NTNU

Logistic management of production chemicals

A simulation Study

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Preface

This MSc thesis has been prepared during the spring of 2011 at the Norwegian University of Science and technology, Department of Marine Technology.

The work has been conducted in collaboration with Statoil in Bergen and Sintef Marintek in Trondheim. They have provided me with an office space in both these organizations, allowing me to get an insight into the daily operations. I would like to thank Per Ove Økland as the main contact person at Statoil for facilitating the field studies, and a sincere thanks to Aud Marit Wahl at Marintek for guidance regarding Integrated Operations during the project on the fall of 2010 as well as on this MSc thesis. I would also like to thank all the employees at the logistics and analysis department at Statoil, Statoil Marin, Statoil Ågotnes and the crew at Havilla Foresight that providing me with the data, and first hand expertise on the subject of offshore logistics needed to do this study.

In final I would like to than my supervisor Bjørn Egil Asbjørnslett for the valuable input during entire process but especially in the final stages of the work.

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Summary

This paper evaluates the logistics for production chemicals used on the offshore installations of the coast of Norway. Statoil provided the following problem description: There are an increasing number of fields on the Norwegian continental shelf that are going in to mature stage of its production. In this part of the field's life cycle the need for production chemicals are increasing. The problem for the supply chain is that the tank capacity on-board the installations are limited and the procurement process is significant. The technology on the tanks on-board is old and manual readings of the tank level are needed. This could lead to the need for priority calls by the supply vessels, which are costly, or in the worst case stop in production.

In the first part of the paper the offshore supply chain at Statoil is described, and a description of the importance of the production chemicals is given. A brief description of the theory related to the problem within the subject of Supply Chain Management is provided, and a chapter describing the field work at Statoil is also given. It was concluded that simulation modelling was to be used in the analysis part of the work.

Discreet event simulation is a common method for analysing complex systems. This method allows the user to evaluate effect of changes on a system prior to making them. This is useful since introducing changes in the existing system could be very costly.

The simulation case looks at the situation on three of Statoil's installation on the Norwegian continental shelf. The values that are evaluated is the tank levels for the different chemicals, and how these values develop over time as changes are introduced to the case in different scenarios. There were developed four different scenarios:

- Scenario one: The systems were modelled with the existing tank capacities with four different demand settings. If no problems were found in this scenario it was assumed that the system functioned satisfactory :
    - AS-IS demand based on the average demand over the last three years
    - 10% increase in this average demand
    - 25% increase of this average demand
    - 50% increase of this average demand
- Scenario two: Introducing increased capacity. This scenario was evaluated for the cases that had an inadequate result during the first scenario. In this scenario the tank capacities were increased to be able to last for 10 days with a demand given as the maximum possible in today's situation. The simulation was conducted for the same demands as in scenario one.
- Scenario three: This report is also evaluating the effect of Integrated Operations, and one important topic in this field is sharing of real time data. Based on this the model was alternated so that the tank levels could be monitored in real time, automatic tank level reading, providing an "IO" improvement to the system. A simulation run with this setup was done for all the installations for the same demand values as in scenario one, and the tank utilization grade was compared to the case in scenario one.
- Scenario four: In this scenario the automatic tank reading setup was combined with the increased capacity of scenario two. This is assumed to be the most realistic of the

improvements, as installation of new and larger tanks offshore most likely would feature this new technology as well.

This simulation study can be seen as a “what-if” analysis. And the results are presented below:

- Scenario one: Satisfactory results for both installation A and B for all the demand levels, indicating a sufficient tank capacity at the given demand. Unsatisfactory results were found for the chemicals H2S remover and Nitrates at installation C
- Scenario two: Increasing the tanks at installation C for the chemicals mentioned above gave a very large improvement in the result, indicating that the capacity in the existing setup is insufficient for the demand situation. The result was also that there were no problems when the demand rose from the initial average to the 50% increased level.
- Scenario Three: Allowing for continuous monitoring of the tank levels gave an improved utilization of the tanks at all the installations. The benefits of this alternation to the system was found to be largest in the situations that had the worst results in the original setup used in scenario one.
- Scenario four: This scenario gave a perfect result for all the demand values that was tested on the case of H2S remover and Nitrates for Installation C. The good results from the alterations in scenario two and three continued to improve when they were combined.

Using simulation as a method for analysing the offshore supply chain provides a good overview of the situation and the possible problems. The two possible improvements, increasing the capacity and implementing automatic tank readings both gave good results. Since the possibility to do this evaluation on the real system would not be possible due to the fact that the cost of such alteration would be too large, it was found that simulation provides a good alternative to evaluating the supply chain. The simulation model does not give a recommended or optimal improvement for the cases where problems were discovered, but could be used to evaluate how the system would perform under different circumstances. As stated in the conclusion, no cost calculations have been conducted on the results from the simulation. The result of such an analysis could be that some, or all, the improvements used in scenario two-four are unfeasible. This would have to be evaluated before a recommended solution could be provided.

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Abbreviations and glossary

IO- Integrated operations

IPL-Integrated planning

OR- Operational Research

ERP-Enterprise Resource Planning

SAP-Short for “Systems, Applications, and Products”, ERP tool used by Statoil

ROP-Reordering point

EOQ- Economic ordering quantity

Block- In ExtendSim this is a term for either a process, queue, equation or monitoring function, and is used to build models.

WOP-Waiting on platform

WOW-Waiting on weather

Floaters-semisubmersible rigs

H_2S-Hydrogen sulphide

1 Introduction

This Master thesis is a continuation of the work I conducted in my project assignment the fall of 2010, where I described the logistic situation in Statoil. This report contains an in depth study of the logistical management of the production chemicals needed offshore. The topic for my master thesis was requested by Statoil, and I will be looking at a current problem.

There are an increasing number of fields on the Norwegian continental shelf that are going in to the mature stage of its production. In this part of the field's life cycle the need for production chemicals are increasing. The problem for the supply chain is that the tank capacity on-board the installations are limited and the procurement process is significant. The technology on the tanks on-board is old and manual readings of the tank levels are needed. The procurement is done in SAP, but mistakes and delays in ordering/delivery is an occurring case. Production chemicals are important in the daily operation of the installation, and are used to ensure safety of equipment, people and environment in different processes. The importance of the different chemicals are described in a later chapter titled "production chemicals". If there are no available chemicals it could lead to reduced production or in the worst case scenario shutdown of production. The most common measure is to issue a priority order. Priority orders come at a cost and is not wanted by Statoil. If other alternatives were available they would most likely be preferred.

This paper will be linked to integrated operations (IO) and the topic of integrated planning (IPL). This involves the use of new technology and real time data to enable people to work across disciplines and companies. The idea is to evaluate whether or not "IO thinking" and remote control of this product could improve the overall efficiency for this segment in the supply chain. An important aspect of IO is the availability of real time data and that this information reaches the right people. As stated in the previous paragraph, the technology on the installations in today's situation does not support sharing of real time data. How the supply chain will respond to the introduction of automatic tank-level readings can therefore be evaluated as an implementation of IO in the process of ordering production chemicals. If the specialist onshore can see this data in real time it is feasible to imagine a situation where it is easier to plan for future demand. Statoil see the following benefits of Integrated Operations:

- Improved HSE
- More efficient drilling operations
- Better placement of wells
- Production optimisation
- Increased recovery
- Better reservoir and production control
- Better monitoring of equipment and more efficient maintenance
- Better resource exploitation
- Increased regularity (uptime)

The IO implementation evaluated in this paper could be seen as a tool to increase regularity or as a tool providing better production control.

This paper is looking at a specialized area of logistics, offshore logistics. The amount of goods that is shipped by the offshore petroleum companies is massive, and there are several actors providing vessels to service this need. Offshore logistics on the Norwegian Continental shelf has been discussed in previous work, such as the article published in Omega by Kjetil Fagerholt and Håkon Lindstad (Fagerholt & Lindstad, 2000). In this article the focus is on routing optimization, and the impact of closing installations for deliveries at night. This article formulated the problem as a vehicle routing problem, and use numerical methods to analyse the situation. The article concluded with annual potential savings of 7 million dollars for the petroleum company. Espen G. Nilsens Master thesis “Robust supply chain design” is a continuation of the work done by Fagerholt and Lindstad (Nilsen, 2009), where the robustness of the routing strategies proposed in the original study was the problem being evaluated. Where these studies focused on the supply chain based on the general demand for cargo, the purpose of this project is to evaluate the supply chain for a given commodity. These reports serve as background material on how earlier work has been conducted within the field of offshore supply chain management. Since Statoil has been the company evaluated in these reports as well as in this study, the supply chain is the same, and experiences made in these previous reports can be useful in this study.

1.1.1 Purpose of project

The main purpose of this work is to analyse the process from the moment the requiring personnel order the chemicals, until this need is fulfilled. Give a description of today’s situation and the wanted situation, as-is and to-be. Find bottlenecks in the supply chain and recommend action for improvement. The evaluation of the logistic chain will be based on time where chemicals are not available offshore, and can be described as an inventory management problem.

1.1.2 Activities

- Describe the logistics for production chemicals, both for the need and the supply process.
- Documentation of the systems linked to production chemicals
    - Ship design, tank capacity and tank layout
    - Tank layouts and capacities for the offshore installations
- Documentation of the capacities for the entire supply chain, onshore, vessel, offshore. And provide documentation of the different loading time needed in the different steps of the chain.
- Find documentation of the cost when shipment of chemicals is delayed.
- Try to develop a simulation model in ExtendSim that can simulate the logistic process for one case.

1.1.3 Limitations

- In the original proposal to this project, a section on routing based on the need for chemicals was optioned. This was removed since the assignment was already large, and this option could be as large as a new project. Routing optimization based on one commodity could also be leading to sub optimization of the supply chain
- The final model could analyse how the situation would be for an unlimited amount of different demands. In the case only three alterations to the original demand was used. This was a limitation in the work based on time, and it was found that these three different demands would provide a sufficient indication on how the system would react as the demand rose.
- The paper is limited to the production chemicals that were found used on the field evaluated in the case. This is reflected in the description of production chemicals.
- No overlying user interface was created to the model. The original idea of the model was to create a user interface that would allow for other users to make alternations to the system parameters without having to go into the detailed model. This would allow for an easier use. This could probably been done, but due to limited time and experience with the program used to create the model this was excluded. The focus was on proving the models validity and getting results for the case problems.
- The model as it stands is limited to the installation evaluated in the case. The model main structure of the model should be able to handle the situation for other fields, but the model has to be validated again for the new field before such a study.

This paper is divided into four main sections. The first is the offshore logistics chapter which starts with a presentation of the case, a brief introduction to the Norwegian petroleum industry and Statoil as an actor in this industry and a description of Statoil’s supply chain. The case description will then be more focused on the subject of production chemicals and a description of these chemicals importance is also provided in this section. The scecond section is a description of the field studies conducted at Statoil and gives a description of how the data used in the analysis part of the work has been collected. The third section is a description of the theory that this paper is based upon, supply chain management. This is a large field of study, and some areas of this field related to the case will be provided in the second part of the paper. The focus of this part will be on Operational Research and inventory management. In this section a detailed description of the method selected for analysis is also given. Some of the data found could be subject to confidentiality rules and will therefore only be presented in the appendix part of the report, this is data directly related to Statoil’s facilities. The analysis will be presented in the fifth chapter, and includes how the model has been built, the results, and also a brief discussion of the results found.

2 Offshore logistics

2.1.1 The Norwegian petroleum industry

From the start in the middle of the sixties the petroleum industry has grown to become the most important industry in Norway, and in 2009 oil and gas exports constituted 50 % of Norway's total exports. In 1965 Norway, The United Kingdom and Denmark divided the continental shelf between the countries, before exploration drilling was conducted in the area. The first rig on the Norwegian continental shelf arrived in 1966 and in 1969 Phillips Petroleum discovered the first field, Ekofisk, of the coast of Stavanger. The Ekofisk field started its production in 1971 and marks the start of the petroleum era in Norway. Since this start 40 years ago the industry has grown and in 2009 there were 65 fields in production of the coast of Norway. A majority of the fields now developed on the Continental shelf is in the mature stages of their lifetime, and since the peak in the early 2000 the production of oil has been reduced with 40%. Increased gas production has however compensated for some of this loss. The industry employs approximately 250000 people directly and indirectly. Since the start in 1971 over 8000 billion Norwegian kroners worth of oil and gas has been recovered from the fields on the Norwegian continental shelf, and investments of over 1600 billion Norwegian kroners have been made in the development of oil and gas discoveries of the coast of Norway. The industry is responsible for 26% of Norway's income as a state in 2009. (The Norwegian Oil Industry Association)

2.1.2 Statoil

The company was founded in 1972 one year after the production at Ekofisk started, and can now look back on almost 40 years of experience. Statoil became the first Norwegian company with operator status on the Norwegian Continental Shelf in 1981. This was on the Gullfaks field, a field which is in production still. In the present time Statoil has the operator responsibilities of approximately 80% of the oil and gas production in Norway and employs 20000 people around the world. In addition the company is the technical operator of several onshore processing facilities in Norway and abroad. Statoil is present in 34 countries around the world and is by Forbes ranked as the 60.th biggest company in the world regardless of industry segment. (Statoil, 2011) (Statoil, 2011) (Forbes)

2.2 The supply chain at Statoil

This chapter will contain a description of the overall supply chain for Statoil's upstream logistics, and what differs the supply chain of production chemicals compared with the supply chain of container goods. The different actors and the roles they play in the supply chain gives an idea of how much work and planning has to be done to ship goods to offshore installations. In the later chapter on simulation modelling the importance of having knowledge about the entire "system", in this case a supply chain, is described.

The size of the logistics operations in Statoil and the resources the company control is best described in key figures:

- 34 Fixed platforms
- 18 Floaters
- 8 Anchor handling vessels
- 20 Supply vessels
- 20 Standby vessels
- 7 Supply bases
- 18 Helicopters
- 4 SAR helicopters
- 6 Helo bases

The total outbound topside cargo each year is said to be from 650.000 ton to 800.000 ton. (Tysseland, 2010)The total bulk load per year is approximately 1.200.000 ton.
In addition to this Statoil’s only way of getting their employees to and from the offshore installations is by helicopter, and each year about 190000 passengers are transported to the over 50 different installations.

Figure 1: Statoil Supply Chain

This image illustrates the typical order of the offshore logistic from the starting point where the requirements for goods arise at one of the 52 installations, to the management of returned goods (Statoil, 2010).This is a continuous cycle.

2.2.1.1 Need/requirement:

Some of the goods needed offshore are initiated from the land organization, and some are coming directly from the installations and the departments mentioned above. These needs are requisitioned in Statoil’s ERP-system SAP. Any goods that the installation wish to return to the base has to be reported to the material coordinator within 10 o’clock the day the vessel leaves the base. Any material that is going offshore has to be at the base the day before departure before 1600.

2.2.1.2 Delivery:

The suppliers receive the order from the purchasing agent at Statoil. The suppliers then prepare the goods for transport, following all rules for securing of goods and labelling. Supplies are then transported to the supply base that serve the installation it is heading for; Dusavik, Ågotnes, Mongstad, Florø, Kristiansund, Sannessjøen, Hammerfest.

2.2.1.3 Receiving goods at base:

- At the base the goods from the supplier is received, and prepared for further transport. This preparation includes:
- Choosing the right type of container for the goods (not all equipment can be transported in open containers/baskets and vice versa.
- Make sure that the goods are stowed in a manner that ensures the safety of the personnel that is receiving the goods offshore.
- Secure cargo in accordance with rules and regulation(some types of cargo needs to be separated)
- Chemicals are delivered either in tanks or as bulk directly at the quay from the suppliers.

The base is also responsible for developing the sailing plan or route. This is done in a module of SAP called VTMIS within 10:00, and the installations, supply vessel and other logistic actors need to make their comments on this plan before 1200 when it is regarded as final. Together with the ship's captain or mate the base develop a loading plan. The overview of the cargo on board the vessel is generated to a manifesto in SAP. A special measure for the chemical logistic in this part of the chain is that they should be reported 48 hours prior to sailing.

2.2.1.4 Sailing:

When the loading of the vessel is completed the responsibility for the ship's sailing plan is handed over to Statoil Marin (land based part of the organization). This sailing plan now includes all cargo and returning cargo as well as the time schedule for when the different installations are to be visited. Even though the responsibility for this plan lies with Statoil Marin it is the ship captain that has the responsibility to ensure the safety of his ship and its personnel, he is in contact whit Statoil Marin and together with them he will decide if it is safe to precede operations (example if there is bad weather). Statoil Marin gives the go ahead signal for the vessel to leave the base and updates SAP VTMIS. Before the ship enters the 500m zone of the installation it is visiting radio contact is established. A thorough check of the positioning system is made.

2.2.1.5 Receiving and returning goods offshore:

Loading and unloading operations an all the affiliated activities which are done by the vessel and installation are considered to be the most hazardous part of the upstream logistic offshore. The installation announces that a supply vessel is due to arrive, so that all work which can be hazardous to the vessel and the unloading operations are stopped. The list of returning goods has as mentioned earlier been reported in SAP, giving the captain as much time as possible to familiarize himself with the new cargo and load it in a suitable manor. This operation involves much sharing of information and communication, between the vessel and the installation and also with Statoil Marin.

