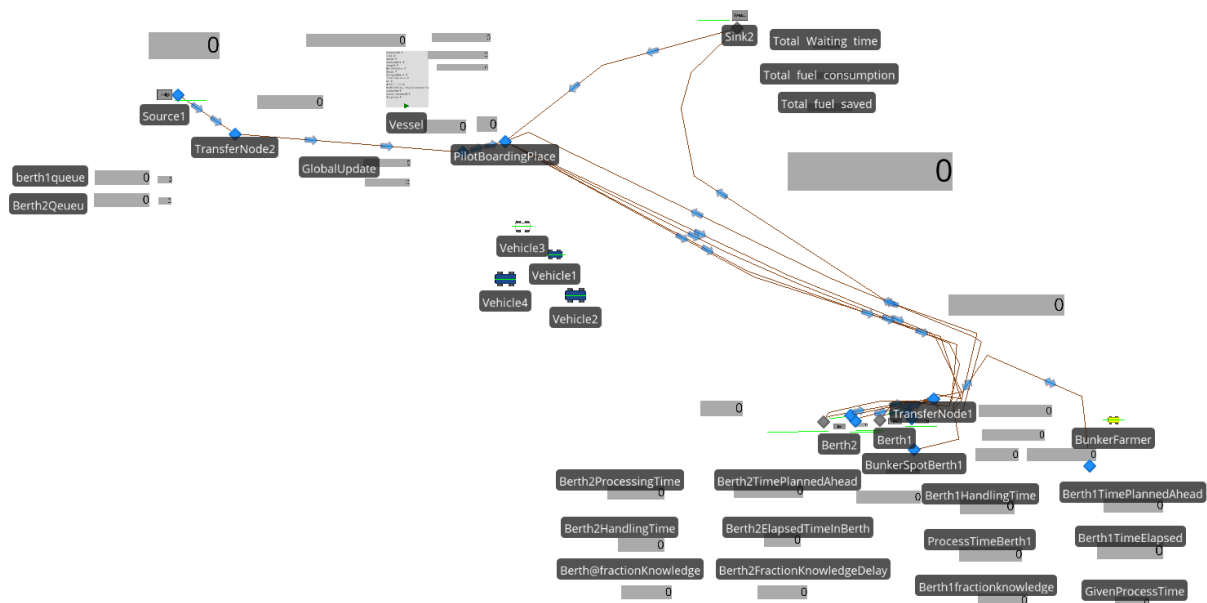


FIGURE 33: REPRESENTATION OF THE MODEL USED

The next parts will focus on the algorithmic logic for different actors or situations in the port call process. In general the method for data sharing is relatively the same for different parameters. Namely data of a particular event or vessel is stored per vessel or global parameter. In this case when data sharing is enabled an algorithm can consult this global variable or just refer to a vessel in front or after it. So data will always be available somewhere but depending on the model levers and settings it will either be used or not. Though the use of timers the interval of sharing can be manually set, which can vary for different processes. These timers will then trigger a particular process on a certain time interval to initiate data sharing.

6.1. VESSEL

As mentioned before a vessel is modelled as a combination of the agent, captain, and vessel. That means that as soon as information becomes available this will be used to undertake action, and no delays in sharing have been included. The purpose is to show the effects of data availability and how this can affect different KPIs. It is therefore a deliberate choice to leave out the softer aspects of delays in sharing and whether it would even be legally possible to share this data.

6.1.1. VESSELS ENTERING THE SCOPE OF THE MODEL

When referring to the model map in figure 32 there is a *source* at the far left. This is the place where the vessels will enter the model. This is the about the average journey distance of large container vessels arriving at the port of Rotterdam. In the source itself vessels will be created according with a

triangular distribution of (7,14,20), meaning there the minimum time between two vessels equals 7 hours, the maximum 20, and the most likely difference is 14 hours. A triangular distribution has been chosen because this one has absolute bounds on the lower and upper side, this means that one particular outlier will never get a negative value. A larger spread in the upper and lower bounds of arriving ships mimics the uncertainty with which vessels come to the port of Rotterdam. Furthermore the nature of such a distribution can also influence the model, by increasing the mode more vessels will arrive, whereas increasing the spread of the edges will increase the variance.

The vessel length will be somewhere between 200 and 400 meters long. Depending on the length of the vessels the number of containers will be assigned where the variation in number of containers increases with the length of the vessel. Eventually the requested time which is equivalent to the service level agreement, the expected and agreed time at the berth. In the last block the length of the journey will also be assigned to the entity as this will help simplify logic ahead.

6.1.2. ASSIGNING A BERTH TO THE VESSEL

During the journey the vessel will get a berth assigned after a certain time, this can be varied depending on the flexibility of the terminal. For example terminals with predominantly AGVs will have more flexibility and can assign berths later⁸. After assignment of the berth the vessel will be assumed to be dedicated to this berth. Assignment of the berth will be done according to the logic given in appendix VI. First a count will be made of all the vessels that have already been assigned to berths, this is done in the first two steps and based on the vessels ahead, their requested times and the time until the berth is available. Next the algorithm will start looking for the vessel with the lowest "NumberInSystem", this is the next vessel in line to get a berth assigned. This vessel will consequently get the berth assigned with the lowest queue.

In case of berth 1 a probability of bunkering will also be given including the bunkering length. This is a lever that can be controlled, however this lever also means that the vessel will get delayed due to the bunker operations. Bunker operations that do not affect the departing time of the vessel are less interesting, therefore the assumption has been made that a bunkered vessel is delayed. In this case there is a probability of bunkering but also a triangular distribution for the length of the delay.

6.1.3. UPDATING OF VESSEL SPEED.

In this model there are two algorithms that can influence the speed of the vessel. The first algorithm is utilised for vessels that have already been given a berth and will therefore depend on the vessels going to the same berth and operations at that berth. This algorithm will be discussed under the sub paragraph of terminal.

The second algorithm is used for early green steaming and focuses on those vessels that have not yet been assigned a berth. The logic for this algorithm is given in Appendix VI. If the lever for early green steaming is turned on the process will start looking for vessels that have not been assigned a berth. When a vessel has been found its current estimated time of arrival at the berth will be compared to the vessels before it and the queues of berth 1 and 2. Purpose of the algorithm is now to check if any of the berth queues plus half of the requested times of earlier vessels without berth is larger than the estimated arrival time. Since the berth of earlier vessels have not been allocated it can go to either berth therefore increasing the expected queue length with half the requested time. If the smallest of

⁸ Terminals that employ Automated Guided Vehicles are more constrained in the number of moves gantry cranes make therefore containers are spread more across the yard so that more gantry cranes can be employed. This wider spread in turn makes the position of the vessel at the berth more flexible.

these queues is larger than the estimated time of arrival then the vessel is encouraged to slow down. Calculation of the advised speed is done as follows:

$$\text{Let } Sa = \frac{(A - D)}{\text{MIN}(Q1, Q2)} \text{ be the advised speed where } Q1 \text{ and } Q2 \neq 0$$

Let $Sv = \text{MAX}(Sl, \text{MIN}(Sgs, Su))$ be the speed of the current vessel with green steaming

| Variable | Meaning |
|----------|--------------------------------------|
| Sa | Speed advised in knots |
| A | Distance ahead |
| D | Total Distance Travelled |
| Q1 | Berth 1 queue |
| Q2 | Berth 2 queue |
| Sv | Speed of the current vessel in knots |
| Sl | Speed lower limit in knots |
| Su | Speed upper limit in knots |
| Sgs | Speed green steaming in knots |

TABLE 12: VARIABLES USED FOR CALCULATION OF VESSEL SPEEDS

The aforementioned equations are put in the last two assign steps in the early greens steam logic. Since the vessel is farther away from the berth the upper and lower limits of operational speeds can be set differently, for example a vessel will only be mildly encouraged to increase speed, an upper bound is held to incorporate possible effects of delays at the berth.

6.2. TERMINAL

The following sections will elaborate on the processes and logics created for the terminal, which include the updating of vessel speed, communicating of delay towards other vessels and the assignment of bunkering.

6.2.1. UPDATING SPEED OF ASSIGNED VESSELS

In the previous paragraph the early green steam algorithm was discussed, but from the perspective of the terminal and in particular the berth the vessel’s speed also gets updated. Depending on the update interval vessel speed times will get updated: the update interval can be changed and its default is every hour. The process logic is incorporated in the appendix. The logic works as follows: the first vessel, vessel A, in line for a berth will check her estimate time of arrival and the planned usage of the berth. If the estimate time of arrival is lower than the planned time of the berth the speed should be reduced. After vessel A comes B. However B will look at the combination of planned time for the berth and the requested time of vessel A. If the combination of requested time vessel A plus the berth planned time is larger than the estimated arrival time of B then B should reduce her speed. Consequently vessel C will take into account the berth time planned ahead and the requested time of vessel B. In addition to the requested times extra time for berthing and unberthing is considered.

In the row of vessels assigned for this specific berth a decision will be made to see if the berth is occupied, if true then the first vessel will change her speed. After that vessel A will get a parameter called *MinimalTimeTillService* and this constant is the requested time of the vessel B which is to be handled before A including the time until berthing from vessel B. And in turn vessel B is dependent on the requested time of vessel C and how long it takes C to get to the berth. In the model for a particular vessel the time of the berth planned ahead with the requested times of the vessels before it will be referred to as *MinimalTimeTillService*. Further in the process the minimal time till service will then be checked against the estimated time of arrival, and if the second one is higher the vessel will be advised

to change her speed. Just as in the early green steam algorithm there will be an upper and a lower bound on the speeds the vessel can take on. Formulas for the new speed are the same as in the previous paragraph.

6.2.2. ARRIVAL AT THE BERTH

Once the vessel arrives at the berth there are a couple of processes that will be triggered before the vessel will depart to her next destination. The first process is a general process that applies to both berths, therefore a decide in the first column will check where exactly the vessel is. The upper line represents the logic for berth one which is slightly more complicated due to the inclusion of bunkering logic. After the first step there will be another decide step to see if a vessel will be delayed or not. For the sake of modelling this is before the actual operations already determined. If there is a delay two different timestamps will be used, the handling time which is the actual time of operations including delay and the requested time.

The arrival at the berth also includes the delays of bunkering if these are set to active. When there will be bunkering the bunkering process will be triggered inside the arriving process. Under the bunker paragraph the exact logic will be explained.

6.2.3. UPDATE ON CARGO OPERATIONS

Both berths have an algorithm for sharing of delay times, if delay sharing is turned off arriving vessels will not be informed of the operational delay. If delay sharing would be turned on the interval of sharing will reveal a percentage of the delay relative to the requested time. What this means is that a vessel with a requested time of 10 hours and a delay of 5 hours will inform the next vessels that it is not delayed at the beginning of the cargo operations, but at 60% percent of the requested time so after 6 hours 60% of the delay will be revealed so the arriving ships know that operations have been delayed with $0.6 * 5 = 3$ hours.

This linear approach of data sharing has been chosen as it is not completely clear when delays will be available, for example exponential or negative exponential distributions could have been chosen as well. However the cause of a delay can be very wide, as well as the moment when this information is available. Therefore this linear approach has been used in which the knowledge of a delay becomes available over time.

6.3.PILOTING

In the model multiple vehicles area are available to transport the vessels from the pilot boarding place to the berth, and in turn from the berth back to the port exit which is represented by a sink. When the vehicle enters the server to be serviced a process is triggered that will order a pilot 3 hours before departure. This is done through a delay, so the time in the berth minus 3 is the time a pilot will be ordered. This is also the timeframe that is used in Rotterdam: within 3 hours there should be a pilot at the vessel. Through the data analysis it becomes clear that pilots are actually almost always on time, therefore the assumption is made that pilots do not have a delay in their operations.

However, a vessel can only enter the pilot boarding place when the number of vessels between the pilot boarding place and the sink is no more than four. This means that a vessel can only be serviced when a vessel from one of the berths has exited the system. Therefore any delay in berth operations will restrict vessels from entering the pilot boarding place.

6.4.BUNKERING

To include the dynamics of bunker operations some of the vehicles that are assigned to the first berth will also get bunkering. For the experiments bunker time can be specified, what the bunker arrival

delay will be, and whether these delays will be shared with other vessels. In the model the bunker is represented by a vehicle that gets a request to visit the bunker spot close to the berth, and the vessel will then have to wait for the bunker until it's finished before leaving. For this model regular bunker operations are not really interesting since these do not affect operations, cause delays or any other inconveniences.

As soon as the bunkering starts and the option for sharing of delay time is turned on the next vessels will be notified of the delay. When the bunker arrives at the vessels it is assumed that the end time is also known because the bunker will come with a predetermined load that has been agreed upon. This could be changed and added as another dimension of information sharing but is not incorporated into this model. When the option for sharing of delay is turned off the vessels coming to that specific berth will not be aware of the extra time needed by the vessel which in turn could yield higher fuel consumption and longer waiting times at anchorage for vessels still to come.

6.5. UNCERTAINTY OF INFORMATION

To include the uncertainty of information an extra feature has been included that will add noise to the simulations. With respect to the real world this feature represents the inaccuracy of information given to other parties. For example an estimated time of arrival is given but appears to be different in hindsight. For this model inaccuracies have been linked to the minimal time until service, as previously mentioned this is the minimal time the berth is occupied before it can handle a particular vessel, this time therefore also changes per vessel. When sharing data and calculating the new advised speed the minimal time until service will be multiplied with a certain inaccuracy. The factor is a random distribution around one with one plus or minus the probability as respectively the upper and lower bound.

7. VERIFICATION AND VALIDATION

Without any form of validation and verification outcomes of the model are often less credible and perhaps not accurate. It is for this reason that the model should be checked against reality and questioned whether it really simulates the situation it should and whether this is done in a valid manner.

7.1. VERIFICATION

Many different methods have been applied to see if the mechanisms made in the model are working as they should. In the following section these methods are discussed.

7.1.1. SIMPLIFIED MODEL

When starting with the general model the level of complexity is thus quite low and it is therefore easy to spot any irregularities and correct them in time. As the model progresses it becomes harder to verify whether everything is working as it should. At a certain point a main model has been defined, and this is an aggregation of many smaller models. In the first model only one berth was made, and after this was done working as it should the second berth was added. With regard to the information sharing algorithms were initially tested on the vessels bound for the first berth as soon as this started working it was also implemented for the second berth.

Smaller models that were made besides the model are for example the nautical services. These nautical services are only used from the pilot boarding place to the berth and from the berth to the port's exit. The mechanism that was tested here is that a vessel bound for departure reserves the nautical services in advance. Services are then moved to a point close to the berth and wait until the vessel is ready for departure.

Another smaller model on the side was that of bunkering operations. In a smaller bunker model a single berth was modelled where vessels would have a certain probability of bunkering. When entering the berth a trigger is sent to the bunker that would come to the vessel at the berth. This model was used to verify that the vessel could only leave when the bunker vessel would leave. Also when no bunker information was shared the newly approaching vessels were not allowed to sail for the berth.

Other smaller processes that are not directly related to the usage of vehicles of, servers, or nodes were sometimes also tested in smaller models. One of these processes is the adjustment of sailing speed. When a vessel moving on a path has such a speed that it would have to wait at the anchorage because the vessel ahead of it is not yet finished it should lower the speed. So the combination of distance to the vessel ahead and the requested time of the vessel ahead should influence the current vessel's speed.

7.1.2. ANIMATION

Since the model is built in a graphical user interface and not hard coded the visual help the see whether the model does what it should do. During the modelling often the animation is used to see whether the implemented mechanisms actually work. When data sharing and speed adjustment are toggled on the vessels should actually move slower through the screen. Also when nautical services are ordered by the vessel they should be close to the berth ready to pick up the vessel and guide it out of the port. The same applies for bunkering, when vessels at the first bunkering place are not completely bunkered they are not allowed to leave nor are the next planned vessels for the berth allowed to be at the berth. Furthermore a simulation time, the time elapsed within the model, of 10 weeks has been monitored at an accelerated pace to see if any strange occurrences happen over these 10 weeks.

7.1.3. STRESS TESTING

Relatively late in the modelling phase some stress testing was applied to see how the model functions under abnormal circumstances. Levers that could be used for testing are mainly the vessel interarrival time. Another method would be to change the terminal handling times. By reducing the interarrival time significantly the number of vessels and their requested time is too much for the capacity of the terminals. As expected a queue is created at the pilot boarding place. Due to this test an error in seizing nautical services has been discovered. Initially arriving vessels were allowed to continue to the pilot boarding place and wait there for nautical services to pick them up. However there would be situations that a new vessel was already at the pilot boarding place seizing nautical services. With insufficient nautical services available the departing could not always be picked up leading to invalid situations around the berth. The departing vessel would then wait at the berth waiting for the nautical services ordered by the vessel currently handled.

Through this method the operational speed limits could also be tested. For green steaming there is a floor on the speed, in other words, the vessels cannot go below a certain speed as this makes no sense operational wise. When there are too many vessels in the system and information sharing is turned on the vessels should not go below the minimum operation speed. Initially there were two main errors in the implemented logic here. First the dimension of the speed was not correct, because during test phase the metric system was used and instead of kilometres per hour the speed was expressed in meters per hour. The second error was in the correct implementation of the speed limits. In the model the speed is compared with a minimum and a maximum through the equation in chapter six. However in the testing phase the maximum and minimum expressions were switched.

7.2. VALIDATION

Besides the verification of structures in the model validation is done. Without validation the assumptions made might not be accepted. If invalid assumptions have been made outcomes of the model are less likely to be applicable to the real world and perhaps even false if modelled under completely invalid assumptions.

EXPERT VALIDATION

Throughout the research a lot of verification has been done with experts within the port of Rotterdam. On a two weekly basis updates were shared and feedback would be given. As soon as the model was close to being done a larger meeting with around 10 persons was held. All participants had different backgrounds, including an ex-employee from one of the terminals in Rotterdam, a former captain of bunker and passenger vessels, but also a developer of the pronto team. During the meeting feedback was given on the scope of the process, in some occasions more information should be included. For example the contracts were not included since the time at berth is assumed to be already negotiated before arrival.

On terminal operations important feedback was given with regard to the shore planning. An assumption was made with regard to berth planning. In the model vessels are dedicated to a particular part of the quay 24 hours before arrival. However this does not always hold true mainly depending on the infrastructure in the terminal. Manually operated cranes are in general faster than automated cranes, in these cases the containers to be loaded are more concentrated on the stacking yard. When the containers are all close to each other there is less flexibility in moving the container vessel along the quay as the berthing window approaches. On the other hand with more automated terminals stacking cranes are slower therefore the containers to be loaded are more spread across the yard to employ more cranes. Here the cranes will be less of a bottle neck and higher utilisation of the AGVs is required as they can serve more stacking cranes over a larger area. Since the containers are now more

widespread among the yard the terminal has more flexibility in planning the vessel and can therefore decide to change it from one part of the quay to another up to 12 hours before arrival. With this feedback in mind another lever could be implemented in the model, when looking at a different terminal, port, or other destination the decision point when a vessel will be dedicated can change.

Other structural feedback was mainly on the constants used in the prototype model. Many of the equations were still too simple or did not have the right dimensions. Two of the major points here are the fuel consumption and the speed at which vessels are travelling. Initially a linear model was used for the fuel consumption which means that an increase in speed would have the same effect on the fuel consumption. However a more realistic model for the calculation of fuel consumption relies on a speed to the third power, increasing speed will thus exponentially increase the amount of fuel that is being consumed. After improving the equation for fuel consumption new cruising speeds were advised. Over the years many container liners have reduced their cruising speeds to a more economical one, this means that the design speeds which the vessels are designed for are often not even attained.

Another point of discussion was the assumption of data sharing among the different actors. In real life when a terminal has a delay information is sometimes hard to share. If for example the crane operator sees a problem arising he can contact his supervisor, and information then has to go to the shipping agent in some way to eventually end up with the captain. And then again the captain has to decide what to do with the information, for he might want to evaluate the effects of slowing down or speeding up first. Information has to go through many layers to eventually reach the actors that can act upon the information. Aside from the time of information to reach someone legal implications have not even been considered. The current model focusses solely on the effects if available information under direct availability with not legal complications. Hypothetically the captain could have something like a live terminal planning on board which includes delays. Based on this information vessel speed could then be finetuned.

For this research only deep sea container vessels with a single berth are considered, although these vessels claim a large part of terminal capacity in the form of quay length and crane capacity, other vessels have to be handled as well. Depending on whether the port is an import, export, or transshipment port, containers will either be exported through the yard and the hinterland or by means of barges and feeders to other ports. To load the really large container vessels many smaller inland boats have to berth at the terminal as well, claiming precious time. These smaller vessel then visits others berths as well, usually they cannot leave their current berth, or are not allowed from the port authority to leave if the next berth in the same port is still occupied. Waiting and drifting vessels in the port can be obstacles for other operations and cause potential collisions. This is where the cascading effect of delays in ports is felt, for vessels at one terminal might affect operations at another berth. In this research only large container vessels are considered, since in daily operations these bigger clients often get priority over smaller feeders and are therefore being less affected by delays.

8. EXPERIMENT SET UP

In the model different controls are defined that can be adjusted to simulate different models. Initially a core situation will be defined, which is the situation that resembles the current situation the most. Next to this base situation two extreme situations will be defined, one to set a lower boundary and one to set the upper boundary. Based on the bounds the base case can be benchmarked and given a score on how it currently performs.

After the benchmarking experiments sensitivity experiments will be performed. These experiments solely focus on the impact of the individual variables. By changing the values for these individual variables the effect can be tested on the outcome variables.

8.1. CONTROLS AND RESPONSES

Controls created in the simulation model are listed below. Changing the controls will imitate different scenarios. For the eventual experiments three main scenarios are will be extremely important besides some other defined scenarios for the analysis of parameter sensitivity.

| <i>Controls</i> | <i>Syntax</i> | <i>Implication</i> |
|-----------------------------------|--------------------------------|---|
| <i>Communication interval</i> | Time in hours | When enabled this is the interval on which vessels will be updated with. |
| <i>Update delay time</i> | Time in hours | Interval on which terminal operations are checked. |
| <i>Cargo delay sharing</i> | Boolean | This control comes together with the update on delay time, the update on delay time checks the remaining time inside the berth. With delay sharing this information is also updated towards other actors. |
| <i>Probability of bunkering</i> | Probability [0,1] | For vessels that are bound for berth one this is the chance that they will also need to bunker. Important note here is that vessels with bunker are by definition also delayed. |
| <i>Average bunker delay</i> | Time in hours | This is the delay caused by bunkering, the minimal delay is the average delay minus half an hour, the maximum delay is the average delay plus half an hour. |
| <i>Bunker delay sharing</i> | Boolean | When set to true delays due to bunkering will be shared with other actors in the chain. |
| <i>Accuracy of the given time</i> | Percentage of time until berth | The time will be multiplied with a random deviation mimicking the inaccuracy in information. |
| <i>Minimal speed</i> | Knots | The minimal speed suggested by algorithms |
| <i>Maximum speed</i> | Knots | The maximum speed suggested by algorithms |

TABLE 13: CONTROLS IN THE SIMULATION MODEL AND THEIR MEANING

In turn the defined controls will affect the system in different ways. Effects of the controls are measured through different responses. In the table below the different responses are listed and what they exactly measure.

| Response | Implication |
|--|---|
| Total fuel consumption | This is the fuel consumed by all the vessels in the system during the journey therefore excluding consumption at anchorage. |
| Fuel saved per vessel | This is the difference in fuel consumed between the actual speed and the initial design speed of the vessel. |
| Consumption at anchorage | When vessels are waiting at the anchorage they still consume fuel, in this case this will be 15% of the designed cruising speed. |
| Average waiting time at anchorage | This is the average waiting time of vessels spend at the transfer node before being towed to the berth. |
| Vessels handled | This is the number of vessels that have been handled by the terminals |
| Cost of journey | This is the fuel consumption during the journey plus the consumption while waiting at anchorage. |
| Total time | Time of the vessel of creation until leaving the pilot boarding place. Combining the time and of the journey and at pilot boarding place. |

TABLE 14: RESPONSES OF THE SIMULATION MODEL AND THEIR MEANING

8.2.DEFINED SCENARIOS

In this chapter the control specifications will be given for the different scenarios that will be tested and their corresponding values. Furthermore a range of other scenarios will be defined to check for the sensitivity of different controls. For example changing the update interval from several minutes up to days.

ZERO BENCHMARK

First the ‘worst case’ scenario, this scenario is characterised as the least favourable scenario due to the total adherence of data sharing. In this scenario absolutely no data is shared also there is the inaccuracy of data and bunkering will continue. This scenario will show what rock bottom would look like and why data sharing is important. On the other side of the spectrum is continuous data sharing all the time. The case of Rotterdam will then be positioned somewhere between these two scenarios. In Table 15: Parameterisation of current case for further comparison the parameters for this scenario are defined.

PERFECT SCORE

Previously discussed is the least favourable scenario that could happen, which is the complete opposite of this scenario. This scenario will test something close to complete data sharing. Since this remains a discrete event model continuous simulation is not possible, therefore the update steps a really small, however not infinitely small. Furthermore the accuracy of information is always 100%, so given data is always true and can be handled upon.

CURRENT SITUATION ROTTERDAM

The Rotterdam case as is, these are the parameters that could mimic Rotterdam in its operations. Tweaking has mostly been done by altering the inter arrival time of the vessels. Given is that terminals in Rotterdam have a high occupancy of the berth. Though the comparison of a real berth occupancy with the occupancy of a discrete berth is ambiguous. Therefore an occupancy of around 80% has been assumed based on expert opinion. By reducing the interarrival time berth occupancy can be increased. Since the arrival of vessels is done by a triangular distribution the upper and lower limit can be used to give more variance to the arrival. Increasing the interval has therefore effect on the waiting time at anchorage. Tweaking of the inter arrival time has been chosen to fit the model as no data analysis has been done on the exact arrival of vessels.

| <i>Controls</i> | <i>Syntax</i> | <i>Zero</i> | <i>Current</i> | <i>best</i> |
|-------------------------------------|-------------------------------------|-------------|----------------|-------------|
| <i>Communication interval</i> | Time in hours | 10000 | 16 | 1 |
| <i>Update delay time</i> | Time in hours | 10000 | 10000 | 1 |
| <i>Cargo delay sharing</i> | Boolean | False | False | True |
| <i>Probability of delay</i> | Probability [0,1] | 0.2 | 0.2 | 0.2 |
| <i>Probability of bunkering</i> | Probability [0,1] | 0.5 | 0.5 | 0.5 |
| <i>Average bunker delay</i> | Time in hours | 1 | 1 | 1 |
| <i>Bunker delay sharing</i> | Boolean | False | False | True |
| <i>Inaccuracy of the given time</i> | Percentage deviation on actual time | 20% | 10% | 0% |
| <i>Minimal speed</i> | Speed in knots | 15 | 15 | 12 |
| <i>Maximum speed</i> | Speed in knots | 18 | 18 | 18 |

TABLE 15: PARAMETERISATION OF CURRENT CASE FOR FURTHER COMPARISON

It should be kept in mind that the model has been fitted such that berth utility gets a value around 80%. However in previous chapters the waiting time before the port has also been analysed and found to be around 12 hours. Tweaking the model this waiting time at anchorage has not been taken into account as fitting for these two parameters could cause overfitting. Since there are other parameters that are also of influence on the waiting time trying to fit the model with fewer parameters will jeopardise validity of the results. Therefore in consecutive analyses the waiting time will be taken relatively, so the average waiting time will be coupled to the average waiting time in the data analysis.

SENSITIVITY ANALYSIS

For the sensitivity analysis parameters will be tested one by one under different scenarios. So from a base case the communication interval will be changed from almost continuous updates with decreasing steps to almost no updates anymore. In this case the impact of the different parameters can be tested on the outcomes. In the table below the ranges for the different parameters are given.

Ranges for the different values are given with respect to reality. For example the inaccuracy of time could be taken to 100% but this is very unrealistic, when having 50% inaccuracy the times given would actually already deviate by a factor 2. The same applies to several other parameters. In the model different experiments will be made for each control. In order to test the sensitivity of update intervals the option for sharing information is set to “True” automatically, otherwise the changes will not affect the scenario and nothing is shared.

Important note here is that there is actually a subtle difference in the levers presented. Changing the communication interval, updating of delays, or early green steaming are actually hard policies. Actors in the port can decide to start sharing more data on a more frequent basis. Other levers such as the probability of a delay, length of bunker delay, or accuracy of information is something harder to change, for this to improve something has to be changed in the operations itself. These are therefore actually closer to port settings. But in the experiments tests can be done to see what the effect would be of higher delays and if data sharing would help in this case.

Also there are two experiments with regard to the communication interval testing, namely the high speed and low speed testing. The main difference in these two experiments is that the upper bound is different. In the first case a vessel can speed up to close the gap with an earlier vessel. In the second case the upper bound is set equal to the standard speed. What this implies is that a vessel does not exceed its cruising speed. Therefore the vessel will only change speed and slow down when he knows the vessel in front of him is late.

| <i>Controls</i> | <i>Syntax</i> | <i>Value</i> |
|---|-------------------------------------|--|
| <i>Communication interval high speed</i> | Time in hours | [0.1, 0.5, 1, 2, 4, 8, 16, 24, 48] |
| <i>Communication interval low speed</i> | Time in hours | [0.1, 0.5, 1, 2, 4, 8, 16, 24, 48] |
| <i>Update delay time</i> | Time in hours | [0.1, 0.2, 0.5, 1, 2, 4, 8, 16, 32] |
| <i>Probability of delay</i> | Probability [0,1] | [0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1] |
| <i>Probability of bunkering</i> | Probability [0,1] | [0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1] |
| <i>Average bunker delay</i> | Time in hours | [0, 1, 2, 3, 4, 5] |
| <i>Inaccuracy of the given time</i> | Percentage deviation on actual time | [0, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5] |
| <i>Early Green Steam + communication interval</i> | Time in hours | [2, 4, 8, 16, 24, 32] |

TABLE 16: RANGE OF PARAMETERS THAT WILL BE TESTED

However testing the sensitivity of an increasing probability of either regular or bunker delays will have an ambiguous effect on the system. Due to the longer time in the berth the total time of all vessel at berth will be larger this would mean the berth utilisation is higher under delays, in a sense this is correct but the productivity remains the same or should not increase as more time is required for the same number of containers.

8.3.RUN SETTINGS

Besides the model and the correct controls there are still some settings that have to be tuned before actually running the experiments. Since this is a continuous system it could run on for ever, operations never seize to stop. Therefore the running period has to be set over a particular length. Since the average time for vessels is close to 20 hours in the berth one week would be too few to accurately say something about the operations. For more reliable results the simulation time, meaning the time elapsed inside the model, is set to 16 weeks. Translated to months 16 weeks is slightly more than three and a half months. This runtime has been chosen after comparing the values of average waiting time at the anchorage and average fuel saved for different runtimes. Results are included in appendix VII. After visual comparison of the results it appears that the variance reaches a steady level somewhere around 16 weeks, further increasing the runtime will not change results much more.

Furthermore the systems starts completely empty without any vessels in it. This means that a certain warm up period is required to get the system in a transient state from which operations can be measured. For this a time of one week has been chosen, this is often also referred to as the burn in period. After this period the system will actually start measuring data and states. To decide what burn in period to use multiple tests have been done of the same scenarios. In other words the same scenario is taken every time while changing the number of burn in days. Results will then be checked for variance. These results are in appendix VI.

Finally the number of repetitions, the question how often the experiment should be repeated. For a deterministic model a single repetition would suffice, however his is not a deterministic model as it has multiple distributions it will draw from stochastic distributions. For a reliable number of repetitions the base case has been tested on a changing number of repetitions. Results in appendix VI indicate that 60 repetitions will return a reliable results while not burdening the software with too much

repetitions. With this number of repetitions the high outliers of higher number of repetitions are captured while the variance does not change a lot with an extra number of repetitions.

8.4. CONTINUATION MODEL

This chapter is the blueprint for the model simulation runs, on what exactly will be tested. In the previous parts are all the scenarios that will be tested including the sensitive analysis and their intervals. The next chapter will therefore fully focus on the outcomes of the model runs including the statistical analyses on the outcomes. The next chapter will therefore give more insight in to how different policies affect the outcomes or how characteristics of operations would affect the operations. Implications of these results will also be reviewed in the next chapter, results could either have a very positive impact on the predefined results be also a negative one. Perhaps due to the way of modelling and assumptions some of the outcomes might appear to be futile. If this is the case probable causes will also be discussed and why this was not expected.

Since the model and most of the work leading up to this model have a strong quantitative focus a bridging chapter is included. Before concluding this research all information gained through the results and earlier qualitative work will be matched in chapter 10. The following will therefore only focus on the outcomes and implications of the simulation model rather than concluding for the whole research.

9. RESULTS

This chapter will discuss the outcomes of the performed experiments and their outputs. Analysis will be done through multiple applicable methods defined in paragraph 9.1. Then the worst case, base case, and perfect score case will be compared with each other including some graphs of the results. In the following paragraph sensitivity of other parameters will be discussed and compared to the base case. Finally the results and some of the anomalies in the data will be discussed before going to the next chapter which is about the connection between qualitative and quantitative results.

9.1. METHODS USED FOR ANALYSIS OF RESULTS

The simulation software Simio automatically returns some statistics and plots that are ready for initial interpretations. For example graphs can tell a lot about the behaviour of parameters before even doing statistical analyses. For complete analysis a combination of the readily available plots will be used, in conjunction with a classical statistical approach.

9.1.1. STATISTICS USED

To do a statistical analysis on the significance of the results some test and classifications have to be performed. Initially a test on the normality of data will be done. If the data is not normally distributed non parametric approaches will be used such as the Wilcoxon rank test.

If the distribution falls within the margin of normal distributions Levene's test of variance for the quality of the variances for different scenarios can be utilised. If the p value exceeds the threshold variances are significantly different, which would have implications for further statistical analysis as homoscedasticity cannot be assumed anymore (Gastwirth, Gel, & Miao, 2009). In Python the SciPy package supports multiple forms of the Levene's test and for this analysis two variations will be used. The first variation centres around the median of the data, this variation is recommended for more skewed data. Levene's test which centres around the mean is recommended for more symmetric distributions.

Furthermore the student T test can be used to assess the significance between results, however this test returns more accurate results if the tested distributions are normally distributed. Besides the test for variance another test on normality is therefore required. If the results of one group were to have a different variance compared to other an alternative for the T test could be used, which is the unequal variances t-test (Welch t-test) (Hayes & Cai, 2007). The complete approach of the this data analysis is presented in Figure 34. As threshold for significance a p-value of 0.05 has been chosen to confirm or reject a null hypothesis. These data analysis will be performed in Python through the *SciPy* package that contains a myriad of statistical functions. Scripts that have been used are included in Appendix VII.