- Testing of radio equipment before using the crane to load/unloading operations begin
- The crane operator and the navigator on duty has to complete a "Safe Job Analysis"
- Hazardous cargo must be reported
- An update must be made on the ship's manifesto
- Delays must be reported, and the routing plan must be updated accordingly.
- New announcement on the installation when the ship departures and regular work is able to resume

2.2.1.6 *Sailing in return:*

After completing visiting all the installations on the route the ship sail in return to the base. The vessel then makes a final report to the land organization, Statoil Marin and Base. This includes:

- Backload
- Final report on inbound cargo from the installations
- Bulk cargo delivered and returning
- Available deck space
- Arrival and departure

The base has to prepare for the vessels arrival:

- A quay space for the ship must be allocated
- The needed crane capacity has to be mobilized
- Reception and placement of bulk cargo must be planned with the different suppliers
- An activity plan for the unloading must be created

2.3 Logistics for chemicals

This paper will focus on the transportation of production chemicals, which occurs as both bulk cargo and deck cargo. It is important to remember that this is a part of a large value chain and therefore make sure that eventual improvement measures does not lead to sub optimization.

There are many actors involved in the upstream logistics of Statoil, but even before the product is ordered several different persons are involved. Due to rules and regulations, the person that has the need can't be the same person that places the order. This person sends a requisition to the acquisition department. The acquisition department then has to collect three or more offers for the service/product, or use an existing contract to order. When this is done the product is ordered and the person placing the requisition can follow his order. When the order is received at base, the financial department must be notified so that payment can be done.

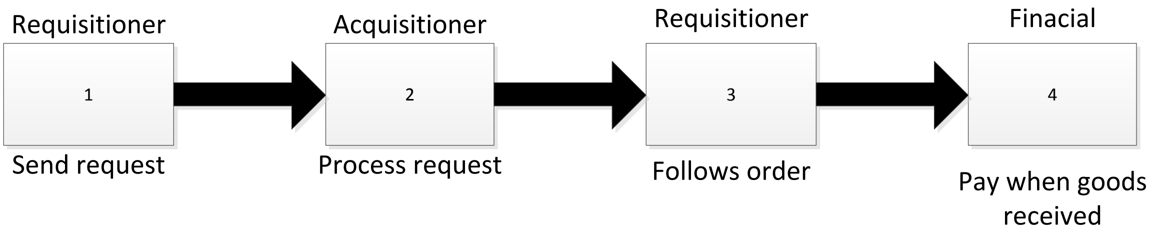


Figure 2: Statoil ordering process

Production chemicals use two methods for transportation, one is the same as for normal container cargo, with mobile tanks, and the other is in Bulk. The transport that occurs in bulk needs to consider limitations on the supply vessels tank capacity. For the products transported in tanks the problem is similar to that of containers, with limitation in deck area on the vessel as well as on the installations. Since chemicals often are subject to classification as dangerous goods there are some special measures to be considered when handling these products. For dangerous goods there are rules on how the goods can be stored, which could lead to new restrictions of the available space on the supply vessel that would not be the case for "normal" cargo. This problem is addressed in the 2004 report from Marintek, "Cargo management for offshore installations", where the problem description is how the cargo going on or off offshore installations could cause problems in the segregation of hazardous goods and general cargo placement options. The result of the work done by Marintek was a suggestion to a load planning tool called LoadManager, which would assist in planning the best way of stowing the cargo on the vessel. This program could be used both for the deck space and the bulk cargo, and had special HazMat handeling which was mad according to the existing rules and legislations at the time. Although this LoadManager has not been implemented, it could provide support to the operators on the vessels ensuring that hazardous goods are shipped in accordance with Norwegian law, and give increased effectiveness of loading and unloading operations. (Fjørtoft, 2004) More effective handling of loading and unloading could be translated into less overall lead time on the sailing route, and less delays.

To get an idea of how the suppliers of the chemicals interact with Statoil an interview at one of the main suppliers was conducted. The supplier is located on the supply base and can deliver the products both in bulk and in mobile tanks. Delivery times for the chemicals are given by contracts between supplier and Statoil. These contracts have a specified maximum delivery time, most commonly this is said to been 48h from the order is placed, but for some products the delivery has to be done within 24h. A central office located off the base handle all the incoming orders from Statoil's SAP system and distribute the orders to the base location along the coast. This is an extra time consuming factor in the ordering process, but as stated by the workers at the base the extra lead time this process generate is in the area of an hour, and the advantage is that the company can have specialized users following up the order with the customer. At the base the supplier can focus on delivering according to the orders they receive at a day to day basis. They use different pumps for different chemicals and there is also a difference in the capacity of the bulk loading system and the one they use to fill the mobile tanks. Descriptions of these capacities are listed in the table below.

Table 1: Pump capacities and filling time at chemical supplier

	Mobile Tanks	**Bulk system**
Pump capacity	500-600 [l/min](30-36 [m^3/h])	100 [m^3/h]
Filling time 2700l M tank	4,5-5,4 [min]	-
Filling time 4000l M tank	6,67-8 [min]	-
Filling time Spec.Bulk Viking Energy	-	Approx. 2 [h]

From this table it is possible to see that the lead time that the contracts allow for is the driving factor when it comes to the delivery of chemicals from the supplier. The time it takes for vessels special tanks to be filled equals to less than 5% of the 48 h allowed, and thus less than 10% of the 24 hour limit.

The mobile tanks come in a variety of volumes, for the purpose of this study, SWIRE oilfield services tanks of 2700l and 4000l are used as an example of capacities and needed area. Both tanks have a 2m^2 ground area, and are commonly used in the supply of chemicals offshore. For the mobile tanks the deck area on the vessel will be a limiting factor where as for the bulk transportation the volume of the tank is the limiting factor. For one of the vessels used from Ågotnes base, Viking Energy, the capacity on the deck is 1030 m^2, but 10% needs to be left unused to facilitate backload. If the only cargo delivered offshore were chemical tanks this would allow the vessel to carry approx. 460 tanks, a maximum volume of 1840 m^3.This is however not the case, the deck area is used for other goods as well, but it shows that the vessel used has a large capacity for delivering the chemicals. Picture of the mobile tanks are shown below.

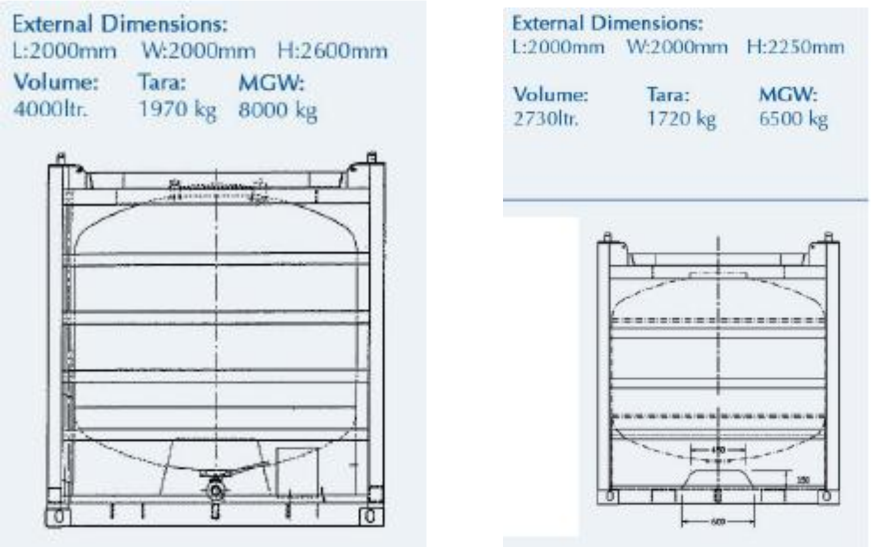


Figure 3: Offshore chemical tanks

(Swire Oil Field Services)

2.4 Production chemicals

The production chemicals are used for different processes in the production of petroleum, and if these chemicals are not available the result will be reduced production or in the worst complete stop of production. Such a stop or reduction in the production generates a cost, so the logistics needs to run smoothly. For the purpose of illustrating the importance of these chemicals I will provide a brief introduction to what they do:

- H_2S remover

Hydrogen sulphide H_2S is a lethal gas when it occurs at elevated levels and it must be removed to satisfy demands for gas export. This demand can be different from installation to installation, an example of accepted levels of H_2S is found at Statfjord B where it is less than 2,5 ppm. The H_2S remover is a chemical that is used in the process of removing this toxic component, and is therefore a crucial chemical in the offshore production process. An image of the process at Statfjord B is illustrated below.

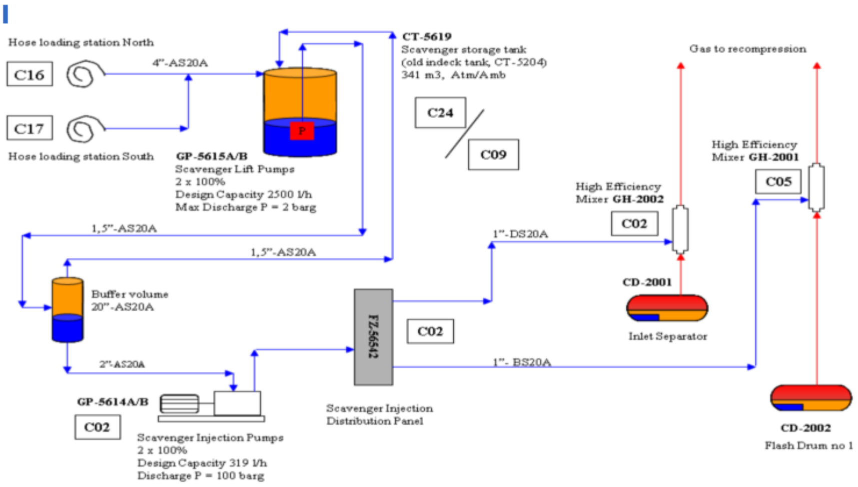


Figure 4:H2S remover, process at an installation

- Scale inhibitor

This chemical is used to reduce the development of scaling in process equipment and pipes. Oilfield scaling consists mainly of salts, calcium carbonates, barium and strontium being the most common. Scale can form from brine (formation water) as it undergoes changes in pressure and temperature, or where two incompatible fluids are intermingled. The pictures below illustrate heavy scaling, and from these pictures it is possible to see the importance of scale inhibitors.

Figure 5:Scale in pipes

Scale problems can arise in various circumstances:

- during drilling and well completion, if the drilling mud or completion fluid is incompatible with the formation water
- at the commissioning stage of new injectors, if the injection water is incompatible with the formation water
- during production, when a well starts to produce formation water with the hydrocarbons
- during well-stream processing, when significant quantities of produced water put process equipment at risk
- Commingled production, where well-streams from various formations, reservoirs or individual wells are mixed together, can make matters worse. (Statoil)

- Corrosion inhibitor
  Corrosion is disintegration of a material due to chemical reaction with its surroundings. Rust is the most familiar form of corrosion. Corrosion is a problem in the offshore petroleum industry and the reason why there is a need for corrosion inhibitor. This inhibitor is a chemical compound that, when added to liquid or gas, decrease the rate of corrosion of a material. If there is no corrosion inhibitor resent on the installation this could result in damages to the system.
- Emulsion breaker
  A water in oil emulsion means that water droplets are contained in a continuous oil phase due to the high surface tension in the oil. Oil in water emulsion may also appear at high water cuts, and then oil droplets are contained in the water phase. Emulsions usually have a higher viscosity than the single phase, and may therefore be harder to produce. Emulsion can be broken using chemicals. The emulsion breaker is used in the water oil separation process, and if there are no emulsion breaker chemicals available this will have a direct and negative effect on the oil production. (Birkeland)
- Nitrates
  Nitrates are used to reduce the development of H_2S. Hydrogen sulphide is as mentioned earlier a lethal gas at elevated levels and there is therefore a need to reduce the development of this gas. Some hydrogen sulphide can occur naturally in the reservoirs, but in many cases it is generated by the injection of seawater. The seawater contains large amount of sulphate which is a nutrient for the bacteria that produce H_2S. Statoil has previously combated this process by injecting biocides to kill the bacteria. On the Gullfaks, Veslefrikk and Statfjord fields biocides are now replaced by calcium nitrate. In addition to the positive environmental gain at lower cost, this solution is also positive for the working environment of offshore personnel involved in chemical dosing. They no longer have to suffer an unpleasant odor or run the risk of direct skin contact with the biocides, which pose a health hazard. (Statoil)

These are the chemicals that will be evaluated in the analysis case in part four of this report.

The production chemicals delivered in bulk MEG (mono ethylene glycol) is delivered in larger quantities and the tank capacities are larger. The problems related to the flow for this product is considered to be less.

3 Field studies at Statoil

This chapter is a continuation of the description of the supply chain above and will provide a description of the process of collecting data from Statoil. This paper is written in close collaboration with Statoil, and for most of the time the work has been conducted from Statoil's offices at Sandsli in Bergen. This chapter is a description of the observations that has been done at Sandsli and other stages of the value chain that was visited, supplier, base and supply vessel. The first-hand experience gained in this field study provided an insight in the organization that would have been impossible to get from the outside. The process has consisted of participation in meetings, interviews and general observation of the day to day conduct of the actors in the supply chain. Below is a list of the areas of the organization visited in this part of the study:

- CCB Ågotnes, which is the supply base serving the following fields: Gullfaks, Statfjord, Troll, Huldra, Veslefrikk and Kvitebjørn.
- The supply vessel Havilla Foresight which is on route from the supply base at Mongstad outside of Bergen.
- Statoil Marin, Gullfaks logistics, Logistics and Emergency response at Sandsli

CCB Ågotnes: This part of the organization was visited twice during the field studies. On the first occasion the visit only lasted for one day, and the purpose was to observe a meeting between the supply base and a shift from the logistics organisation offshore for three of Statoil's installations. During this meeting different problems that the two actors in the supply chain encounter in their work were discussed. In many of the cases it was easy to see that the different actors agreed on what was wrong in the situation today and which easy measures that could improve this situation. Similar meetings have been conducted afterwards, and at the next visit to the base the last of three such meetings was conducted. In addition to the meeting a brief tour of the facilities was done to provide an idea of the work done at the base.

The second visit to the base lasted for one week, and provided a more in depth understanding of the work processes in this part of Statoil's organization. The personnel working at the base were very cooperative and answered any questions to the best of their ability. In general conversations people talked about the different problems they encountered, and how they felt improvements could be made. Such statements are subjective and was not used as data, but provided valuable insight in the organization. The following is a list of areas that were observed at the base:

- Daily video-meeting between the base at Ågotnes, Statol Marin and all the other bases along the coast. On this meeting the different operations that were scheduled for that day was discussed and any special cases and needs were informed about.
- Internal meeting between Statoil base logistics and external actors on the base that are involved in the supply. This meeting was scheduled every week and was a status-meeting where positive and negative experiences from the last week were briefly discussed.
- Interviews with different persons working for Statoil at the base were conducted. The main purpose of these interviews was to get a better understanding of the supply chain and can maybe be seen as conversations rather than interviews.
- An interview with the largest supplier of chemicals was conducted during this visit to the base, and from this interview data on the capacities at the supplier was collected. These data can be found in table 3 and 4.

- One day was spent in the operation room where the contact between the base, vessel, Statoil Marin and installation result in load planning. If priority needs arise this part of the organization is responsible for organizing that the vessel has space available for the extra cargo, and that a load carrier is made available. Such situation interferes with the original plan and amounted to extra work load for the operators. A common statement made by the personnel was that it was perhaps too easy to order priorities, and that a more limited amount of personnel should be able to request priorities to better hold the original plans. Priorities should be a last resource option that compensate for unforeseen events, and the experience from the visit to base is that this is not always the case.
- An important aspect to emphasise is that most of the time the logistics operations at the base are going as planed and that the work done is good.

Trip with supply vessel Havilla Foresight:

Two days was spent on board one of the supply vessels that are serving the installations offshore, Havilla Foresight. During this round-trip from Mongstad, insight in how the crew on the supply vessel feels about the supply chain was gathered. One of the things that the personnel on the vessel would like in regards to bulk cargo was a visual load plan, and better visualisation of the load-list than the existing SAP printout. For the vessel, the important information is weight and dimensions of the cargo, as well as dangerous goods declarations. If such information is provided in good time and in accordance with the needs of the vessel staff, the result could be shorter lay time at the installations. Special measures when dealing with chemicals were limited to the paperwork needed since mobile tanks are like any other deck cargo, and for the bulk the difference is the loading unloading process which then is conducted by a hose. During this trip how delays at one installation affected the next since there were visible due to some minor delays. This experience provided much needed insight in how the different actors in the chain are connected in the transportation leg.

Observations at Statoil Sandsli:

Most of the time used on the field study was spent at Statoil's offices at Sandsli. At sandsli access to installation specific personnel as well as the general logistics group was possible, and Statoil facilitated the work by providing offices and computer access. In the start of this period , much of the time was spent observing different meetings between the different branches in the organization, but in the later stages more and more time was devoted to gathering statistical data to support an analysis of the chain. The figures that was collected was available statistics and historical data used to describe and evaluate the logistics of Statoil. This was gathered in an easy to use database were it was possible to search for specific installation over a given time period. The specific numbers may be subject to company confidentiality rules and will therefore be given in a special appendix.

The following is a presentation of what categories of data collected:

- Supply calls for a given installation over a period
- Total lay time over period
- Extra calls
- Extra lay time
- Average lay time per call
- Average lay time extra calls
- Inbound lifts
- Outbound lifts
- Avg. Lifts per call
- Inbound bulk cargo
- Outbound bulk cargo
- Tonnage specified to branch(drilling and well, production, project)
- Total tonnage
- General routing plan (provided by Statoil Marin)

From the analysis division at Statoil more specific data for the production chemical problem was gathered, and again this data will be provided in the appendix:

- Tank capacities at some installations
- Consumption of the chemicals investigated, 2008,2009 and 2010

3.1.1.1 Summary of field study and choice of analysis method

In the supply chain chapter of this paper, different methods of analysing a supply chain is described. Together with the results of the field study an approach for the analysis was found. The field study gave an impression of a complex supply chain, with several actors from different disciplines interacting. This was expected when the work started, but the offshore logistics is a special field and must be seen first-hand in order to be understood. It was also possible to get a large data background making it possible for data “hungry” analysis methods to be used. The results of this field study would be used in the selection of analysis method.