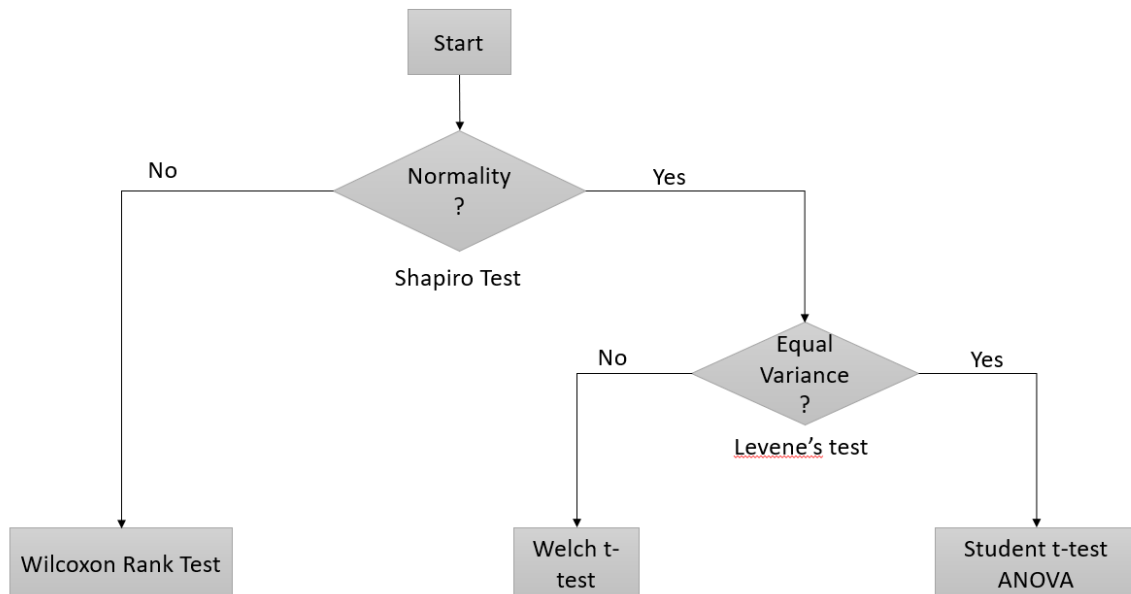


FIGURE 34: APPROACH TO DATA ANALYSIS AND TESTS

9.2. TESTED SCENARIOS

With regard to the responses defined in the model the three most remarkable are shown here, all other responses have been included in the appendix. In the simulation software plots are automatically created, these Simio Measure of Risk and Error (SMORE) plots include the minimum, maximum, and mean value. Furthermore the SMORE plot can also return a lower and upper percentile with corresponding confidence interval, the percentiles and confidence interval can be manually changed. In Figure 35 is an explanation of the intervals show in the SMORE plots with a more elaborate explanation on the different elements in Table 17.

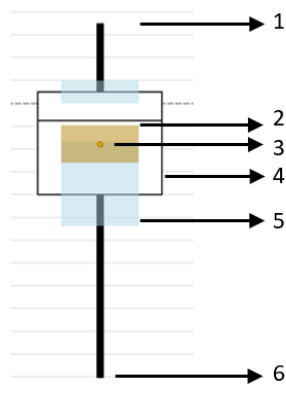


FIGURE 35: DIFFERENT ELEMENTS OF SMORE-PLOT

| | |
|---|---|
| 1 | Top of black bar as maximum value |
| 2 | Brown area as confidence interval mean |
| 3 | Dot in the middle as mean |
| 4 | Black box as quarter, half and three quarter value. |
| 5 | Blue box as confidence interval of upper and lower quarter percentile |
| 6 | Bottom of black bar as minimal value |

TABLE 17: EXPLANATION WITH SMORE PLOT ELEMENTS

In a first observation it becomes clear that with increased data sharing the waiting time at anchorage will reduce. Figure 36 shows that almost all waiting times before the port for the best case are shorter than the shortest waiting time in the current case. Since the consumption of fuel at anchorage is dependent on the waiting time at anchorage the same results yield for this response.

For the savings in fuel consumption the current case uses slightly more fuel compared to a no contact at all case (Figure 38). In this latter case no fuel is saved as speed is not altered. And in the current case vessels are able to speed up, and since speeding up will use more fuel than slowing down with the same speed the net savings are negative. However the full sharing case is quite interesting as the average fuel savings are considerably better but there are also scenarios where vessels will burn more fuel than in the worst case. Here again the speeding up can be costly in some situations.

Although the fuel consumption is increased the vessels have a lower time in the system than in the worst case, this is mostly due to the more optimal arrival of vessels though speeding up and slowing down (Figure 38). The difference between the current case and worst case is approximately 2 hours here and the best case outperforms the current case with one and a half hour.

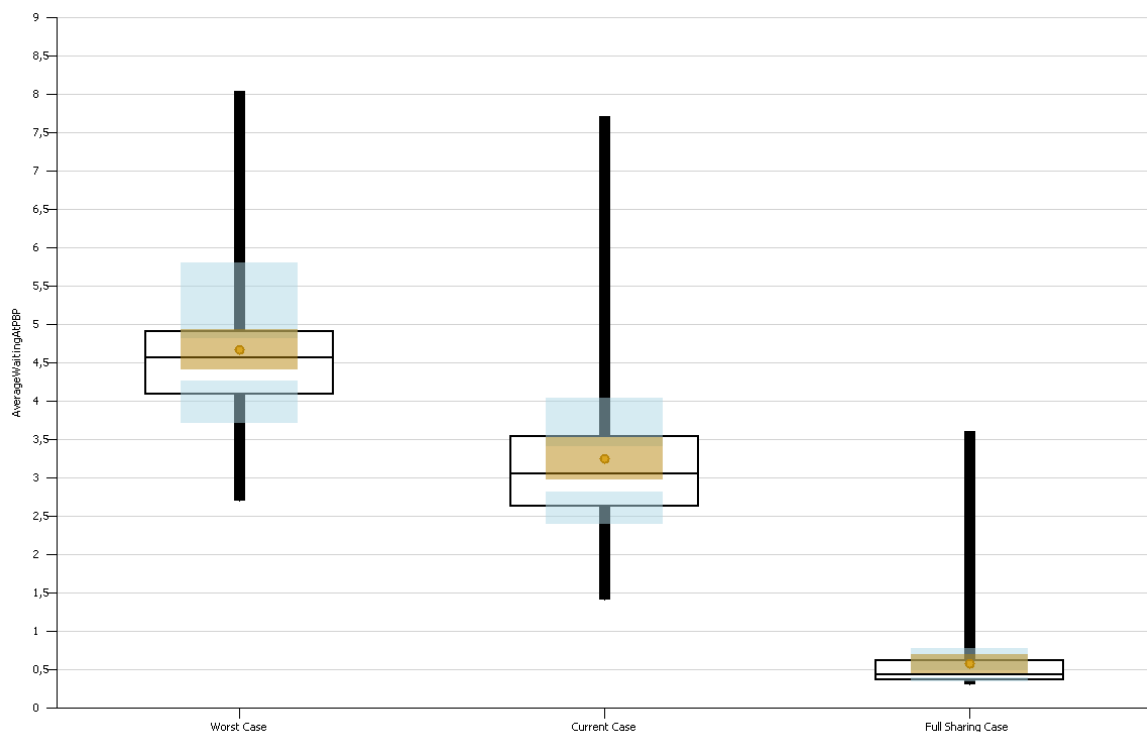


FIGURE 36: AVERAGE WAITING TIME AT THE PILOT BOARDING PLACE

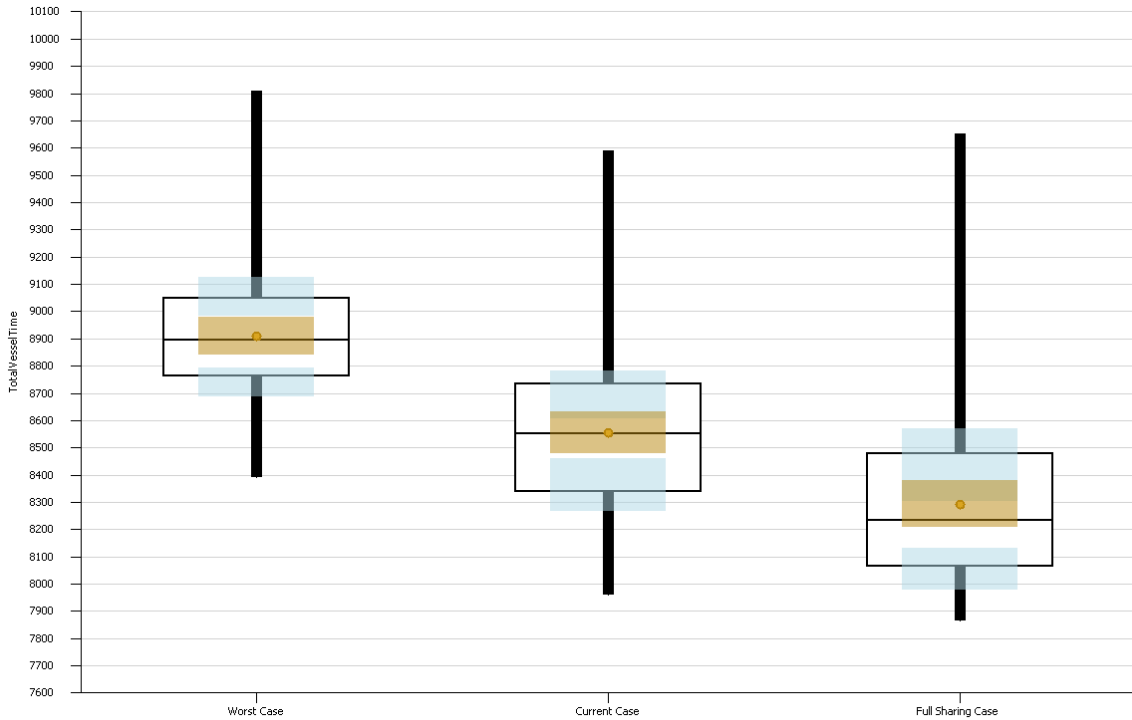


FIGURE 37: AVERAGE TIME IN SYSTEM

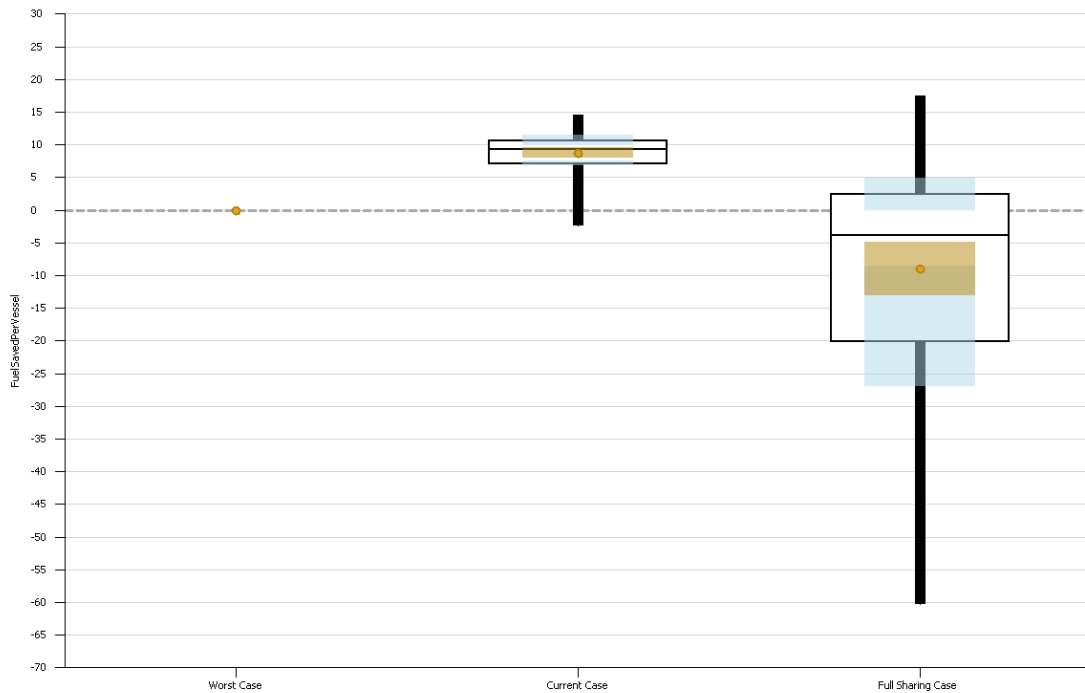


FIGURE 38: AMOUNT OF FUEL SAVED PER VESSEL

CLASSICAL STATISTICAL ANALYSIS

When turning to the statistical analysis the first step is checking for normality in the distributions. The H_0 , null hypothesis is that the numbers are normally distributed with an confidence threshold of 0.05, any value lower than 0.05 means that the H_0 should be rejected indicating a non-normal distribution. Results have been included in Table 18: Normality test fir worst, normal and best scenario parameters where green cells indicate p-values larger than 0.05 therefore accepting the hypothesis that the

distribution is normal. Red cells reject this hypothesis. The majority of the hypotheses are rejected and are smaller than 0.05, however the parameter “fuel saved per vessel” appears to be normal initially but since there is no variance in the worst case the Shapiro value is logically 1.0. Furthermore only in the current case does the Shapiro and KS test yield normal distributions. Therefore since none of the responses is normally distributed for all cases the Wilcoxon Rank Test will be used.

| | P-value | | | | | |
|--------------------------|------------|----------|--------------|----------|-----------|----------|
| | Worst case | | Current case | | Best case | |
| | Shapiro | KS | Shapiro | KS | Shapiro | KS |
| Average Waiting time PBP | 0.000917 | 0.000306 | 7.27-06 | 2.14-08 | 4.39-13 | 1.05-2 |
| Fuel saved per vessel | 1.0 | 0.588 | 0.000433 | 3.97e-05 | 0.000153 | 0.000859 |
| Consumption at anchorage | 0.000406 | 0.000147 | 4.58e-06 | 6.84e-09 | 3.55e-13 | 1.05e-21 |

TABLE 18: NORMALITY TEST FIR WIRST, NORMAL AND BEST SCENARIO PARAMETERS

In Table 19: Significance test for parameters compared to current case, the results of the Wilcoxon Rank test are shown. For this table the hypothesis is that there is no significant difference between the current case and either the worst case or best case. So if the p-value will be smaller than 0.05 there is a significant difference between the groups and the null hypothesis should be rejected. Results indicate that for all but the vessels handled and berth 1 entered with the best case there is a significant difference between the scenarios, which also complies with the SMORE plots presented earlier.

| | P-value | |
|------------------------------|------------|-----------|
| | Worst case | Best case |
| Total Fuel Consumption | 1.629e-11 | 1.629e-11 |
| Average Waiting At PBP | 1.629e-11 | 1.629e-11 |
| Fuel Saved Per Vessel | 1.994e-11 | 1.714e-11 |
| Vessels Handled | 0.00117 | 0.0832 |
| Consumption At Anchorage | 1.629e-11 | 1.629e-11 |
| Berth 1 Entered | 0.0101 | 0.935 |
| Berth 2 Entered | 1.957e-05 | 0.0298 |
| Percentage Lower Consumption | 1.994e-11 | 1.714e-11 |
| Total vessel time in system | 1.629e-11 | 1.896e-11 |

TABLE 19: SIGNIFICANCE TEST FOR PARAMETERS COMPARED TO CURRENT CASE

POSTERIOR DISTRIBUTION

When plotting the data in histogram it is slightly easier to see how the distributions relate to each other. In the Figure 39, Figure 40, Figure 41 are the distributions for the average waiting time at anchorage, fuel save per vessel, and the berth utility. Furthermore symbols on the x-axis have been included, stars represent the means of a distribution, “+” indicate the edges of the Highest Posterior Density (HPD) with an interval of 95% for the best case. For Bayesian posterior analyses the HPD in conjunction with the Region Of Practical Equivalence (ROPE) is often used to see if something is significantly different (Kruschke, 2013). In the figures the ROPE is indicated by the red line with red triangles on each side.

The ROPE is a chosen area by the user depending on the problem and problem definition, justifiable to the situation and metrics in place (Kruschke, 2013). For the graphs the ROPE has been chosen as the

HPD of the current case extended by half an hour of waiting time or 5 tonnes of fuel consumption, depending on the metric. Important for the conclusions is that overlap in HPD and the rope are considered to be undefined results, full overlap of ROPE over HPD as acceptance, and HPD outside of the ROPEd area as rejected hypothesis.

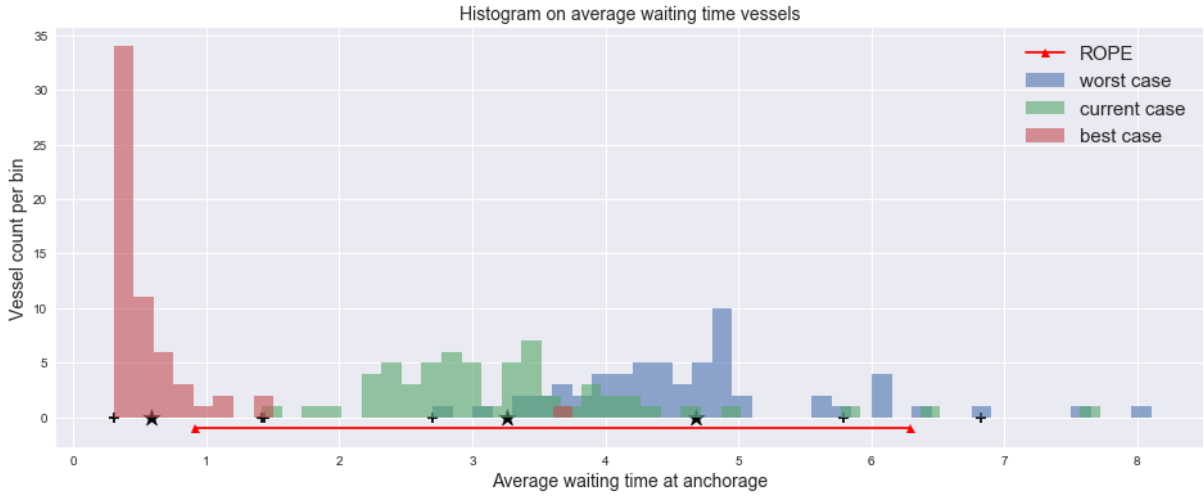


FIGURE 39: DISTRIBUTIONS OF THE PREDEFINED CASES WITH REGARD TO AVERAGE WAITING TIME

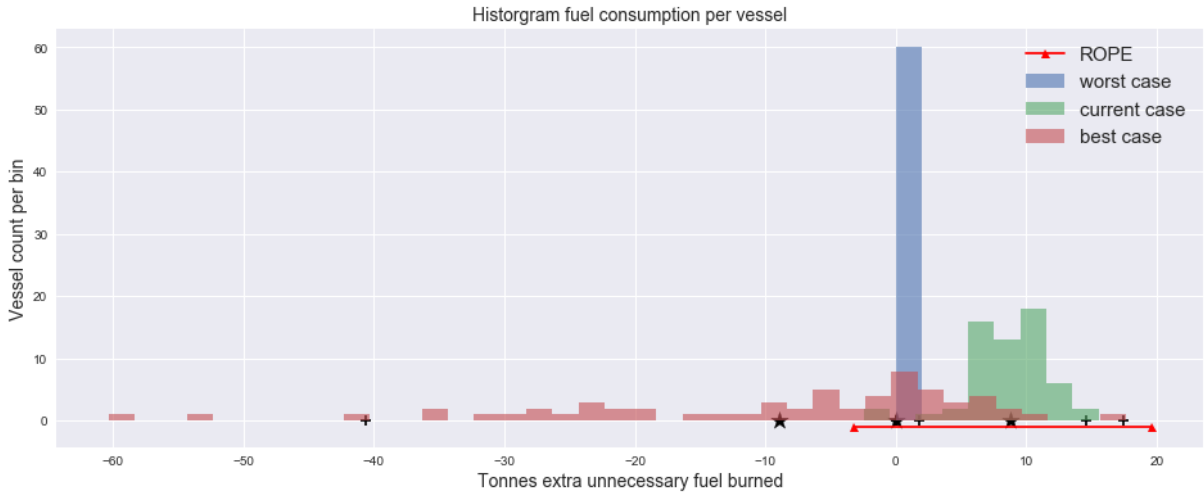


FIGURE 40: DISTRIBUTIONS OF THE PREDEFINED CASES WITH REGARD TO FUEL CONSUMPTION PER VESSEL

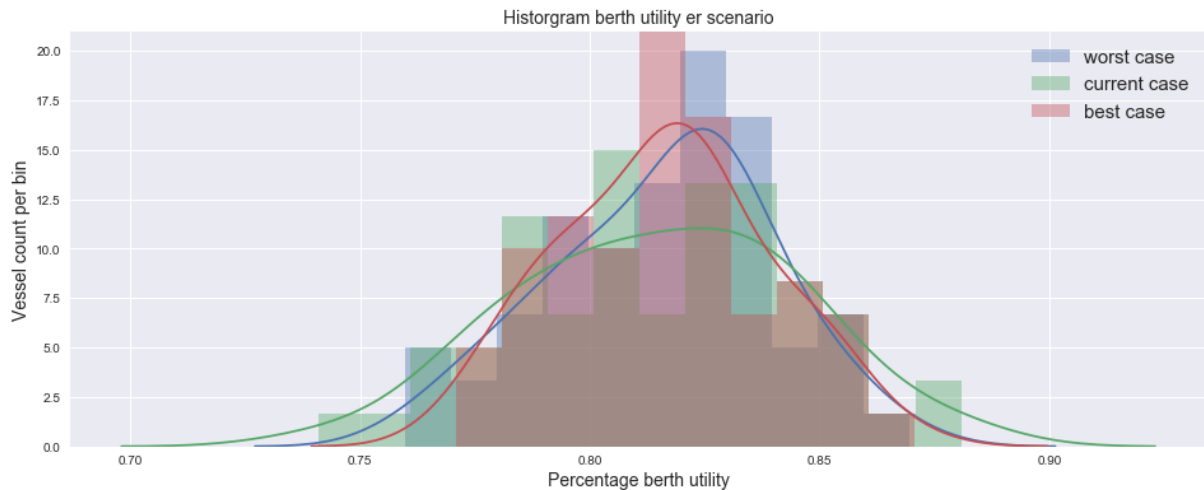


FIGURE 41: PERCENTAGE OF BERTH UTILITY IN THE THREE PREDEFINED CASES

For the average waiting time the HPD of the best case scenario falls just inside of the ROPE which means that the situations are not significantly different. When comparing the intervals of the worst case and the current case there is quite some overlap, which means that significance cannot be rejected nor can it be accepted. The difference between the lower boundary of the waiting time of the current case with the HPD upper limit of the best case is close to zero. Thus improvement of information sharing will only return better results in terms of waiting time.

With regard to the fuel consumption the worst case does not really have a distribution as speed is not altered and fuel consumption therefore remains the same as expected. For the best case scenario the interval is actually larger than the defined ROPE which means that significance cannot be accepted or rejected.

After eyeballing the average berth utility using a ROPE and HPD would be highly unlikely to yield a results as the bars are highly overlapping with peaks close to each other. This also makes sense from model as the number of vessels entered in the model should be approximately the same. What this graph therefore says is that eventually all the vessels will be handled and that there are not uncontrollable queues at the anchorage. But what this graph does not show is how the planning of the terminal is optimised, the average waiting at anchorage is reduced, the planning is more robust. This could imply that the terminal would be able to handle more vessels, however this is not shown.

Averages and maxima for the waiting time and time in system are included in Table 20: Extremes and means of the responses. Also included is the performance on a normalised scale which compares the averages of the responses. The worst case is taken as the lowest possible performance and therefore given a score of 0, the situation with the most sharing is given a 100 percent score. When comparing means of these scores the port of Rotterdam is performing somewhere around 45% on average, this means it is already doing a lot of data sharing and that operations are far from rock bottom.

However it also says that there still plenty of room for improvement. As mentioned before waiting times have not been normalised for the model so an improvement of 50% would get the efficiency up to 86% which would require the waiting time to be halved. According to real life halving the waiting time before the port translates to a reduction of on average 7,8 hours.

| | | Min | Mean | Max | Mean percentage performance |
|------------------------|--------------|-------|-------|-------|-----------------------------|
| Waiting time anchorage | Worst case | 2,703 | 4,677 | 8,051 | 0 |
| | Current case | 1,419 | 3,261 | 7,719 | 34,5 |
| | Best case | 0,305 | 0,582 | 3,606 | 100 |
| Total time in system | Worst case | 48,48 | 49,70 | 53,02 | 0 |
| | Current case | 46,02 | 47,82 | 52,12 | 55,5 |
| | Best case | 45,33 | 46,30 | 52,46 | 100 |

TABLE 20: EXTREMES AND MEANS OF THE RESPONSES

9.3.SENSITIVITY OF PARAMETERS

Under this paragraph the sensitivity experiments from Simio will be discussed. In these experiments more scenarios are made with changing intervals for the different controls defined. Furthermore to keep this paragraph clear and comprehensible focus is laid on two parameters *Total Fuel Consumption* and *Average Waiting Time At PBP*. Other figures have been included in appendix IX.

Purpose of these sensitivity analyses is to see the effects of different policies with regard to the responses. By examining the effects of different levers their impact can be tested. For example changing the interval time might have a higher impact than early green steam information. If this would be true further research could be spend on why this is more effective and possibly prioritise when implementing a data sharing initiative. Now the impacts of the individual parameters is being tested, this entails the only the experiments performed before use a combination of parameters. This could mean that a potentially assumed worst case might not actually be the worst setting available.

EXPERIMENT COMMUNICATION INTERVAL HIGH SPEED

In this experiment the interval on which vessels can change their speed is tested. Besides the base case eight other scenarios have been made where the lowest interval is 6 minutes, the second interval 30 minutes and all intervals after that the duplicate of the previous.

As expected the waiting time at the anchorage will decrease with increased communication as vessels can now better anticipate when to arrive exactly. As the interval gets smaller the improvement seems to stagnate and at the lowest interval the waiting time actually increases again.

Opposite to the waiting time the fuel consumption per vessel actually increases with increased contact. As time intervals approaches the one hour time interval fuel consumption appears to reach a steady state.

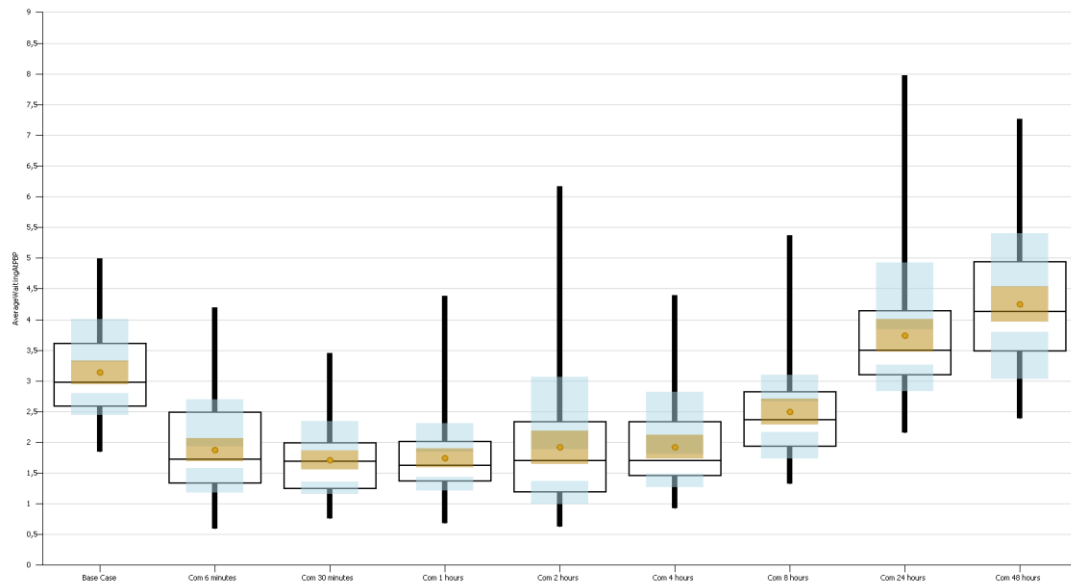


FIGURE 42: AVERAGE WAITING TIME PBP FOR DIFFERENT COMMUNICATION INTERVALS

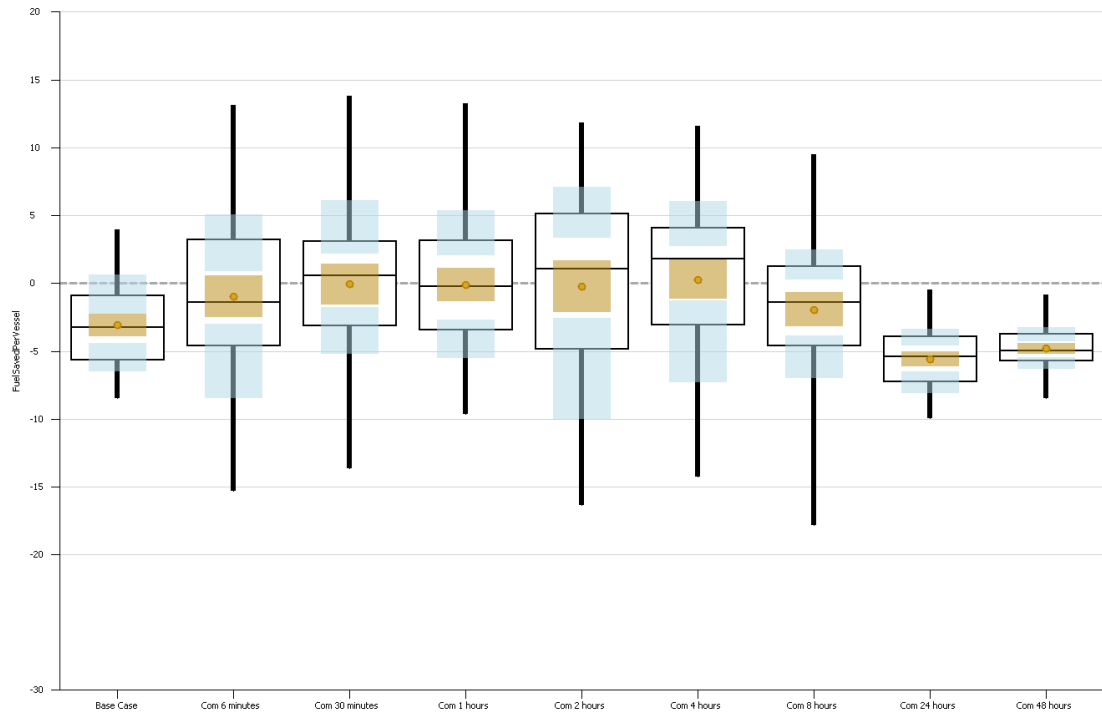


FIGURE 43: FUEL SAVED PER VESSEL FOR DIFFERENT COMMUNICATION INTERVALS

In Table 1 test for normality is done on the average waiting time at PBP and the amount of fuel saved per vessel. Again as in the previous analysis of normality the values that reject the hypothesis are coloured red. With a 0.05 threshold in mind the fuel saved per vessel is the response which is normally distributed and therefore tested on the difference in variance.

| | p-value | | | |
|------------|--------------------------|-----------|-----------------------|--------|
| | Average waiting time PBP | | Fuel Saved per vessel | |
| | Shapiro | KS | Shapiro | KS |
| Base Case | 0.03107 | 0.0857 | 0.279 | 0.360 |
| 6 minutes | 0.00335 | 0.00933 | 0.917 | 0.951 |
| 30 minutes | 0.0411 | 0.0494 | 0.744 | 0.747 |
| 1 hour | 1.409e-05 | 3.802e-08 | 0.686 | 0.839 |
| 2 hour | 1.056e-05 | 7.783e-07 | 0.0744 | 0.209 |
| 4 hour | 1.553e-05 | 0.000414 | 0.0935 | 0.238 |
| 8 hour | 4.706e-05 | 1.868e-05 | 0.254 | 0.0419 |
| 24 hour | 3.484e-05 | 5.295e-07 | 0.729 | 0.385 |
| 48 hour | 0.0346 | 0.0412 | 0.811 | 0.680 |

TABLE 21: NORMALITY TESTS FOR COMMUNICATION INTERVAL SCENARIOS

Levene’s test returns a p-value of 6.53e-20 which is extremely small, therefore the Welch t-test will be used to check the variances between the base case and other cases for the fuel saved per vessel. In Table 22 are the results of this test. Again the values that exceed the given 0.05 threshold are coloured red. Only in one case changing the communication interval appears to have no significant effect, sharing every 8 hours would return results that are not significantly different than sharing on a 16 hour interval. However sharing more data or less data does have a significant impact on the results.

LeveneResult(statistic=15.010608994520855, pvalue=6.530795136665341e-20)

LeveneResult(statistic=17.13046008408186, pvalue=9.681794650316565e-23)

For the average waiting time at the PBP the Wilcoxon signed rank test is used, outcomes of this test indicate significant changes as all values exceed the 0.05 threshold. With the graphs in mind and this significance test the average waiting time at PBP is significantly dependent on the time interval and will improve with increased sharing and decrease with less data sharing.

| | p-value | |
|------------|---------------------------|-----------------------|
| | Wilcoxon signed rank test | Welch t-test |
| | Average waiting time PBP | Fuel saved per vessel |
| 6 minutes | 1.6295e-11 | 0.01795 |
| 30 minutes | 1.6295e-11 | 0.0006248 |
| 1 hour | 1.6295e-11 | 0.0001160 |
| 2 hour | 2.8351e-11 | 0.007201 |
| 4 hour | 1.6295e-11 | 9.9196e-05 |
| 8 hour | 1.9945e-11 | 0.1329 |
| 24 hour | 1.6295e-11 | 2.3689e-06 |
| 48 hour | 1.6295e-11 | 0.0002982 |

TABLE 22: SIGNIFICANCE TESTS FOR COMMUNICATION INTERVAL SCENARIOS

EXPERIMENT COMMUNICATION INTERVAL LOW SPEED

Compared to the previous experiment this experiment changed the maximum speed to the standard speed. This means the vessels can only slow down and not speed up to close the gaps with a previous vessel in order make the terminal planning a better fit. However when a vessel has the option to slow down it will without hesitating. The assumption thus that a vessel will respond on action also applies here, the vessel will slow down when possible, but never speed up exceeding the normal cruising speed.

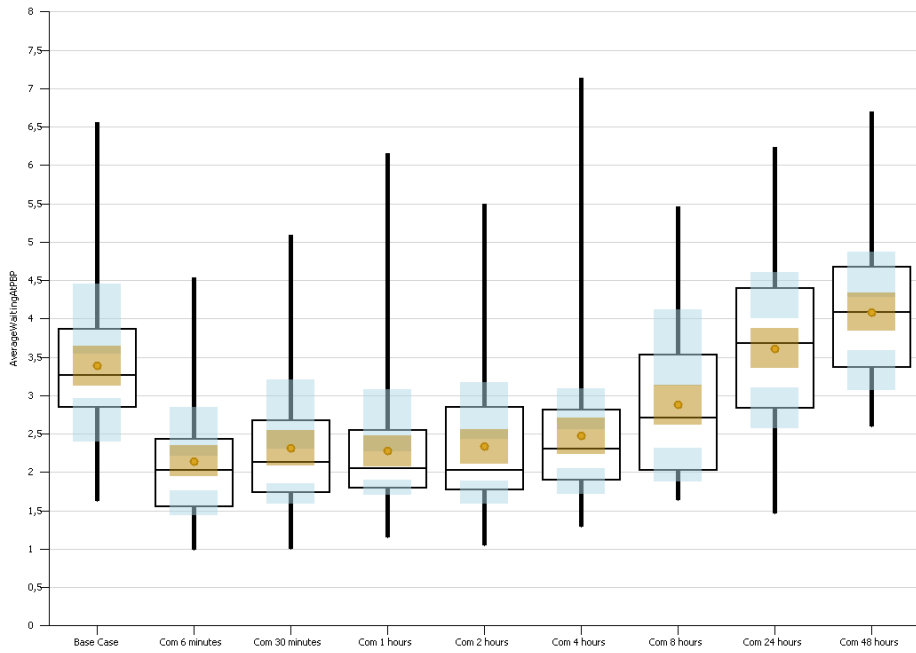


FIGURE 44: AVERAGE WAITING TIME AT ANCHORAGE

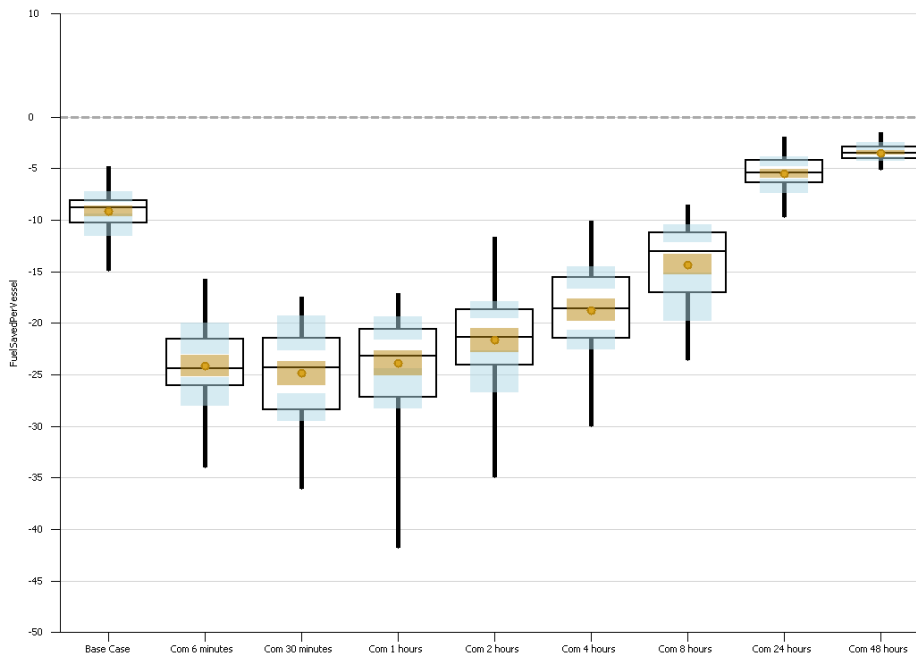


FIGURE 45: AVERAGE FUEL SAVINGS PER VESSEL

When looking at the waiting time of Figure 44 this really resembles the results from the previous experiment where increased communication will lead to shorter waiting times. However the biggest difference here is in the fuel consumption, when comparing the fuel consumption savings in Figure 45 with the ones in the previous experiment savings seem to be quite significant and increase with almost every step.

In Table 23 is the test for normality to see what statistical tests can be used to assess the significance in difference.

| | p-value | | | |
|------------|--------------------------|----------|-----------------------|----------|
| | Average waiting time PBP | | Fuel Saved per vessel | |
| | Shapiro | KS | Shapiro | KS |
| Base Case | 0,00527 | 0,00253 | 0,132 | 0,164 |
| 6 minutes | 0,0000962 | 0,000221 | 0,644 | 0,845 |
| 30 minutes | 0,0000311 | 4,18E-05 | 0,256 | 0,377 |
| 1 hour | 0,0000000307 | 4,51E-12 | 0,000403 | 1,92E-05 |
| 2 hour | 0,000111 | 7,94E-05 | 0,416 | 0,162 |
| 4 hour | 0,000000165 | 2,08E-12 | 0,786 | 0,675 |
| 8 hour | 0,000305 | 0,0283 | 0,000926 | 0,0388 |
| 24 hour | 0,819 | 0,836 | 0,549 | 0,474 |
| 48 hour | 0,00572 | 0,023 | 0,934 | 0,762 |

TABLE 23: TEST FOR NORMALITY COMMUNICATION INTERVAL 2

After testing for normality the average waiting time does not seem to be normally distributed. For the fuel saved per vessel all but two cases are normally distributed with the 0.05 significance interval. Because of the normal distribution Levene's test on variance will be used prior to choosing the appropriate test.

LeveneResult (statistic=15.450816385456, pvalue=1.6710030041169463e-20)
 LeveneResult (statistic=17.1788956043270, pvalue=8.355337750419567e-23)

Since the outcomes of Levene's test are highly significant the Welch t-test has been used instead of the student t-test. Outcomes indicate that changing the communication interval then has a significant impact.

| | p-value | |
|------------|---------------------------|-----------------------|
| | Wilcoxon signed rank test | Welch t-test |
| | Average waiting time PBP | Fuel saved per vessel |
| 6 minutes | 2,97E-08 | 8,04E-43 |
| 30 minutes | 1,30E-07 | 4,23E-39 |
| 1 hour | 5,32E-08 | 1,84E-37 |
| 2 hour | 3,64E-07 | 9,69E-34 |
| 4 hour | 3,00E-07 | 2,15E-27 |
| 8 hour | 0,008044 | 2,09E-14 |
| 24 hour | 0,2273 | 5,60E-19 |
| 48 hour | 0,0003465 | 9,44E-32 |

TABLE 24: TEST FOR SIGNIFICANCE COMMUNICATION INTERVAL 2

EXPERIMENT ON UPDATE INTERVAL

In this experiment the interval of data sharing with regard to cargo delays is changed. Since cargo delays have a smaller time window than the arrival of vessels smaller steps are included. Also because sharing of data can only be done while the vessel is still in the berth which is also fewer time than the journey towards Rotterdam. Figure 46 shows the boxplots for the waiting times at PBP, at first glance most scenarios appear to be very similar to each other. Figure 47 says the same about the fuel consumption, apparently sharing delays does not have an high impact on the fuel savings.

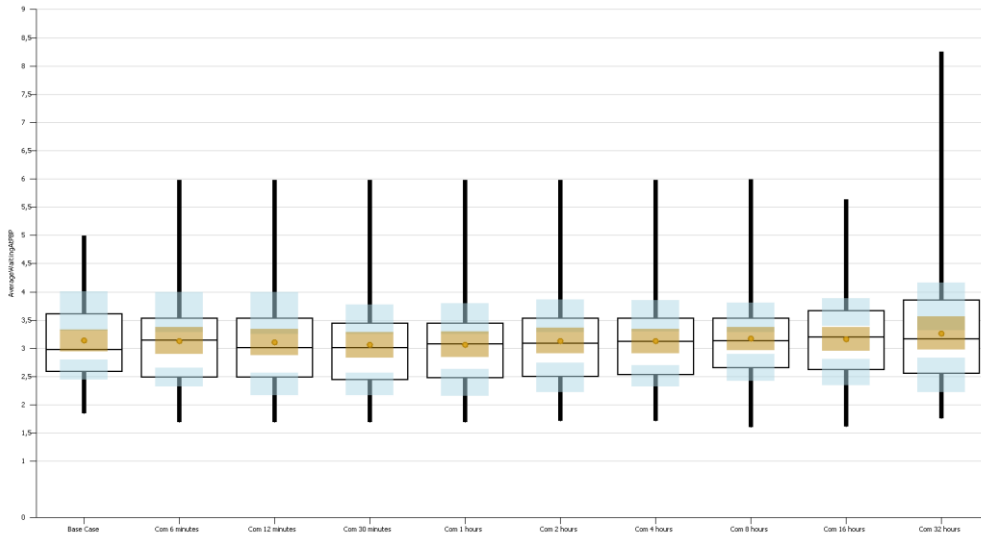


FIGURE 46: AVERAGE WAITING TIME AT PBP FOR DIFFERENT CARGO DELAY UPDATES

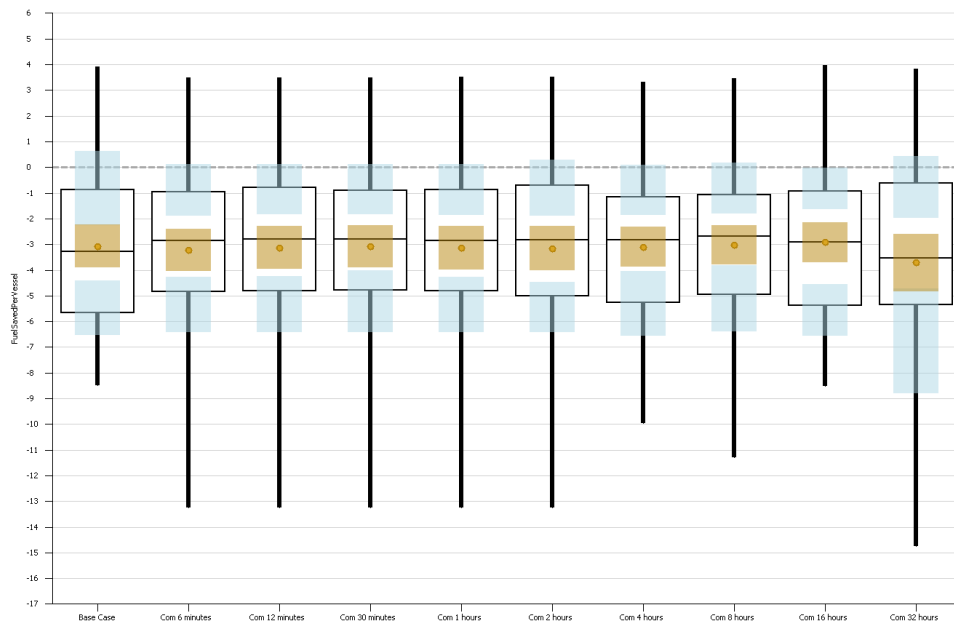


FIGURE 47: FUEL SAVED PER VESSEL FOR DIFFERENT CARGO DELAY UPDATE INTERVALS

In Table 25 are the results of the normality analysis. For the average waiting time almost all scenarios are considered to be non-normal distributed, therefore the Wilcoxon test will be performed on this set. For the fuel saved per vessel all values are considered to be normally distributed, therefore a test for variance will be done followed by the most appropriate test for significance between the sets.

| | p-value | | | |
|------------|--------------------------|------------|-----------------------|---------|
| | Average waiting time PBP | | Fuel Saved per vessel | |
| | Shapiro | KS | Shapiro | KS |
| Base Case | 0.03107 | 0.08576 | 0.2790 | 0.3602 |
| 6 minutes | 0.002940 | 0.001960 | 0.5716 | 0.2125 |
| 12 minutes | 0.002271 | 0.002355 | 0.4568 | 0.1620 |
| 30 minutes | 0.0002727 | 0.0001408 | 0.3163 | 0.08587 |
| 1 hour | 0.0008878 | 0.0004588 | 0.5841 | 0.2201 |
| 2 hour | 0.002294 | 0.001061 | 0.5664 | 0.2549 |
| 4 hour | 0.01605 | 0.002242 | 0.6079 | 0.7065 |
| 8 hour | 0.01182 | 0.0009251 | 0.6402 | 0.4045 |
| 16 hour | 0.25842 | 0.09255 | 0.2363 | 0.3822 |
| 32 hour | 5.64522e-6 | 1.0857e-08 | 0.07443 | 0.1337 |

TABLE 25: TEST OF NORMALITY ON CARGO UPDATE SCENARIOS

After testing for difference in variance the probability does not exceed the 0.05 threshold. It is therefore that the null hypothesis of equal variances remains in place leading up to the student t-test and ANOVA test. For the Average waiting time at PBP updating between 12 minutes and 4 hours returns significant changes. However too frequent updating in turn does not yield any significant changes. When testing for significant change (Table 26) in the amount of fuel saved none of the scenarios exceed the threshold, therefore updating on cargo delay does not have a significant effect on the fuel consumption.

LeveneResult (statistic=1.0288740635112454, pvalue=0.41521500654913224)

LeveneResult (statistic=1.0389393812777687, pvalue=0.4072082174017842)

| | p-value | | |
|------------|---------------------------|-----------------------|--------|
| | Average waiting time PBP | Fuel saved per vessel | |
| | Wilcoxon signed rank test | Student t-test | ANOVA |
| 6 minutes | 0.07129 | 0.8090 | 0.9860 |
| 12 minutes | 0.007370 | 0.9258 | |
| 30 minutes | 2.4626e-05 | 0.9961 | |
| 1 hour | 3.5153e-05 | 0.9248 | |
| 2 hour | 0.03722 | 0.8809 | |
| 4 hour | 0.03461 | 0.9636 | |
| 8 hour | 0.1350 | 0.9397 | |
| 16 hour | 0.1118 | 0.7784 | |
| 32 hour | 0.06463 | 0.3541 | |

TABLE 26: TEST FOR SIGNIFICANCE FOR SCENARIOS CARGO UPDATE DELAY

EXPERIMENT ON PROBABILITY OF DELAY

In this experiment the probability of delays has gradually been increased from 10 to 90 percent combined with the same set of scenarios where sharing of delays is turned on. In Figure 48 is the base case on the far left followed by the scenarios with increased probability of delays. Then the last eight scenarios are the same however with cargo delay sharing turned on, with an interval of three hours. The first things that can be seen is that maximum values decrease, highest outliers are still lower than 7 hours whereas this could be over 11 hours when not sharing cargo delays.

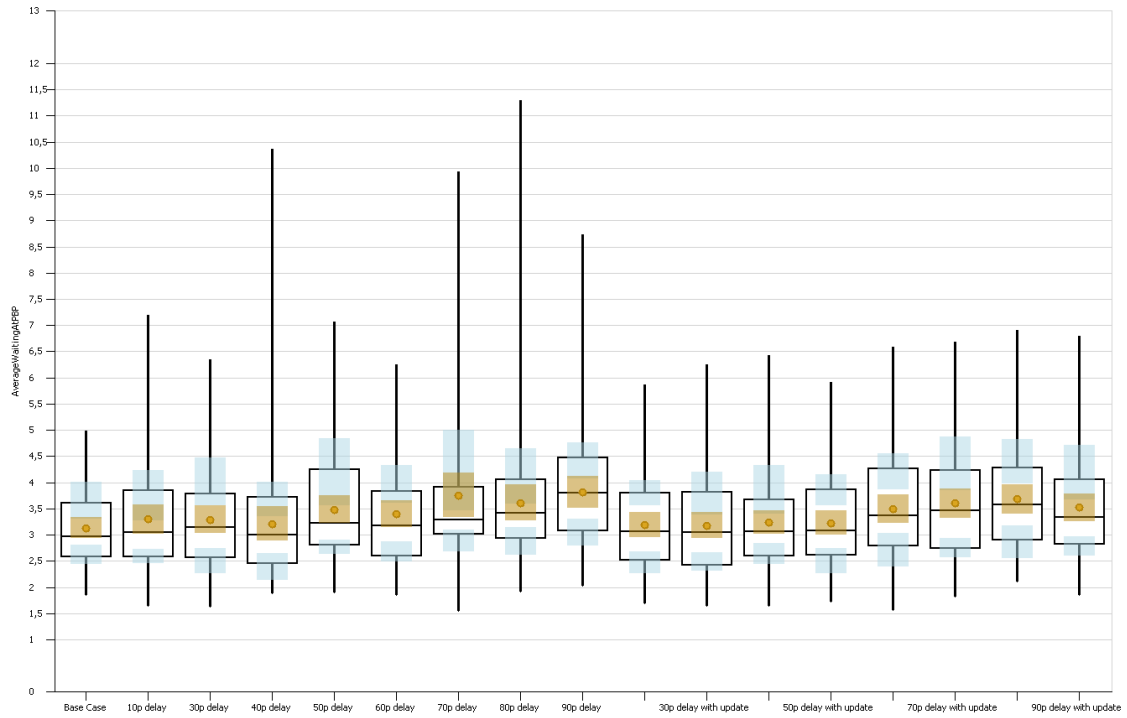


FIGURE 48: AVERAGE WAITING PBP FOR INCREASED PROBABILITY OF CARGO DELAYS

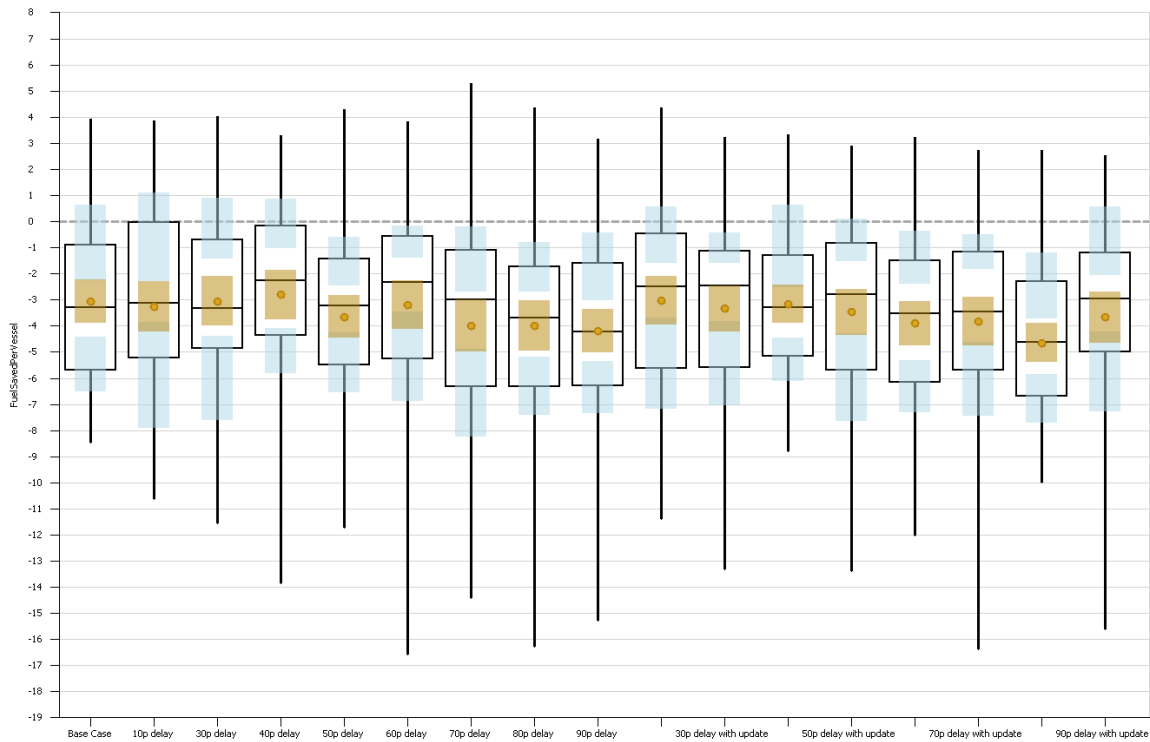


FIGURE 49: AVERAGE EXTRA FUEL CONSUMPTION FOR INCREASED PROBABILITY OF CARGO DELAYS

In Table 27 are the results of the normality analysis, for the average time at PBP most values are not normally distributed. However for the fuel saved per vessel four out of the sixteen different scenarios are considered to be not normal in the Shapiro test. Although these cases are not normal the overall set will be taken down the normal branch and tested for difference in variance. The fact that some of

the distributions are not normal will have implications for the consecutive test performed, and these consequences will be kept in mind.

| | p-value | | | |
|-----------------------|--------------------------|------------|-----------------------|-----------|
| | Average waiting time PBP | | Fuel Saved per vessel | |
| | Shapiro | KS | Shapiro | KS |
| Base Case | 0.03107 | 0.08576 | 0.2790 | 0.3602 |
| 10p delay | 3.7485e-05 | 7.3967e-06 | 0.09979 | 0.5383 |
| 30p delay | 0.009065 | 0.008908 | 0.7113 | 0.8826 |
| 40p delay | 2.6487e-09 | 3.5938e-16 | 0.01137 | 0.007851 |
| 50p delay | 0.0009747 | 0.001815 | 0.2299 | 0.2787 |
| 60p delay | 0.001104 | 0.007143 | 0.002880 | 0.0003039 |
| 70p delay | 7.8094e-09 | 1.1053e-09 | 0.3135 | 0.3532 |
| 80p delay | 1.7599e-09 | 8.2294e-17 | 0.2296 | 0.07279 |
| 90p delay | 8.5596e-05 | 2.6239e-07 | 0.1948 | 0.09320 |
| 10p delay with update | 0.04635 | 0.07266 | 0.5145 | 0.6494 |
| 30p delay with update | 0.005329 | 0.004563 | 0.02137 | 0.03452 |
| 40p delay with update | 0.004108 | 0.0006978 | 0.1592 | 0.3035 |
| 50p delay with update | 0.04106 | 0.06743 | 0.1827 | 0.1895 |
| 60p delay with update | 0.05612 | 0.02318 | 0.9793 | 0.8981 |
| 70p delay with update | 0.006114 | 0.03071 | 0.08791 | 0.01606 |
| 80p delay with update | 0.001731 | 0.003218 | 0.7574 | 0.6838 |
| 90p delay with update | 0.001494 | 0.003738 | 0.003916 | 0.003060 |

TABLE 27: RESULTS OF NORMALITY ANALYSIS FOR DELAY PROBABILITY

Testing on difference in variance yields the following scores:

LeveneResult (statistic=0.5518303495039855, pvalue=0.919388246551908)
 LeveneResult (statistic=0.6662138759783326, pvalue=0.8289697652074531)

This means that the variances are much alike and the standard student t-test plus the ANOVA test can be performed, these results are, together with the results of the Wilcoxon Signed Rank test included in Table 28. From the results it appears that delays have no influence on the fuel saved per vessel compared to the base case even when these delays are shared on an three hour interval. Delays do have an effect on the time waited at the pilot boarding place, most of the situation have a significant effects as long as the difference in probability of delay is more than 10% of the base case. This also seems logical as the same number of vessels would arrive while vessels at the berth in general take more time to be serviced.

| | p-value | | |
|-----------------------|--------------------------|-----------------------|--------|
| | Average waiting time PBP | Fuel Saved per vessel | |
| | Wilcoxon | Student t-test | ANOVA |
| 10p delay | 0.0001253 | 0.7642 | 0.2235 |
| 30p delay | 0.0005863 | 0.9725 | |
| 40p delay | 0.5559 | 0.6664 | |
| 50p delay | 5.6837e-11 | 0.3183 | |
| 60p delay | 6.9200e-11 | 0.8567 | |
| 70p delay | 8.0162e-11 | 0.1561 | |
| 80p delay | 1.6295e-11 | 0.1460 | |
| 90p delay | 1.6295e-11 | 0.05957 | |
| 10p delay with update | 0.1350 | 0.9378 | |

| | | |
|-----------------------|------------|----------|
| 30p delay with update | 0.5171 | 0.6744 |
| 40p delay with update | 9.0655e-08 | 0.8881 |
| 50p delay with update | 0.0004976 | 0.5142 |
| 60p delay with update | 7.5409e-10 | 0.1642 |
| 70p delay with update | 1.7141e-11 | 0.2306 |
| 80p delay with update | 1.6295e-11 | 0.005372 |
| 90p delay with update | 1.6295e-11 | 0.3564 |

TABLE 28: SIGNIFICANCE ANALYSIS ON DIFFERENT PROBABILITIES OF DELAY

EXPERIMENT ON PROBABILITY OF BUNKERING

In this experiment the probability of bunkering at berth 1 is stepwise increased to see the effects of bunkering. However the average bunker delay is kept the same, changing the delay will be tested in the next experiment. Scenarios will be increased with 10% of bunker probability every time, in addition a second set of scenarios is included where bunker delay sharing is enabled. When looking to the different scenarios it appears that bunker delays do not have a significant effect on either the fuel consumption or the average waiting time at PBP. Apart from some extreme values no really eye-catching anomalies are witnessed.

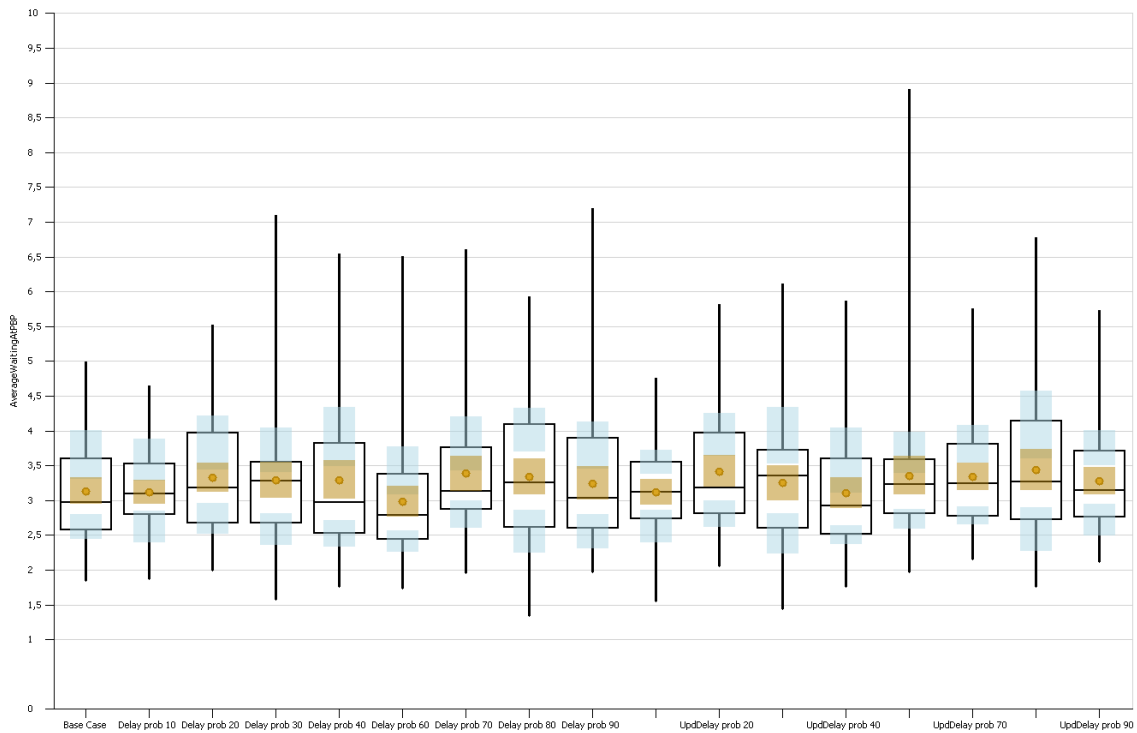


FIGURE 50: AVERAGE WAITING TIME PBP FOR DIFFERENT BUNKER PROBABILITIES

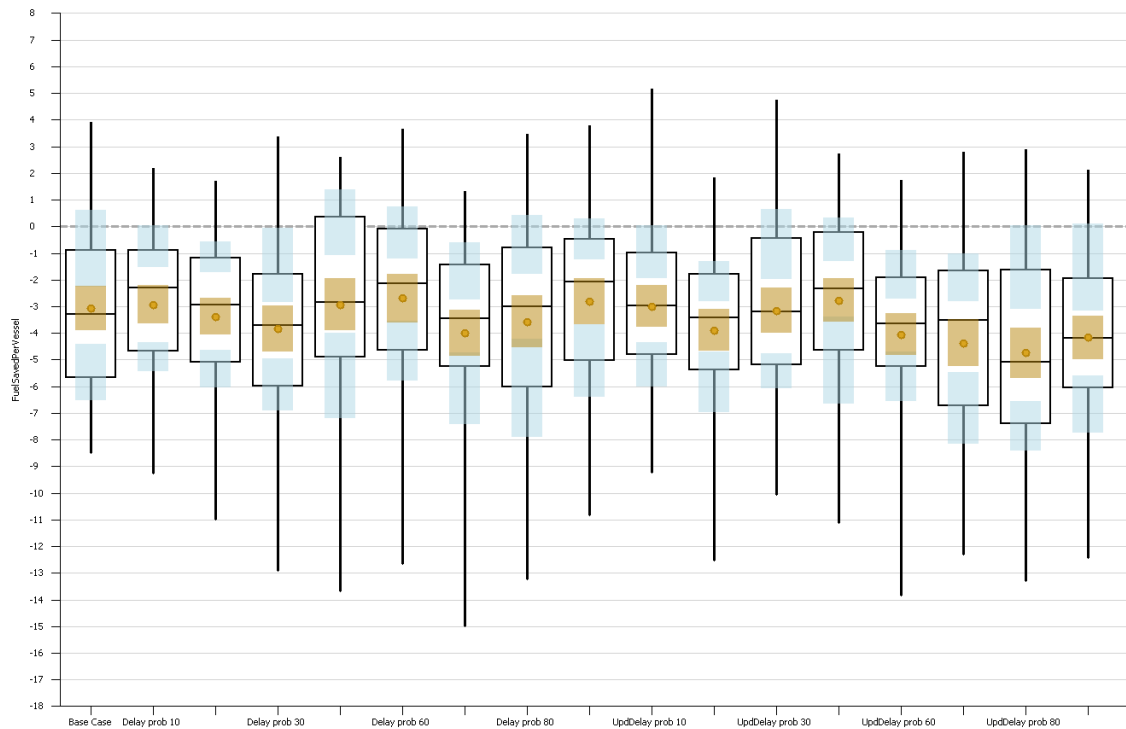


FIGURE 51: FUEL CONSUMPTION FOR SCENARIOS WITH DIFFERENT PROBABILITY OF BUNKERING

Table 29 shows the results from the normality analysis. Although some of the scenarios for the average waiting time are not normally distributed a Wilcoxon test will be done. For the other response namely the fuel saved per vessel there are also some scenarios that are not normally distributed, despite this the set will be tested for its variance so that parametric tests can be done.

| | p-value | | | |
|------------------|--------------------------|------------|-----------------------|----------|
| | Average waiting time PBP | | Fuel Saved per vessel | |
| | Shapiro | KS | Shapiro | KS |
| Base Case | 0.03107 | 0.08576 | 0.2790 | 0.3602 |
| Delay prob 10 | 0.1397 | 0.3763 | 0.2056 | 0.5012 |
| Delay prob 20 | 0.04526 | 0.1146 | 0.06700 | 0.08817 |
| Delay prob 30 | 0.0001369 | 7.5721e-06 | 0.8882 | 0.8958 |
| Delay prob 40 | 0.0001087 | 0.0002125 | 0.008679 | 0.03145 |
| Delay prob 60 | 1.1521e-06 | 9.4859e-09 | 0.02310 | 0.01690 |
| Delay prob 70 | 2.7090e-06 | 1.2457e-06 | 0.007170 | 0.002421 |
| Delay prob 80 | 0.3563 | 0.2961 | 0.1786 | 0.2142 |
| Delay prob 90 | 7.6303e-05 | 6.6286e-07 | 0.2103 | 0.2939 |
| UpdDelay prob 10 | 0.6900 | 0.8761 | 0.9069 | 0.7755 |
| UpdDelay prob 20 | 0.002588 | 0.01860 | 0.1354 | 0.09702 |
| UpdDelay prob 30 | 0.1240 | 0.1093 | 0.9583 | 0.9184 |
| UpdDelay prob 40 | 0.0002276 | 0.0006443 | 0.04744 | 0.1479 |
| UpdDelay prob 60 | 1.8047e-09 | 7.3911e-15 | 0.01510 | 0.004008 |
| UpdDelay prob 70 | 0.002676 | 0.001486 | 0.1849 | 0.3201 |
| UpdDelay prob 80 | 0.006772 | 0.011259 | 0.25674 | 0.5140 |
| UpdDelay prob 90 | 0.008591 | 0.0062448 | 0.52687 | 0.8322 |

TABLE 29: NORMALITY ANALYSIS ON SCENARIOS WITH DIFFERENT BUNKERING PROBABILITY

Before choosing the Welch t-test or regular t-test the set of data will be tested on difference in variance. In the lines below the p-value does not exceed the threshold and therefore the student t-test and ANOVA will be used.

```
LeveneResult (statistic=0.9088566683758983, pvalue=0.5587154170562421)
LeveneResult (statistic=1.0377451483019988, pvalue=0.41309128854543725)
```

In Table 30 are the results for the tests on significance. For the average waiting time at the pilot boarding place the probability of bunkering is not significant as the p-value is not lower than 0.05. On the analysis of fuel saved most scenarios appear to be insignificant to the base case except for the probabilities 70 and 80 percent with delay sharing which seems odd as these scenarios without delay sharing did not have a significant change. Also the outcome of the ANOVA test is a bit contradictory to the student t-test as it rejects the hypothesis that probabilities of bunkering have a significant effect on the fuel saved per vessel. An explanation for these opposite values could be that the ANOVA test can be more sensitive to distributions that are not normal.

| | p-value | | |
|------------------|--------------------------|-----------------------|----------|
| | Average waiting time PBP | Fuel Saved per vessel | |
| | Wilcoxon | Student t-test | ANOVA |
| Delay prob 10 | 0.8482 | 0.7852 | 0.003331 |
| Delay prob 20 | 0.1370 | 0.5853 | |
| Delay prob 30 | 0.1925 | 0.2105 | |
| Delay prob 40 | 0.5909 | 0.8134 | |
| Delay prob 60 | 0.3131 | 0.5259 | |
| Delay prob 70 | 0.2388 | 0.1251 | |
| Delay prob 80 | 0.2824 | 0.4404 | |
| Delay prob 90 | 0.5559 | 0.6714 | |
| UpdDelay prob 10 | 0.9237 | 0.8971 | |
| UpdDelay prob 20 | 0.06150 | 0.1556 | |
| UpdDelay prob 30 | 0.6640 | 0.8882 | |
| UpdDelay prob 40 | 0.8597 | 0.6038 | |
| UpdDelay prob 60 | 0.2958 | 0.08739 | |
| UpdDelay prob 70 | 0.1389 | 0.03342 | |
| UpdDelay prob 80 | 0.1900 | 0.009141 | |
| UpdDelay prob 90 | 0.1779 | 0.06359 | |

TABLE 30: TEST OF SIGNIFICANCE FOR SCENRIOS WITH DIFFERENT PROBABILITIES OF BUNKERING

EXPERIMENT ON AVERAGE BUNKER DELAY

In the following experiment the time of the average bunker delays is stepwise increased. In the model the average delay can be changed, deviations from this average can then go up by half an hour or down by half an hour. Besides the set of scenarios with increased bunker delays the same set is analysed with delay sharing enabled.