4 Supply Chain Management

This paper is based on supply chain management and this chapter will give a brief description of the theory behind the analysis that is done in the simulation chapter. The problem described in the introduction is a problem of inventory management, which is also closely related to demand forecasting. This is the areas of supply chain management that this chapter will focus on. The theory mostly based on the lectures in the course TPK4160 Value Chain Control and Applied Decision Support at NTNU lead by Heidi Dreyer the fall of 2010, and lecture book by Chopra and Meindl (Chopra & Meindl, 2010). After the theory is presented, and the different methods of Operational Research is described , a more in-depth explanation of the method chosen will be given.

4.1 Demand forecasting

Demand forecasting form the basis of all supply chain planning, whether it is to facilitate a push process or a pull process. For push it is used to plan the transportation and for pull it is used to plan the level of available capacity and inventory. For the problem discussed in this paper demand forecasting is used to be able to plan the needed amount of chemicals on the installation. An important issue to remember when dealing with demand forecasting is that they are always inaccurate, it is therefore important include demand uncertainty as a key input to most supply chain decisions. In general there are many factors that a company must knowledgeable about that is related to demand forecasting, for the upstream logistics of production chemicals at Statoil these are some important factors:

- Planed activities at the installation
- Lead time of product replenishment
- Past activities

Since the demand changes with the activities the planning horizon can become very short, Work order plans are made for 1-2 weeks. The importance of good control over the inventory offshore is therefore very visible.

4.2 Inventory management and operational research

Inventory management problems are characterized by holding cost, shortage cost and demand distribution for products specified at a detailed stock keeping unit. (Shapiro J. F., 2001). The field of inventory management look at how to create buffers against the uncertainties of supply and demand. A large part of the models used on Inventory management is used to determine the optimal level of safety stock, as this is the protection the system has against the uncertainties in supply and demand. (Shapiro J. F., 2001) This section focus on inventory management and different methods used to decide the optimal point for reorder, the need for safety stock, and storage facilities. An important aspect of supply chain management is decision making, and then decision support tools. The methods are used to improve a managers understanding of a problem, and can be as simple as a checklist or a drawing. More advanced methods of decision support is what is called Operational Research (OR), and are based on quantitative models. This means that the system and the relationships between different parts of the system are described with variables and mathematical expressions.

Some OR methods are listed below:

- Spread sheet cost models
- Decision trees
- Queuing theory
- Discrete-event simulation
- Inventory theory
- Mathematical programming(optimisation)

Each of the techniques has different strengths and weaknesses, and will therefore be suited for different problems. In the next section a brief introduction to the different techniques and their strengths and weaknesses will be described.

4.2.1.1 Spread sheet cost models

In this technique, different costs for different scenarios are calculated. It can be seen as a simple form of simulation which is static and deterministic. Spread sheet cost models are used to conduct "what-if" analysis, and is one of the most frequently used modelling tool in industry. This method requires little training, and is very cheap since the tools needed are usually available for everyone (excel). The disadvantage is that it is not normative and the fact that it is static and deterministic.

4.2.1.2 Decision tree

This is a graphic devise used to evaluate different decisions under uncertainty. The model is based on probability and statistics and is good for evaluating the flexibility of a supply chain. It will usually consist of choices between long-term and short-term options, where the short-term option provide more flexibility but at a cost. Below is a description of a binomial representation of uncertainty, where a price P in period 0 has multiple outcomes after n periods.

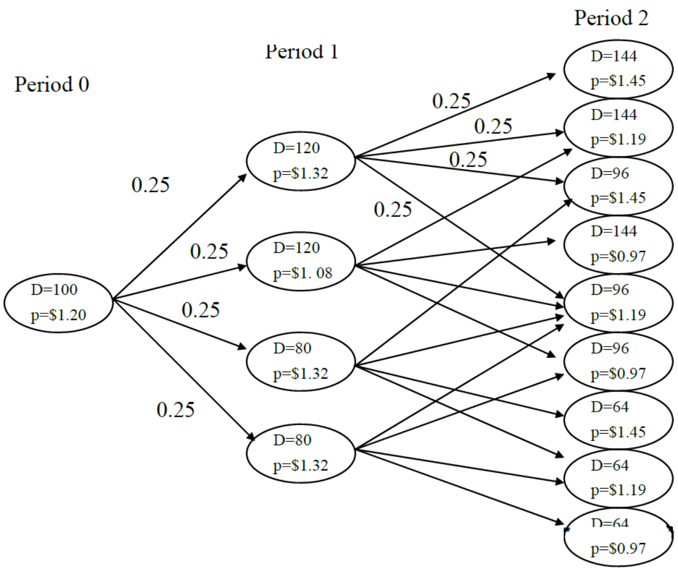


Figure 6: Decision tree

4.2.1.3 Queuing theory

This is used to evaluate expected through-put of a system, the time an entity spends in the system, how the systems resources are utilized and also the average waiting time. A typical example of the use of queuing models is the example of a bank with bank tellers needed to attain a certain degree of service. The arrival rate is most commonly given by an exponential distribution and the processing time can be given by a normal distribution. Queuing theory can then estimate the number of tellers needed. The method is easy to use and gives a fast result, if however the system gets more complex this model will not be a good option. The results given by this technique is often descriptive results.

4.2.1.4 Discrete event simulation

Simulation can be seen as a continuation of the queuing theory model, where more complex systems can be evaluated. Since most of the systems found in the world would be regarded as complex this technique could provide more realistic results. Complex systems can contain many resources, different queues with different rules and other distributions than exponential. A discrete-event model consists of entities, resources and queues and allows for dynamic simulation. The advantages with this model is that it is considered to be realistic, easy to understand and able to provide intuitive visualisation of a problem. On the other hand a simulation can be expensive, time consuming, unable to provide a recommended solution and provide little besides than a "what-if" analysis. Below is a brief description of a case where discrete event simulation was used on an offshore supply chain.

4.2.1.5 Example of a simulation study done on a supply chain: Robust supply chain design

The number of articles on simulation studies done on the offshore logistics supply chain is limited. In 2009 a master thesis on the subject of robust supply chain design was written at NTNU in collaboration with what was then StatoilHydro. This provides a good background for the problem discussed in this paper, since the supply chain evaluated is the same and some important inputs to the model is identified in the paper on robust supply chain design. This paper use a routing optimization decision tool that was developed by Marintek as a basis, and tries to evaluate how robust the routing developed with this tool is. The robust supply chain design study use a general purpose simulation tool similar to the one that is used in this paper called Arena. The model that was developed dealt with the following issues:

- Evaluating if a plan held time-window constraints given disruptive scenarios
- Determining where the bottle necks were
- Determining which was the most disruptive elements of the system
- Would the optimal routing provide a robust system?

The model generated in this study measured:

- Delays at the installations due to queuing and violation of time windows
- Delay at base
- Inventory levels
- Vessel utilization
- Intervention of additional vessel trip to face shortage of consumables

The simulation was conducted for different scenarios which was created based on the problem description. The total number of scenarios in this paper was 9. For each scenario the simulation model would provide data that gave an indication on how well the system functioned under the different conditions. The results found in this work were that the simulation model provided a good "what-if" analysis that would help increase planers proactive capability, and was very useful in determining bottlenecks. (Nilsen, 2009)

4.2.1.6 Inventory control

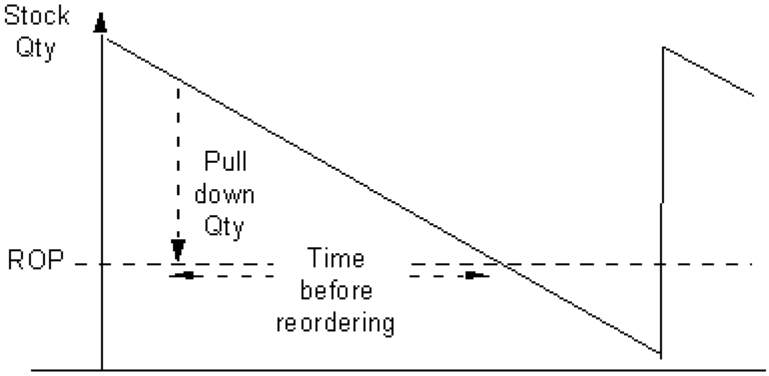


Figure 7: Inventory Control Graph, inventory development over time

The graph above shows how the inventory is reduced with a continuous stable demand and how the reordering point is placed to ensure that there is no stock out. The area of the graph under the ROP is the needed quantity of stock needed to get the new supply when the stock level reach zero. The equation used in inventory control to find the value of the re-ordering point is given as:

$$ROP=Demand * Lead\text{-}time + (Safety\ stock) \quad (1)$$

For the case of production chemicals in this paper the demand is not so certain, and the lead time from supplier can also vary from one delivery to the next. This leads to the need for safety stock, an extra buffer level to ensure that stock out does not occur since the cost of not having chemicals offshore could be huge. The appropriate level of safety stock is determined by the following two factors:

- The uncertainty of both the demand and the supply
- The desired level of product availability Giving the following equation:

$$S=K\sqrt{}(L\sigma_d^2+D^2\sigma_L^2) \quad (2)$$

Table 2: K-values for different service levels

Required service level	Value for K
99%	2,33
97,5%	1,96
95%	1,65
90%	1,28
75%	0,67

As the uncertainty of supply and demand grows the required level of safety inventory increases. Measuring Demand uncertainty need some values for average demand D, standard deviation of demand σ_d (forecast error per period), lead time L and the standard deviation of the lead time σ_L. Since the equations used in this model is based on forecasting, and forecasting is based on assumptions the result provided by this technique must be understood as an approximation at best. It is easy to use and quick and can provide a good starting point for other OR methods like simulation studies.

4.2.1.7 Mathematically programing

This is also called optimization and is often used on network design, value chain master planning production scheduling and vehicle routing and scheduling problems. The method is based on algorithms that describe the given problem, and is particularly useful when the number of decision variables and alternatives are many. In the example of robust supply chain design, such a method was used in the optimization tool developed by Marintek. This gives the user a recommended optimal solution based on the input which is one of the absolute advantages of this method. The problems with this type of OR are that it can be expensive, time consuming and so advanced that external experts are needed.

4.2.1.8 Factors affecting the choice of Operational research method¨

When selecting what method to use there is several factors that need to be considered, and some are listed below. Together with the description given of the different methods this list of aspects will lead to the best method. It is important to know that there is nothing that states that these methods can't be combined, and often the best solution will be a combination of two or more methods.

- The type of problem that we considered
- Degree of complexity for the problem
- What answers are we looking for?
- Desired model simplicity
- Requirement to speed, visualisation and accuracy
- The data available
- End user experience and competence
- Modelling time available
- Modelling expertise available

4.2.1.9 State of the art within OR and the field of inventory management

There are many state of the art studies available on the subject of inventory management. Most of these papers are related to the subject of suppliers and retailers where the objective often is to minimize the inventory cost. A paper which seemed interesting is the paper by Francesco Longo "Supply chain management based on modelling & simulation: Application examples in inventory and warehouse management". This paper provides a survey on how previous work on the subject of supply chain inventory problems has been conducted. The result of the literature study conducted by Longo was that the most common method for analysing supply chain scenarios was simulation combined with statistical techniques (Longo). The paper continues with a description on how to build a model and the description of such a process. From the papers read on the subject of inventory control it is very common that the evaluated parameter is the cost generated by the inventory. Either as holding cost, shortage cost or ordering cost. Such a representation can be found in chapter two of the book "Quantative models for supply chain management" written by Roman Kapuscinski and Sridhar R.Tayur. (Tayur, Ram, & Michael, 1999)

4.3 Simulation modelling

This chapter focus on the theory about simulation modelling, and give a description on how this method is used as well as how a model should be built. In simulation computers are used to evaluate a model numerically, and data are gathered to estimate the true characteristics of the model. There are many application areas for simulation, and it is one of the most widely used operations-research and management science techniques in the world. Some particular kinds of problems where simulation has been found to be a useful and powerful tool are listed below.

- Design and analysis of manufacturing systems
- Evaluation of military weapons or their logistics requirements
- Determining hardware requirements and/or protocols for communications networks
- Determining hardware or software requirements for computer systems
- Designing and operating transport systems, ports, airports etc.
- Evaluating designs for service organizations such as, hospitals, post-offices etc.
- Reengineering of business processes
- Analysing supply chains
- Determining ordering policies for an inventory system
- Analysing mining operations

A common word in the field of simulation modelling and analysis is “system”. A system is defined to be a collection of entities, like people or machines that act and interact together toward the accomplishment of some logical end. This definition was proposed by Schmidt and Taylor (1970), and is used by Averill Law in his book “Simulation Modeling and Analysis”. There are two categories for a system, discrete or continuous. A discrete system is one for which the state variables change instantaneously at separated points in time. A bank where the number of customers are evaluated is such a system, change occur when customers arrive and when they depart. Continuous systems are systems where the state variables change continuously whit respect to time. Examples of such systems can be a train or a plane where velocity and position is continuously changing.

At some point in the lives of most systems there is a need to study them to gain some insight into the relationships between different components. There are different ways of conducting such a study. This is illustrated in the figure below.

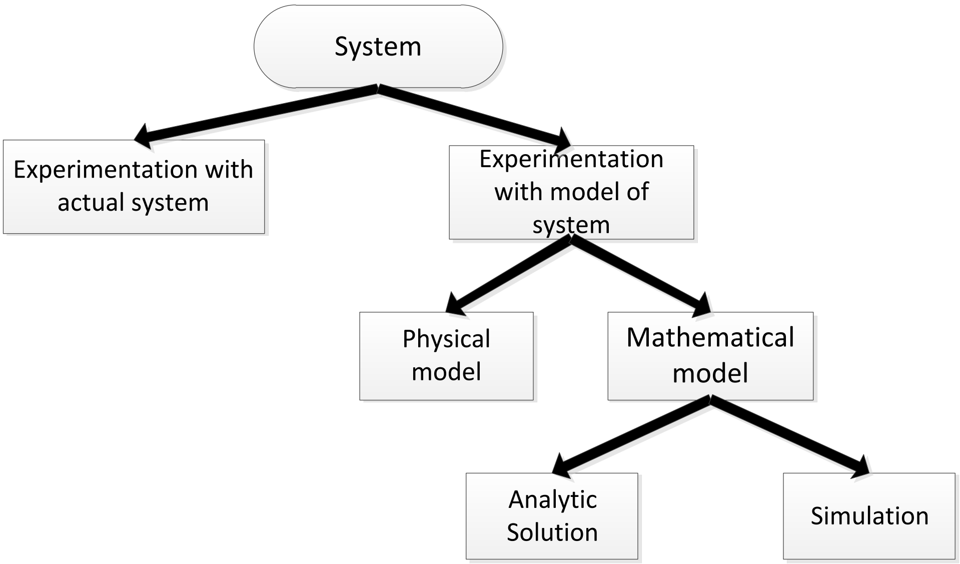


Figure 8: Ways to study a system

(Law, 2007)

If it is possible and cost effective the option of experimenting on the actual system is probably the most desirable. This method will always result in a valid study. However it is rarely the case that this is possible since such experimentation is often either too costly or too disruptive to the system. For these reasons, it is usually necessary to build a model of the system. Physical models are not very common in operational research, and the vast majority of models built for operational research purposes are mathematical. This is again divided into analytic and simulation. The analytical model can be used on simple systems and will result in an exact analytic solution. If an analytic solution is available and computationally efficient it will be the most desirable mathematical model. For complex systems this is often not the case, and the mathematical models will also be complex. It is in these cases that the model is studied numerically with simulation. (Law A. M., 2007)

The simulation model can be created using programing languages like C, C++ or Java. An alternative to this is to use a simulation software package. This option results in a significant decrease in programming time and the models are generally easier to modify and maintain. Such software is classified as either general-purpose or application-oriented. The application-oriented package is designed for a specific application whereas the general-purpose software can be used for any application. The case study conducted later in this report use Extend Sim which is a general-purpose simulation software.

4.4 Simulation modelling of a supply chain

Using simulation software and models to evaluate a supply chain is not a new method. Computer simulation can be applied to operational problems that are too difficult to model and solve analytically. Discrete event simulation permits the evaluation of operating performance prior to the implementation of a system. This can be seen as a powerful “what-if” analysis, leading to better planning decisions (Chang & Makatsoris, 2001).Simulation tools aid human planners to make the right decision by providing information. Law and McComes describe simulation as a surrogate for experiment, allowing the operator to test consequences on a model rather than an actual system. This is a very good description of the positive aspects of simulation modelling. The complexity of a supply chain could lead to large costs if alternations of it are done on an experimental basis, so doing a simulation prior could provide great savings. The problem occurs if the model is not a “close” approximation to the actual system. In that case the model will most likely be erroneous, and the result may lead to costs instead of savings. It is therefore of importance to see what is done in earlier studies, so that the simulation model is built in the best way possible. (Law & McComas, How to build valid and credible simulation models, 2001)

4.5 Benefits of simulation in supply chain management

- Helps the user to understand the overall SC process and characteristics by using graphics.
- Able to capture system dynamics using probability, user can model unexpected events and understand the impact of these events
- Could reduce/minimize the risk of changes in the planning process

The simulation model could serve two different purposes when we apply it to a supply chain. It could either be used as a decision support tool, or it could be used to serve as learning tool describing the complex system. This means that the model will have a different value for different users. The simulation model can then be applied two different areas. It is possible that both areas are present in a model, however one is dominant. The application areas are

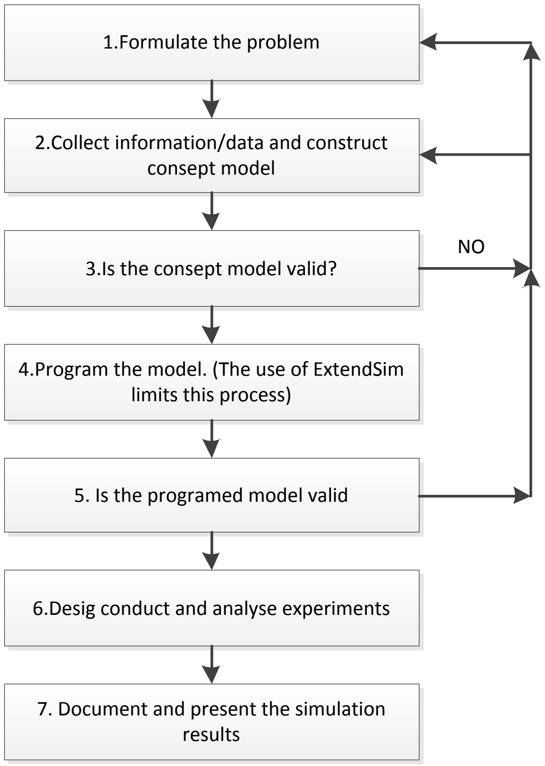
- Simulation for comparison, find the best setup of two or more alternatives
- Simulation for prediction, use existing data to predict future demand, problems etc.