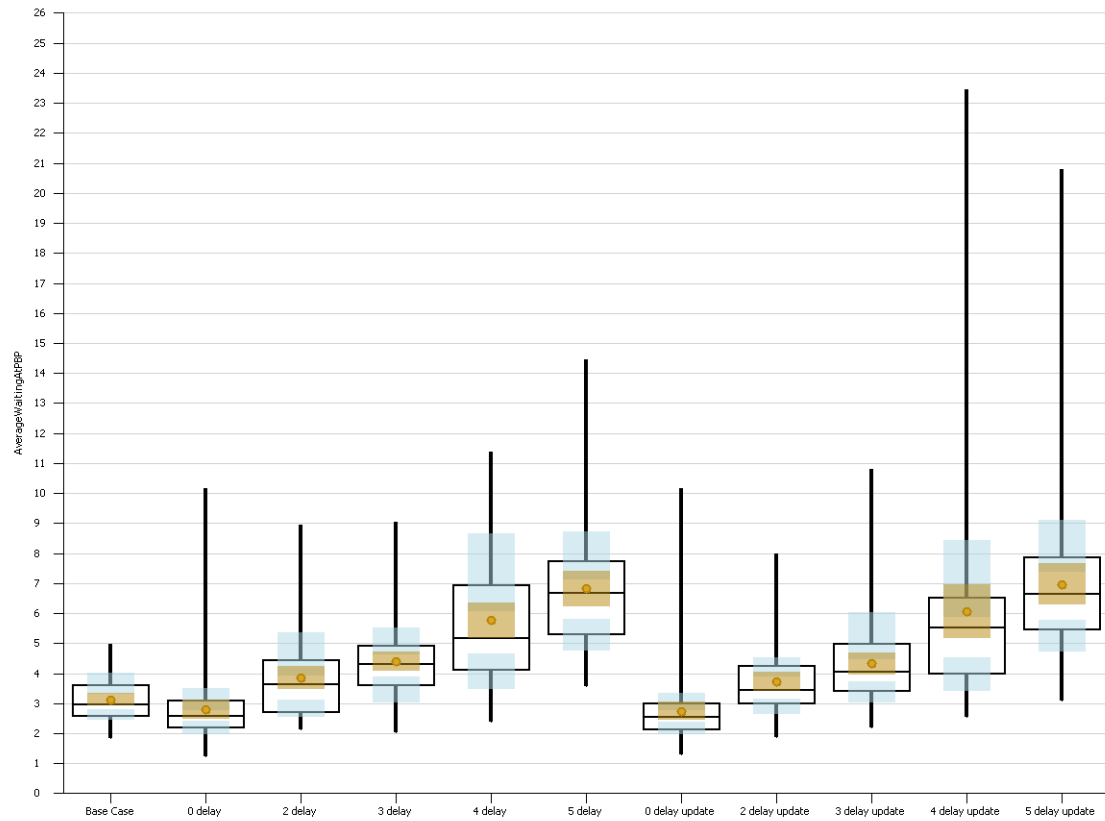


FIGURE 52: WAITING TIME FOR SCENARIOS WITH DIFFERENT BUNKER DELAYS AND BUNKER UPDATES

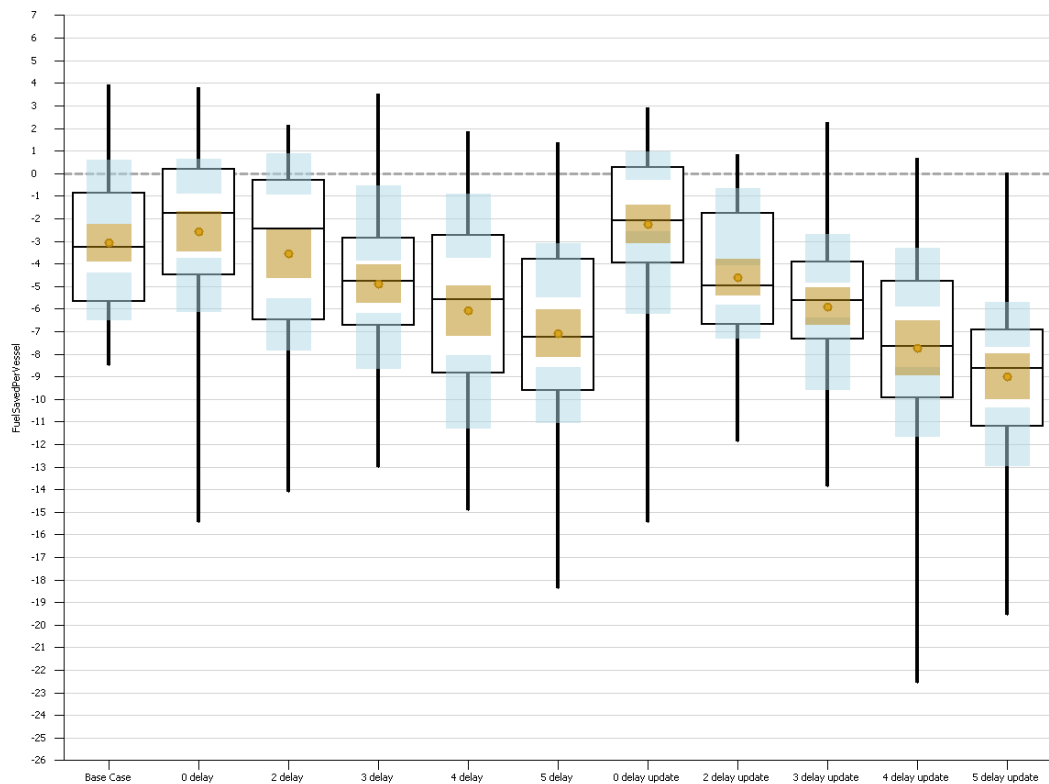


FIGURE 53: FUEL SAVED PER VESSEL FOR DIFFERENT BUNKER DELAYS WITH AND WITHOUT SHARING

Figure 53 includes increased delays with and without information sharing concerning these delays. At first glance the graph looks very counterintuitive as the fuel consumption decreases, but this can mainly be attributed to the following fact: vessels will in general have longer times at berth 1 because bunkering will have higher delays. Therefore vessels handled by these two berths remain longer at the berth, at some moment this information will start flowing through the chain and because of that vessels far away will start slowing down earlier. Because of this it seems that the vessels are saving extra fuel due to longer bunker delays. To confirm this another lever response has been defined namely the total time in system which is the time from entering the simulation until departure from pilot boarding place. This extra figure shows that vessels stay longer in the system because travel time to the port will be longer and the average waiting time at the anchorage increases.

In Table 31 are the results of the normality analysis for the scenarios with different bunker delays. For the average waiting time at anchorage none of the newly defined scenarios appear to be normally distributed. For fuel saved per vessel there is not one clear outcome, some of the scenarios are normally distributed while other are not.

| | p-value | | | |
|----------------|--------------------------|------------|-----------------------|-------------|
| | Average waiting time PBP | | Fuel Saved per vessel | |
| | Shapiro | KS | Shapiro | KS |
| Base Case | 0.03107 | 0.08576 | 0.2790 | 0.3602 |
| 0 delay | 9.4184e-11 | 3.1668e-19 | 0.009596 | 0.001518 |
| 2 delay | 2.2261e-06 | 8.6086e-07 | 0.003647 | 0.1016 |
| 3 delay | 0.001980 | 6.3214e-05 | 0.8542 | 0.9962 |
| 4 delay | 0.0008119 | 0.02044 | 0.09336 | 0.01944 |
| 5 delay | 0.0002244 | 5.4881e-05 | 0.8878 | 0.7183 |
| 0 delay update | 1.4079e-11 | 2.9815e-21 | 0.0002128 | 7.6094e-06) |
| 2 delay update | 7.4165e-06 | 8.6042e-07 | 0.08640 | 0.5241 |
| 3 delay update | 1.7679e-05 | 2.8565e-08 | 0.2235 | 0.2929 |
| 4 delay update | 3.3603e-09 | 2.1587e-13 | 0.01816 | 0.005410 |
| 5 delay update | 2.6925e-07 | 1.3155e-12 | 0.6853 | 0.6833 |

TABLE 31: NORMALITY TESTS FOR AVERAGE BUNKER DELAY SCENARIOS

Since more than one third of the distributions for fuel saved per vessel are not normally distributed for both parameter the Wilcoxon Rank test will be used. Results of these analysis are included in Table 32. With almost all comparisons exceeding the threshold increases of bunker delays will have an significant effect on the waiting time at anchorage as well as the amount of fuel wasted per vessel.

| | p-value | |
|----------------|--------------------------|-----------------------|
| | Average waiting time PBP | Fuel Saved per vessel |
| | Wilcoxon | Wilcoxon |
| 0 delay | 0.005900 | 0.2694 |
| 2 delay | 0.001080 | 0.5559 |
| 3 delay | 3.9795e-08 | 0.002195 |
| 4 delay | 6.8713e-10 | 0.0003369 |
| 5 delay | 1.7141e-11 | 3.1156e-07 |
| 0 delay update | 0.0007472 | 0.03998 |
| 2 delay update | 0.003082 | 0.02248 |
| 3 delay update | 2.8411e-06 | 7.0300e-05 |
| 4 delay update | 1.6602e-10 | 3.5016e-07 |
| 5 delay update | 1.9945e-11 | 1.6602e-10 |

TABLE 32: SIGNIFICANCE TESTS FOR AVERAGE BUNKER DELAY SCENARIOS

EXPERIMENT ON INACCURACY OF INFORMATION

In this experiment the inaccuracy of information will be tested therefore the inaccuracy will be increased up to a value of 50%. This means that information inaccuracies will not always have this deviation but that the upper and lower limit of the distribution that is multiplied with the minimal time to service.

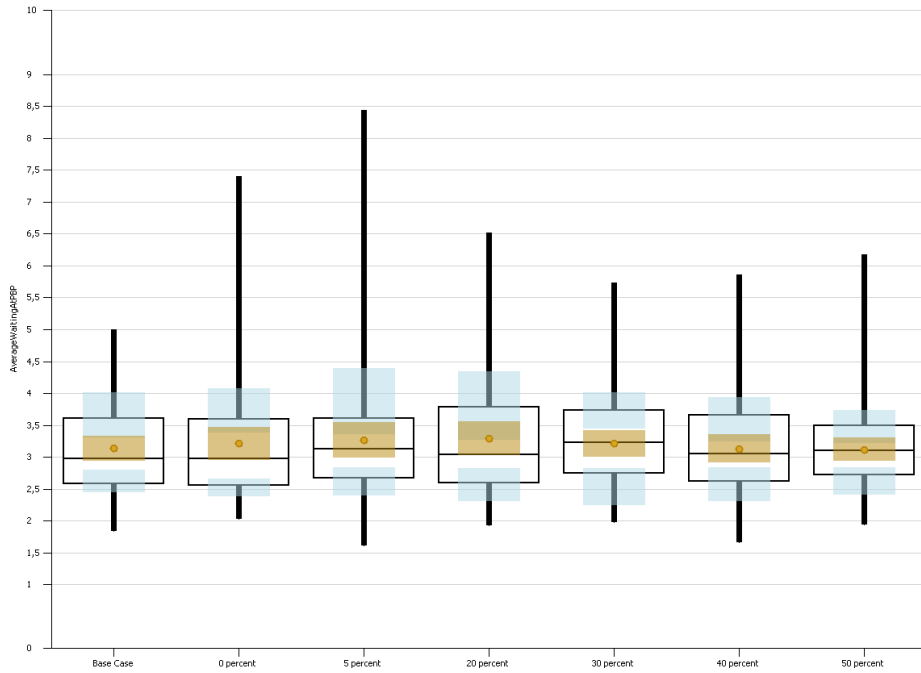


FIGURE 54: AVERAGE WAITING TIME AT ANCHORAGE FOR SCENARIOS WITH DIFFERENT INFORMATION ACCURACIES

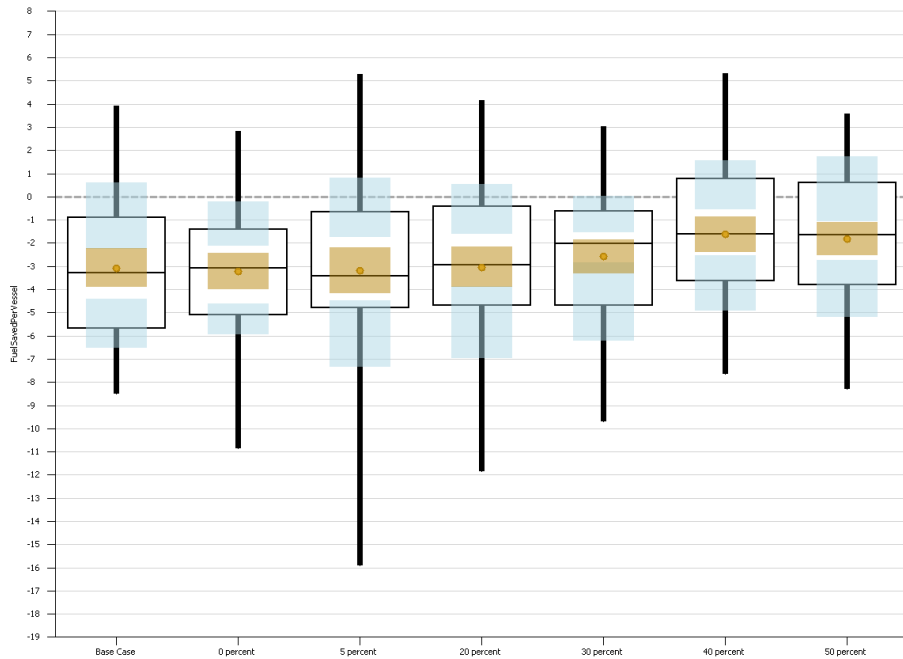


FIGURE 55: AVERAGE FUEL SAVED WITH DIFFERENT INFORMATION ACCURACIES

When testing on normality all but the scenario with 30% intervals for average waiting time are not normally distributed. For fuel saved all scenarios are normally distributed (Table 33).

| | p-value | | | |
|------------|--------------------------|------------|-----------------------|--------|
| | Average waiting time PBP | | Fuel Saved per vessel | |
| | Shapiro | KS | Shapiro | KS |
| Base Case | 0.03107 | 0.08576 | 0.2790 | 0.3602 |
| 0 percent | 7.3665e-07 | 1.0631e-08 | 0.6837 | 0.8030 |
| 5 percent | 4.3423e-06 | 5.2127e-10 | 0.4458 | 0.1008 |
| 20 percent | 0.0001887 | 0.0006370 | 0.9511 | 0.8259 |
| 30 percent | 0.09586 | 0.1298 | 0.21914 | 0.4159 |
| 40 percent | 0.006979 | 0.001766 | 0.6525 | 0.8078 |
| 50 percent | 0.0003009 | 5.3294e-07 | 0.3913 | 0.3727 |

TABLE 33: NORMALITY TESTS FOR INFORMATION ACCURACY SCENARIOS

Testing the fuel saved per vessel on difference in variance will yield the following results:

LeveneResult (statistic=1.0114120790608603, pvalue=0.41723357175104003)
 LeveneResult (statistic=0.9887012493430698, pvalue=0.4323871532204433)

Since the significance threshold is not exceeded the student t-test and ANOVA test can be utilised which are included in Table 34. With 95% certainty the accuracy of information does not have any effect on the waiting time at pilot boarding place. Furthermore only when the information deviates 40% or more the implications on the fuel consumed are significantly different in the sense that in these situations more fuel is burned than in the base case.

| | p-value | | |
|------------|--------------------------|-----------------------|---------|
| | Average waiting time PBP | Fuel Saved per vessel | |
| | Wilcoxon | Student t-test | ANOVA |
| 0 percent | 0.8829 | 0.7905 | 0.01385 |
| 5 percent | 0.5411 | 0.8638 | |
| 20 percent | 0.3691 | 0.9446 | |
| 30 percent | 0.4013 | 0.3715 | |
| 40 percent | 0.9706 | 0.01144 | |
| 50 percent | 0.6322 | 0.02363 | |

TABLE 34: SIGNIFICANCE TESTS OF INFORMATION ACCURACY SCENARIOS

EXPERIMENT ON GREEN STEAMING

This is the last lever that is checked for its sensitivity. The green steam lever indicated that before a berth has been appointed to a vessel an advice can already be given regarding speed. This is because the accumulation of earlier vessels and their requested time will yield a minimum average time to service. When having a first look at the SMORE plots it appears that the average waiting time will be slightly lower for the higher intervals. However the fuel consumption increases a lot on the small interval.

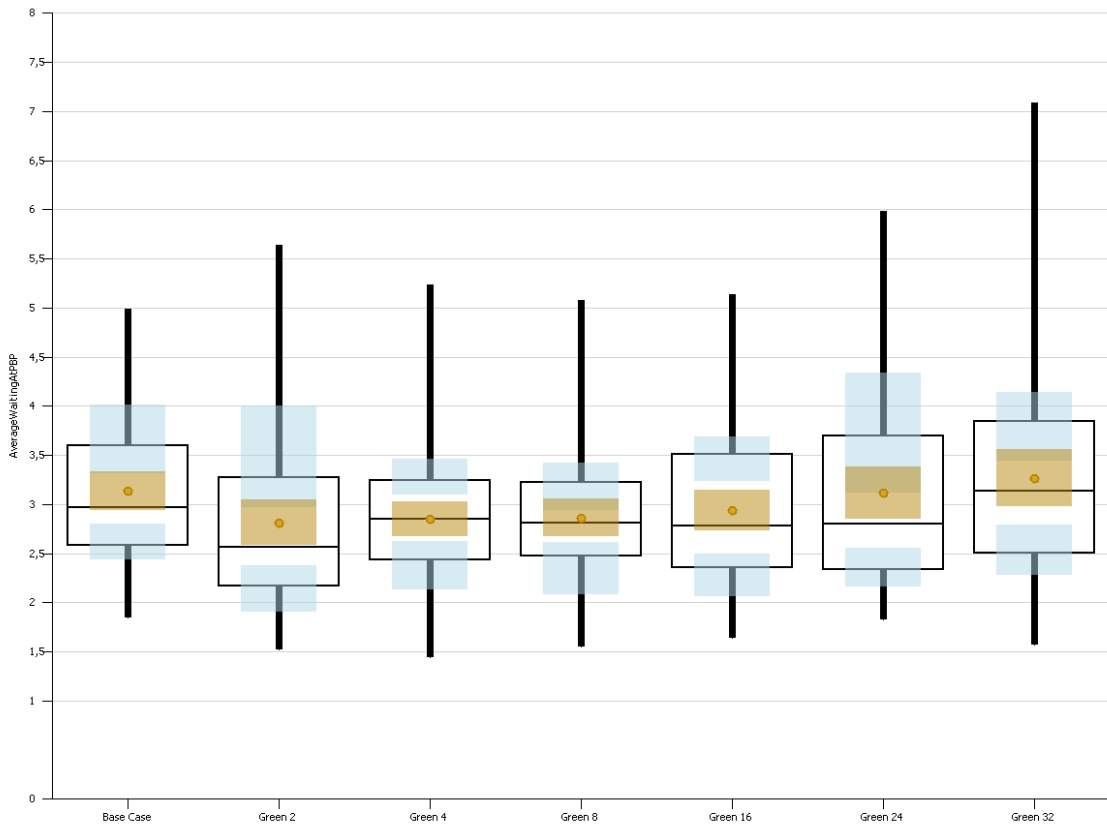


FIGURE 56: AVERAGE WAITING TIME AT PBP FOR DIFFERENT GREEN STEAM INTERVALS

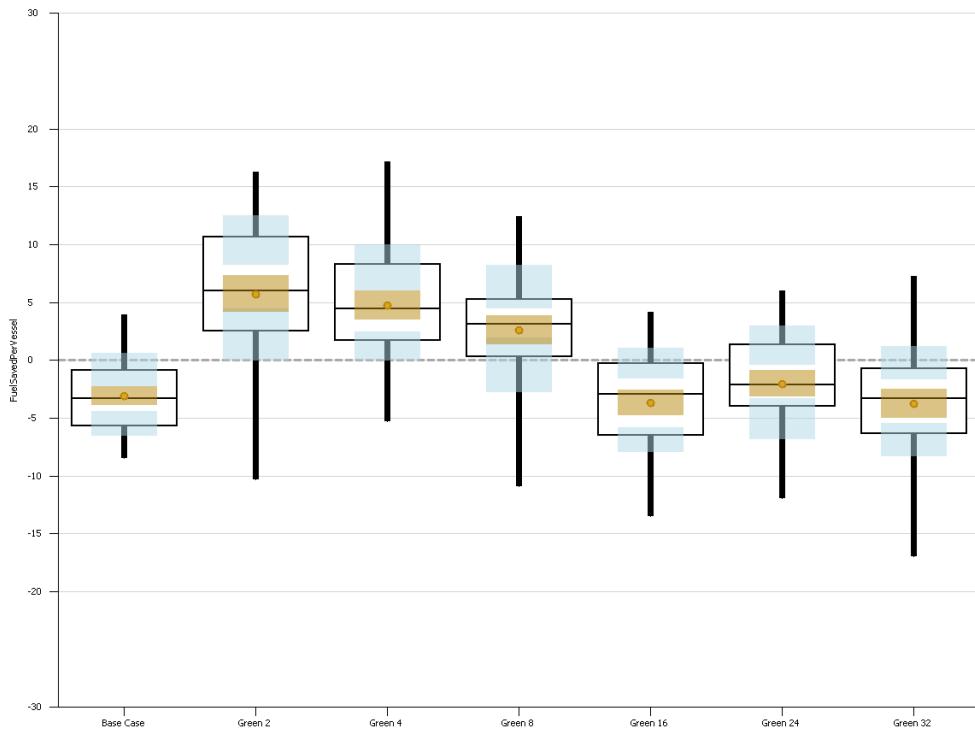


FIGURE 57: AVERAGE FUEL CONSUMPTION PER VESSEL FOR DIFFERENT GREEN STEAM COMMUNICATION INTERVALS

In Table 35 Test on normality is done. For all scenarios the fuel per vessel saved can be assumed normally distributed which implies that Levene's test for difference in variance can be used. For the waiting time at PBP the Wilcoxon signed rank test will be used.

| | p-value | | | |
|-----------|--------------------------|------------|-----------------------|--------|
| | Average waiting time PBP | | Fuel Saved per vessel | |
| | Shapiro | KS | Shapiro | KS |
| Base Case | 0.03107 | 0.08576 | 0.2790 | 0.3602 |
| Green 2 | 0.0009832 | 0.007824 | 0.1776 | 0.2837 |
| Green 4 | 0.1665 | 0.02985 | 0.6846 | 0.5761 |
| Green 8 | 0.002193 | 0.001336 | 0.2073 | 0.1226 |
| Green 16 | 0.01344 | 0.03562 | 0.3575 | 0.3057 |
| Green 24 | 8.7316e-05 | 0.007307 | 0.1368 | 0.3816 |
| Green 32 | 0.0001192 | 1.2893e-05 | 0.9913 | 0.6933 |

TABLE 35: NORMALITY TESTS FOR GREEN STEAM SCENARIOS

When performing Levene’s test both outcomes yield a significant difference. Since the outcomes of the two variations are below the significance level the Welch t-test has been chosen as this one is more robust as variations start to differ.

```
LeveneResult (statistic=3.1235409060527184, pvalue=0.005270893712125379)
LeveneResult (statistic=3.1958277771344545, pvalue=0.004454397185598141)
```

Testing shows that waiting time is significant shorter for an interval of 2 or 8 hours, for the longer intervals there is no difference (Table 36). However shorter intervals appear to be detrimental for the fuel consumption of vessels, the p-values exceed the threshold easily approaching zero.

| | p-value | |
|----------|--------------------------|-----------------------|
| | Average waiting time PBP | Fuel saved per vessel |
| | Wilcoxon | Welch t-test |
| Green 2 | 0.03277 | 4.4878e-16 |
| Green 4 | 0.08765 | 8.2583e-18 |
| Green 8 | 0.04217 | 1.2529e-11 |
| Green 16 | 0.1429 | 0.3842 |
| Green 24 | 0.8771 | 0.1384 |
| Green 32 | 0.5076 | 0.3668 |

TABLE 36: SIGNIFICANCE TESTS FOR GREEN STEAM SCENARIOS

9.4. SUMMARY ON RESULTS

First experiment performed is the one with the current, worst and best case, for this case the current case performs relatively low, only a score of 35% is achieved with regard to the fuel consumption and the waiting time at anchorage. However these results are strongly bound to the assumptions of the worst and best case. In the worst case no information is shared, therefore vessels are sailing at their standard speed towards the port. The variation in performance is therefore on the one hand determined by the vessel dimension and assigned containers and on the other hand output statistics of the source. There is one source producing vessels with a particular distribution. Hypothetically there would be a very low queue if vessels arrive at the average interval time as the berths are modelled such that their capacity is sufficient. With higher intervals berth utility would go down and the waiting time would approach a value close to the minimum. However waiting time will only increase with vessels arriving rapidly after each other in the lower region of the arrival distribution. Since the berth will then build up queues. But because the model actually has two berths impact of two closely arriving vessels will be abated. Probabilities of four or more vessel having arrival times in the lower part of the distribution is therefore less likely. On the other hand this also suggests that having more than one

berth available provides robustness and flexibility in the schedule. Perhaps this is also typical for a model in container shipping. For terminals it is easier to shift a bit with vessels along the quay. However for large tankers or bulk vessels there is only a single place at the quay or jetty available. This can actually be seen in Appendix X where an extra simulation run has been performed with a single berth situation. Since this research is more focussed on container shipping not much more emphasis will be put on the results of the single berth although it would be a good input for further research.

Besides the arrival of vessels the data sharing interval of the current case is set at 16 hours being fixed for the whole journey. In real life the interval of communication actually narrows down, where the interval is set to some days far ahead, up to an hour when close to the anchorage place.

In the end the most significant results are the reductions in average waiting time at anchorage which can be huge for improved data sharing. Also the fuel consumption can be reduced a lot compared to the normal and worst case. Other results such as berth utilisation do not seem to vary a lot. There are some differences in the utility of berth one and two however this could be due to the different values for bunkering at berth one. In the end the number of vessels handled remains approximately the same. What is not taken into account for these simulation runs, both in this experiment as well as the sensitivity analysis in the next one is the allocation of extra time. If vessels save time by arriving just in time at the berth this would imply that the berth can be used better and that the arrival of vessels could increase. However the arrival of vessels is a stochastic given and does not change with the system. But hypothetically if vessels speed up to get an earlier time window it would be possible for the terminal to be more productive.

For the sensitivity of the levers the results have been summarised in Table 37.

| Levers tested | Conclusions |
|-----------------------------------|---|
| Communication interval high speed | Affect the waiting time at anchorage and fuel consumption to a large extent. Waiting time will decrease with an increased interval. Fuel consumption will also increase with increased communication. |
| Communication interval low speed | Just as with the high speed the waiting time at anchorage is significantly reduced. However the fuel consumption decreases with smaller communication intervals. |
| Update of cargo operations | Increasing the interval of schedule integrity of cargo operations has minor effect, no effects were seen for the fuel consumption. For waiting time high sharing intervals will have a negative effect on waiting time at anchorage. |
| Probability of delay | When the port has a higher probability of delays while maintaining the same schedule will barely affect operations. With higher probability the fuel consumption will remain approximately the same. Waiting time however increases, mainly due to higher maximum values. |
| Probability of bunkering | According to the test there are no significant implications for increased probabilities of bunkering while maintaining the same arrival schedule of vessels. |
| Average bunker delay | Differences in the average delay in bunkering does have a major effect on the waiting time at anchorage especially for higher delays. Furthermore sharing information about delays does not significantly improve waiting times. Also for higher delays fuel consumption will increase. |
| Accuracy of information | Accuracy of information does not have a significant effect on waiting time at anchorage. Very high inaccuracy does have an impact on the |

| | |
|----------------------|---|
| | fuel consumed per vessel. Since the distribution of inaccuracy is symmetrical lower interval will in this case have a correcting effect on the speed ⁹ . |
| Early green steaming | High green steam intervals will have no significant effect on the fuel consumed and waiting time at anchorage. However lower intervals do improve the average waiting time while at the same time aggravating fuel consumption. |

TABLE 37: RESULTS OF LEVER SENSITIVITY ANALYSIS

For some of the experiments the fuel consumption would increase with shorter intervals. Hypothesized was that fuel consumption would reduce with more frequent data sharing as vessels can adapt better. However in some cases the fuel consumption would increase in the scenarios with the highest frequency of data sharing. Potential causes for this could be that with increased updates the vessels sail some more intervals on an higher speed thus consuming more fuel.

Especially with the two experiments on the communication interval times it becomes apparent what the implications of the maximum speed are on the fuel consumption. When vessels are only allowed to slow down they can only save fuel, it would be impossible to burn more. In the first experiment with a higher maximum speed the vessels are often encouraged to speed up with regard to the next vessel if this is possible. This would be very useful for the terminal as vessels will come as close as possible after each other, however for the vessels more fuel is required. When putting the experiments in to perspectives a few things can be done: if vessel A and B are overlapping in the terminal planning a few things could be done, either A speeds up so it doesn't overlap with B anymore. Or B slows down such that it doesn't overlap with A anymore. Or both vessels adjust their speeds a little, letting A arrive a little earlier and B a little later. With regard to the first interval experiment vessels are encouraged to speed up if possible, and other vessels are then encouraged to slow down if necessary. In the second experiment vessels are only encouraged to slow down if it is still overlapping in time with the previous vessel otherwise they are sailing at cruise speed.

This is also the part where good policies can be questioned since information sharing seems to be helping only some stakeholders. When vessels would speed up this would probably be more beneficial for the terminal and its planning. On the other hand only sailing speeds up to the cruising speed would be very beneficial for the vessel. But in this case some probable gap with a prior vessel will not be shortened. In turn this does give some predictability for the terminal, perhaps planning smaller vessels or barges would be a good alternative.

Thus for the results in most cases the higher possibility in speed often abates the effect of reduced fuel consumption. This is also in combination with the assumption that vessels will always act on information and therefore change their speed immediately. Without any additional policies with regard to actions fuel consumption will not be as low as it could be. Potential policies could be that not all vessels will speed up, for example only the vessels that already have a certain delay and not all vessels that could berth earlier. Other policies would be acting on information only if the implications are bigger than a particular time.

By distinguishing two experiments with regard to the maximum speed this has not been done for the other experiments anymore. For the experiments with higher probability or longer delays other effects can be noticed. When increasing the probability of a delay or length of a delay in general the fuel

⁹ For example in the first iteration a lower time to service is returned due to the inaccuracy, however in the next iteration it is more likely that an higher time to service is returned therefore correcting the information at lower intervals.

consumption will increase. Especially in the experiments with longer bunkering delays this becomes clear. Since bunkering delays increase the vessels will remain longer in the berth. However the source still produces the same number of vessels, with the same distribution. Results of this is that vessels will wait longer at the pilot boarding place as time at berth one is hogged by bunkering. And since information sharing is still enables incoming vessels will be encouraged to reduce their speed. Reduction in speed and therefore fuel savings will only increase with increased delays. In the particular case of longer bunker delays a slight improvement can be seen with the updates. However the updates with regard to the operations of either bunkering or cargo operations appear to have a minor effect.

Furthermore there are also other consequences to lower waiting times at the anchorage. CO2 emitted at anchorage is at the account of the port of Rotterdam. So there is a high interest in reducing this. Figure 58 shows the fuel consumption at anchorage for different communication intervals. In the normal case the fuel consumption at anchorage is 3.80 tonnes of fuel on average. Comparing this to the best available scenario in the experiment with changing communication intervals and a maximum of 17 knots speed the best case is only 63.2 percent of the normal case. This means that more than 35% of fuel can be saved at anchorage.

$$\text{Let } \frac{BC}{CC} = 0.632 \text{ where } BC \text{ is best case and } CC \text{ is current case}$$

According to Rob (2018) every ton of fuel equals 3.16 tonnes of CO2. Thus with 36.8% savings in the model 1.4 tonnes of fuel can be saved which equals approximately 4.2 tonnes of CO2 per vessel. In the earlier data analysis it was found that 2043 vessels have a single berth visits in Rotterdam and length over 200 meter. This is the 93 percent population of single berth vessels used for the research. These are the vessel that visit Rotterdam in one year. In the case of optimal data sharing it would therefore be possible to reduce the amount of CO2 emissions with the following:

$$\begin{aligned} \text{Let } R &= V * CO2 \text{ be the reduction in tonnes } CO2 \\ R &= 2043 * 4.2 \\ R &= 8581.82 \text{ [tonnes]} \end{aligned}$$

The reductions in CO2 emissions on a year basis would therefore be tremendous. And since the model is not fully fitted to the real world waiting times are approximately one fifth of those in the real world, savings could therefore reach levels of up to 37603 tonnes of CO2 reduction. Waiting times in real life are 4.6 times higher, this factor could therefore give an indication what the relative optimisation would encompass in real life. As the consumption at anchorage is heavily linked to the time at anchorage this figure looks like a duplicate of Figure 58. When in turn comparing the potential savings, 35% of time at anchorage can be reduced. When comparing this to the 15.6 hours waiting time found in chapter 5 slightly more than 1/3, equalling more than 5 hours can be saved in time.