An thesis (Strandhagen, 1994) written on simulation modelling in manufacturing lists the success factors for a simulation:

1. Ability to produce results interesting to the user
2. Ability to produce results that cannot be obtained by other measures
3. Resemblance between the model and the real world system
4. The time an inexperienced user has to spend from the time he starts using the tool and till he has the model running.
5. The validity and accuracy of the results

These success factors are important to consider when starting building the model, and should repeatedly be checked as the modelling is conducted. As described by Averill Law, validation is not something to be done at the end of the process if there is time, but should be a continuous part of the process.

The book Simulation modelling and analysis has been the basis for the simulations done in this report. Averill Law describes a seven step approach for conducting a successful simulation study.



(Law & McComas, How to build valid and credible simulation models, 2001)

Figure 9: Steps for conducting a successful simulation study

The work done in this report will try to follow these seven steps, and use the experience of earlier studies on supply chains as a guide.

4.6 Data requirements

A model is only as good as the data it uses, which was also stated in the work by Espen G. Nilsen. In the paper by Chang and Makatrosis, there is a section on the data requirements for supply chain modelling, and suggested procedures for simulation studies of a supply chain.

- Understanding supply chain processes
- Design scenario(focus on the problem areas, do not model the entire supply chain)
- Data collection
- Performance measures
- Define target
- Define termination condition
- Evaluation of supply chain policies.

The paper also describes data requirements for a supply chain model for different areas in the supply chain. These areas are:

- Manufacturing process and time information
- Inventory control policies information
- Procurement and logistics information
- Demand information
- Policies/strategic information

The problem described in this paper is closest related to the area of inventory control policies information and procurement and logistics information. The data required according to this paper is then:

- Safety stock level
- Reorder point
- Supplier lead-time
- Supply lot size
- Supplier capacity
- Procurement horizon
- Procurement time

This data was collected in during the field study, as mentioned previously in the report. Safety stock levels and re order point was calculated based on this data, and the lead-times found by using the simulation model, in accordance with the formulas described in the chapter on OR.

5 The simulation case: The supply chain of production chemicals

5.1 Building the model

The first stage in Averill Laws recipe for a successful simulation study is to formulate the problem. The initial problem description given by Statoil was used to formulate the problem in the simulation. There is an increasing need for production chemicals as the fields on the Norwegian continental shelf are entering the later stage of their lifetime. The initial statement from Statoil was that the process of ordering chemicals is significant, the tank capacities offshore are insufficient, and the lack of automated monitoring of the tank levels makes it hard to plan the ordering according to supply chain management ideals. It is also stated that lack of the chemicals offshore result in production reduction or in the worst case production shutdown. To evaluate if the capacity of the offshore tanks are sufficient the output value for the simulation must be the tank levels with regards to time, and since the cost of shutdown in the petroleum industry the amount of time accepted to be without chemicals is zero. Evaluation of the ordering process should look at the lead time and changes in the lead time with different methods of generating orders. So the desired outputs from this simulation are:

- Amount of time without specific chemical available
- Lead time for the supply process

In the cases that are to be evaluated in this paper the first problem will be to evaluate the situation today, with the current amount of chemicals needed offshore for three of Statoil's installations. Then to evaluate the effect of changes in the capacity where bottlenecks are found, and lead time due to introduction of "new" monitoring technology.

- Are the capacities and processes sufficient as they are?
- Will today's capacities be able to handle increased demand?
- Which changes to the system will prove to be most efficient?

With these desired outputs it is possible to determine the needed inputs to the model. Since the idea is to simulate the supply chain these inputs are determined by the capacities and procedures of the different actors in the chain, which are described in an earlier chapter of this report, such as processing time, sailing time, ordering time, routing, and tank capacities. Getting these input variables is the second step of the process described by A.Law, data collection. It is of the utmost importance to collect accurate data since the accuracy of the input variables determine the accuracy of the output and thus the validity of the model.

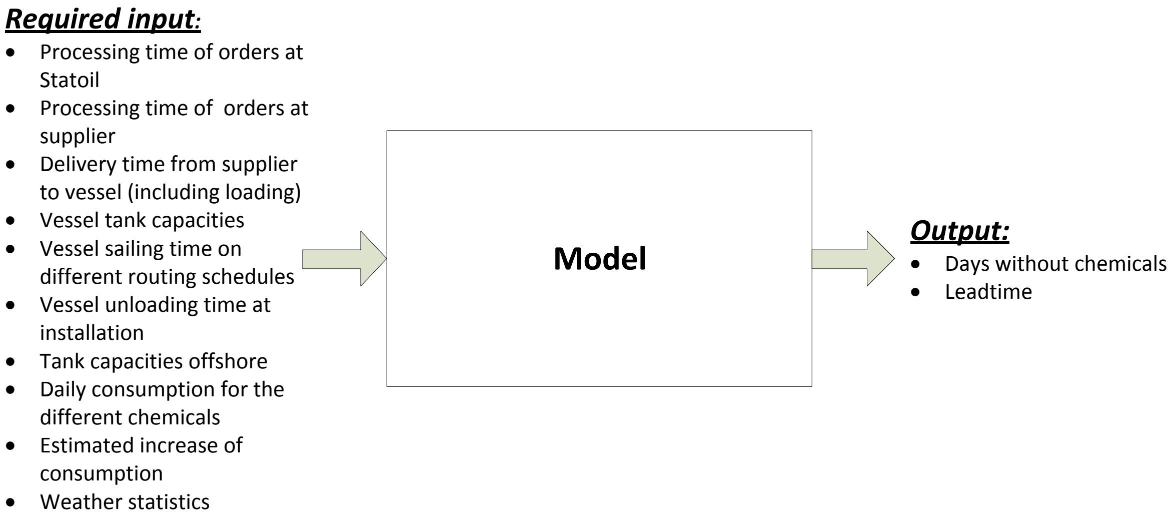


Figure 10: Input and output for simulation model

5.2 Information and data collection

The needed data for the simulation were gathered by conducting interviews with the different actors in the supply chain, and from Statoil's historical database. Personnel from suppliers, base, Statoil marine, supply vessel and the logistics department have supplied data for the different stages, but these interviews have mainly been used to get an understanding of the supply chain. Historical data for consumption and capacities for the installations were provided by Statoil AI, and were used in the building and the validation of the simulation model. Some of these inputs are given in the table below. Some of the data may be restricted, and as stated in the introduction can be found in appendix B and/or E.

Table 3: Tank capacities in the different stages of the Supply chain

Tank capacities and size	Supplier [m^3]	Mobile tanks [m^3]	Mobile tanks area [m^2]	Vessel bulk [m^3]	Vessel deck [m^2]	Platform A [m^3]	Platform B [m^3]	Platform C [m^3]
H2S remover	For all purposes infinite	2.7/4	4	208	1030	Appendix C	Appendix C	Appendix C
Emulsion breaker 1	For all purposes infinite	2.7/4	4	208	1030	Appendix C	Appendix C	Appendix C
Emulsion breaker 2	For all purposes infinite	2.7/4	4	208	1030	Appendix C	-	Appendix C
Nitrates	For all purposes infinite	2.7/4	4	208	1030	Appendix C	Appendix C	Appendix C
Scale inhibitor	For all purposes infinite	2.7/4	4	208	1030	-	-	Appendix C
Corrosion inhibitor	For all purposes infinite	2.7/4	4	208	1030	-	Appendix C	-

In interviews with the supplier the option of them having stock out was said to never occur, for this reason their capacity for storage is said to be infinite, since they always are able to deliver according to contract. Pump capacities at Supplier is provided by personnel at the supplier on CCB Ågotnes. The capacities for the vessel is given for one of the vessels sailing on the route that service the Tampen area, Viking Energy, and the vessels data sheet is provided in appendix D. Offshore capacities are collected from Statoil's internal reports on logistics for the years 2008-2010

Table 4: Pump and lifting capacities across the supply chain

Pump/ lifting capacity	Supplier	Base	Vessel	Offshore
Mobile tanks	5-600 [l/min]	8 [min/lift]	Se offshore and base	8 [min/lift]
Bulk	100[m^3/h]	See supplier	2*75[m^3/h]	See vessel

As these tables show the capacities are higher at the vessel and supplier than that of the offshore installations, indicating a bottleneck in this stage of the chain.

Routing information was gathered from representatives at Statoil Marin which handle the planning of sailing routs. The sailing time and thus the lead time will vary depending on what order the installations are visited. This will have to be modelled in the simulation. Another factor that influence the sailing time is the weather which for some time of the year will make it impossible to deliver goods offshore. The installations evaluated in this paper is rarely the first on a route from what was found in the routing master plan provided by Statoil, the percentage use of this option is therefore based on the number of priority calls these installation has had in the years 2008-2010. The percentage given for the use of route two and three are calculated based on the routing master schedule from Ågotnes, this can be found in appendix H. This statistic data for this is presented in the table below:

Table 5: Routing and siling times with probability of use

Routing one installation is first on route	Time from base	%Use of route
Installation A	8,5h	2.309468822
Installation B	8,5h	1.466992665
Installation C	8,5h	1.154734411
Routing Two:		
Installation A	16h	65.45265589
Installation B	20h	66.01711491
Installation C	23h	66.22632794
Routing three:		
Installation A	31.5h	32.23787529
Installation B	34,5h	32.51589242
Installation C	38,5	32.61893764

With these times implemented in the simulation model it was possible to find values for the lead time and standard deviation. How this was done is described in the model description. The lead time and standard deviation are important values when calculating the ROP and safety stock.

Table 6:Lead times and standard deviation

Installation	Average lead time [h]	Standard deviation [h]
A	59,68	11,33
B	65,03	11,89
C	70,14	11,76

5.3 Conceptual model

The conceptual model is largely based on the picture depicting the supply chain found on "Logistikk portalen"

Figure 11: Statoil logistic chain

The picture depicts the most important activities that occur in the part of the chain that needs to be simulated to answer the problems that is studied in this paper. For the simulation Extend Sim, a general-purpose simulation software has been used. This chapter will describe what assumptions and simplifications that are made to describe the system. The following is a screenshot of the model for one type of chemical to one installation:

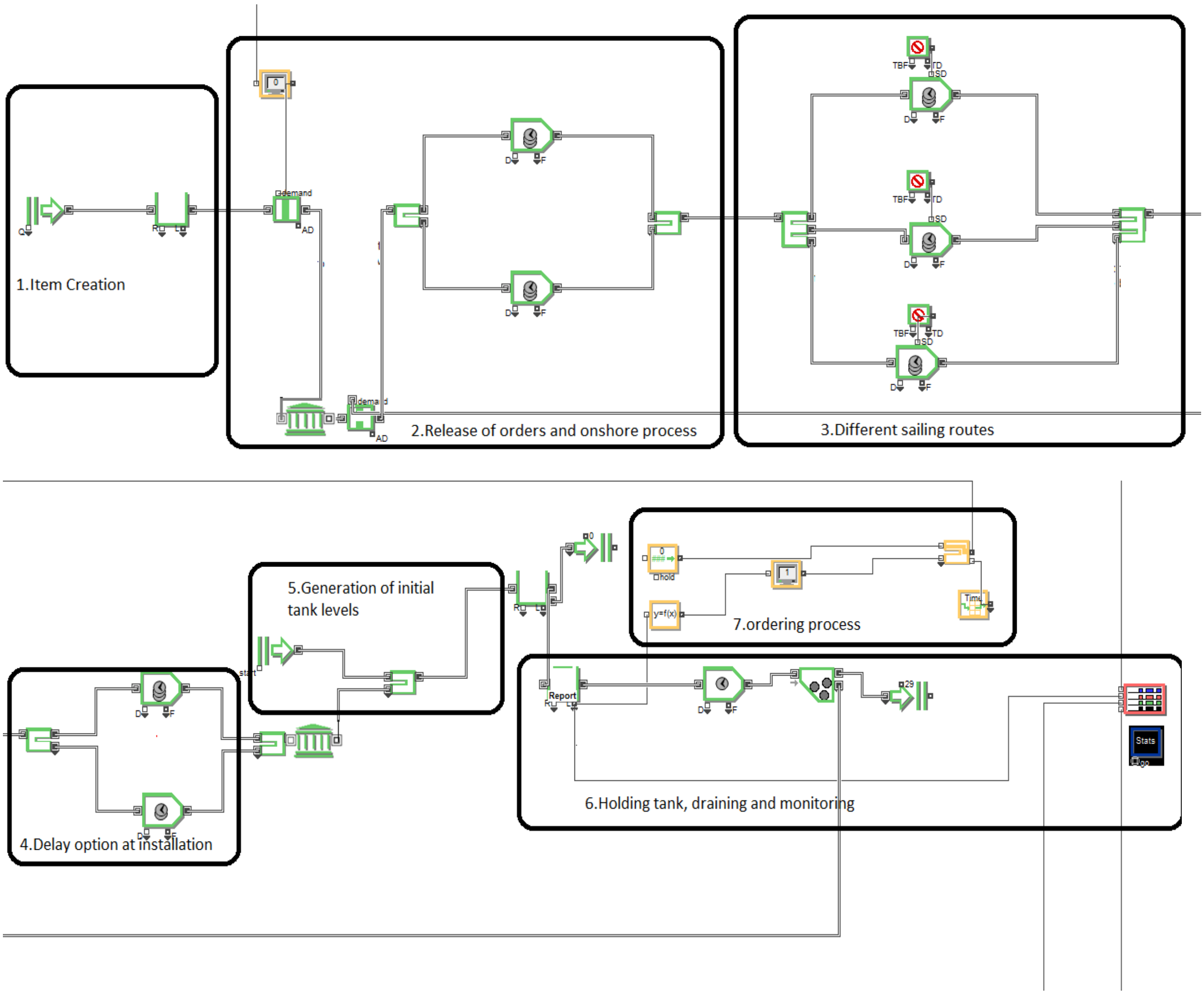


Figure 12: Simulation model for one chemical at one installation

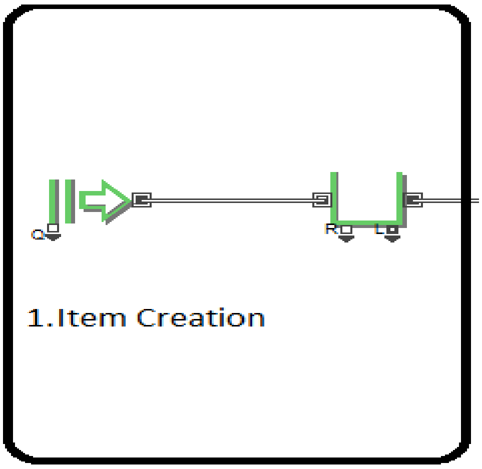


Figure 13:The Item creation step of the model

As a start to the system the first block generates what is called items in the “create” block. The creation of these items can be set to occur according to several different types of distributions. In these models an exponential distribution has been used whit a mean time between arrivals at 6 hours. This result in an infinite queue in the following queuing block since this arrival rate is larger than the service rate provided by the rest of the system. The reason for this setup is that the onshore supplier stated that they will have chemicals available within the timeframe stated in the contracts with Statoil. The items created represent a 2,7[m^3] mobile tank for the chemicals which has offshore storage tanks with less capacity than 80[m^3], and 40[m^3] of chemicals in bulk for when the case is the opposite. This splitting of delivery method is assumed, and not necessarily the case for Statoil. The items are held in this queue until they are released into the next part of the system which represents the onshore handling of orders and delivery to the supply vessels.