Table 38: Fuel and CO2 savings in tonnes per vessel and per year Table 38 shows the optimal savings potential that can be realised by shortening communication interval. In the first column is the percentage time required from the normal case, so anything lower than 100 is optimised. In the other columns are the savings in the model for an individual vessel as well as the whole population over one year. In the last two columns the consumption at anchorage is multiplied by 4.6 to give an indication of the potential savings in real life if the same percentages of optimisation could be realised.

| | PERCENTAGE [%] | MODEL SAVINGS PER VESSEL | MODEL SAVINGS TOTAL POPULATION | REAL LIFE SAVINGS PER VESSEL | REAL LIFE SAVINGS TOTAL POPULATION |
|------------------|----------------|--------------------------|--------------------------------|------------------------------|------------------------------------|
| ANCHORAGE - FUEL | 63.2 | 1.40 | 2860.61 | 5.82 | 11900.11 |
| ANCHORAGE - CO2 | 63.2 | 4.20 | 8581.82 | 18.04 | 37603.38 |
| JOURNEY – FUEL | 94.4 | 15.71 | 32101.21 | | |
| JOURNEY – CO2 | 94.4 | 49.65 | 101439.83 | | |

TABLE 38: FUEL AND CO2 SAVINGS IN TONNES PER VESSEL AND PER YEAR

Figure 58 has a continuous x scale, since the intervals for the experiment are not equally distant some scenarios are closer to each other. To really see the distributions of the scenarios with smaller time intervals another figure has been included in the appendix which has equally spaced steps.

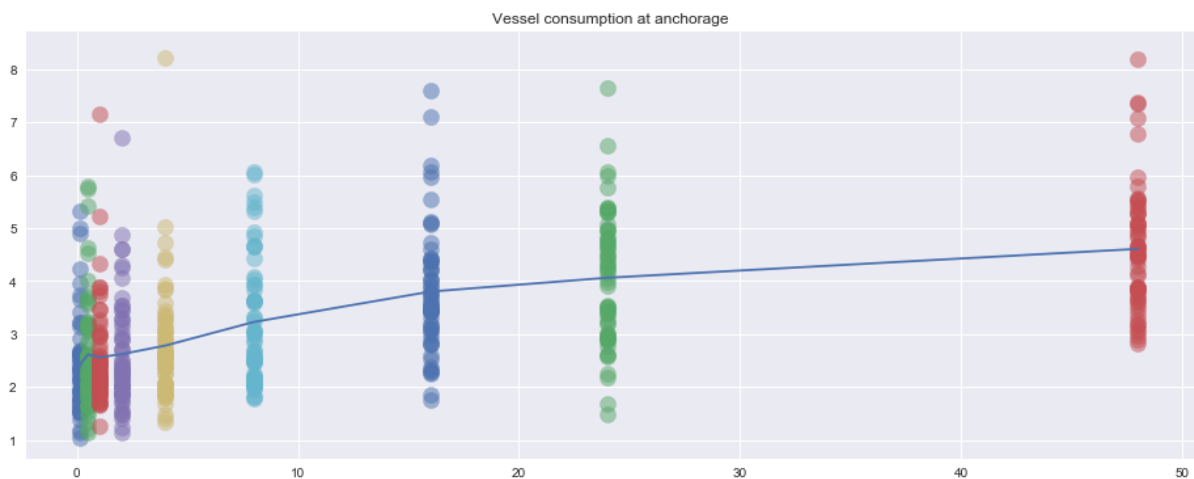


FIGURE 58: AVERAGE VESSEL CONSUMPTION AT ANCHORAGE

In Figure 58 is the fuel saved during the trip for the experiment of changing communication interval with an upper speed bound of 17 knots. When comparing the normal case and the best case a difference of 15.71 tonnes of fuel can be found. If all vessels where to do this journey of 650 nautical miles savings of 15.71 times 19961 vessels would be more than 310,000 tonnes of fuel a year.

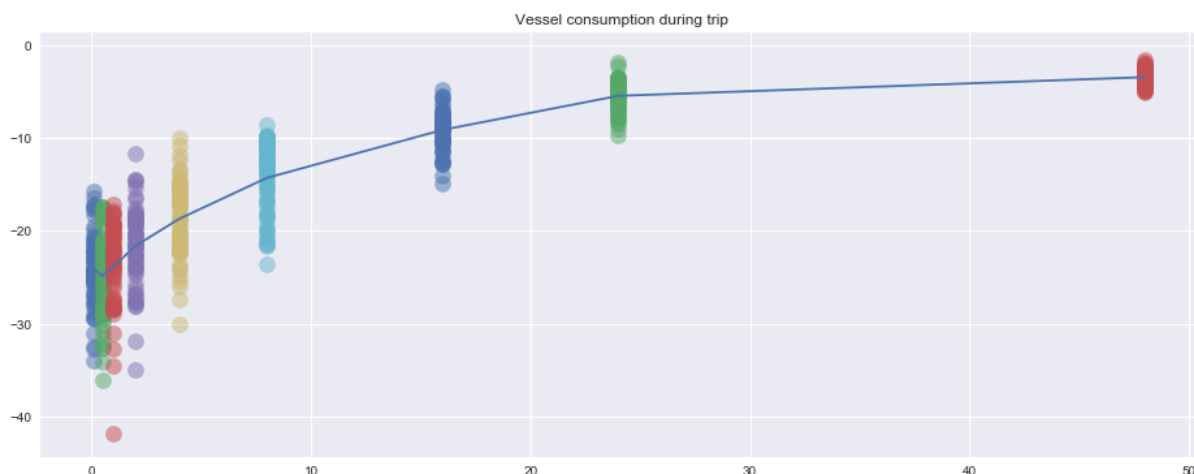


FIGURE 59: AVERAGE FUEL SAVED DURING TRIP

10. IMPLICATIONS OF THE QUANTITATIVE AND QUALITATIVE

Up till now paragraphs have returned both quantitative and qualitative results. First was the actor and event analysis exploring most actors that are involved during a port call and all events that occur during the port call. Initially this information was used as input for the model but on itself also has implications for the results of the simulation. The quantitative part includes the data analysis and the results returned by the simulation model. This paragraph is used to mend these results together and bridge the gap between qualitative and quantitative. The first part will put the performed experiments in perspective to a bigger whole whereas the second part of this chapter combines the results of the previous chapter and earlier qualitative analyses.

10.1. DIMENSIONS IN THIS RESEARCH

In chapter three an elaborate actor analysis has been done on the actors that are involved. Initially this qualitative analysis served as exploration to get a better understanding of who is involved and how do these actors relate to each other. After that a deep dive was taken into the events that occur during the port call. Port calls have a general structure but can deviate from each other in a few ways, for example: some vessels have restrictions regarding their dimensions, differences in services to be performed, or a different purpose of their visit. Where some vessels come to exchange thousands of containers other vessels might only pick up a few hundred containers scattered across different terminals in the port. This exploration therefore returns different dimension on which operations in a port can change and therefore also the implications information sharing will have. This research has been narrowed down to prove the impact of data sharing in a particular situation, part of a bigger whole. Previous qualitative analyses were performed on deep sea container shipping coming from mid ranges visiting a single berth in the port of Rotterdam.

By means of the initial actor and event analysis a situation sketch is given of the possibilities with regard to container operations in the port. In the consecutive quantitative analysis the case of Rotterdam is analysed to prove the potential impact of data sharing. In a sense scoping down to the Rotterdam case in turn narrows the generalisability of the research as data from the port of Rotterdam is being used. With these considerations in mind three levels of resolution are touched upon. Where the middle resolution is the Rotterdam case specified to one particular operation. When considering this resolution other ports could be considered with different features. On the low resolution are the port operations, in this research focus is on container shipping. However operations will change for dry bulk, liquid bulk, or perhaps even the difference between transshipment and import or export ports. As mentioned before bulk operations change significantly from container shipping which would therefore require different assumptions and modelling. The highest resolution would include more actors and details about the actors, this would include information from the terminal, operations of barges, feeders and other smaller vessels at the berth as well as changing berths in the port. Switching from one berth to another affects many operations, since more than one terminal is included, nautical services and many others. But as long as the second berth is not available this will also affect the first berth. These are processes that have a smaller time window but do have a rippling effect on operations in the port. Operations mentioned before such as switching berths require smaller time intervals and more accuracy of information.

For the scenarios examined in this research, focussed on container deep sea shipping, with an average resolution there is a difference between the data analysed and created. In the port there is a lot of data available, but this does not describe the implications of data sharing. This is where the model continues, in the simulation data is generated about different scenarios where data is shared. Using a model like this can explore and examine consequences of data sharing without actually testing this in

real life bound to high costs. Results of this model therefore test the implications of different policies that can be applied and changed when implementing a data sharing initiative.

Besides defining the resolutions the actor analysis also elaborates on the information received and given by some of the actors. One of the implicit deductions that can be made is about the inefficiencies in port calls. For example the work of agents is focussed at matching the needs and demands of parties in the port, and supporting the captain during the stay in the port. Therefore making the agent a sort of problem solver aiding the captain thriving on the inefficiencies in the port. If the operations in the port would have been more predictable and communication between parties would be straight instead of going by many actors efficiency could be enhanced. In the model these considerations have not been taken into account, and thus mainly testing on the implications of certain policies. What this implies for further development is that some actors in the port might not want to cooperate and start sharing data as this could harm their operations. As long as some information is not clear or there is a certain level of chaos in the port actor maintain their flexibility and ability to provide services. Introducing a central hub where actors can exchange information and arrange business would reduce the need to have a middleman doing this therefore endangering some actors in the port.

Operations in ports have not changed much over the years, due to the complexity, scale and international diversity having an impact can be hard. This will probably also apply to the information sharing, it seems that this mechanism although its proven effect in other industries is a few steps ahead of current developments. A strong legacy in marine operations are also the contracts used. Contracts for sailing and operations, such as charter parties, have been around for many years and have a big influence on operations. Things like these indicate that changes in the maritime sector often go slow and need time.

10.2. INTERESTS OF ACTORS IN THE LEVERS AND OUTCOMES

In the previous chapter the main emphasis was on qualitative outcomes from the simulations runs in conjunction with the data analysis. This part will combine the numbers and information from chapter three into a scorecard. Table 39 couples the actors to the responses and the levers and gives a score between zero and two for its applicability and interest. “0” means almost indifferent about the topic, “1” is considered to be interested, and “2” is important. Goal of this table is to see who of the actors will benefit most through the mechanisms of data sharing or is the most affected, and on the other hand what responses and levers are considered to be important. For the classification only three classes have been chosen as the scores are based reasoned through the combination of quantitative and qualitative research. Scores are therefore more of an indication of importance subject to actors in the port of Rotterdam. In the following sections the actors and some of the scores will briefly be highlighted.

TERMINAL

In general the terminal is not so much interested in the fuel consumption by the vessel or the operational excellence of a shipping line. Important for the terminal is the berth occupancy, to have vessels at the quay and cranes operating. A terminal might therefore rather see a vessel at anchorage ready to sail in than arrive just in time and perhaps lose a bit of time. Terminals are interested in having information about the vessels and when they arrive. With more accurate and reliable information they can make a more robust and optimal planning in advance.

SHIPPING LINE

For the shipping line fuel consumption and therefore costs are really important as well as schedule integrity. Therefore information from terminals and other parties in the port is highly desired. In this

way operations can be adjusted accordingly. Important levers for this are the communication interval, getting the data which should be accurate as well.

CAPTAIN

In general the captain has overlapping interests with the shipping line, however due to the contracts he might sometimes be less interested in the sailing speed. What distinguishes the captain from the shipping line is that he is in the middle of the operation, information about services and their arrival is therefore highly desired. This could foster preparations, contractual clearances, and better crew planning.

AGENT

In service of the captain and the shipping line the agent is responsible to make to port visit as smooth as possible. If the agent can therefore aid in operations this will be valued, so accurate information would be key here.

NAUTICAL SERVICES

Since nautical services have a contract to service vessel within a particular time the average waiting time at anchorage is an interesting parameter. Furthermore nautical services are highly interested in receiving information on time, since this will not only enhance planning but also service. Planning can be improved if the right people and the right number of tugs can be reserved in time, at the same this will also increase service as it reduces uncertainty and waiting time.

BUNKERING

In a broader perspective bunkering might have a more ambiguous interest. Bunkers need to know when the contracted vessels arrive, so accuracy of this information will make operations more predictable. However reduction of waiting time or fuel used might not be in the best interest of bunker parties as this would mean less bunkering in the port assuming vessels depart previous ports with the same amount of bunker.

PORT AUTHORITY

As for the bunker parties the port also earns more when more bunkering operations are performed in the port. However this is a cause that is not quantified, the severity of this consequence might therefore also be overestimated. Nevertheless it is something to think about in other research or mechanism design. With regard to other actors in the port the port authority is less interested in small interval updates since most of the data is administrative and will not change over time.

CONTROLS AND RESPONSES

In the far right is a summation made of interests in the controls and responses for all the actors. Three important controls are the communication interval, accuracy of information, and cargo delay. Although the last two did not seem very significant in the previous chapter these cause a lot of uncertainty in operations. These uncertainties in turn have been accused of disturbing operations to a great extent and in particular the planning.

ACTORS

It appears that the terminal, shipping line, captain, and agent are the most affected stakeholders so far. For further research this would imply that these actors should have a leading role in developing mechanisms that improve data sharing in port calls.

| | | Actors | | | | | | | total |
|-----------------------------|--------------------------------|----------|---------------|---------|-------|-------------------|-----------|----------------|-------|
| | | Terminal | Shipping line | Captain | Agent | Nautical services | Bunkering | Port Authority | |
| Effect - levers | Communication interval | 2 | 2 | 2 | 2 | 1 | 1 | 0 | 10 |
| | Early green steam | 1 | 2 | 2 | 1 | 0 | 0 | 0 | 5 |
| | Bunker information | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 9 |
| | Accuracy | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 12 |
| | Cargo delay | 2 | 2 | 2 | 2 | 2 | 1 | 0 | 11 |
| Interest – responses | Total fuel consumption | 0 | 2 | 2 | 1 | 0 | 1 | 1 | 7 |
| | Fuel saved per vessel | 0 | 2 | 2 | 1 | 0 | 1 | 1 | 7 |
| | Average waiting time anchorage | 1 | 2 | 2 | 1 | 2 | 0 | 2 | 10 |
| | Average berth utility | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 3 |
| Total | | 10 | 14 | 16 | 11 | 8 | 8 | 7 | |

TABLE 39: SCORES ON LEVERS AND RESPONSES

When looking at Table 39 some actors have more interest in outcomes than others, they might therefore also benefit more. This could lead to a rather difficult situation where not all actors will be incentivised to help data sharing as they do not benefit. For example in a global optimum a lot of improvements will be made by applying as many of the improvements as possible. Leading to a lot of reduction in waiting time and fuel consumption. However these improvements have a far larger effect for some of the stakeholders. If therefore in a less optimal situation not all actors would contribute to the data sharing initiative the total optimisation will be lower. This issue might therefore be something for further research where a fair distribution of benefits will be given with regard to their contribution. If actor s contribute to the optimisation they should also be rewarded for this.

WRAPPING UP THE ANALYSIS

In the following chapters the conclusions will be given from all analyses done so far. These should then answer the sub questions posed at the beginning of the research and the main research question. After the conclusion the final chapter discusses the outcomes found in this research, to what extent they are applicable and fit in with other research, but also the limitations and further research to be done in this area.

11. DISCUSSION

After all analyses have been done, both quantitative and qualitative it is time to review the research questions from chapter one again. All sub questions will be answered one by one leading up to the main research question which will be answered in the last sub paragraph.

11.1. EVENTS AND ACTORS DURING THE PORT CALL

In chapter 3.1 an elaborate overview has been given of the actors that are included in the port call and what their responsibilities are with respect to the port call. Many actors have been introduced but only a few of them have in the end actually been modelled. All actors need port calls to do their business, however to some of the actors the port calls are a slightly more intense process. For example the captain of the vessel is at all times responsible for granting people access to board. Other actors are slightly less involved in the port call such as the shipping line, in general they leave most of the responsibilities in an operational sense to the agent and captain of the vessel.

So for operational activities there are a few actors that would have a high interest in getting more data on a more frequent base with higher accuracy. Actors in this high frequency range are the terminal, shipping line, captain, and agent. The shipping line is still mentioned here since the frequency of contact are of high interest to them, improved operations would lead to more gains. These actors can immediately take actions on information and alter planning for the better. Other actors that would also favour more accurate information but on a slightly larger interval would be the nautical services and bunkering. These services need to know the arrival and departure times of vessels to be serviced. Reliable data in advance would be of high interest. For the port authority the interval of data sharing is actually the least interesting as they have more administrative function impacting operations mildly. Only VTS is involved in the short term communication and planning of for example water ways.

The most important events in the port call are the estimates of arrival and departure. One of the leading events in this process is the estimated departure of a vessel from the terminal. Based on this departure the schedules of vessels are kept or changed. Any delays in departures from the berth will have implications for the next vessels that are to berth at that part of the terminal. Also if consecutive vessels come from other berths in the port these will also cause delays at their current terminals as they cannot leave. Furthermore the estimates of arrival and their accuracy are of utmost importance. In the past it has happened that a vessel was planned for berthing in four hours while it was still sailing 200 nautical miles from Rotterdam. Better estimates of arrival will therefore have positive effects on service providers in the port, as early notifications can be taken into account.

11.2. INFORMATION AVAILABILITY

Availability of information can be hard to track and differs a lot due to the differences in operations and relations between actors. Differences in availability can be accounted for by different responsibilities such as who is responsible for the bunkering, since this often is contract bound. But there are also the more complex relations between actors, for some of the shipping lines actually have an alliance or fall under the same holding as terminal operators. Especially this last creates an interesting dynamic in operations also yielding these parties more freedom in operation. As mentioned in chapter 3 the relation between shipping lines and terminals under a common holding can give them the freedom to change slots between vessels.

Next issue in data availability is the communication between the many actors. Although not deeply elaborated on, the communication of some information takes quite some time and is in some cases dependent on the time of the day. Delays in the terminals are known for the terminal operator, this is information which could be of important for a vessel coming for the next berth slot. However in a

traditional style to get this data the terminal should communicate it towards the agent which in turn communicates it through to the captain of the vessel. If this information would even reach the captain it is also subject to delays. A very practical example of absent data is weekend, since in the port of Rotterdam many terminal planners do not work during the week. So from Friday to Monday morning many things might change affecting planning of actors.

11.3. EVENT DISTRIBUTION FOR PORT CALLS

The main purpose of this question is to retrieve distributions that can be used in a model as a better representation of reality. Outcomes would therefore also be closer to reality and in the case of Rotterdam have more meaning. Main distributions that have been found and used in the model are as follows:

- Arrival of vessels: With regard to the number of vessels that arrive at a terminal data is available from multiple channels. After the assumption to model berth in a discrete manner it was a bit harder to find the exact number of vessel that will visit, since in the end, berths do remain continuous. Based on expert opinion the arrival of vessels has been modelled such that berth utility remains approximately 80% based on expert opinion. As literature stated vessels can be delayed up to 50% of their visits, and this characteristic has been included by increasing the boundaries of arrival.
- Vessel length: for the scope of this research only vessels bigger than 200 meter are considered. Within the population of vessels more than half are longer than 300 meter which as mentioned are often constructed with particular limits in mind. In the model limitations such as canal widths are not considered. Vessels are therefore distributed between 200 and 400 with a mode over 300 meters.
- Number of containers: based on the length of the vessel the capacity of containers would also increase, but does not immediately imply more moves. For the number of containers four discrete groups have been created based on vessel length with a different distribution for the number of containers to carry.
- Waiting time at anchorage: by means of events defined in one of the sources waiting times at anchorage are defined as the difference between anchorage arrival and departure. Waiting times average somewhere around 17.5 hours for all vessels at anchorage, though the dataset has a very long tail to the right where some vessel sometimes wait up to 3 days.
- Journey length: journey length has been set to a medium range so as to approximate the effects of both longer sailing and shorter sailing time. Roughly 1 out of 5 vessels come to Rotterdam straight from an Asian port, and other vessels often come from somewhere in Europe. To better capture the effects of green steaming distance has been set to 650 nautical miles.
- Fuel consumption: this parameterisation is actually more towards the implementation of a basic formula than utilising a found distribution. In practice there are slight differences between the calculation of fuel consumption for vessels. However almost all of them include the displacement, speed, and some engine constant. For the model one of these basic formulas has been used. Displacement is calculated through a formula derived from the correlation between vessel length and its maximum capacity in TEU.
- Accuracy of arrival estimates: as described in chapter 5 the difference between an actual time and estimated time of the particular event is used as accuracy. This research mainly considers the accuracy of events with regard to arrivals. What can be seen is that absolute deviations in estimates do decrease when the vessel gets closer to the port. But relatively the deviations increase when closer to the port.

- Time at berth: as mentioned under the terminal paragraph, time at berth is really dependent on a myriad of parameter that are not included in this research. A favourable combination of contract, many cranes, and timely services could lead to a vessel being services faster than expected. Though this is not always the case berth times differ a lot also depending on the operational excellence of terminals. More experienced terminals are often more reliable.
- Pilotage distributions: after analysis of the data it appears that pilots are almost always on time, for incoming vessels pilots are sometimes a bit late, however this is a matter of minutes. For departing vessels pilots are almost never late, which can also be accounted to 'sharp ordering' where pilots are sometimes ordered too early.
- Bunkering: through a combination of data analysis and interviews a distribution for delays in bunkering has been established plus the average delay. For the number of delays due to bunkering 10% of the visits is used and deduced from data. For the length of the delay information from an interview was used mentioning average delays of one hour plus or minus half an hour.

11.4. CHARACTERISTICS OF ROTTERDAM

Of course every port in the world is different, but often the sizes and function of ports can be grouped and compared. For other ports that resemble Rotterdam this research might therefore also be interesting. Some of the characteristics considered for Rotterdam are the following:

- Operation type: in the model only container vessels are considered although this is not typically Rotterdam. Only part of the operations come from containers other come from operations such as bulk shipping. Issues that come in ports with more operations are shared resources such as nautical services and water ways. In turn due to the draught of bulk vessels container vessels do not have to worry about tidal windows as waterways are often dredged deeper anyway. A different operational type perspective is the vessel size. Ultra large vessels often take more time at terminals receiving higher priority at the cost of smaller vessels. These smaller vessels are more flexible and often require less time but also value their own planning. Complications from smaller vessels is often that they visit more berths in a port and are less predictable. Whereas large container vessels sail directly to one berth making them predictable. Terminal do often not know what smaller vessels have planned when already berthed somewhere in the port.
- Transshipment or import/export: Rotterdam is considered to be more of an import port, meaning that containers will be unloaded and transported through the hinterland. To a certain extend this reduces the complexity at the terminals as it is more of a one way stream of goods.
- Location of the port: Rotterdam is a port with many other ports in the vicinity such as Antwerp, Bremen or Felixstowe, vessels from these ports have very low travel times to Rotterdam. Lower travel times mean tighter planning, consequently lower opportunities for green steaming.
- Infrastructure: briefly touched upon is the dept of waterways, for container vessels making call for Rotterdam dept is not an issue. In other ports this might pose a problem. Larger ports inherently mean more business and often more terminals, with more terminals more complexity is introduced as vessels might visit more than one terminal, although this is not considered in this research it can be cause for delays.
- Environment: some weather circumstances can cause complications for vessels, aside from typhoons and other extreme weather conditions wind is also important. Heavy wind can prevent large vessels from entering a port due to safety hazards. More unfavourable weather conditions could therefore require more tug boats in certain situations. With unpredictable weather this is hard to anticipate and can complicate matters.

11.5. SCENARIOS TO BE TESTED AND SENSITIVE POLICIES

Through scenarios the behaviour of the system can be tested, in the first place this will be done for the system as it currently is and then enriched with some extreme cases. In other experiments the sensitivity of parameters will be tested on their effect.

For the first part a worst case has been defined with very unfavourable parameters, few data sharing and less accurate information. This scenario sets the lower benchmark for the current case. On the other side is the most favourable situation with a lot of data sharing and more accuracy. If the current case of Rotterdam were to be placed between these two scenarios it would score about 1/3th. This means that there is a lot to be gained when leveraging all policies. However the current case and worst case might be subject to a degree of uncertainty. In the model the worst case scenarios is now mostly dependent on the variance in the source, in real life a worst case could therefore be even worse. In turn if the lower bound would decrease the current case of Rotterdam would appear to be scoring better.

After the predefined cases experiments have been set up to see the effects of certain situation and policies. With regard to the levers the following conclusion can be drawn:

- Changing communication interval has a large effect on waiting times and fuel consumption.
- Cargo updates have a minor effect on waiting time and fuel consumption.
- Delays probabilities have moderate effects on waiting time and fuel consumption.
- Probability of bunkering has a low effect on waiting time and fuel consumption.
- Average delay of bunkering has a significant impact, increased delays will have an increased effect on metrics such as waiting time and fuel consumption.
- Accuracy of information has a low impact on the model responses such as waiting time and fuel consumption.
- Green steaming seems to have a moderate effect on waiting times and fuel consumption.

This indicates that sharing of information is of crucial importance when trying to lower waiting time at anchorage and impacting fuel consumption. Parameters about the probability of delays also say something of the applicability for other ports. If other ports have fewer or more delays this would actually not make a huge difference. Policies of sharing data would have more or less the same impact for ports with different delays. And according to the data this would also be true for ports with different information accuracies.

11.6. EFFECTS AND CONSTRAINTS OF DATA SHARING

With this model there are a few effects that can be measured with respect to data sharing. The main effects can be seen with regard to fuel consumption and waiting times at anchorage, where both will tend to reduce. However these results are returned under special circumstances which have to be kept in mind when striving for and implementation over a wider scope. Nonetheless they show significant improvements and potential for shipping. Although in some situations levers trigger a higher fuel consumption these actions are not bound by a limit. What this means is that if information suggests that a vessel should adapt a different sailing speed it will do so without hesitating. This is one of the constraints that puts a bound on the effect. If for example the captain by logical reasoning can use the information and not change speed carelessly better outcomes might be possible.

So with regard to information the main constraint are in the form of availability and usage. Availability has only be partly tested and proven however there are many more parameters within the realm of available data. All of this other information could also have its implications and perhaps positive effects on the port calls. Then aside from the information itself is the way in which it is used. Outcomes might

be improved if knowledge is correctly applied. Perhaps in real life priors and expectations might also pose its limits on development. As actors experience certain situations over and over they create expectations for the next time, letting go of these and handling along the logic of new data might be hard. An example of this was the ordering of pilots for departure, which are often order too early. Over time pilots might therefore adjust their expectations towards certain clients and come later. Although the effects of more accurate data have not been proven it could still be tested in different ways and for other events, certainly as this appeared to be a hot topic under people in the port.

11.7. THE POTENTIAL IMPACT OF DATA SHARING IN THE PORT OF ROTTERDAM

In this research mechanisms of data sharing have been tested on their consequences and the impact of these. In chapter three and five respectively qualitative and quantitative analyses have been done on events in the port of Rotterdam, at this moment the first inefficiencies in the port were exposed. For example the complexity in information transfers, are myriad of canals and information lines that lead to a high system complexity. This was also recognised by people in the port and mentioned as a soft factor for the implementation of a new system: “people only want to work with one system, not more”. Furthermore the job of the agent is to accelerate the stay of a vessel in the port, supporting in all possible ways by matching the arrival of vessels and services. In some cases the agent can be seen as information hub in the port, it is in contact with almost all other stakeholders and communicates towards the captain and to others on behalf of the captain. A bit later in chapter five the data analysis showed that on average vessels wait over 17 hours in front of the port. With regard to the previous mentioned a model was utilised to see what the effects are when data is shared directly to the ones that require it. Potential implications were highly significant with regard to waiting times at the anchorage. Also the fuel consumption showed improvement in most of the cases. Due to the modelling some vessels would sail faster towards the port, resulting in statistics that do not really capture the effects on fuel consumption savings for the complete journey.

Besides the more quantitative research interviews and maps of the processes in the port also resulted in apparently large opportunities for improvement in the port. Many actors spoke about more accurate information with regard to event times. For many stakeholders that are dependent on the arrival and departure more insight and earlier knowledge of these events would highly aid in planning accordingly. For nautical services for example some activities are only planned a couple of hours ahead due to this inaccuracy and uncertainty in information. As mentioned in the actor analysis almost all actors could anticipate in a sense on better information. This is not only limited to sailing speeds and waiting times at anchorage. If planning could be made further in advance and more reliable for example a more optimal planning for nautical services availability or crew shifts in terminals could be achieved.

12. CONCLUSION

In the previous chapter conclusions and findings of the research were presented. In this final chapter the results will have one last critical review. Furthermore the scientific relevance, limitations and recommendations for further research.

12.1. RECOMMENDATIONS AND FURTHER WORK

After the literature review it became clear that the concept of data sharing in ports is quite a new branch and has received minor attention. Only in a very recent research the impact of data sharing has been pointed out (Minderhoud, 2018). Despite the marginal pre work done this research will be placed somewhere along the different research possibilities in an port.

As discussed in chapter ten this research only focusses on particular part of a specific port. What this implies is that there are other operations that are not considered and that this might differ for other ports. With a dominant focus on numeric analysis and effects mechanisms might have a rather soft side to this topic is slightly kept covered. With soft side the implementation is meant, and what action will be needed to get these mechanisms in place. Further research should therefore focus on the following aspects:

- First of all the current research could be shifted towards a different operational type. In this research the focus was primarily on the container shipping. Differences to bulk shipping have been mentioned, including some of the characteristics of bulk shipping. Further research should look into the effects that information sharing would have in other types of shipping. Especially in bulk operations where information is considered to be more valuable than in container shipping.
- Within the same type of shipping a higher resolution of modelling could be taken into account. Whereas this model only focusses on an few big and important stakeholders others are affected as well. How would results differ when smaller vessels would be included, maybe these feeders and barges mitigate the effect found in this research. With higher resolution more detail from actors could be included, parameters affecting operations at the terminal, the actual number of cranes and available workforce. In the case of nautical services include the communication between the different actors and model the number of tugs required. All in all there is much to be won in detail and accuracy.
- A combination of the aforementioned research suggestions would yield a model with different types of shipping and a higher resolution. This would be especially interesting for the port. In this way operations can be modelled and analysed on weaknesses which in tun can be used for improving the overall performance of the port.
- Research on a lower resolution would be the interconnectedness of ports. Although some research has already been done in this topics the mechanisms of information sharing do deserve more attention. Research should focus on the information shared from one port to the other with respect to cargo operations and delays. This is especially interesting for ports that lie close to each other. When vessels would only start sharing information when they leave their current port for Rotterdam the time window to act will be really small.
- Of major importance is the method of implementation. Proving that information sharing will benefit most actors is one thing, the second is to actually get these actors to start sharing data. This research can be separated in two main focusses, one would be more on the technical and legal aspects, as to what is allowed to be shared, when should this be shared and what technology should be used for this. Since almost all vessels have internet nowadays mobile applications might be the perfect solution. The other part of the implementation focusses on

the stakeholders involved. What actors bear most responsibility for the implementation. And how are some of the actors incentivised to cooperate although they would only benefit very little compared to others in sharing information. Methods could include mechanism design to get actors behaving in a desired manner. But game theory might also be very well applicable to see what situations play out if some actors are involved that try to mislead others with information or do not share information at all.

For the Port of Rotterdam it is recommended to do more research to get additional and a deeper insights for data sharing. Furthermore the efforts for current data sharing initiative should be intensified. In the results it can be seen that huge gains can be made in both waiting time and fuel consumption. Also the planning of multiple actors could gain a lot when starting to share data. To actually make this a success more research should confirm the findings of this thesis as well as taking it to a next level, what are the implications for other actors and what would be a good implementation. Especially implementation should receive more attention as some actors are probably less inclined to contribute as their gains or interests are lower seen from Table 39.

12.2. RELEVANCE AND REPRODUCIBILITY

In foregoing research emphasis was mainly on optimisation individual processes, how one stakeholder could improve its operations. Especially for terminals a lot of research has been done how productivity could be enhanced through better berth planning, yard planning, and connection to the hinterland. Same for shipping lines how could performance be improved by altering routes, changing the number of vessels, or utilise different vessels. These have all focussed around one actor and to a lesser extend other stakeholders involved. By means of this research a first step is taken in the multi actor optimisation through data sharing.

For the credibility of the conclusions this research should be reproduced. Reproduction could be done in in the Port of Rotterdam or perhaps in other ports. However information might change over time. For this research a lot of event data of Pronto has been used, if continuation of this project would go as planned more data with more reliability would be the result. Research could therefore lead to slight differences in results due to the different data available. As the application of Pronto will grow it is likely that actors will use event data to improve their operations. If this is the case new research should also measure to what extend data sharing has already helped. When turning to other ports the differences should be explicitly mentioned both in characteristics of the port as well as the definitions of events. Other ports might have fewer or more data with respect to events also with different meanings. "Arrival" might be measured as the actual berthing in one port where it is referred to as the arrival at anchorage at another port.

Apart from the scientific relevance there is also the social relevance. This research does not only have its implications for academia but also for the everyday life. If results are robust and the mechanisms will be implemented this will have its consequences for society as well. On the one hand there is the environmental impact, reduced speed and fuel savings will have a great contribution to the reduction of CO₂. As seen in the results savings for single vessels can already add up to tonnes of fuel, let alone all the vessel coming towards Rotterdam. Reduced waiting time at anchorage could also have effects on the air quality in residential places close to the coast.

With reduced costs and prices for bunkering operation will become more efficient. Consequences for this could be that services become cheaper as shipping companies still remain in competition with each other. For clients this could mean lower shipping costs and products in stores could get cheaper because of reduced shipping expenses.

12.3. LIMITATIONS

Every research has its limitations as simplifications and assumptions are made. For this research big assumptions and reductions are made in the size of the model. Port infrastructure and operations have a mind boggling complexity. Numerous events and operations performed by many companies in a very large environment. The port of Rotterdam itself is already close to 42 kilometres wide. In this research only a small part of the port is taken into account, from one terminal two berth places are considered leaving out most other processes in a port. It is inevitable that other activities in the port could have impacts that are not considered. The model is a boxed part from reality where inputs have been manipulated to see how the system reacts and the outcomes will change overtime. Nonetheless other activities should be kept in mind as potentially affecting the operations.

Already briefly mentioned is the usage of data. Data from different sources has been used with the prime source being the Pronto database. Issues with this data is that the number of participants of the problem slowly increased over time, indicating that the first data was from a few actors, potentially causing bias, or describing operational excellence of that particular actor. In the port this has also been mentioned as a limitation, namely that the most recent data is more accurate. For some of the events manual inputs are used. Actual arrivals of the pilot at the vessel for example is entered through a mobile application. Since this is a human interaction there could be occasions that the pilot forgets to submit an event and does this somewhere later when he finds the time to. This could cause inaccuracies in the data.

Since the study only focusses on a particular part of the port the results might not completely be generalisable. The impact on waiting time might therefore be valid in this situation, however when in including more detail and other operations the implications for outcomes might mitigated. These impact limitations could be a consequence of a scope solely around container shipping.

12.4. REFLECTION

This paragraph will be used to give a reflection on the research process, and some of the issues that popped up during the process.

In the start-up phase of the research it was really hard to scope down to a manageable research domain that would fit the timeframe of a master's thesis. Combined with the few to no experience in the port it took some time to get the process going. In the end this "knowledge" deficit was handled effectively. By using an exploration in the port with interviews and readings a better understanding of the port was created while at the same time creating the foundation for the third chapter.

After some time to get comfortable in the port it was easier to scope down to a manageable topic which made the to do list more clear for the rest of the research. Although it was clear what to do now the approach in how to do this would pose the next problem. Initially the planning was to do the data analysis and use outcomes for the implementation of the model. However this was not the best idea. Without a model it was hard to decide what information was necessary. So in the end there was a lot of overlap between the modelling and the data analysis part. In general the middle part of the research started with the data analysis followed quickly with some modelling. After a while all data would be available and most problems would shift to the model.

Especially in the end modelling appeared to be the bottleneck timewise. Since the last modelling experience with Simi was almost a year before some issues arose. Especially in the last weeks a lot of problem solving had to be done. Sometimes structural problems with the logic but in other cases some equations were entered or copied a bit carelessly, not changing an operation sign from minus to plus for example.

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APPENDICES

APPENDIX I

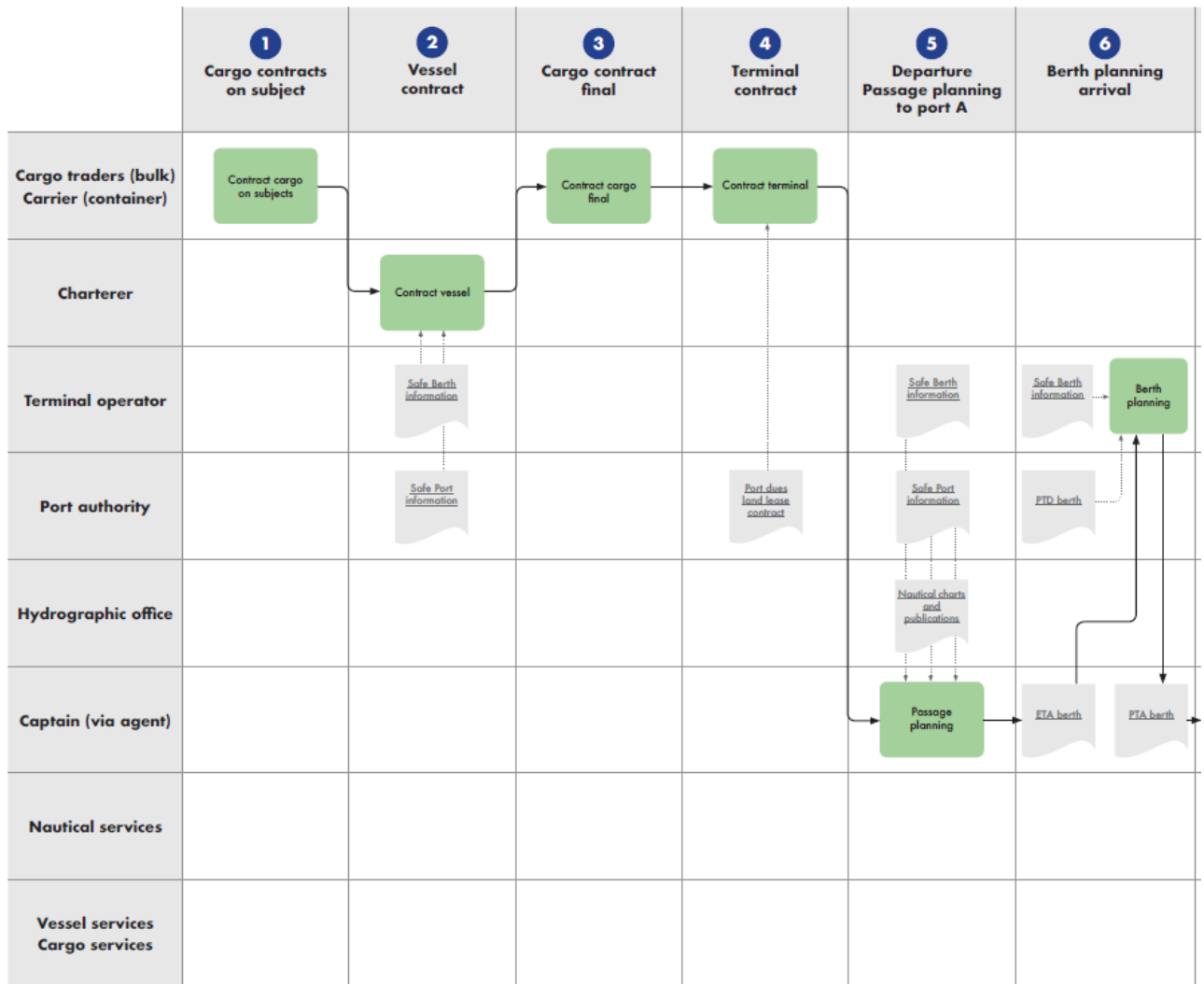


TABLE 40: LEFT SIDE ROTTERDAM BUSINESS PROCESS

APPENDIX II

| get information shipping line | Shipping line | Charterer | Agent | Captain | Terminal Operator |
|-------------------------------|---|--------------------------------------|---|--|---|
| | x | | contract, vertegenwoordiger all services and dues | Estimates operations Actuals operations bill of lading | planning stowage planning agree cargo times at berth berthing window ETCC information about delays |
| Charterer | contract | x | contract, vertegenwoordiger all services and dues | Estimates operations render NOR bill of lading for containers Actuals operations | berth planning berth information |
| Agent | contract, schedule planned visits | | x | ETA PBP, planningen vessel info ATA, PBP | plannings informatie, ETC updates los laad process PTD at least 2 hours before |
| Captain | eigen vloot gechartered | Orders/ schedule in containers | orders (wachten, sneller varen, getijden) safe berth planning Planning terminal | x | lossen en laden operaties terminal rules berth prospects |
| Terminal Operator | contract, container information and quantity agree on proposed PTD special cargo information | proposes visit | Planning, ETA, ETD which bunkering ships and when mention other vessel services agree on productivity terminal; eg cranes | Agree on stow age plan mention when reefers for unloading | x |
| Bunkering | contract (agent plant) | contract | aanvraag, ETA (wisselend per agent) amount of bunkering | geeft akkoord | communicate location quay crane |
| Vessel services | | | aanvraag, ETA | geeft akkoord | |
| Pilot | | | besteld loads via PCS ETA PBP besteld pilot ETD terminal | | |
| Tug Boat | | | besteld tugboat via PCS ETA PBP besteld tugboat PCS ETD terminal | | |
| Linemen / roeiers | | | besteld linemen via PCS ETA PBP besteld linemen PCS ETD terminal | | |
| PA/HCC | safe port operation | safe port operation | te kennisgeving, updates, bezoekinformatie afvalstoffen gevaarlijke stoffen bericht bijzondere aanvragen port dues notifications and declarations | information about vessel dimensions loading services ETA, ETD and travel information Health, dangerous goods, waste, security issues | safe berth information terminal planning |
| PA/VTs | | | | melden binnen bereik haven (12miles?). Draught, request to enter | |
| Pronto | schedules via tussenpartij | | info PCS, bestelling met tijden | | cargo times, ETSC, ETCC, + updates terminal planning ETA, ETD ATSC, ATCC |

| get information shipping line | Bunkering | Vessel services | Pilot | Tug Boat | Linemen | PA/HCC | PA/VTs | Pronto |
|-------------------------------|---|-------------------------------------|---|--------------------|---|---|---------------------|---|
| | contract bunkering, local level bunker delivery note | | | | | safe port information | | |
| Charterer | contract bunkering, local level bunker delivery note | | | | | safe port information berth information | | |
| Agent | ? Bevestiging (na aanvraag) no ETD, inaccurate information | ? Bevestiging (na aanvraag) | | | | PTA PBP berth information | VHF contact, safety | |
| Captain | melden operations, niet zozeer ETA | melden operations melden vertrek | | | | | VHF contact, safety | |
| Terminal Operator | bunkerprotocol bunkerwindow and bay | contact required to enter yard | give PTA only contact due to disruptions | | | | | PT < PTD more data like overlaps with other terminals |
| Bunkering | x | x | | | | | | |
| Vessel services | x | x | | | | PTA PBP | VHF contact, safety | |
| Pilot | | | | | | PTA PBP | | |
| Tug Boat | | | | | | PTA PBP | | |
| Linemen / roeiers | | | | | | PTA PBP | | |
| PA/HCC | melden start bunkeren | | afstemmen planning | afstemmen planning | | | | |
| PA/VTs | | | operationeel contact | | | | | |
| Pronto | | | Planned time pilot boarding actual time pilot boarding ATD ship | | lines secured and lines released vessel | | | |

APPENDIX III

In Table 42 are all the parameters from the port authority data for this research. Floats and integers indicate that solely numbers of these kinds have been included. In for data types object others could also be included for example a ship length with “undefined” which is a odd one int a list of floats. These also indicates some incomplete and dirty data which has been cleaned in the python scripts.

| | |
|----------------------------------|---------|
| TEU Totaal | object |
| # containers | float64 |
| Throughput | float64 |
| Throughput ZHG | float64 |
| Shore side name | object |
| Shore side number | int64 |
| Cargo type name | object |
| Activity name | object |
| Activity number | object |
| UCR nummer | object |
| Zeeschip Lloyds nummer | object |
| Zeeschip naam | object |
| Zeeschip capaciteit TEU | object |
| ATA | object |
| ATD | object |
| Shipnumber | object |
| Ligplaats (VM) | object |
| Ligplaats | object |
| Ligplaats code | int64 |
| Ligplaats Oeverfront | object |
| Ligplaats Oeverfront code | object |
| Stevedore name | object |
| Shipping company name | object |
| Ship agent name | object |
| Maximale breedte schip | object |
| Maximale diepgang schip | object |
| Totale lengte zeeschip | object |
| portcall_id | object |

TABLE 42: ALL PARAMETERS FROM PORT DATASET

APPENDIX IV

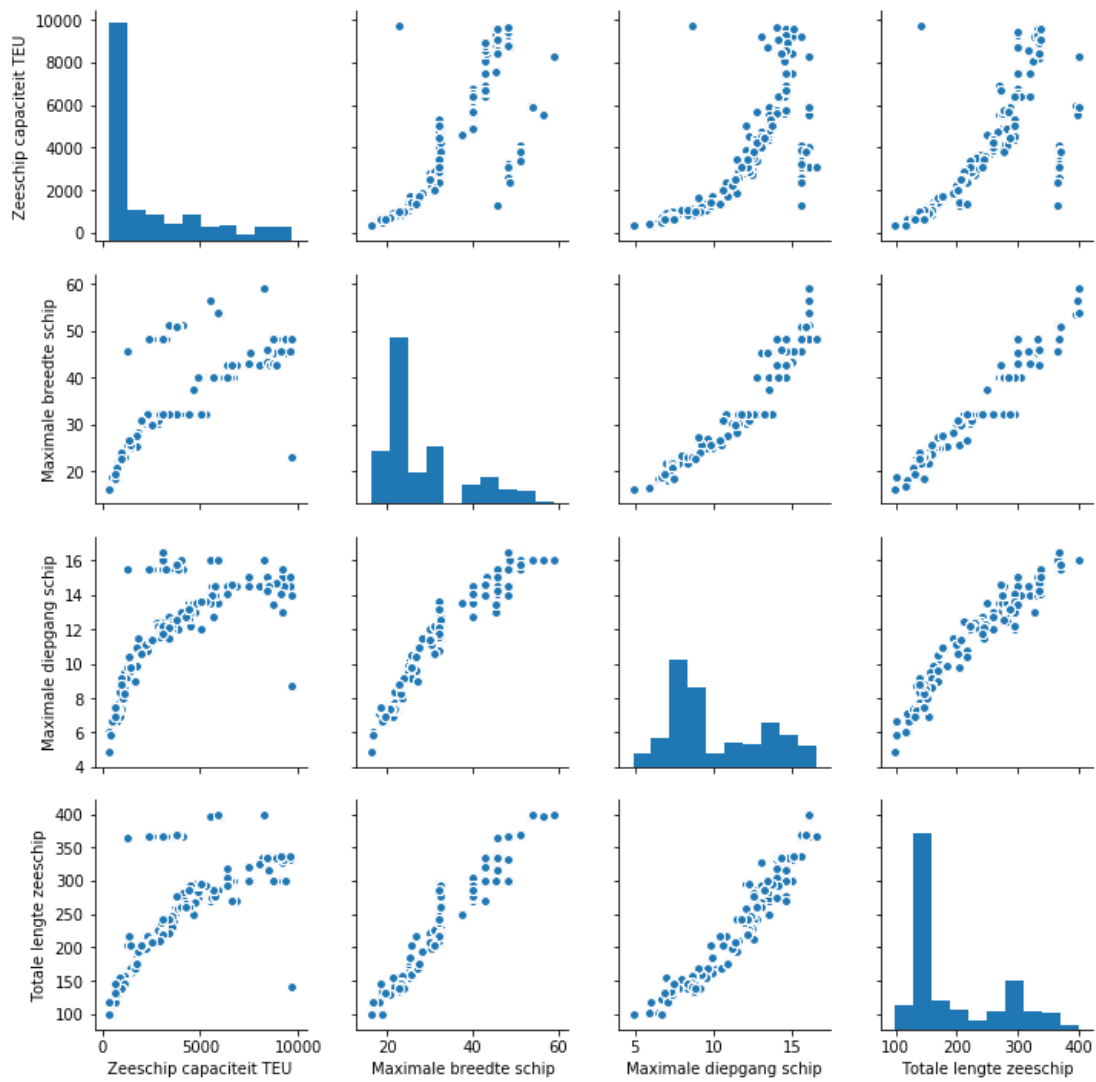


FIGURE 60: PAIRPLOT OF VESSEL CHARACTERISTICS

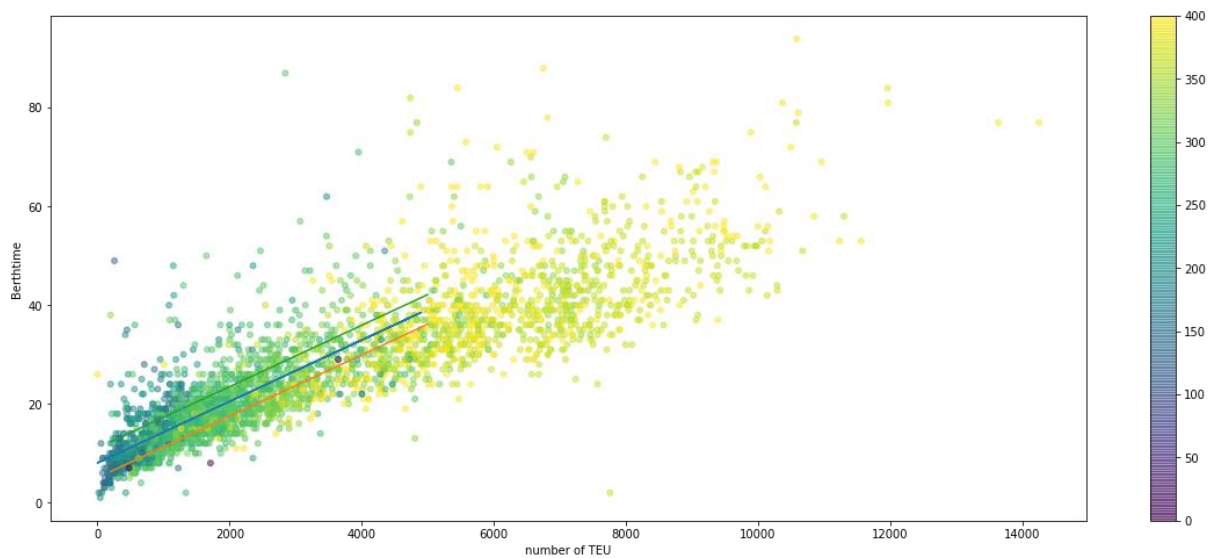


FIGURE 61: LINEAR REGRESSION LINES OF BERTH LAY TIMES

APPENDIX V

Return harbours and specifics for the different terminals:

[confidential]

Returning the table with berth visits in the port of Rotterdam

[confidential]

Getting estimate and actual times for the pilot distribution.

[confidential]

SQL statement for data of the prediction algorithm and HaMIS for the actual times of arrival and departure

[confidential]

Return estimate and actual times from berth events

[confidential]

Return visits including the number of berths visited

[confidential]

APPENDIX VI

VESSELS ENTERING THE SCOPE OF THE MODEL

Once created and before exiting the source they get the following logic:

NumberOfContainers

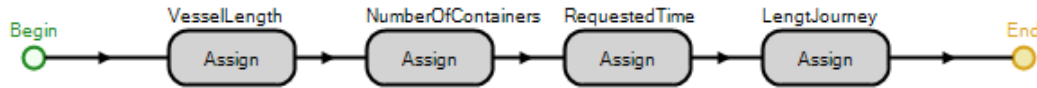


FIGURE 62: CREATION OF VESSEL BEGINNING OF THE SIMULATION

The vessel length will be somewhere between 200 and 400 meters long. Depending on the length of the vessels the number of containers will be assigned where the variation in number of containers increases with the length of the vessel. Eventually the requested time which is equivalent to the service level agreement, the expected and agreed time at the berth. In the last block the length of the journey will also be assigned to the entity as this will help simplify logic ahead.

ASSIGNING A BERTH TO THE VESSEL

During the journey the vessel will get a berth assigned after a certain time, this can be varied depending on the flexibility of the terminal. In the process an execute command will run another process to find all vessels that have already been assigned to a certain berth. Next the times per berth will be compared and the one with the shortest time will be assigned to the vessel. After assignment of the berth the correct node is set for the vessel to sail for. In the case of berth 1 and additional step will be included that determines whether the vessel will require bunkering in the port.

NominateBerth

NominationTimer.Event

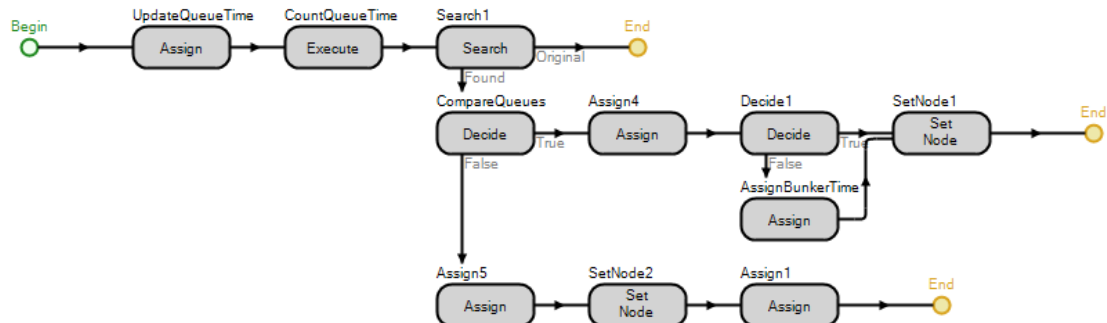


FIGURE 63: ASSIGNMENT LOGIC FOR BERTHS

UPDATING OF VESSEL SPEED.

In this model there are two algorithms that can influence the speed of the vessel. The first algorithm is utilised for vessels that have already been given a berth and the other for vessels without a berth. For the unplanned vessels the logic is given in Figure 65. Initially there is a decide step to see if the green steaming policy is turned on. Next is a searching algorithm looking for all the vessels that have not been assigned a berth yet. After the found step are a couple of assign steps that will assign the new recommended green steam speed to the vessel as well as updating a constant used for the next vessels. The constant adds the requested times of the vessels that have already been advised, and since the search start with the vessel first in line to get a vessel assigned all later vessels will be dependent on this.

UpdateSpeedUnplannedVessels

EarlyGreenSteamUpdate.Event

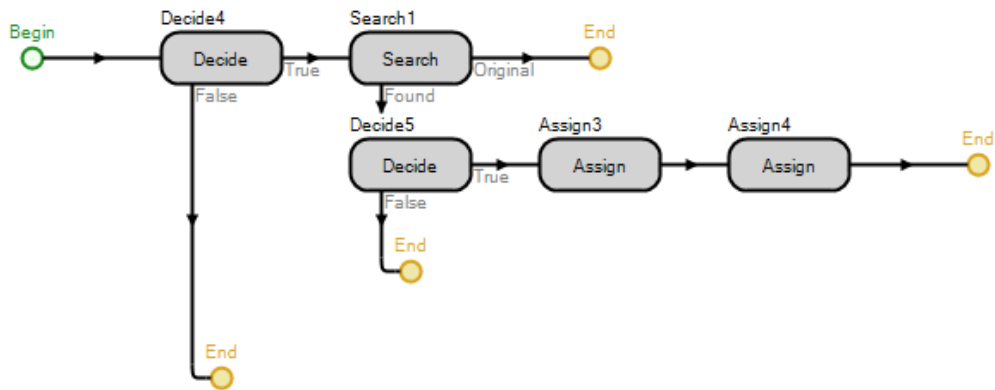


FIGURE 64: SPEED UPDATE LOGIC FOR VESSELS BEFORE ASSIGNMENT BERTH

UPDATING SPEED OF ASSIGNED VESSELS

Depending on the update interval vessel speed times will get updated: the update interval can be changed and its default is every hour (Figure 65). In the logic a search step will be used to find all vessels bound for a specific berth. After finding all the relevant vessels a decide is included alter logic for the first vessel found. The first vessel is sort of assumed to be on time, and will not alter speed if there are no other vessels in the berth.

Berth 1 TimeToServiceUpdate

UpdateFrequency.Event

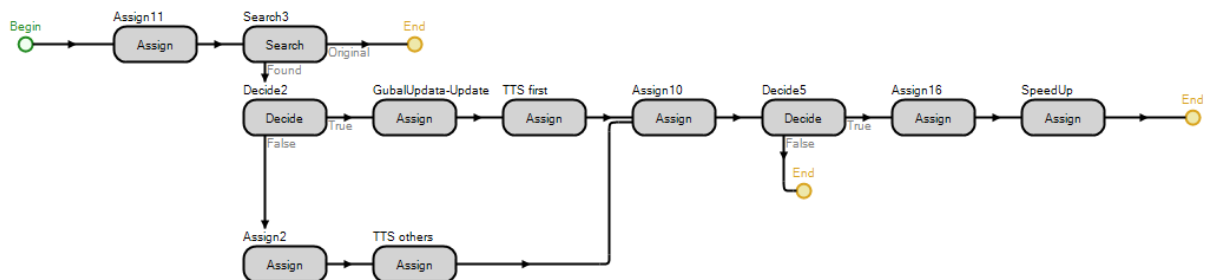


FIGURE 65: LOGIC SPEED UPDATE FROM THE BERTH

ARRIVAL AT THE BERTH

The logic in Figure 66 will be followed if a vessel arrives in the berth. First a decide will run to see what berth the vessel is in, for berth 1 the process is slightly different because of the bunkering. First in another decide the delay will be determined, this will update a parameter that is necessary for ordering the nautical services later. Then for berth 1 a decide will be done for vessel bunkering. If the vessel will bunker an execute is triggered that will call a bunker vessel to the berth. After that the two lines come together and averages for the journey will be calculated. As only fuel consumption to the berth is taken into account and not to the next port universal parameters are updated in this process.

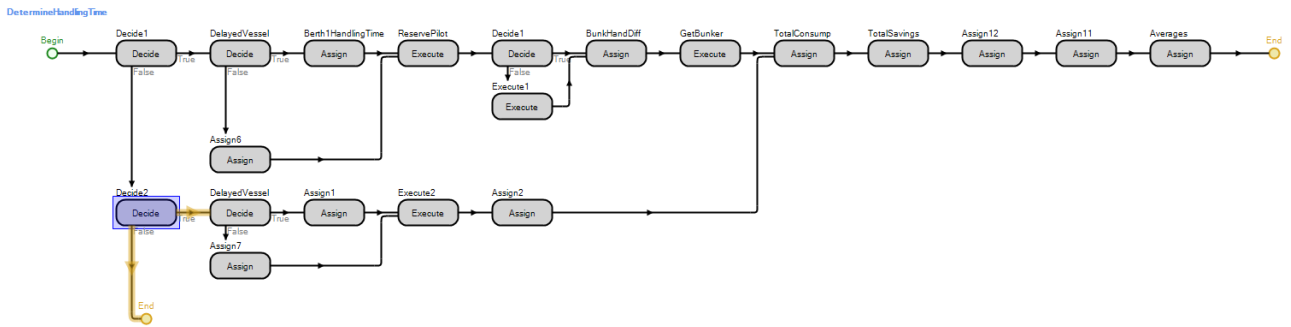


FIGURE 66: BERTH ENTERING LOGIC

UPDATE ON CARGO OPERATIONS

Both berths have an algorithm for sharing of delay times, if delay sharing is turned off arriving vessels will not be informed of the operational delay. If delay sharing would be turned on the interval of sharing will reveal a percentage of the delay relative to the requested time. What this means is that a vessel with a requested time of 10 hours and a delay of 5 will inform the next vessels that it is not delayed at the beginning of the cargo operations, but at 60% percent of the requested time so after 6 hours 60% of the delay will be revealed so the arriving ships know that operations have been delayed with $0.6 * 5 = 3$ hours.

PILOTING

Piloting is taken together with the nautical services and linesmen. In the model pilots will go to the pilot boarding place when they are idle. As soon as the next vessel will then enter the PBP a pilot will be seized. For the departure of a vessel the process in Figure 67 will be triggered. Here the delay is dependent on the requested time, potential delay and the travelling time to the berth.

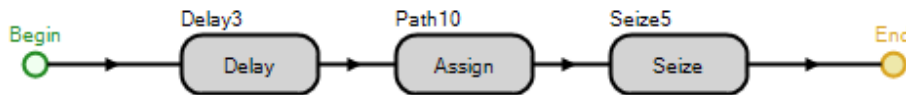


FIGURE 67: PILOT RESERVATION LOGIC

BUNKERING

When a vessel comes in berth one and it will be bunkered the process in Figure 68 will be triggered. First a few parameters will be assigned to determine delay time and availability of the bunker. Next a delay is triggered that will wait a certain time until seizing the bunker vessel. Also a decide had been included which represent the lever for delay sharing. When delay sharing is on an extra assign will be triggered which will update the berth time planned ahead with the delay.

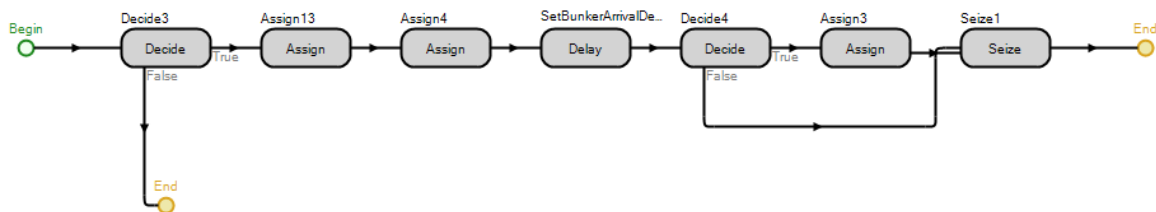


FIGURE 68: BUNKERING LOGIC

The logic for releasing bunkering is actually very much the same as for the reservation for pilots (Figure 67Figure 68). Once the bunker get at the designated bunker place it will immediately trigger a process with a delay, assign and finally a release. Since the delay is already stochastically determined earlier in

the model the required delays is given. Next a general parameter will be updated which indicates if the vessel is ready for bunkering or not. And eventually the bunker vessel is released.

APPENDIX VII

In the software it is possible to add a burn in time, this is the time for the system to start up and get into a transient state. For example vessels have to be generated and sail towards the port. If this is not done the average time at anchorage might be biased in the end. Since a standard vessel will take approximately 40 hours to cover a distance of 650 nautical miles at 17 knots it makes sense to have a burn in period of at least two days, also considering the interarrival time at the source and the first vessel of the second berth. However in the three figures for respectively 0, 2, and 10 burn in days there is no difference.