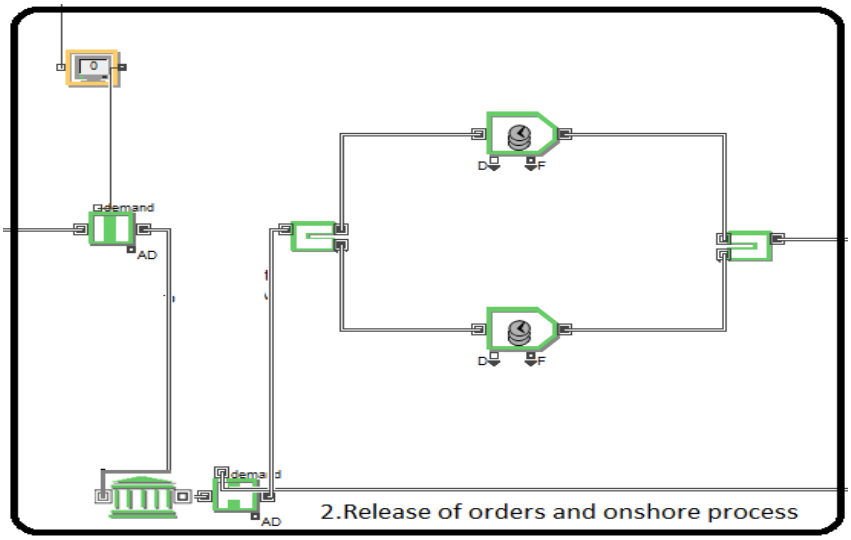


Figure 14: The release of orders and onshore process in the model

This part of the system starts with two “gate” blocks, which are set to open under different circumstances. The first block will open for a given amount of items based on the orders requested by the ordering mechanism created at the end of the model. And the second gate is a restricted by the need for an item to exit the system before it allows a new one in. The second gate is a failsafe mechanism made in order to avoid accumulation of items in the system due to failing of the first gate. Between these two gates there is a “history” block. This block register the time as an item passes, and together with another “history” block placed at the end of the delivery process this data was used to find the lead time and standard deviation of the lead time for the supply. After an item is released through the gates in this area it arrives to a routing block called select item out. In this block the probability of the item being routed one way or the other is set. This was initially made since it was expected that the different chemicals evaluated could have different contract delivery time, this was however not the case so the probability was set to one for the item being routed to the bottom activity block. As described in the appendix on blocks the activity blocks are used to simulate delay in the process. This delay can be either a constant or described as a distribution. In this model most of the activities are described by normal distribution. For this activity it was important that the values did not exceed the limit of 48 hours, so a mean of 30 [h] with a standard deviation of 5[h] gave a good match. The choice of normal distribution can be attributed to the fact that this is a common distribution used for processes in a queuing system. The item is then held in the activity block until the time has passed before it is moved along to the part of the system that simulates the transportation with the supply vessel.

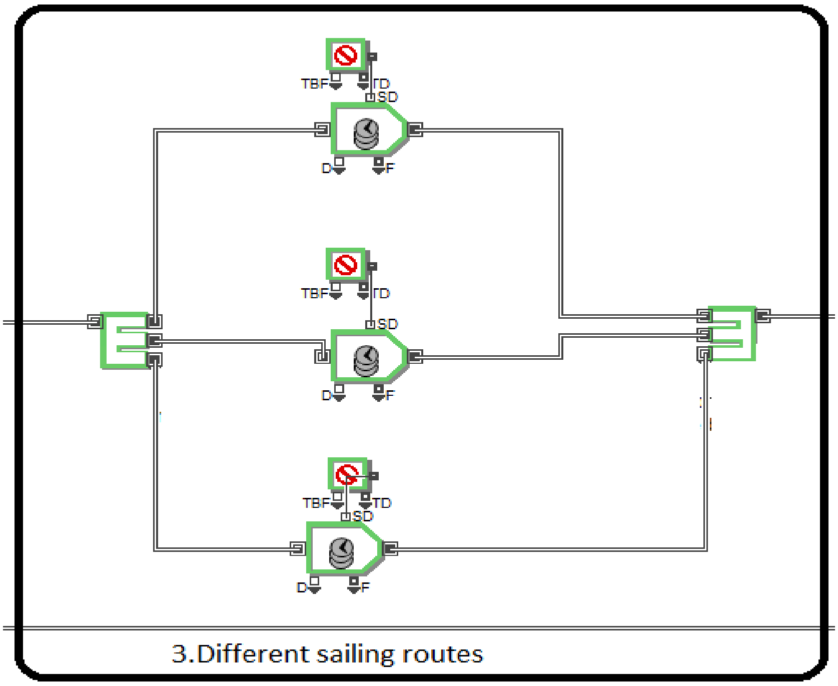


Figure 15: The different sailing routes in the model

For the vessel simulation three activity blocks with capacities matching that of Viking Energy are the options, whit a split that is probability based. The three different activities represent different routing options and with a delay according to this routing option. These different routing options are based on statistical data for priority call, and the different routes described in the master schedule for the vessels leaving from Ågotnes base. These different delay times was given in table4. Since a vessel is scheduled to leave base every day at four o’clock in the afternoon a breakdown block is connected to each of these activities. This breakdown function makes it impossible for new orders to enter the activity for a period of time. This is done to simulate that the vessels are in fact sailing, which make it impossible to do loading from base at the same time. The breakdown makes vessels unavailable for

24 hours when the next boat is scheduled. In the breakdown block it is possible to choose the mean time between failure and the meantime to repair, and it is these two inputs that make the shutdown function work. After the sailing activities the items are collected in the select item in block which only gathers the items to one “string” again. In this last block in the picture above no extra input value was added.

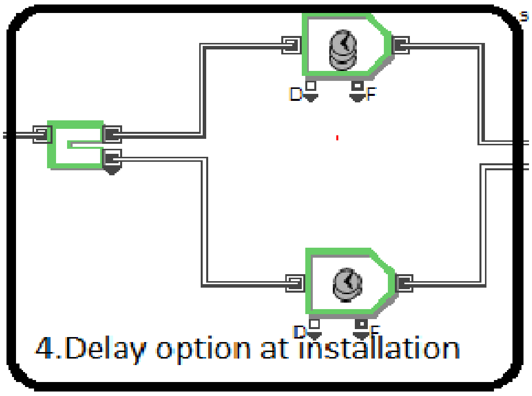


Figure 16: The modelling of delay possibilities at the installation

Sometimes the vessel has to wait for the platform before they can deliver the goods and regardless of whether it has to wait or not, it takes some time to unload the cargo. This is simulated in this part of the system, with a probability switch that results in a lay time at the installation which is based on historical data provided by Statoil. The probability for the different types of delay is different from installation to installation, and these different probabilities are calculated based on the WOP value given in the data fond in appendix B. After this process the item is placed in the offshore holding tank. After this block is passed the items pass through another history block before entering the holding tank offshore, as stated earlier.

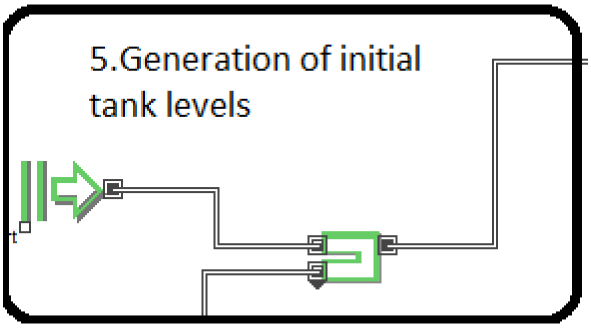


Figure 17: Generation of initial values in the model

At the start of the simulation the amount of items in the queue describing the holding tank is zero. In order to get the system up and running in a stable condition from the start this create block was used. This block generates the needed amount of items to fill the tank at time zero of the simulation, and for the rest of the time does nothing. The amount of items created varies based on the different tank capacities. The select item out block will in this case choose the input where there are items and has no probability setting.

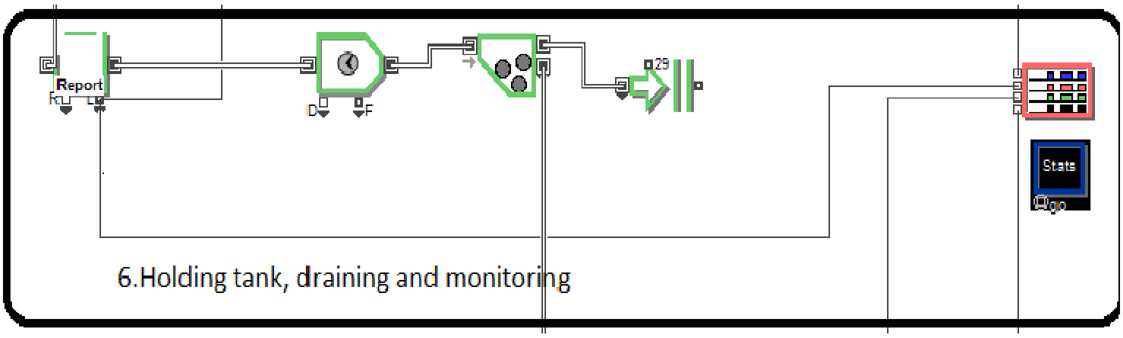


Figure 18: The holding tank and draining part of the simulation model

The tank offshore is like the tank before the gate simulated using a queue function, but this queue has a limited capacity which depends on the installation and chemical we look at. The draining of the tank is simulated using an activity block that has a delay which equals the average time of consumption of one “item” for the given case. Since items stored in this activity is also a part of the offshore tank, the queue capacity is on “item” less than the tank capacities given in the data. From this activity the item exits the system and the number of exits multiplied whit the “item” value in [m^3] is the represent the consumption. As mentioned earlier in this chapter, items are only allowed into the system when items have left the system. This is done with the gate in part two of this model description, and the “un-batch” block sends this input. As an item is released from the activity it enters this block and gets duplicated, one exit the system and one trigger the gate. The tank level is plotted in a graph in the block shown in at the top right in the picture above, and statistical data on the tank level is gathered whit the “stats” block. This data is transported to excel for further calculations. The queue block is also generating a report in Extend which shows the utilization of the queue, if the utilization is equal to 1 it is never empty and no calculation in excel is needed. The cases that are evaluated have utilization values below 1.

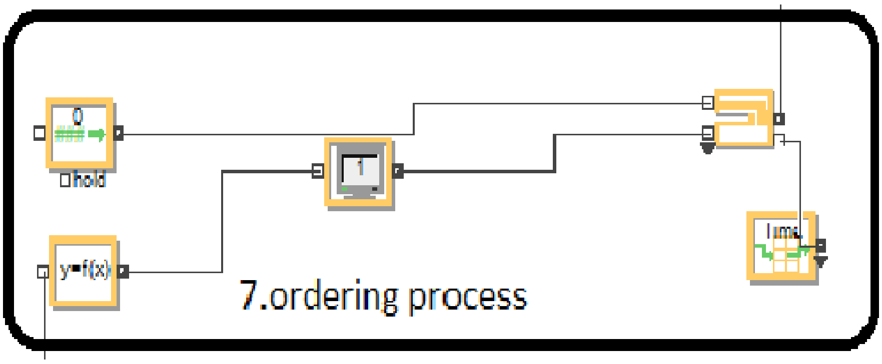


Figure 19: The modelling of the ordering process

The tank level in part six is also linked to the equation block in this part of the model. These are the blocks that send the signal to the first gate on whether to open or stay closed. In the equation block the output is generated by fulfilling some “if” and “else” limitations based on the input which is the tank level. If the tank level reaches a certain point the output level is set to be the maximum capacity of the tank subtracted the level at the time, else the output is zero. The point where orders are to be placed is the Reorder point. Running the model one time with estimated values was done so that the values gathered from the history blocks could be used to find the mean lead time and the standard deviation of the lead time. Together with the demand and standard deviation of demand this could be used to find the ROP. Once the calculated ROP was available this was used in the equation block.

Since the original setup at the installations used manual readings of the tank levels extra blocks was added to the ordering process. The block above the equation block is constantly sending out the value zero which leads to a closed gate as long as this is the value chosen in the select value in block. The select value in block will always choose the top input unless it receives a value of one from the block below, which is called look up table. In the look up table block the setting is set to time, which means that for given times in the simulation the output can be set to a given value, and a repeat schedule function is also available in this block. The look up table block in this model is set to send out the value 1 every 12 hours, which was chosen since 12 hour shifts is common offshore. The assumption is that the tank level is checked at least once every shift. When this event occurs, the select value in will select values from the equation block, which can be either orders when the tank level is at the ROP or below or no orders if the level is above. The use of ROP calculations in the original system is assumed since this is a common and easy way to set the ordering policy. In these calculations it is also assumed that the highest level of service is chosen due to the importance of the chemical availability. The following is a representation of the different blocks, input data, and tables used in the model:

Table 7: Model description with reference to tables with input values

Model area	Block types used in area (description in Appendix A)	Input data used	Tables where input is found
1. Item Creation	Create, Queue	Exponential arrival Infinite queue	No values used from tables
2.Order reception and onshore process	Gate, history, select item out, Activity, select item in	Gate receives input from later stage of model Activity: normal distribution	Activity values given as normal distribution with mean value 30 h ad std.dev of 5 h, which keeps it within the 48 h limit.
3.Different sailing routes	Select item out, select item in, activity, shutdown	Activity: Delay based on routing alternative Select item out: probability distribution Shutdown: MTBF and MTTR (items in already in process is finished)	Activity delays found in table 4 Select item out probability values found in table 4 MTBF:24 MTTR: 24
4. Delay option offshore	Select item out, activities	Activity: delay Select item out: probability	Activity delay found in appendix B under WOP Select item out probability found as WOP/Total supply hours in appendix B
5. Generation of initial tank levels	Create, select item in	Create: scheduled creation of items to fill tanks at time 0 Select item in: choose	None of the values used are found in tables.

		input with item	
6. Holding tank, draining and exit	Limited Queue, Activity, un-batch, exit, discreet event plotter, stat	Queue: max limit given by tank capacity Activity: Normal distributed demand, mean and standard deviation values from statistic Un-batch: Split item in two so that one can exit and one can alert gate block two. Exit: drain of items has no input	Queue capacities given in appendix B Activity delay time mean and standard deviation found in appendix B
7. Ordering process	Equation, constant value, select value in, look up table	Equation block use ROP Look up table use scheduled output of 1 every 12 [h]	ROP for different installations found in Appendix E

The queues that are of the most importance to evaluate in this case are the ones representing the holding tanks. The following is a description of the queue block name and the chemical holding tank it represents for the given installation:

Table 8: Identification of tank queues for the different installations

Queue block number	Installation A	Installation B	Installation C
39	H2S remover	H2S remover	H2S remover
136	Emulsion breaker1	Emulsion breaker1	Emulsion breaker1
245	Emulsion breaker2	Corrosion inhibitor	Nitrates
348	Nitrates	Nitrates	Scale inhibitor

5.4 Validating the conceptual model

When the concept model was created, the historical data needed to validate it was not available. The inputs for capacity and delays where therefore quite bad. To validate the model, data form Statoil's analysis department is used. This data includes average consumption of the chemicals over the last three years and the actual tank sizes for the different chemicals offshore. Each of the three installations in the case has its own simulation model, which was done to simplify it in the creation, and because the different installations use different chemicals. In the process described by A.Law there is first a validation of the concept and then a validation of the programed model. Since general purpose simulation software has been used in this case, the concept model is already programed and the validation is done on the actual model. In this part of the process the model results are compared with historical data to see how well it represents the real world system. The more detailed the model is the more it will resemble the real world, but simplifications must be done so that the simulation can run properly. A large problem in validating the model is that no data historical data for downtime could be provided. An approximated yearly value for this is then based on the experience of the personnel at the logistics department for the given installations. In order not to violate any confidentiality rules the data used for the validation can be found in appendix? A problem which was solved by adding an extra "gate" function to the model was that there were too many items continuously in the system. This was solved during the validation process, when this was done the results were quite similar to what was expected based on the historical data. The input data used in the validation can be found in appendix C, and was the historical average demand, with the simulation setup shown in the model above. The model used the expected amount of chemicals, the lead time seemed reasonable according to the assumed routing, and the total amount of cases where problems could arise was also around the expected value.

5.5 The different cases

With the validated model it is possible to analyse the different cases or problems described previously. Below are the cases that we look upon using the model:

- Today's situation; is the capacity sufficient offshore?
- What is the effect of increased demand on the existing system for the different installations?
- How will improved capacity offshore influence the system with today's demand, and future demand?
- How will improved planning (reduced delay in ordering and better monitoring) improve the system with today's demand, and future demand?

For the different cases, the model generates two results. One report and one graph, the report give the numerical value for the situation, where the graph is an illustration of the tank levels variation over the simulated period. For some of the cases described in the different scenarios these graphs are presented in the result, and this is will serve as a general description on how to evaluate these graphs:

- The graphs are generated for one chemical at the time, the type of chemical evaluated will be stated in the figure text.
- The y axis in the graph starts at zero and stops just above the maximum tank level for the given chemical in the given situation. The X axis is the time axis, and start at zero and end at 17520 hours.
- The graphs show how the consumption is reducing the inventory levels in the tanks, as the time passes. And how the system is replenished. For some of the chemicals this will look like a periodic graph, where the level is reduced by one and replenished by one immediately. This happens for cases where one item equals a large part of the tank capacity and consumption is low.
- For better understanding of the graphs see Figure 7: "Inventory Control graph, inventory development over time". This is showing the same data, but in a close up scale.
- ROP, time between orders and time when levels are at zero can be viewed in these graphs in the model, where there is a possibility to zoom inn on the most interesting areas. But an indication can be viewed in the graphs shown in the report.

5.5.1 Scenario 1 Keeping the system AS-IS and introducing elevated mean demand

For the different installations the first simulation runs was done on the "as-is" model with the following mean demands:

- Historical mean demand (validation case)
- 10% increase
- 25% increase
- 50% increase

The model was running on a setup where the time would start at zero and end at 17520 which is the amount of hours in two years. The model runs five times for each of the installations at each of the demand levels. ExtendSim generated reports show the utilization of the tanks which is the amount of times there are items in the queue, the amount of items that have been received and amount of items departed. In cases where the utilization number is 1 there are no problems. For utilization less than zero further investigation is needed to evaluate the impact this has on the system. The model plots the value of the tank level as time progress, for all the different chemicals. Each of these plots can be found in Appendix G, and for some of the cases evaluated, the graphs are included in the report. Although effort was made to get a hold of Statoil's prediction for future demand, no data was collected supporting the increase. The choice to stop when the demand had increased with 50% was a choice made as it was assumed that this would be a large enough increase to indicate how the systems would react.