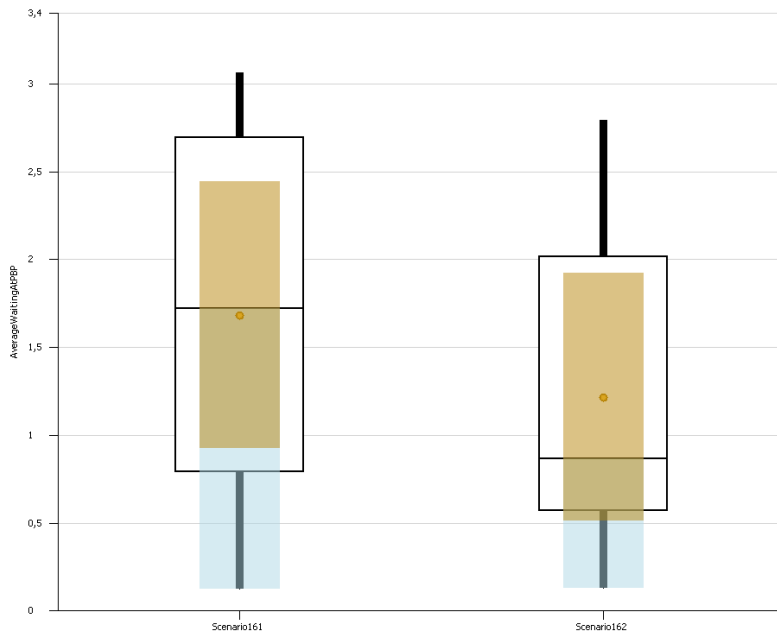


FIGURE 69: BURN IN PERIOD FOR 0 DAYS

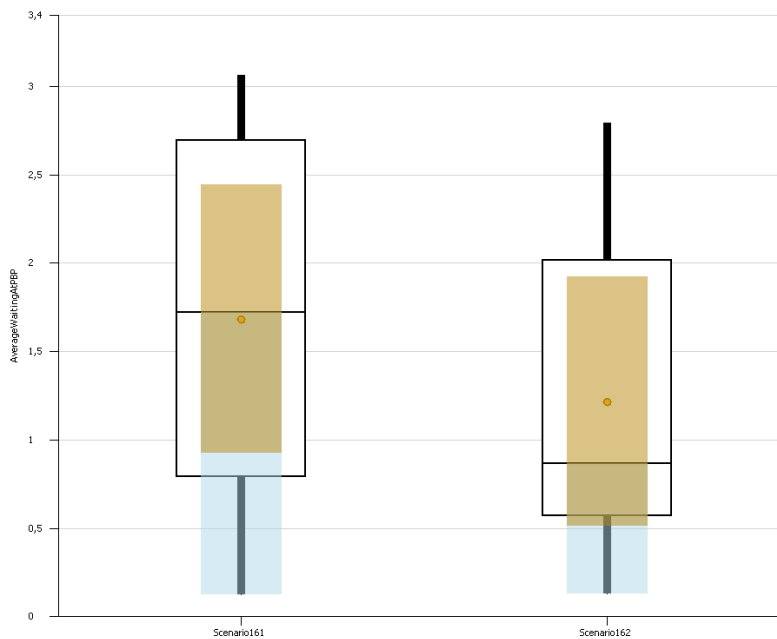


FIGURE 70: BURN IN PERIOD FOR 2 DAYS

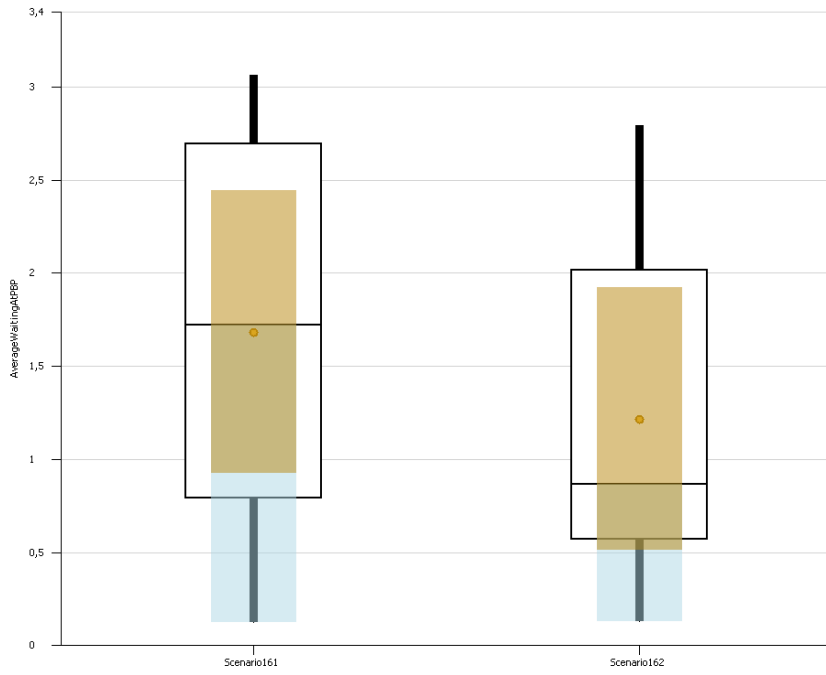


FIGURE 71: BURN IN PERIOD FOR 10 DAYS

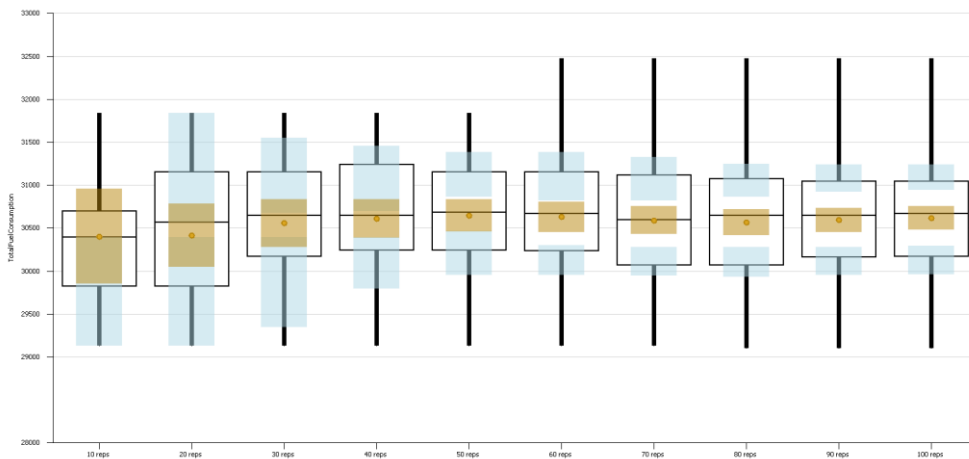


FIGURE 72: TOTAL FUEL CONSUMPTION UNDER DIFFERENT REPETITIONS

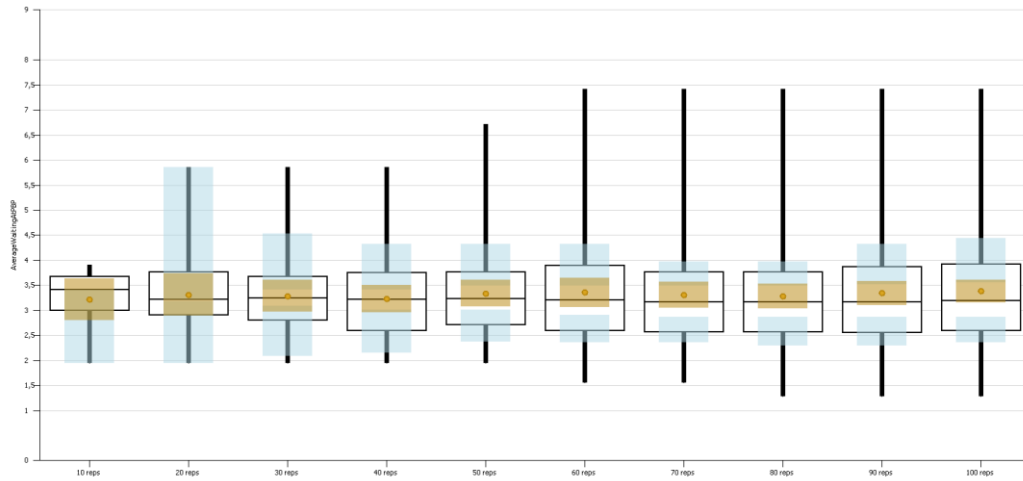


FIGURE 73: AVERAGE WAITING TIME AT PILOT BOARDING PLACE

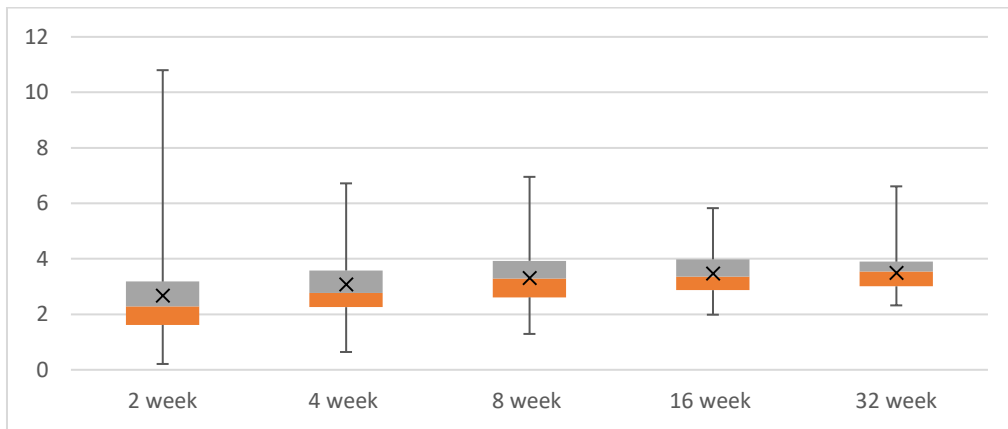


FIGURE 74: AVERAGE WAITING TIME AT ANCHORAGE FOR DIFFERENT SIMULATION LENGTHS

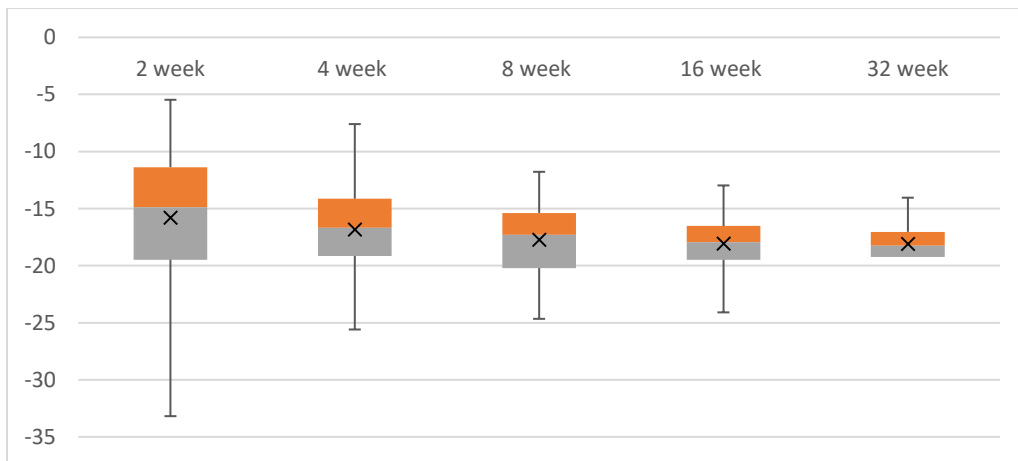


FIGURE 75: AVERAGE NUMBER OF TONNES SAVED PER VESSEL

APPENDIX VIII

Due to their size the python notebooks that have been utilised for this research have been shared in a separate document.

APPENDIX IX

This appendix shows the results of other parameters that have been measured by the SIMIO model.