5.5.1.1 Installation A:

The generated report from ExtendSim can be viewed in Appendix G In this section the results from the simulation will be presented, and an explanation to the results will also be given. The table below shows the average utilization of the queue for the chemicals used at installation A:

Table 9: ExtendSim report values for installation A, simulation scenario one

Chemical	Utilization As-Is demand	Hours with utilization less than one	Utilization 10% increased demand	Hours with utilization less than one	Utilization 25% increased demand	Hours with utilization less than one	Utilization 50% increased demand	Hours with utilization less than one
H2S remover	0,995148	85	0,988426	203	0,971138	506	0,93492	1140
Emulsion breaker 1	1	0	1	0	1	0	1	0
Emulsion breaker 2	1	0	1	0	1	0	1	0
Nitrates	1	0	1	0	1	0	1	0

As this table shows the only chemical with possible problems is the H2S remover. Due to the build-up of the model, utilization values less than zero does not mean that there is a stock out. This is because one “item” would/could be in the activity-block draining the system. The amount of hours with utilization less than one is the total amount of hours within the two years of the simulation. The tank level for H2S remover varied over the time and did not have a continuous level of zero equal to the amount of hours in the table above. This can be seen in the graphs below:

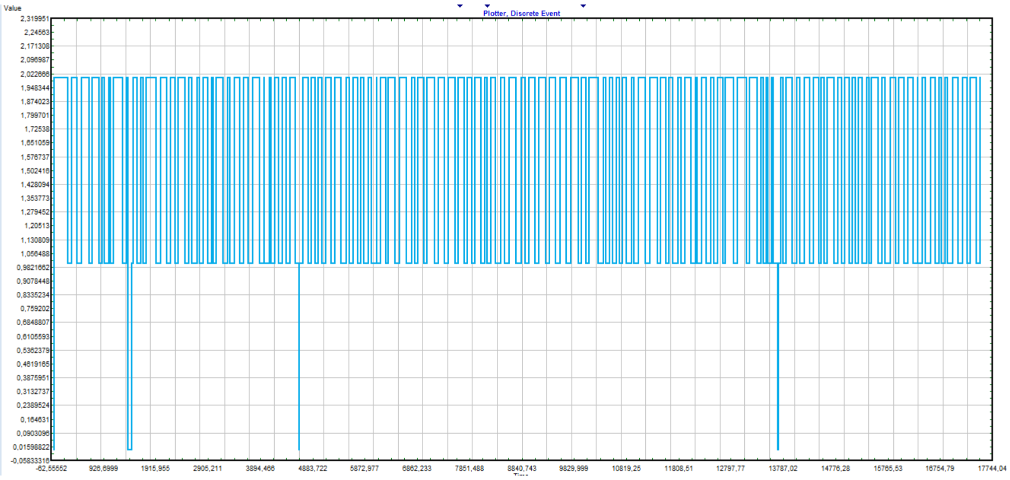


Figure 20: H2S levels installation A, scenario one, with original demand

The blue line in this graph indicates the amount of H2S “items” there are in the tank at a given time. The bottom value of the graph is zero and the top value is the maximum capacity of the tank. As time progresses an item will be removed and blue line drops a level, when new orders are received the value rise again. The graph above has three negative spikes that differ from the general pattern. In these cases the value drops to zero, which according to table 9 is the case for a total of 85 hours over the entire simulation period.

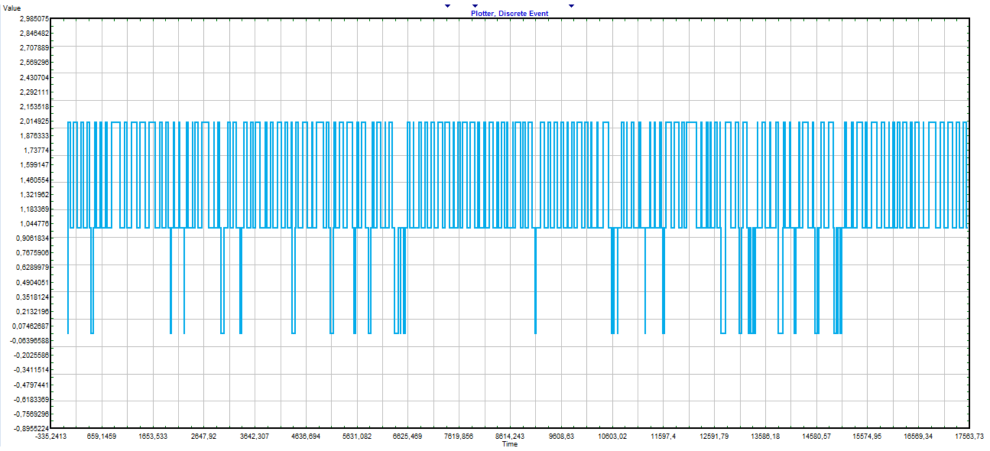


Figure 21: H2S level, Installation A, scenario one, 50% increased demand

These graphs illustrate the tank level of H2S for installation A in the case of As-Is demand and with 50% increased demand. From these graphs it is possible to see the amount of times where the stock level is at zero. By dividing the total amount of time with utilization below one of the number of possible stock outs we find the average time before the tank is replenished. If this time is found to be less than the average time to consume the item still in the activity block, there would not be a stock out.

Table 10: Resulting possible time without chemical offshore for scenario one, installation A

Model setup	Total time with utilization less than 1 [h]	Number of times with tank level of zero	Average time without items in tank [h]	Ave time to consume one item
As-Is setup	85	3	28	Se appendix C or E
50% increased demand setup	1140	27	42	Se appendix C or E

For this installation, with the 50% increased demand, the time it take to use one item quantity of H2S far exceeds the average time it take to replenish the tanks when the level is zero, and the average time without chemicals in tank found in table 9 above. The results indicate that there are few, if any, problems with the existing capacity of the system.

5.5.1.2 Installation B

As the case was for installation A the full report of this scenario can be found in Appendix G. The results will be presented in a similar manner as for installation A with one exception. During the simulation for this installation it was found that the model for corrosion inhibitor was faulty after further examination it was concluded that this fault was a result of the huge increase in consumption in 2010 compared with the other years. The capacities for this particular chemical were also so low that it made the model fault. When further examining the case for this chemical it was found that even with the highest of consumption in the resent years, the capacity exceeded 140 days. This long huge capacity compared to the lead time and consumption result in the assumption that no problems should arise with this component. As a result of this assumption the corrosion inhibitor was removed from the simulation done on installation B. Giving the following table based on the reports.

Table 11: ExtendSim report values for installation B, simulation scenario one

Chemical	Utilization As-Is demand	Hours with utilization less than one	Utilization 10% increased demand	Hours with utilization less than one	Utilization 25% increased demand	Hours with utilization less than one	Utilization 50% increased demand	Hours with utilization less than one
H2S remover	0,9997	5,26	0,988808	196,1	0,991834	143	0,943862	983,54
Emulsion breaker 1	1	0	1	0	1	0	1	0
Nitrates	1	0	0,99933	11,73	0,999814	3,25	1	0

In this table there are some areas that need commenting. The values found for nitrates are very high and as the reports will show the utilization for most of the runs with 25% increased demand was 1. This indicate that the capacity for this chemical is very good, which was further proven with the result when having 50% increased demand. And the total amount of hours with less than 1 for utilization is lower than the consumption time of one item. There is also an improvement in the utilization when the demand increases from 10% to 25%, the reason for this is that when the demand is 25% higher than the original demand, the ROP gets a higher value. The value used as ROP in the simulation is the first whole number above the ROP found in the calculations shown in Appendix E. The most interesting chemical to review is in this case, as it was for installation A the H2S remover. The following is the graphs found for installation B when looking at the tank levels or H2S remover

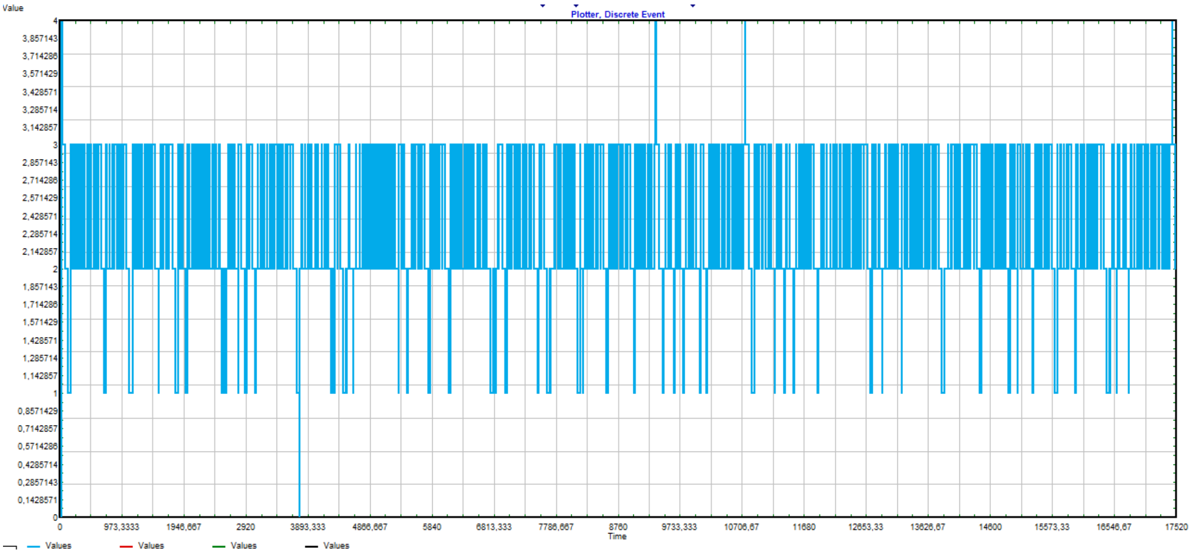


Figure 22: H2S levels installation B, scenario one, with original demand

As this graph clearly shows the amount of time with utilization below 1 is the result of one event where the level was zero, which it was for 5.26 hours. This would not be a problem and the value is much less than the time it would take to consume the last item which was in the draining activity.

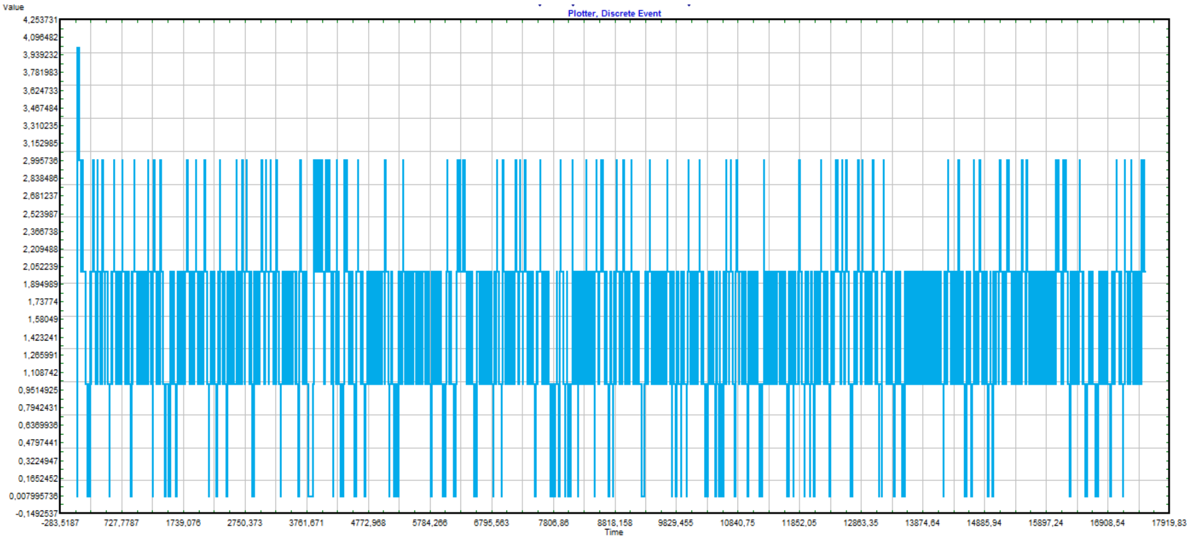


Figure 23:H2S levels installation B, scenario one, with 50% increased demand

The amount of times with zero items in the tank is significantly increased for the case when the demand is 50% higher than the original case, but again we see that the level is above one again very fast. If we set up the same table for H2S as for installation A the following values are found.

Table 12: Resulting possible time without chemical offshore for scenario one, installation B

Model setup	Total time with utilization less than 1 [h]	Number of times with tank level of zero	Average time without items in tank [h]	Ave time to consume one item
As-Is setup	5,26	1	5,26	Se appendix C or E
50% increased demand setup	983,54	58	16,96	Se appendix C or E

The difference between the consumption time of the last item and the average time without chemicals in tank is for installation B as for installation A higher, and the result indicate that the as-is setup for this installation is also working and can withstand higher demands.

5.5.1.3 Installation C

From the data provided by Statoil this installation has the highest potential for stock out. The simulation study on installation C starts with the existing system capacities and demands, as was the case for installation A and B as well.

Table 13: ExtendSim report values for installation C, simulation scenario one

Chemical	Utilization As-Is demand	Hours with utilization less than one	Utilization 10% increased demand	Hours with utilization less than one	Utilization 25% increased demand	Hours with utilization less than one	Utilization 50% increased demand	Hours with utilization less than one
H2S remover	1	0	0,999956	0,77	0,996612	59,36	0,939058	1067,5
Emulsion breaker 1	1	0	1	0	0,99928	12,61	0,996626	59,11
Nitrates	0,99785	37,668	0,984774	266,75	0,905754	1651	0,677062	5657,87
Scale inhibitor	0,996552	60,4	0,994644	93,83	0,991164	154,8	0,983614	287,1

Compared with installation A and B it is easy to see that this installations have more problems related to the inventory levels of its chemicals. It was found that for some of the chemicals the recommended reorder point was actually higher than the available tank levels. This could indicate a capacity problem at the installation. The same evaluation as for Installation A and B were done for Installation C, but for the scale inhibitor and the nitrates as well as for H2S remover.

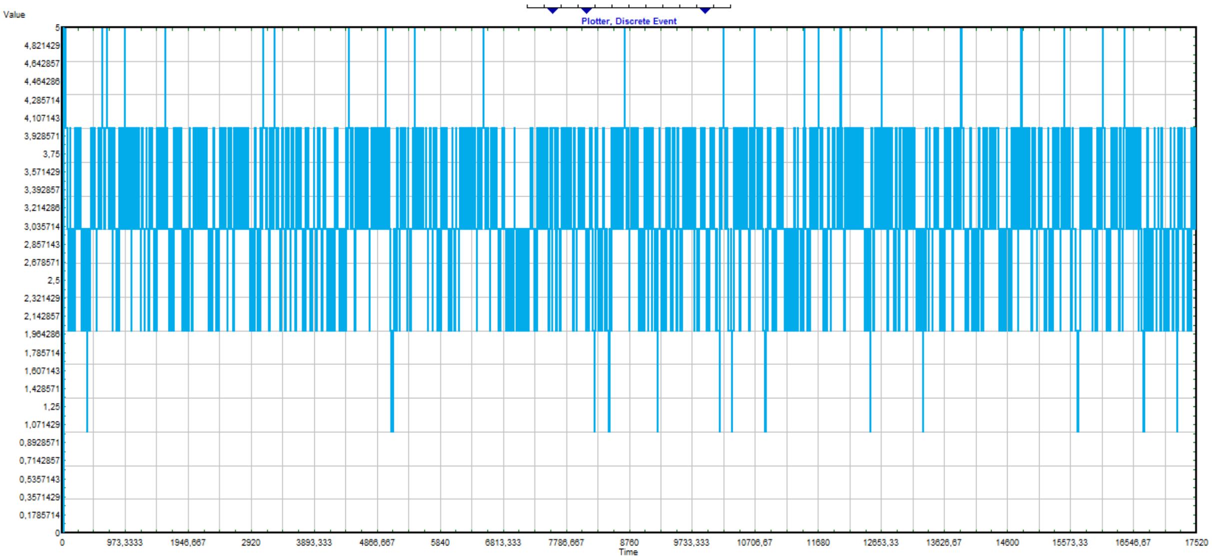


Figure 24: H2S levels installation C, scenario one, with original demand

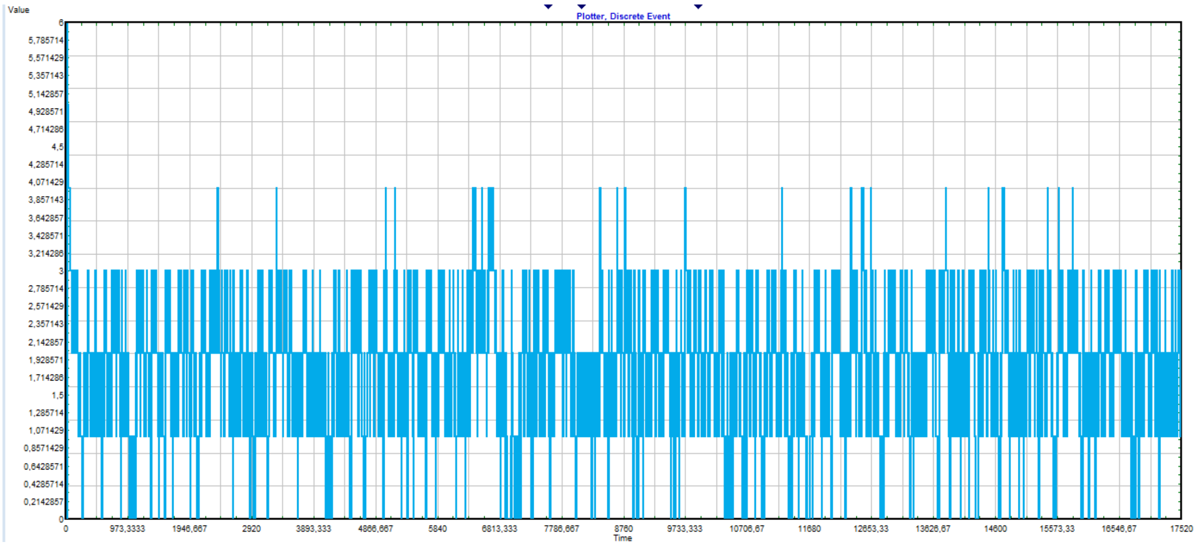


Figure 25: H2S levels installation C, scenario one, with 50% increased demand

Table 14: Resulting possible time without H2S remover offshore for scenario one, installation C