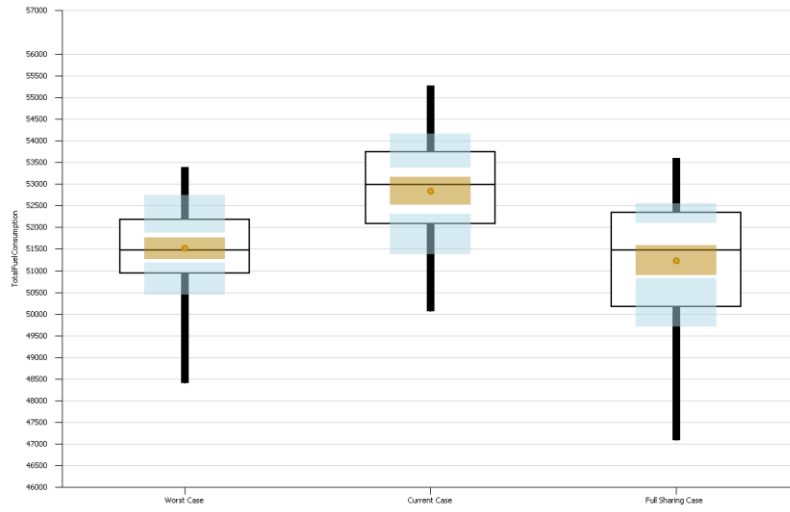


FIGURE 76: TOTAL FUEL CONSUMPTION

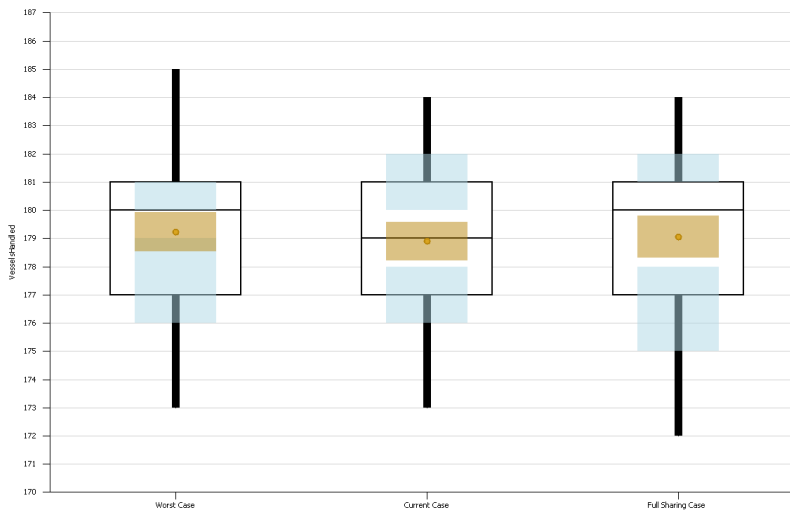


FIGURE 77: NUMBER OF VESSELS HANDLED

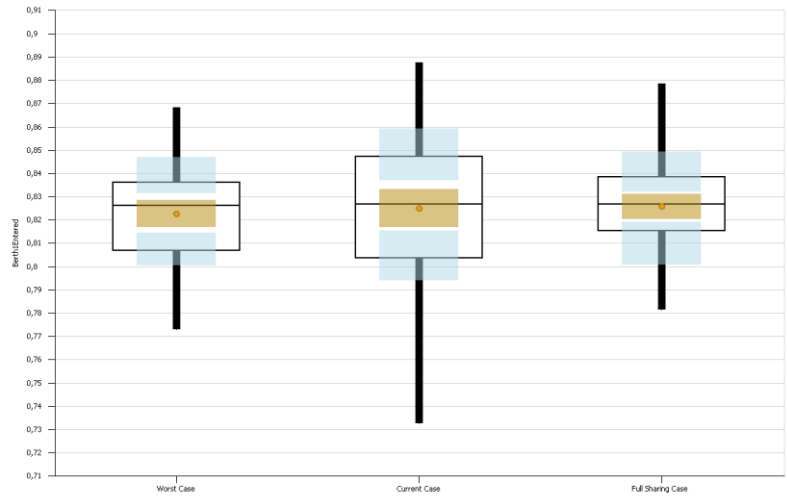


FIGURE 78: BERTH 1 ENTERED

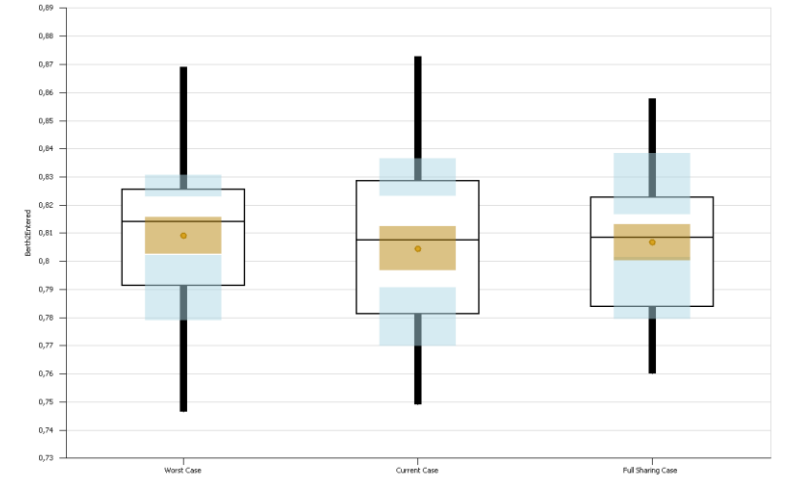


FIGURE 79: BERTH 2 ENTERED

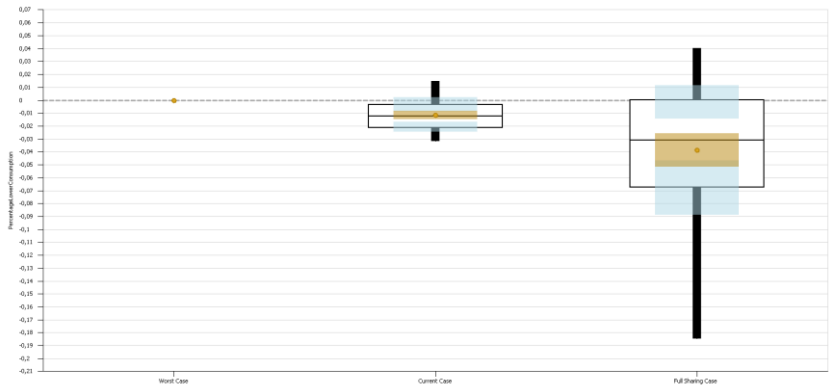


FIGURE 80: PERCENTAGE LOWER CONSUMPTION

APPENDIX IX

Communication interval high speed

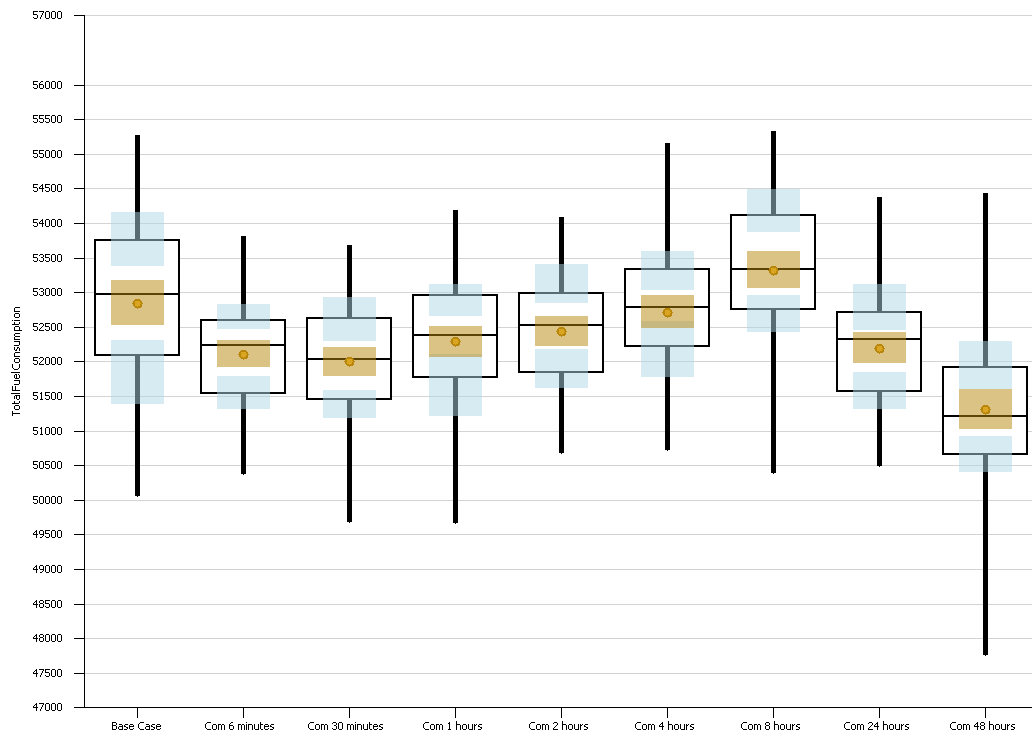


FIGURE 81: COMMUNICATION INTERVAL HIGH TOTAL FUEL CONSUMPTION

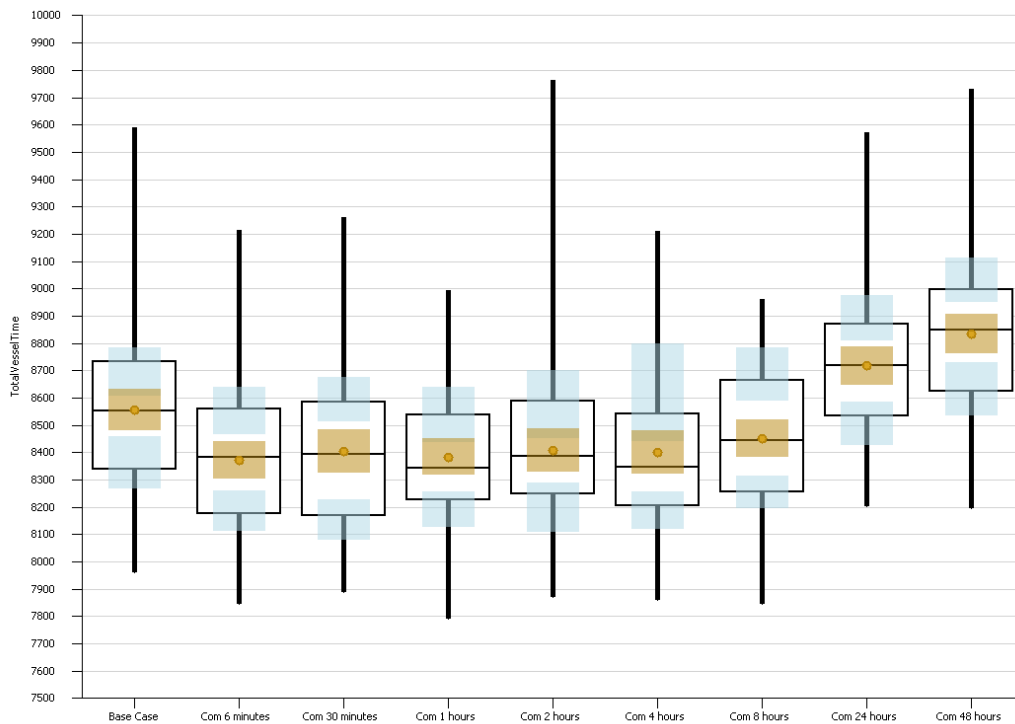


FIGURE 82: COMMUNICATION INTERVAL HIGH TOTAL VESSEL TIME

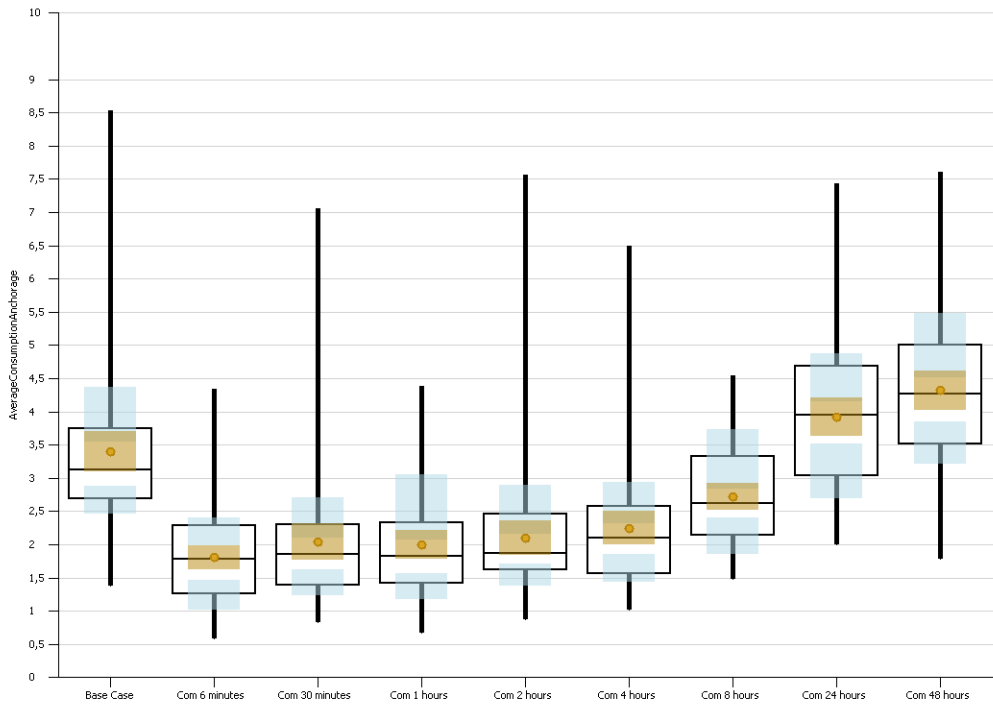


FIGURE 83: COMMUNICATION INTERVAL HIGH AVERAGE CONSUMPTION ANCHORAGE

Communication interval low speed

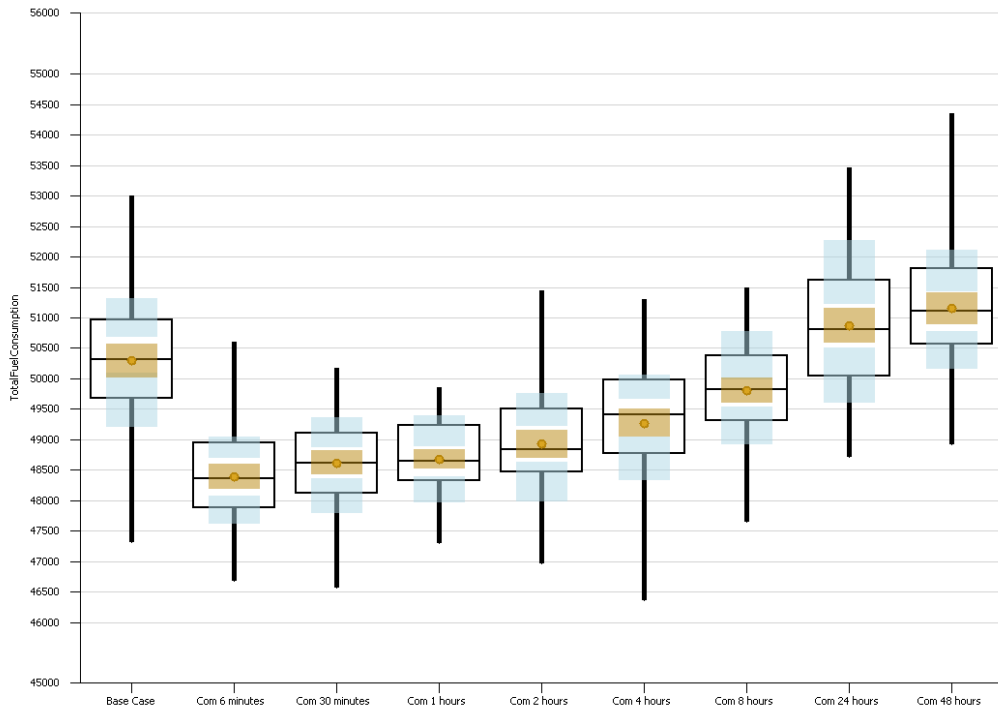


FIGURE 84: COMMUNICATION INTERVAL LOW TOTAL FUEL CONSUMPTION

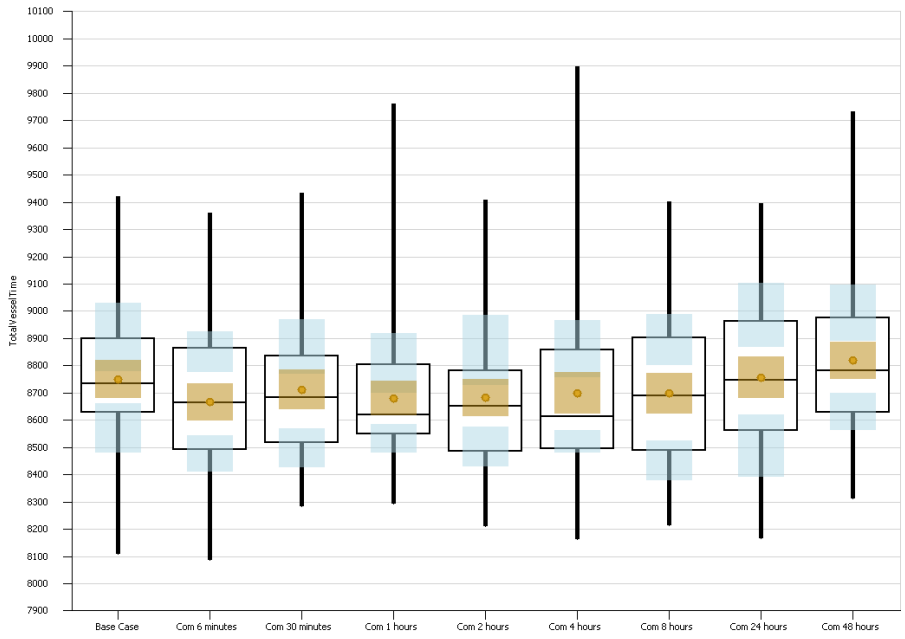


FIGURE 85: COMMUNICATION INTERVAL LOW TOTAL VESSEL TIME

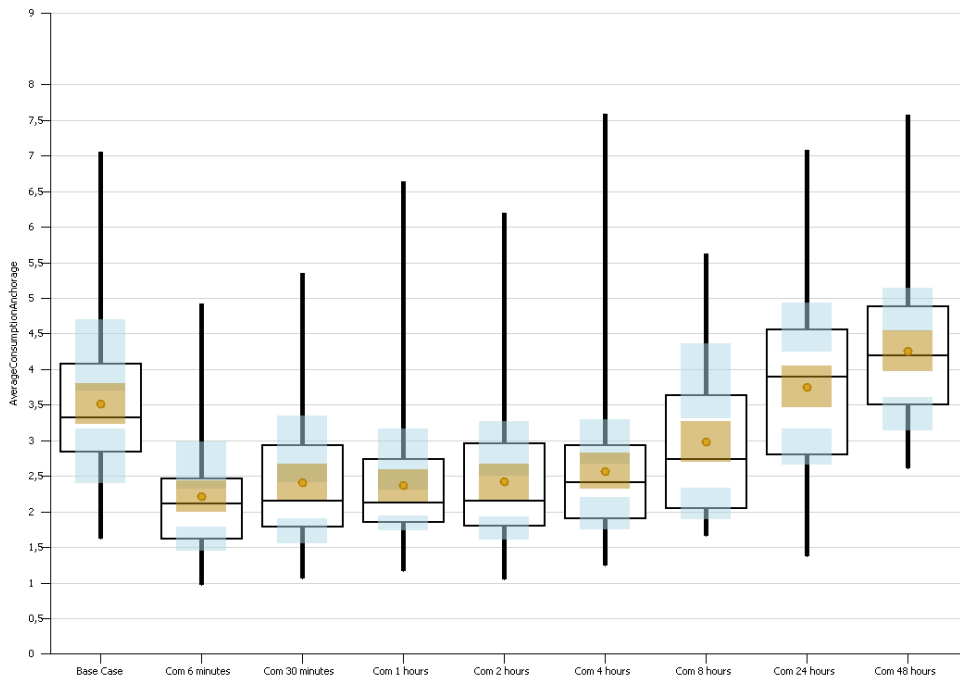


FIGURE 86: COMMUNICATION INTERVAL LOW AVERAGE CONSUMPTION ANCHORAGE

Update interval

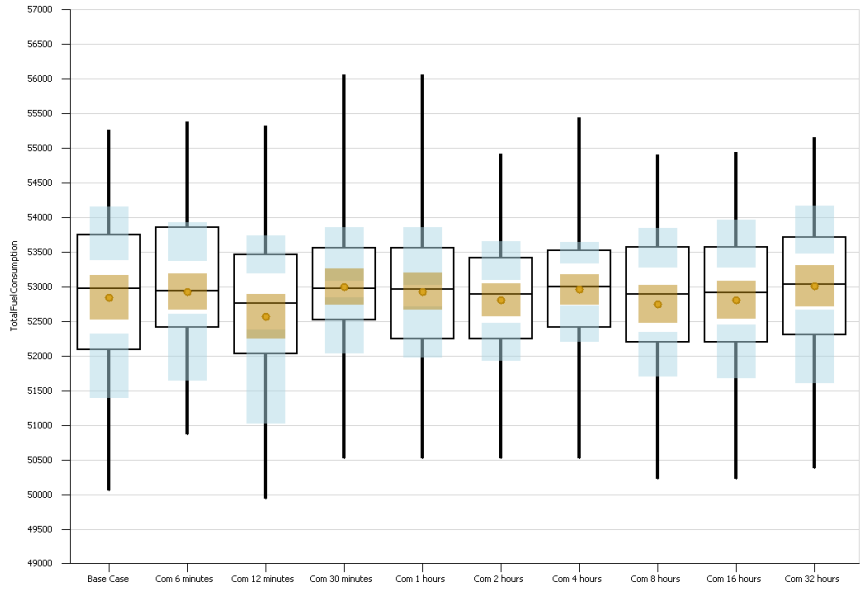


FIGURE 87: DELAY UPDATE INTERVAL TOTAL FUEL CONSUMPTION

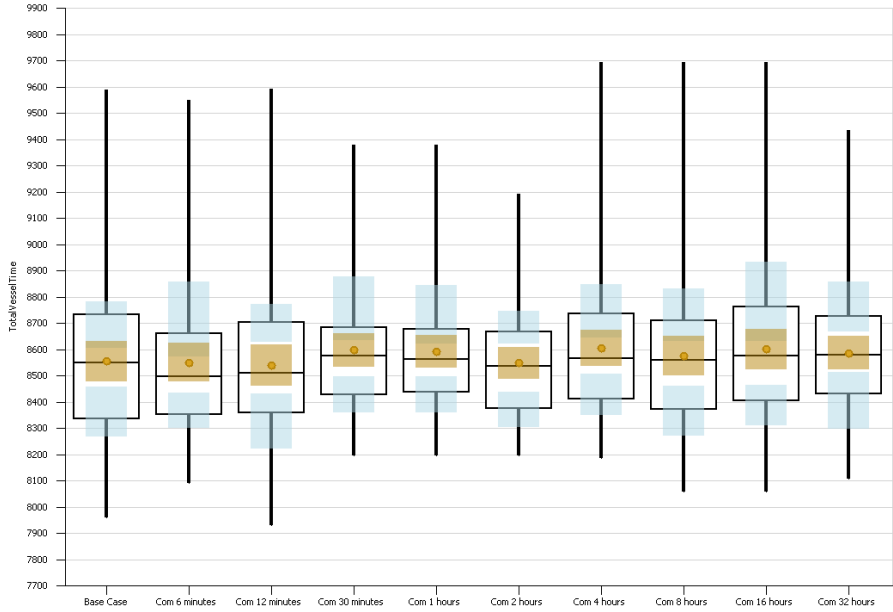


FIGURE 88: DELAY UPDATE INTERVAL TOTAL VESSEL TIME

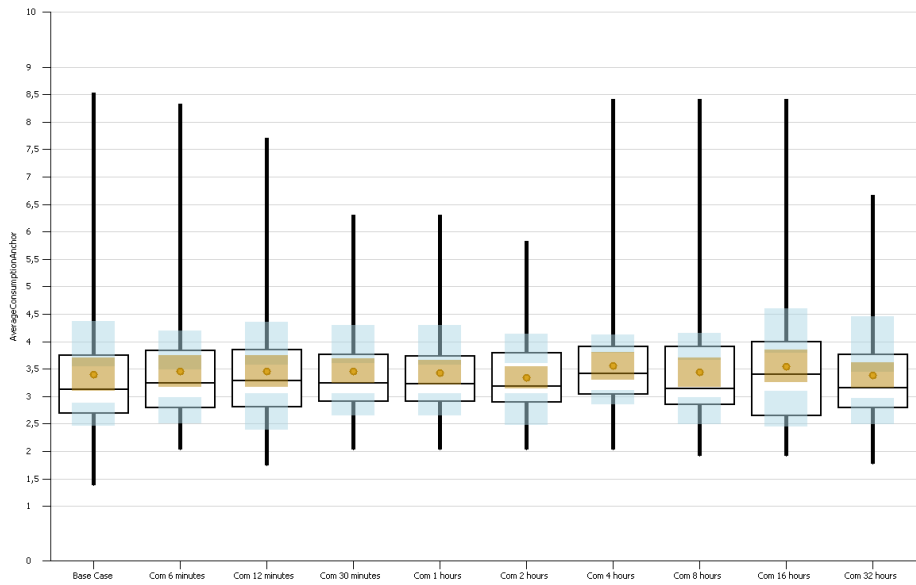


FIGURE 89: DELAY UPDATE INTERVAL AVERAGE CONSUMPTION ANCHORAGE

Probability of delay

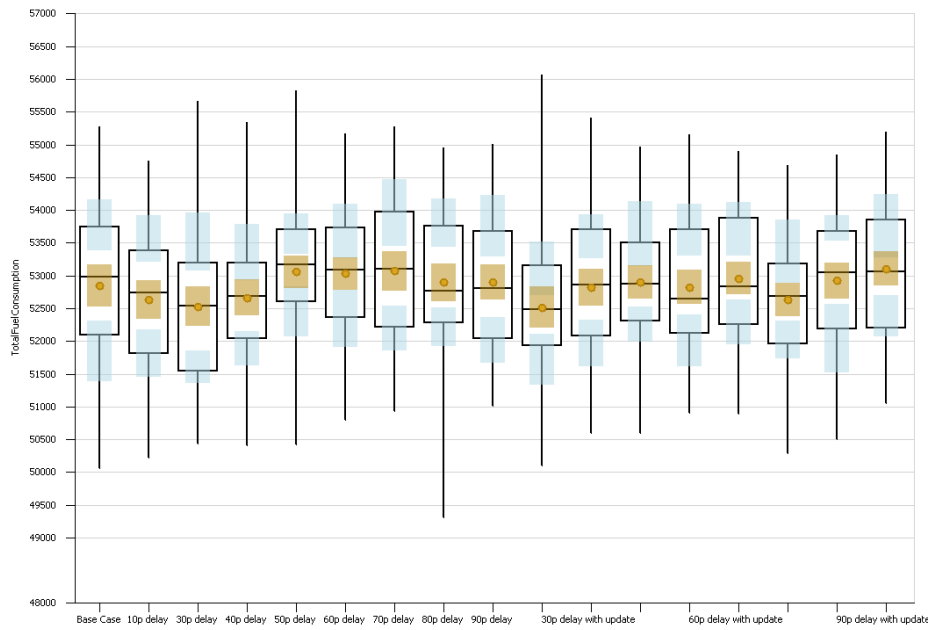


FIGURE 90: PROBABILITY OF DELAY TOTAL FUEL CONSUMPTION

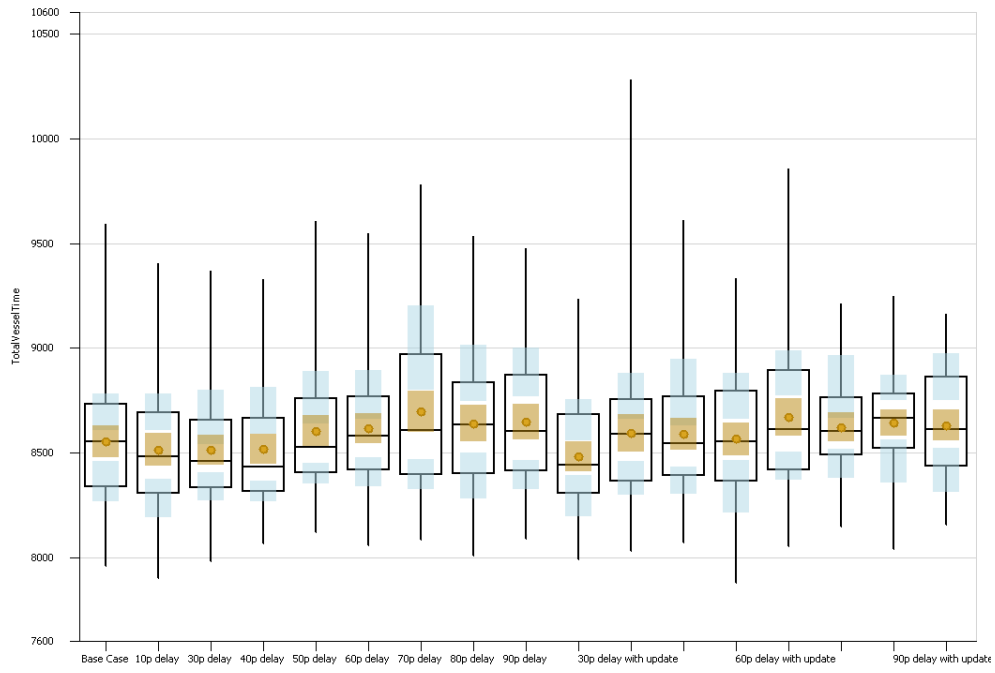


FIGURE 91: PROBABILITY OF DELAY TOTAL VESSEL TIME

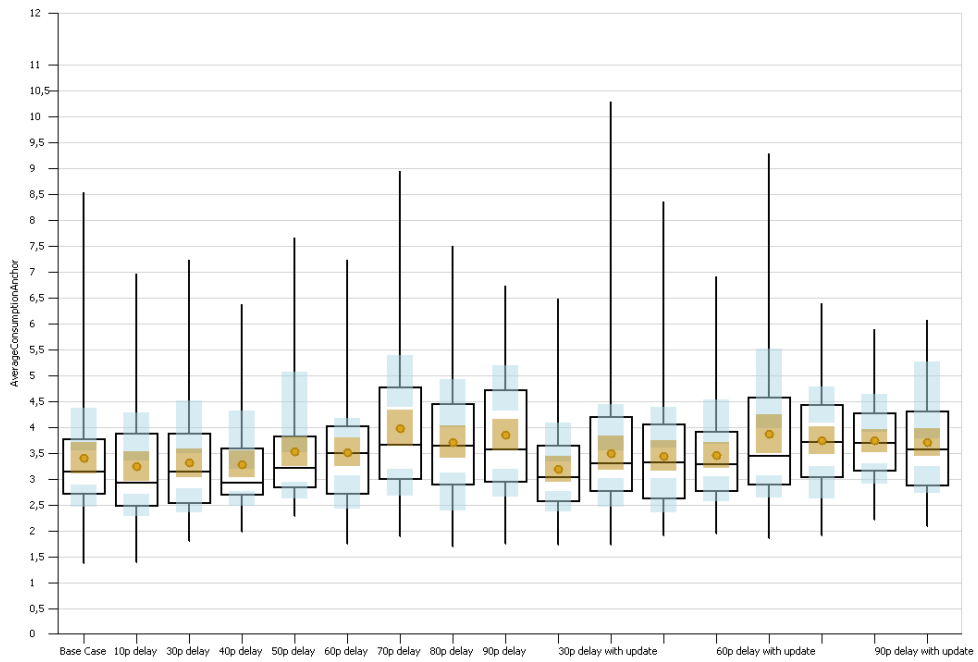


FIGURE 92: PROBABILITY OF DELAY AVERAGE CONSUMPTION ANCHORAGE

Probability of bunkering

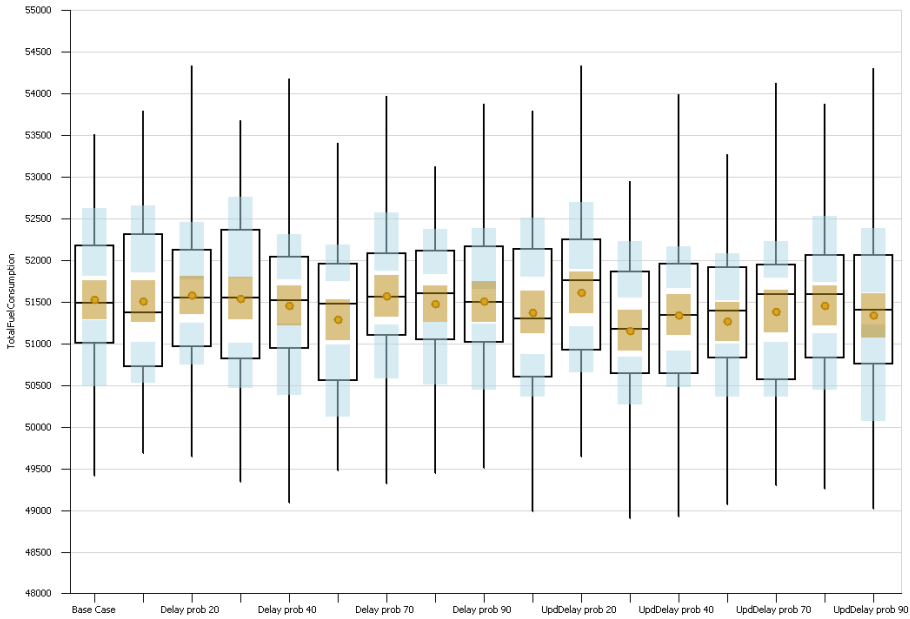


FIGURE 93: PROBABILITY OF BUNKERING TOTAL FUEL CONSUMPTION

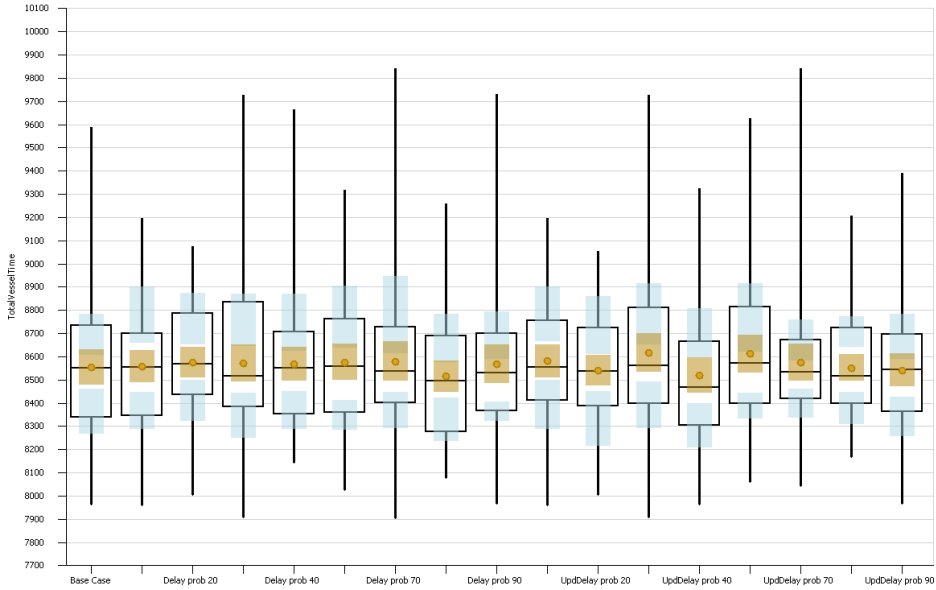


FIGURE 94: PROBABILITY OF BUNKERING TOTAL VESSEL TIME

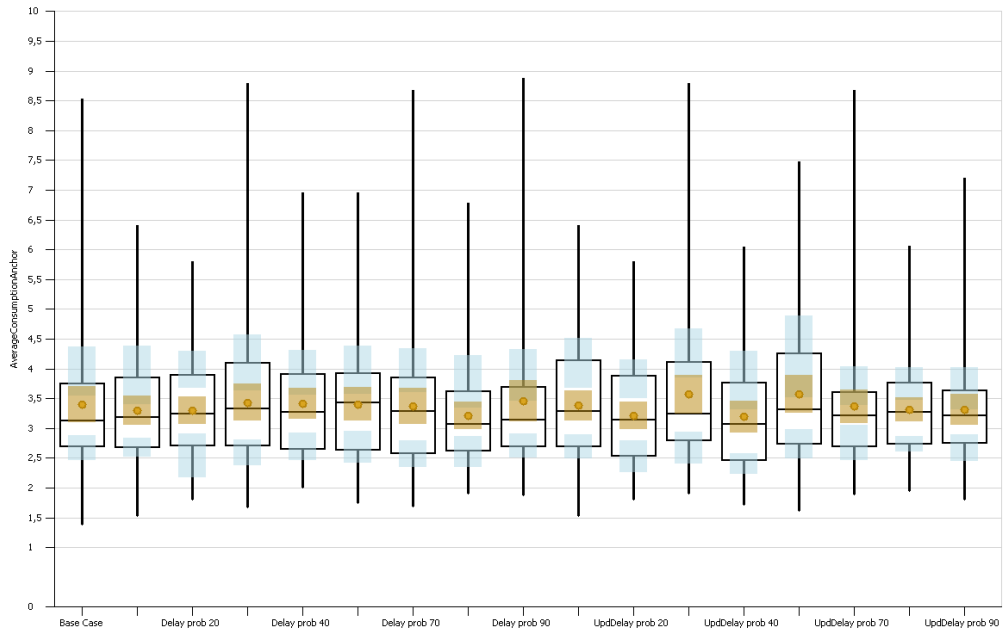


FIGURE 95: PROBABILITY OF BUNKERING AVERAGE CONSUMPTION ANCHORAGE

Average bunker delay

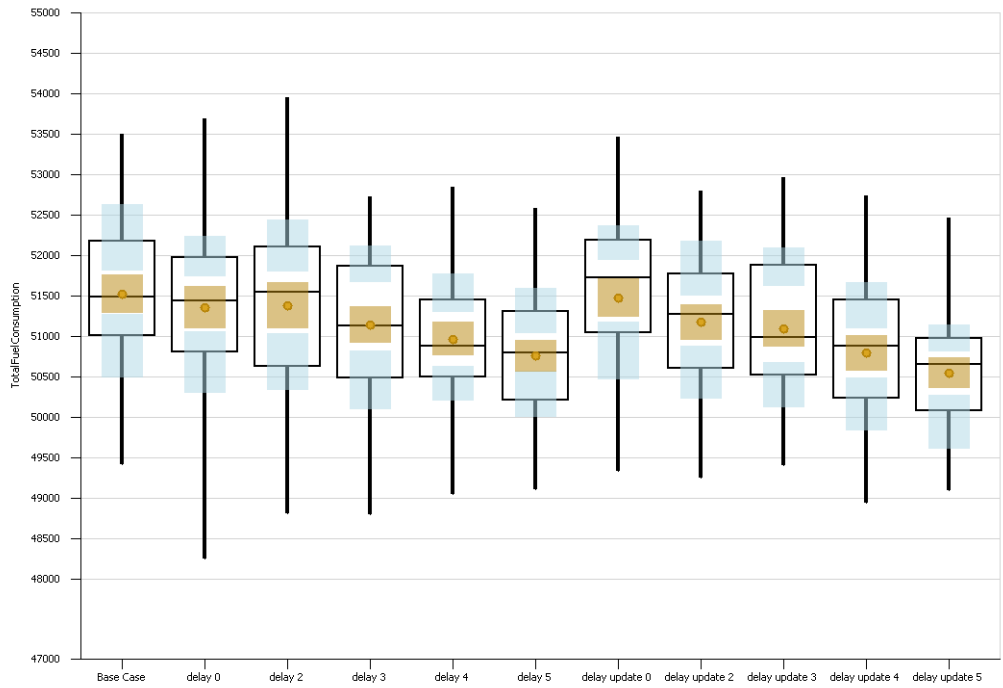


FIGURE 96: AVERAGE BUNKER DELAY TOTAL FUEL CONSUMPTION

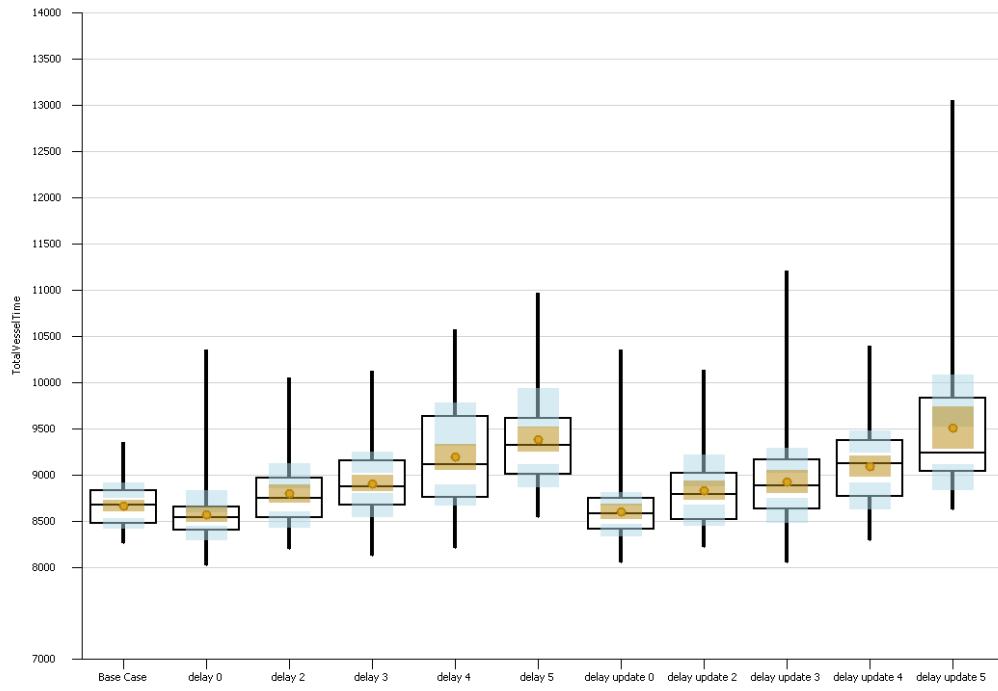


FIGURE 97: AVERAGE BUNKER DELAY TOTAL VESSEL TIME

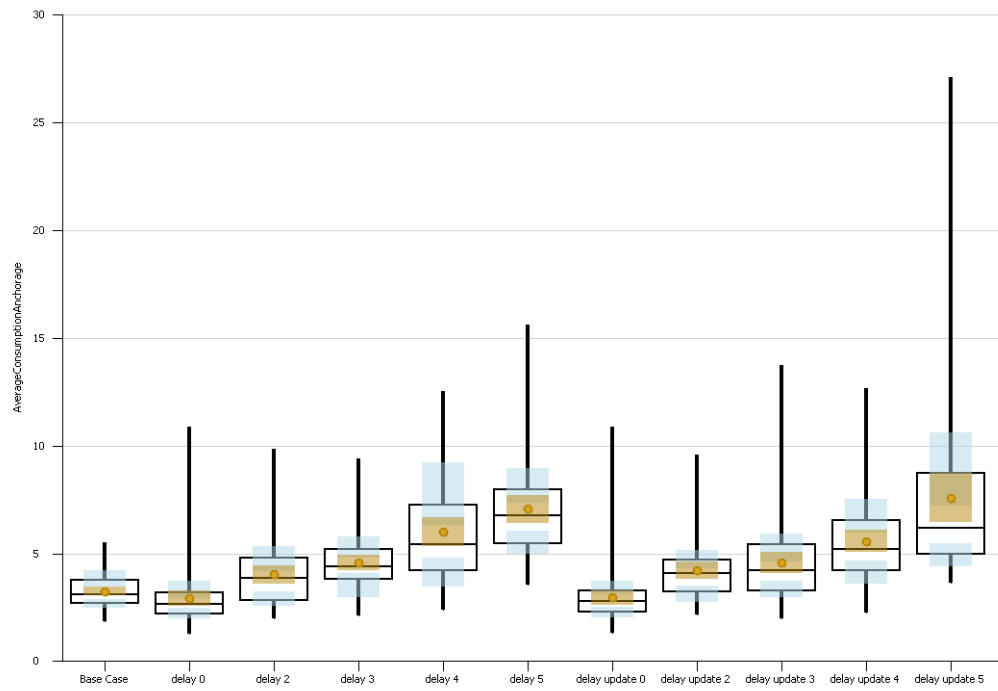


FIGURE 98: : AVERAGE BUNKER DELAY AVERAGE CONSUMPTION ANCHORAGE

Accuracy of information

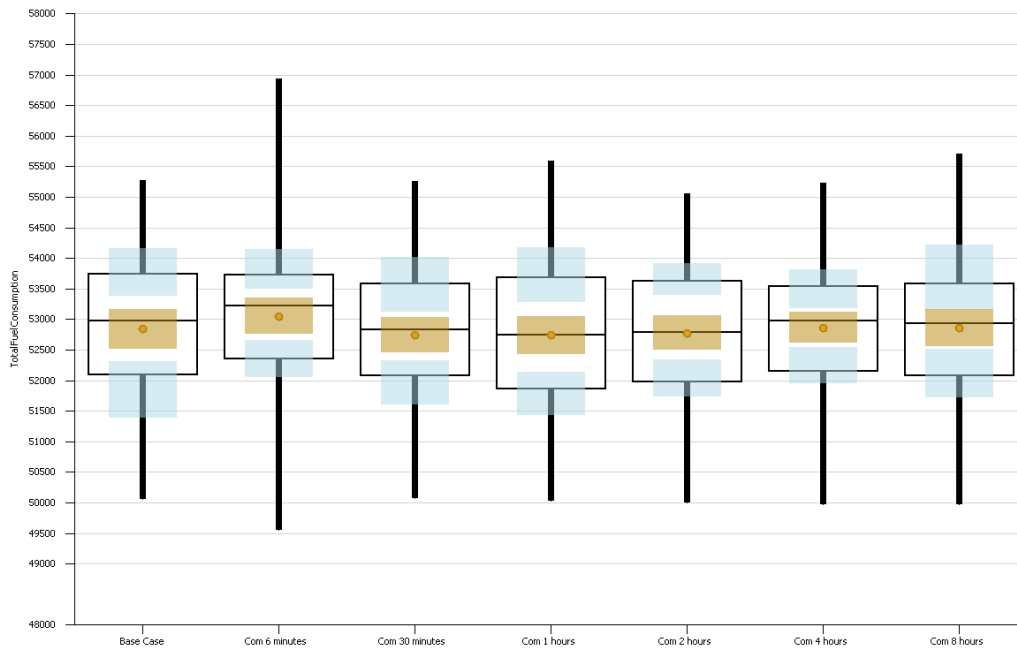


FIGURE 99: ACCURACY OF INFORMATION TOTAL FUEL CONSUMPTION

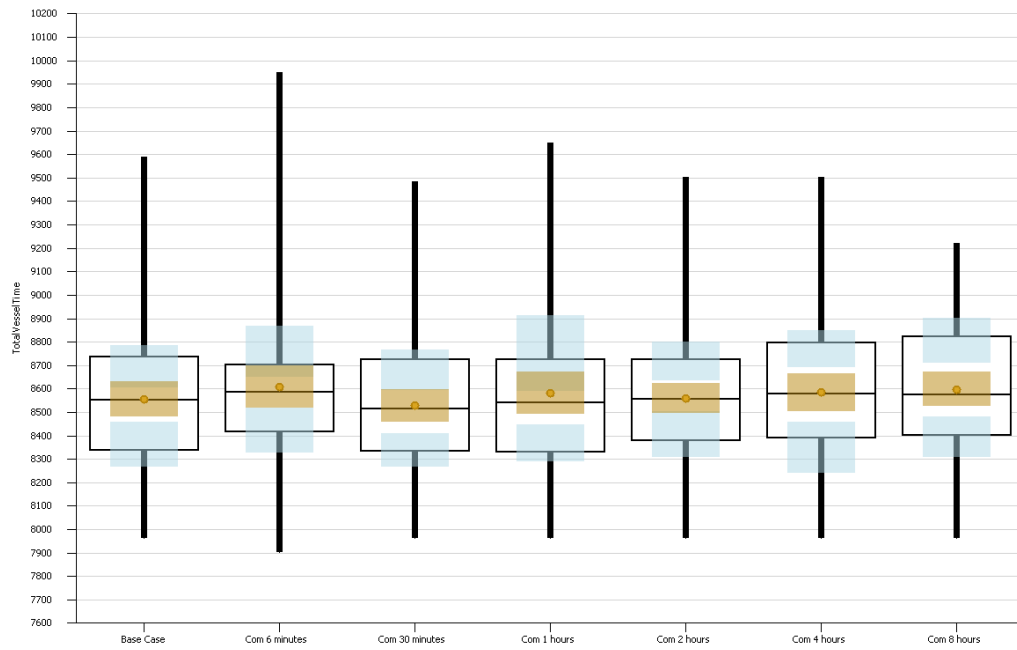


FIGURE 100: ACCURACY OF INFORMATION TOTAL VESSEL TIME

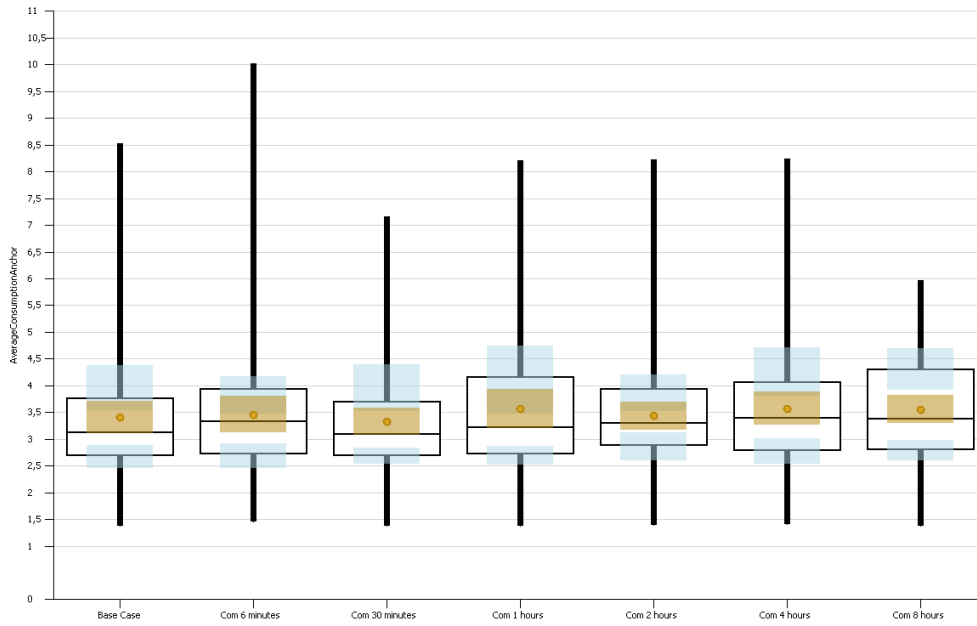


FIGURE 101: ACCURACY OF INFORMATION AVERAGE CONSUMPTION ANCHORAGE

Green steaming

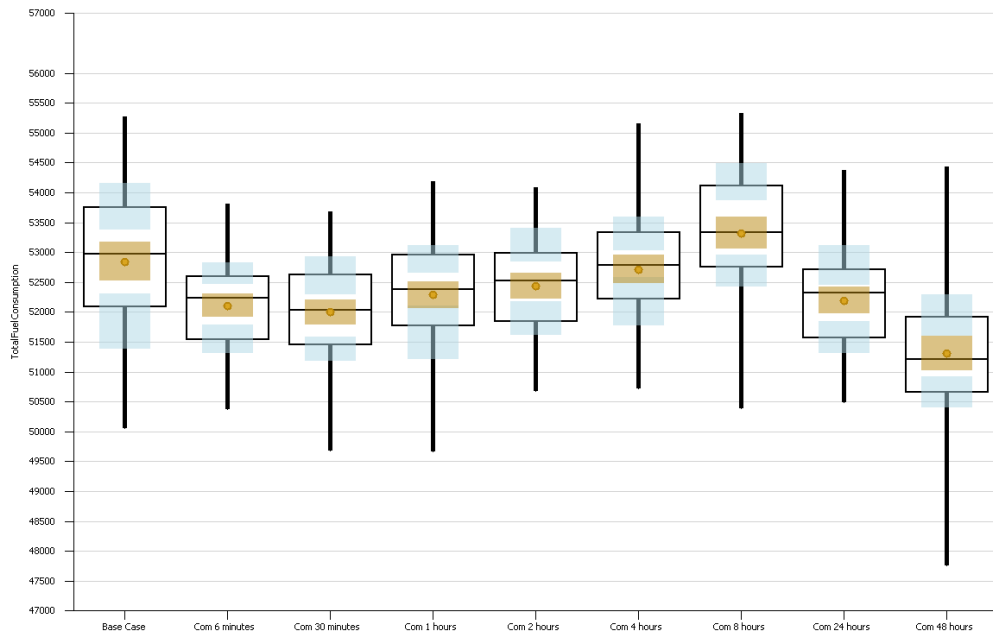


FIGURE 102: GREEN STEAMING AND COMMUNICATION INTERVAL TOTAL FUEL CONSUMPTION

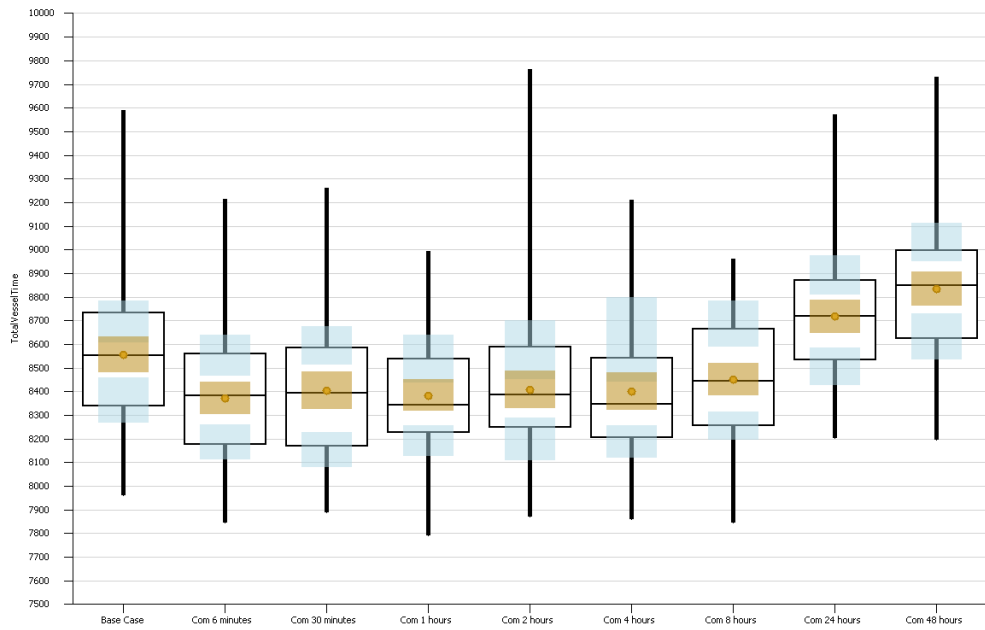


FIGURE 103: GREEN STEAMING AND COMMUNICATION INTERVAL TOTAL VESSEL TIME

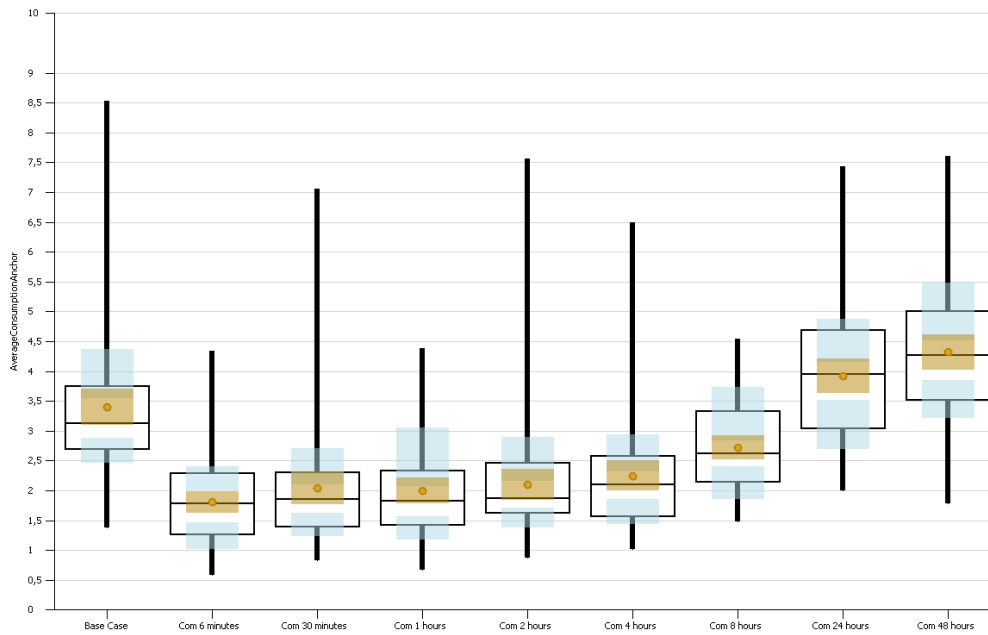


FIGURE 104: GREEN STEAMING AND COMMUNICATION INTERVAL AVERAGE TIME AT ANCHORAGE

Experiment with changing communication intervals and a maximum speed of 17 knots. Compared to the figure in the results chapter this one is equally spaced between the scenarios.

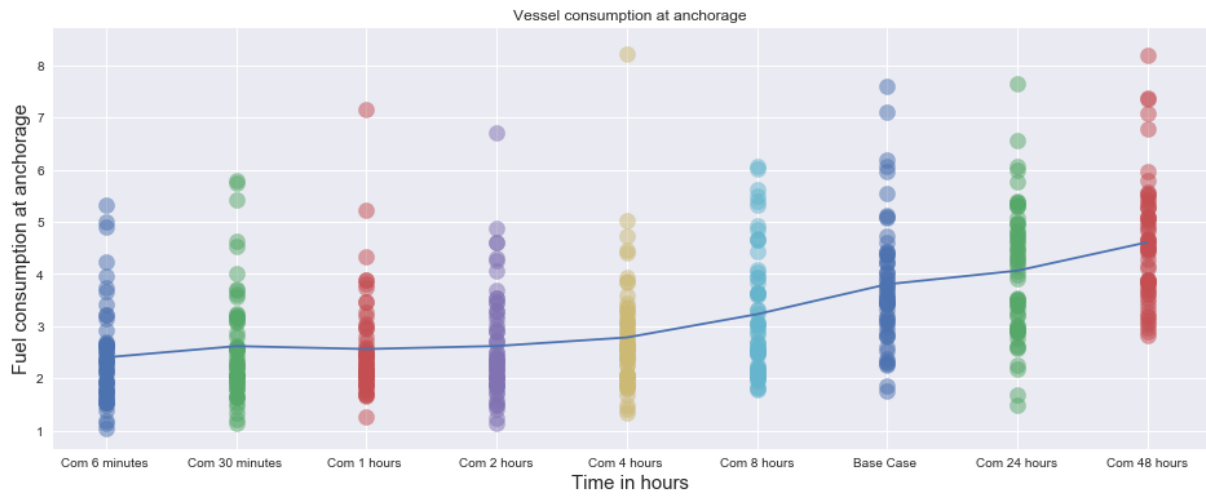


FIGURE 105: FUEL CONSUMPTION AT ANCHORAGE WITH EQUALLY SPACED SCENARIOS

APPENDIX X

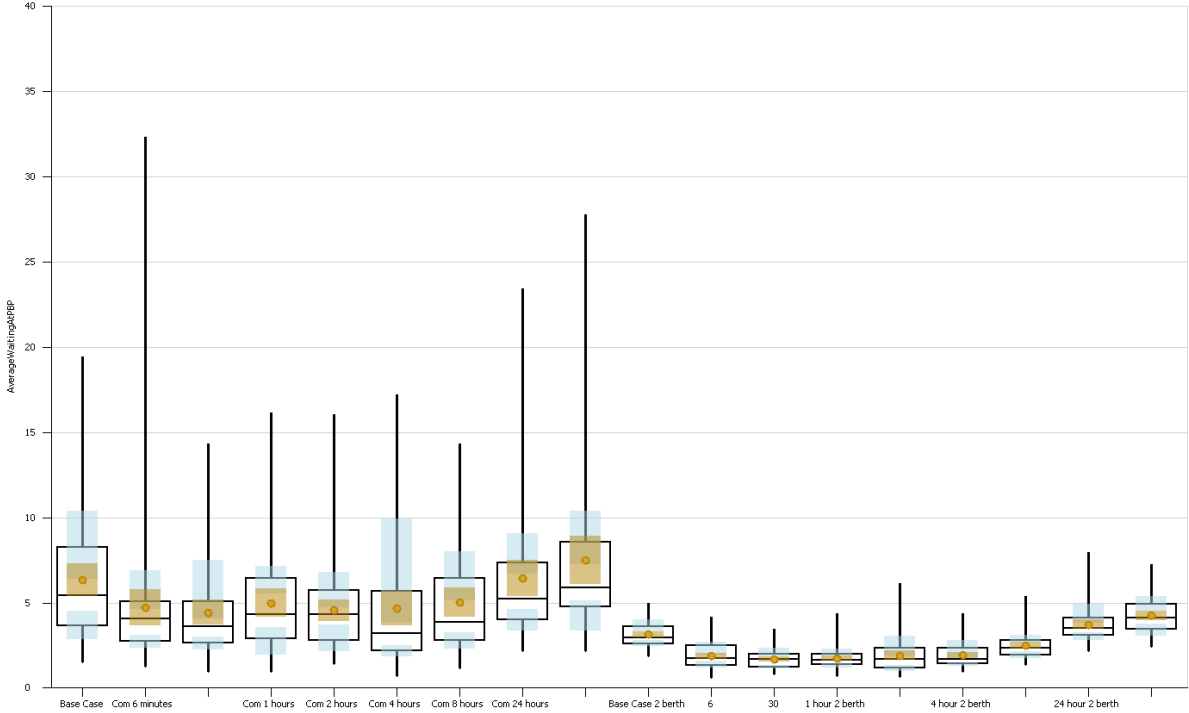


FIGURE 106: BONUS SIMULATION RUN WITH A SINGLE BERTH

In Figure 106 the scenarios on the left of the middle only utilise one berth, on the right are two berths. With only eyeballing the information it is clear that the scenarios on the left perform far worse than on the right. What this means is that for a single berth the potential for savings is much higher, and that for places with more berths there is more flexibility thus already mediating some effects. This effect is especially interesting for other research areas where only one berth is available, for example smaller terminals or jetties utilised by tankers. Or extend this research to larger terminals and see how this effect develops with size.