Model setup H2S Remover	Total time with utilization less than 1 [h]	Number of times with tank level of zero	Average time without items in tank [h]	Ave time to consume one item
As-Is setup	0,77	Initiation delay	0,77	Se appendix C or E
50% increased demand setup	1067,5	Approx.90	11,86	Se appendix C or E

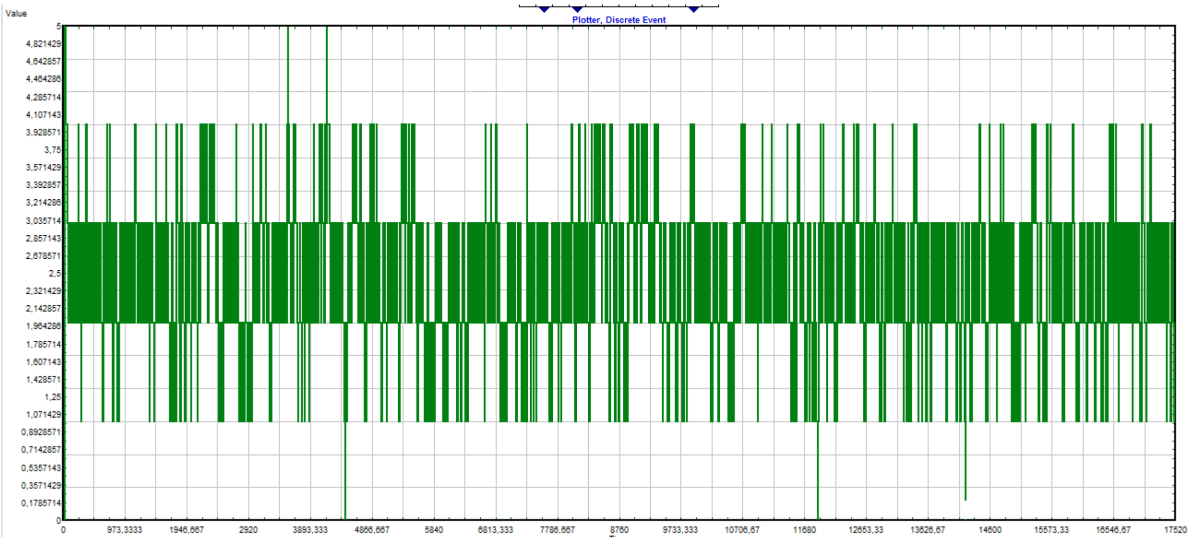


Figure 26: Nitrate levels installation C, scenario one, with original demand

From the graph it is possible to see three times when there is a risk that priority order has to be made in order to keep the inventory level up.

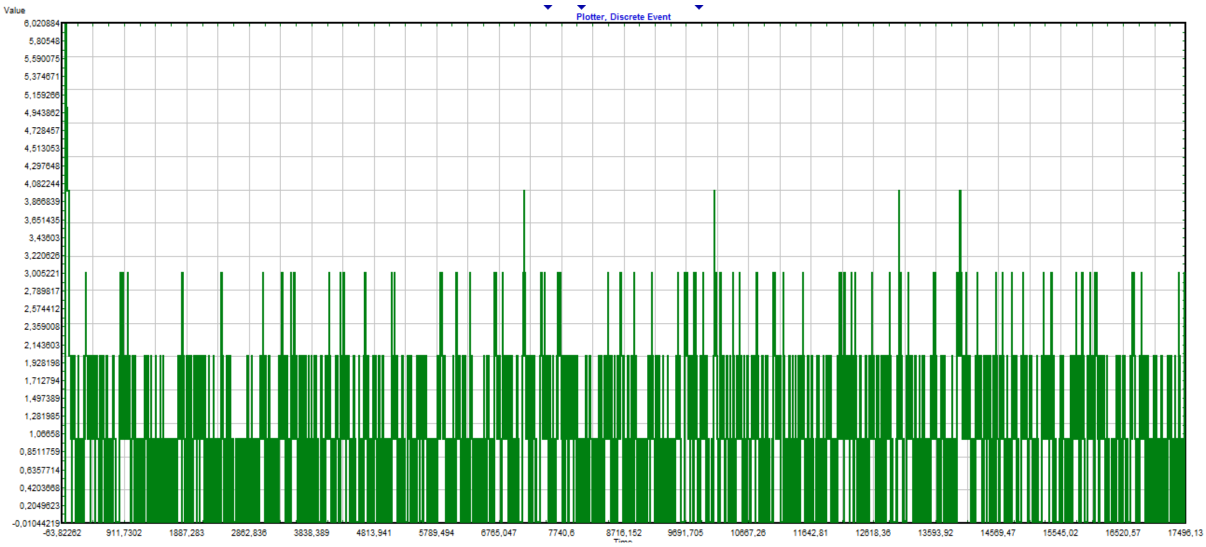


Figure 27: Nitrate levels installation C, scenario one, with 50% increased demand

In this graph it is not possible to count the amount of times the level is zero. It clearly shows that the safety stock level is non-existing, and incomparable with the sketch in figure from the chapter on inventory control. Not providing a good solution.

Table 15: Resulting possible time without Nitrates offshore for scenario one, installation C

Model setup Nitrates	Total time with utilization less than 1 [h]	Number of times with tank level of zero	Average time without items in tank [h]	Ave time to consume one item
As-Is setup	37,68	3	12,56	Se appendix C or E
50% increased demand setup	5657,87	N/A	N/A	Se appendix C or E

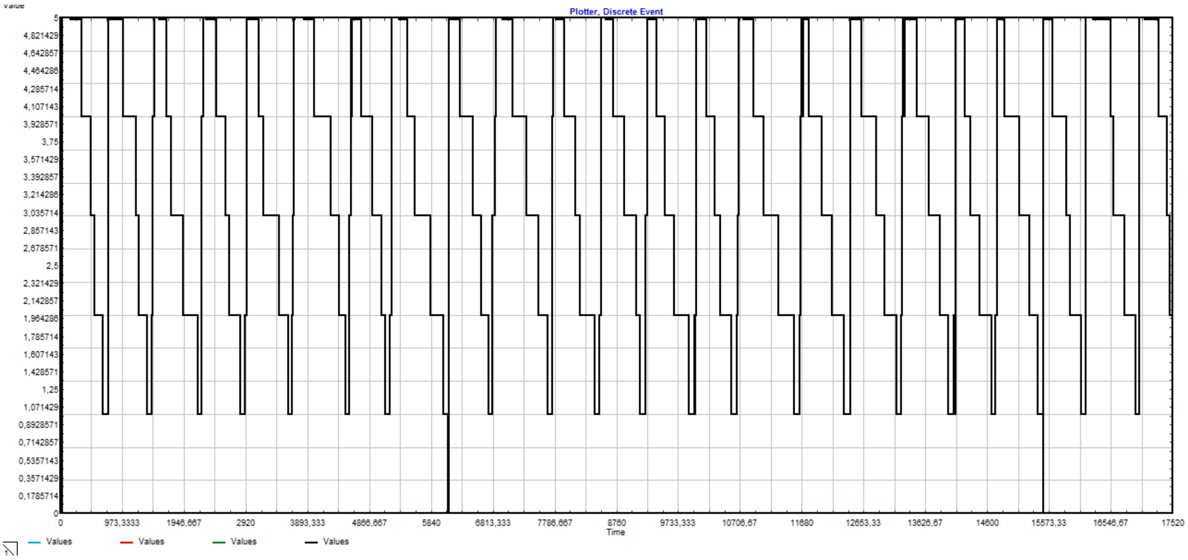


Figure 28: Scale inhibitor levels installation C, scenario one, with original demand

The graph shows a nice and predictable reduction of the inventory before re orders is made. On two occasions the level in the tank is zero, but only for a very limited period of time.

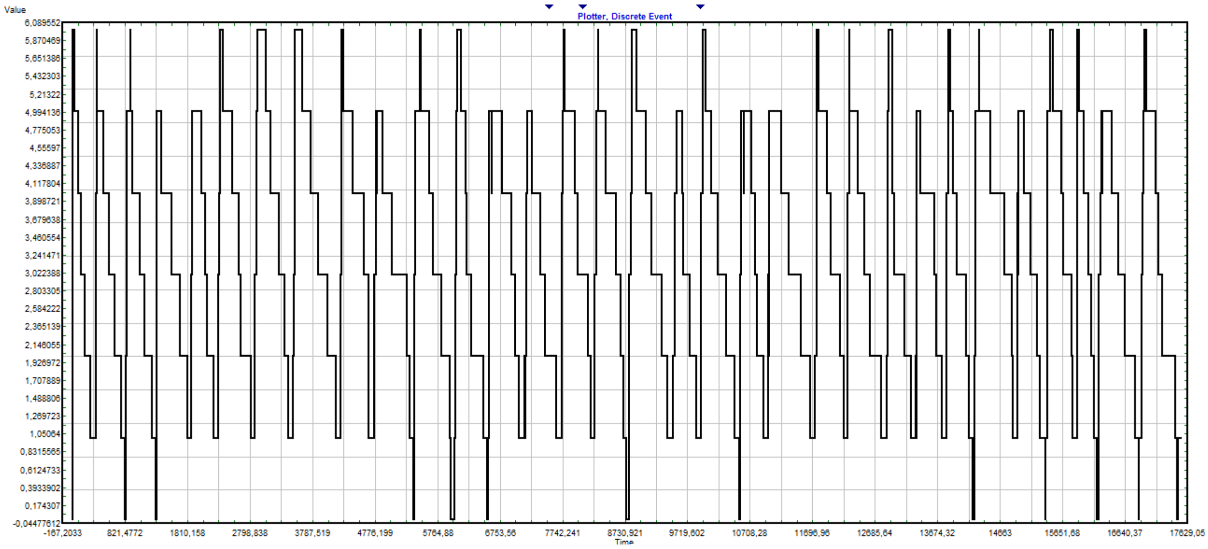


Figure 29: Scale inhibitor levels installation C, scenario one, with 50% increased demand

When the demand is increased to 50% if the average the frequency of re-orders rise for the scale inhibitor, but the graph still shows a nice and predictable development for this chemical.

Table 16: Resulting possible time without Scale inhibitor offshore for scenario one, installation C

Model setup Scale inhibitor	Total time with utilization less than 1 [h]	Number of times with tank level of zero	Average time without items in tank [h]	Ave time to consume one item
As-Is setup	60,4	2	30,2	Se appendix C or E
50% increased demand setup	287,1	12	23,92	Se appendix C or E

The values for the scale inhibitor are much less than the consumption time of one item and it is assumed, for the same reasons as in the case of H2S remover for installation A and B, that the capacity for scale inhibitor can be regarded as good for this installation. This is not the case for the H2S remover and nitrates. The average difference between the consumption time and the average time without item in tank for these chemicals, together with the consumption time and lead time relationship, indicate that there could be a need for priority calls to this installation. For this installation a worst case consumption table was made available from Statoil, and this consumption is even higher than 50% more than the average consumption, giving further indications towards low tank capacities.

5.5.1.4 *Summary of the results in first scenario simulations*

The first scenario was built to see how the installation with the current set-up would respond to an increasing demand. From what was found in this part of the study, both installation and B are well suited for an increased demand, whereas installation C seems to be struggling. Based on these results it is concluded that there is no need to see the effect of increasing the capacity at installation A and B since they are at sufficient levels at the moment. The scenario on how more IO tools in the ordering process could affect the installations availability of chemicals will be tested for all installations.

5.5.2 Scenario 2: Increasing the capacity at the installations

By increasing the capacity more items can be ordered at the when the tank level reach the recommended ROP. In this scenario it is only installation C that is evaluated since this was the installation where priority orders due to low chemical levels seemed most likely to occur. Since the problem was found for the H2S and the Nitrates in scenario one, these are the chemicals were increased capacity is evaluated. The new increased tanks will be sat to have a capacity equal to the minimum of 10 day capacity when the demand is at the level given in appendix F. The results of the reports for these two types of chemicals are presented below:

Table 17: ExtendSim report values for installation C, simulation scenario two

Chemical	Utilization As-Is demand	Hours with utilization less than one	Utilization 10% increased demand	Hours with utilization less than one	Utilization 25% increased demand	Hours with utilization less than one	Utilization 50% increased demand	Hours with utilization less than one
H2S remover	0,999958	0,7358	0,999754	4,31	0,998676	23,19	1	0
Nitrates	1	0	0,99984	2,8	0,999978	0,38544	0,999432	9,95136

The table shows great improvement for these two chemicals. The ROP is increased for H2S remover when the increased demand is 50% higher than the starting demand and for nitrates when the demand has increased with 25% of the original demand. This alternation to the ROP is resulting in improvements even though the demand has increased. The graphs showing the tank levels are also showing a much nicer development of the tank level than what was the original case, they also show that the tank levels are newer at zero for a longer period:

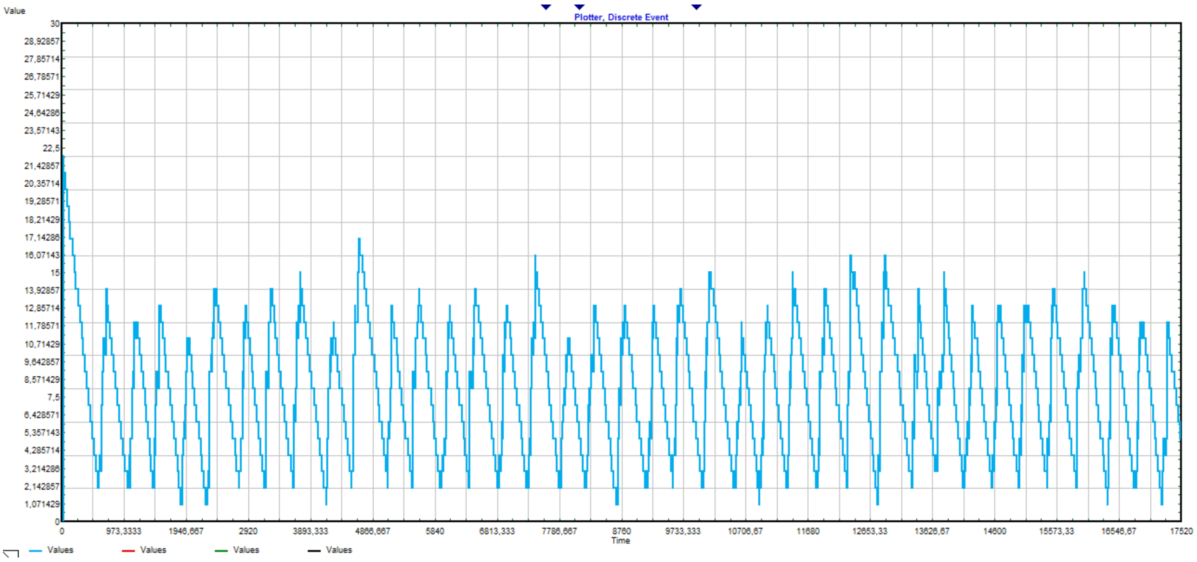


Figure 30: Level of H2S with increased tank capacity offshore, and original demand

H2S increased capacity original demand

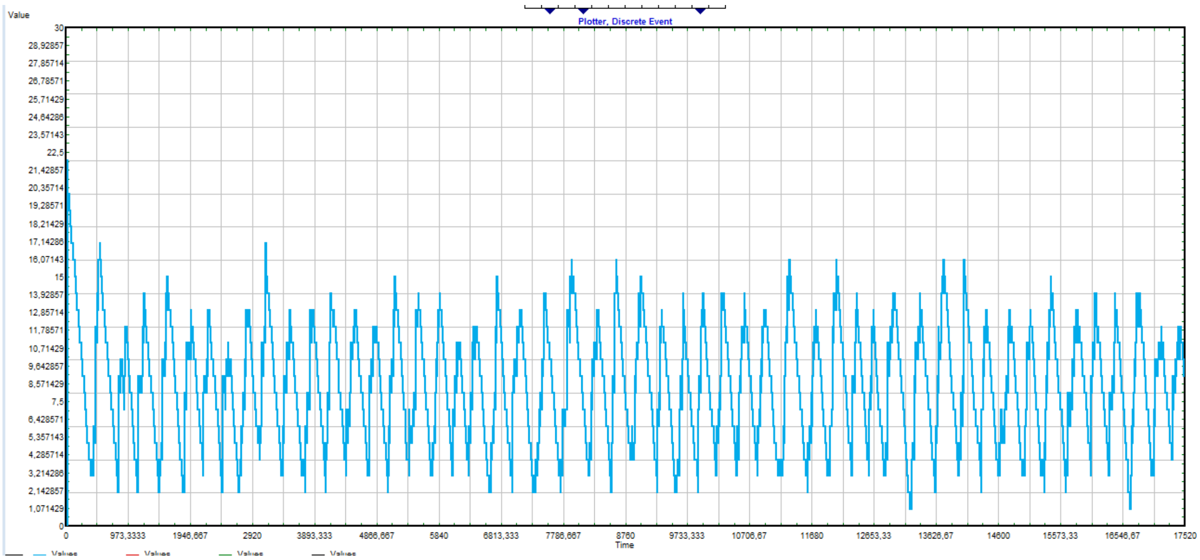


Figure 31: Level of H2S with increased tank capacity offshore, and 50% increased demand

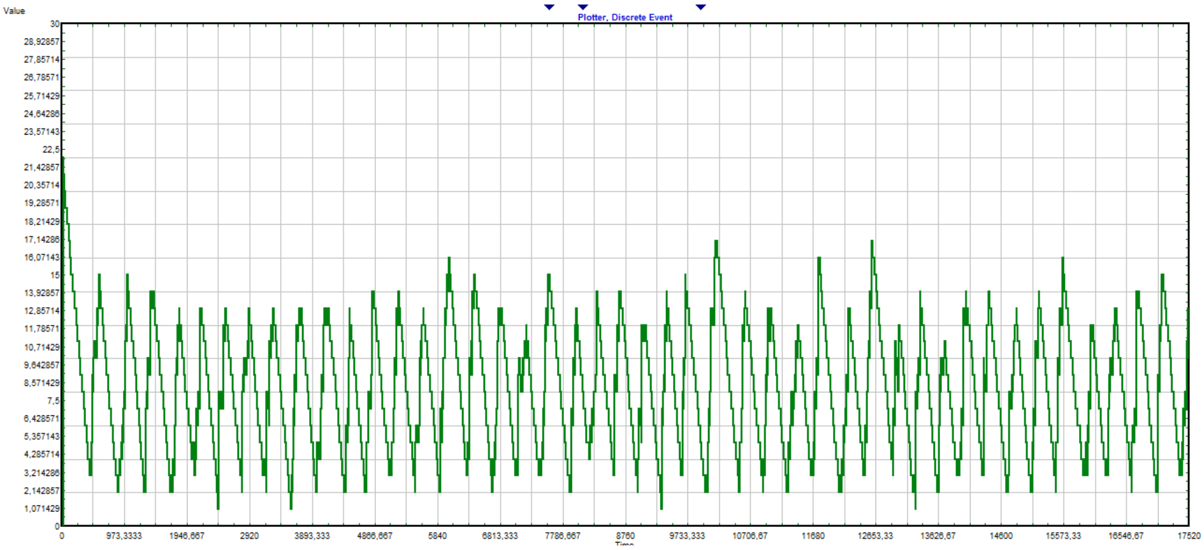


Figure 32: Level of Nitrates with increased tank capacity offshore, and original demand

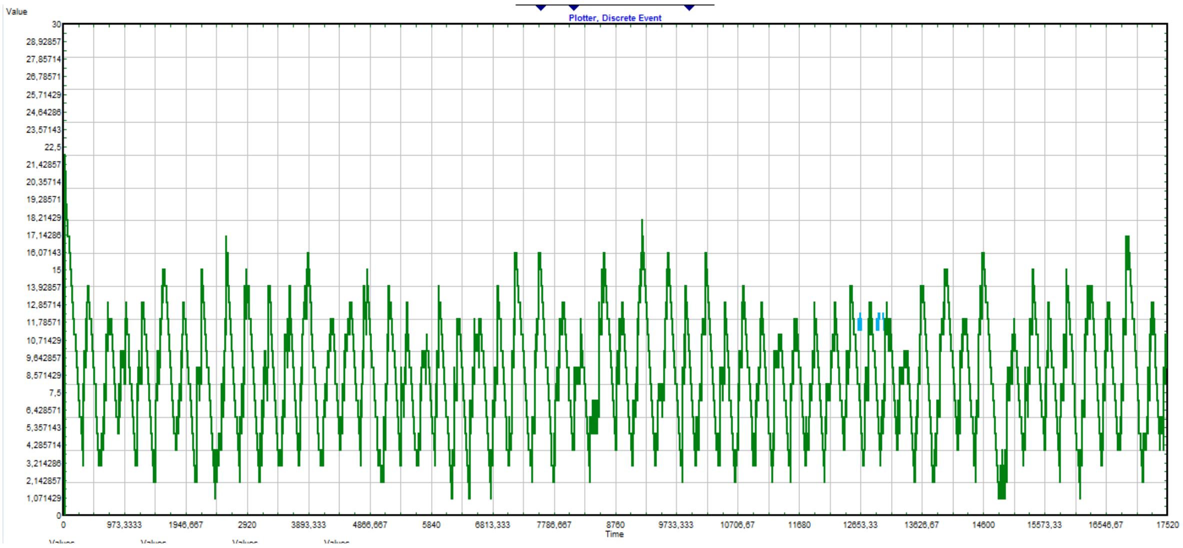


Figure 33: Level of Nitrates with increased tank capacity offshore, and 50% increased demand

5.5.3 Scenario three: IO through automatic tank level reading to improve order.

In this scenario the model is alternated by removing the block look up table and the block that creates constant values of zero. The result is that the first gate receives the order for needed chemicals instantly, and is not depending on the twelve hour schedule in the original model. The new ordering part of the system is illustrated below:

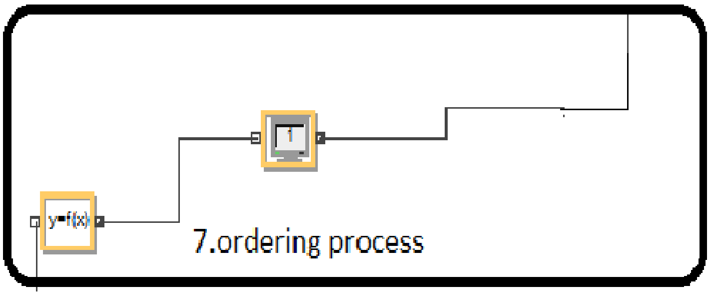


Figure 34: Model image of new IO ordering setup

For this scenario the effect on all the installation were reviewed and the result is presented in the following tables for the different installations, the value reviewed is the utilization value for the different demands:

Table 18: Comparison of ExtendSim report values for utilization of tanks, with and without IO ordering, Installation A

Chemical	Utilization As-Is demand	Utilization As-Is demand IO order	Utilization 10% increased demand	Utilization 10% increased demand, IO order	Utilization 25% increased demand	Utilization 25% increased demand, IO order	Utilization 50% increased demand	Utilization 50% increased demand, IO order
H2S remover	0,995148	0,996288	0,988426	0,99438	0,971138	0,98614	0,93492	0,96094
Emulsion breaker 1	1	1	1	1	1	1	1	1
Emulsion breaker 2	1	1	1	1	1	1	1	1
Nitrates	1	1	1	1	1	1	1	1

As the table shows the result of having automatic reading of tank levels gives a slight improvement in the utilization of the H2S tanks for this installation. Something to notice in the result is to see how the benefit of this ordering mechanism increases with the demand.

Table 19: Comparison of ExtendSim report values for utilization of tanks, with and without IO ordering, Installation B

Chemical	Utilization As-Is demand	Utilization As-Is demand IO order	Utilization 10% increased demand	Utilization 10% increased demand, IO order	Utilization 25% increased demand	Utilization 25% increased demand, IO order	Utilization 50% increased demand	Utilization 50% increased demand, IO order
H2S remover	0,9997	1	0,988808	0,999274	0,991834	0,999728	0,943862	0,990752
Emulsion breaker 1	1	1	1	1	1	1	1	1
Nitrates	1	1	0,99933	1	0,999814	1	1	1

Installation B comparing utilization with and without IO ordering

The results for this installation are similar to what was found in the case of installation A, general improvement increasing with the demand.

Table 20: Comparison of ExtendSim report values for utilization of tanks, with and without IO ordering, Installation C

Chemical	Utilization As-Is demand	Utilization As-Is demand IO order	Utilization 10% increased demand	Utilization 10% increased demand, IO order	Utilization 25% increased demand	Utilization 25% increased demand, IO order	Utilization 50% increased demand	Utilization 50% increased demand, IO order
H2S remover	1	1	0,99997	1	0,99661	1	0,93906	0,99234
Emulsion breaker 1	1	1	1	1	0,99928	0,99961	0,99663	0,99903
Nitrates	0,99785	1	0,98477	0,99925	0,90575	0,98856	0,67706	0,86466
Scale inhibitor	0,99655	0,99909	0,99464	0,99837	0,99116	0,99352	0,98361	0,98412

Installation C comparing utilization with and without IO ordering

The result follows as for the other two installations, but since this installation had more difficulties in the original set up, the improvement in the tank levels are larger. For nitrates when the demand is 50 % higher than the average demand, the utilization of the tanks with IO ordering is almost 128% of the utilization of the original model. This is a good improvement.

That adding automatic readings of the tank levels would be beneficial, was expected. The effect was found to be highest in the cases with highest demand and lowest original utilization grade.

5.5.4 Scenario 4: Increasing the capacity and using IO ordering system

To increase the capacity and not introduce automatic reading of tank levels would probably not be a realistic option in the real world. New tanks would have this option available. This last scenario will look at how the situation for H2S remover and Nitrates on installation C would be if both these improvements were added to the system. There would be no problem in conducting this simulation for all the chemicals at all the installations, but since these cases where the most interesting ones they are selected.

The setup used for this scenario was the one where the demand was 50% higher than the original demand. This was chosen since the two improvements had good results by themselves, and the combination was therefore assumed to be even better.

Table 21: ExtendSim report values for installation C, simulation scenario four, increased capacity and IO ordering

Chemical	Utilization As-Is demand	Hours with utilization less than one	Utilization 10% increased demand	Hours with utilization less than one	Utilization 25% increased demand	Hours with utilization less than one	Utilization 50% increased demand	Hours with utilization less than one
H2S remover	1	0	1	0	1	0	1	0
Nitrates	1	0	1	0	1	0	1	0

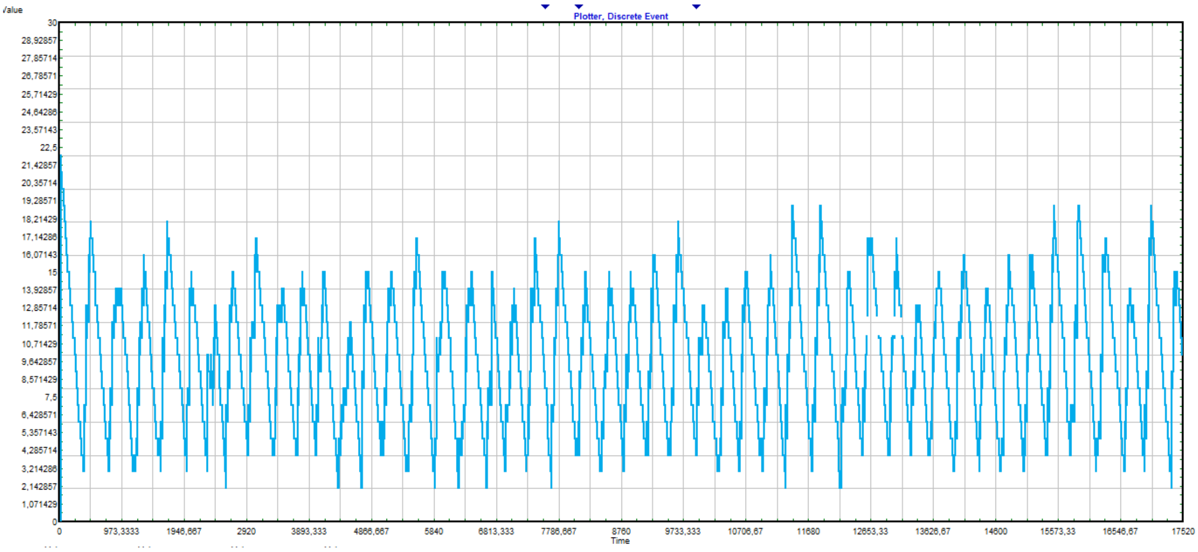


Figure 35: Tank level H2S, Scenario four, 50% increased demand

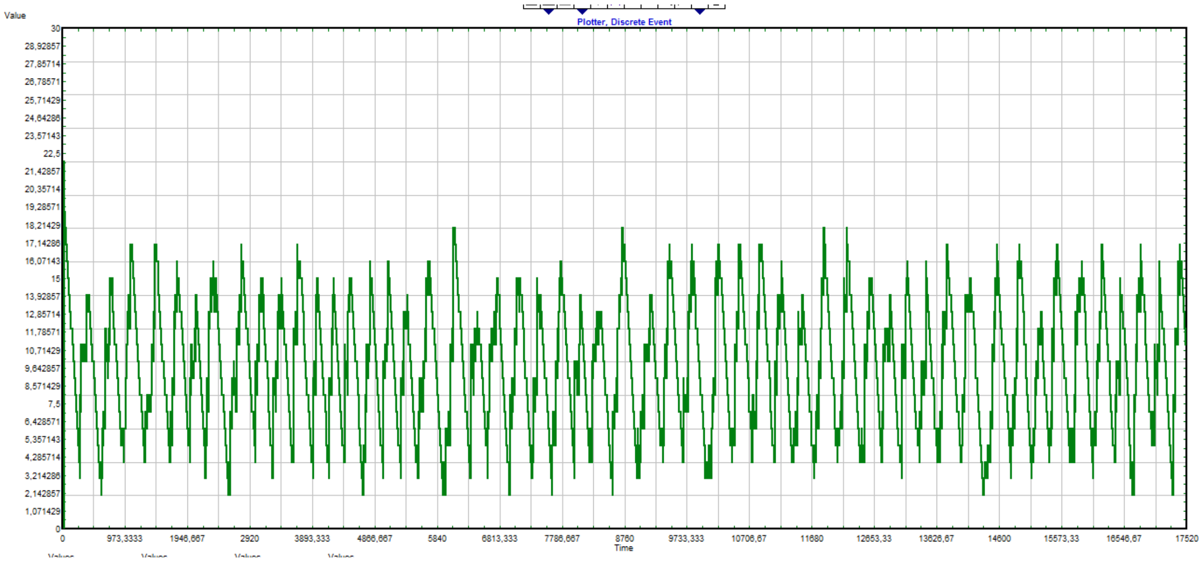


Figure 36: Tank level Nitrates, Scenario four, 50% increased demand

It became a perfect result when both improvements were added to the system.

5.5.5 Evaluation of the results:

In the first scenario the intention was to evaluate how the different installations would handle and increase in demand. For installation A and B the results was found to be that these installations were capable to handle the increase in a satisfactory manner. At Installation C the increase lead to a problem. The need to restock at this installation happened extremely often. If it is taken in to consideration that the increased values of demand used in the simulation, were lower than the maximum consumption per day given for this installation in appendix F, the problem is even more visible. The results given in the reports do not give the maximum time with tank levels at zero, this is the time needed to be compared with the average consumption time for the last item. The way this was done was to try and count all the times the graph was at zero and divide the total time without items in the tank by this value. This was probably not entirely accurate, but for installation A and B this average time was so much lower than the consumption time in the same situation, so it was found that this assumption provided an acceptable approximation.

Scenario two introduced increased capacity for the tanks at the installation with the larges problem in handling the demand. Since it is Statoil policy to have at least 10 days of capacity, which was not the case for these chemicals at this installation, it was expected that this would give a good result. The new capacities gave a much nicer development in the inventory levels, and reduced the need to be re-stocked every day. By raising the ROP as well the H2S remover got a perfect result with the highest increase in demand after this modification. The results for nitrates were also very good and for the two year run of the simulation, an average of fewer than 10 hours where there was no items in the tank was found.

In the third scenario the idea was to introduce IO thinking by allowing continuous automatic reading of the tank levels. This would allow the experts onshore to make alternations to the order according to the latest plans affecting the demand, which could further improve the results found in this model. The difference from the first scenario to this was only the removal of the restriction to when orders could be sent. For all the installation an improvement in the utilization of the tanks was found. It was also found that improvement was greatest for the situations which were most problematic in the original setup of the model. As in the second scenario an improvement was expected, but the results of this implementation were found to be better than expected. The best result improved the utilization of the nitrate tank on installation C from 67, 7% to 86, 5%. This is a reduction in the possible hours when stock out could occur from 5659 hours to 2365 hours, a difference of 3294 hours over the two years simulated in the model.

As stated in the introduction to scenario four it is very likely that the improvement in scenario two would be implemented without the improvement method given in scenario three and vice versa. In this scenario both these improvements was conducted for the problem cases found at installation C, and the result was found to be very satisfactory. This was without a doubt the best result, which came as no surprise. With both the improvements in place there was no time during the two years simulated where there was a danger of stock out. This can be directly translated to no need for priority shipments due to lack of chemicals. These results do not take into consideration if they are possible to do in the real world. If a conclusion should be made based on the simulation, the capacities for installation C should be improved and the tanks fitted with automatic reading of tank level.

Table 22: Summary of the results of the different scenarios

Installation	Result Scenario 1	Result Scenario 2	Result scenario3	Result scenario 4
A	Acceptable for all demand values	No need to evaluate for this installation	Slight improvement for all chemicals	Not evaluated
B	Acceptable for all demand values	No need to evaluate for this installation	Slight improvement for all chemicals	Not evaluated
C	Problems discovered for H2S Remover and Nitrates	Large improvement for the evaluated tanks	Good improvement found, especially for the worst cases	Best result found, no problems for the tested demand values

6 Discussion

In the chapter “benefits of simulation in supply chain management”, a list of success factors was given. Based on these factors the model is evaluated.

The first success factor was based on the models ability to produce results interesting to the user. The model as it stand can find the lead time and standard deviation of this value with the help of an excel sheet. It generates a report indicating which can be used to see the amount of chemicals consumed over the simulated time period and most importantly the utilization of the queues representing the offshore tanks. These results can be used to evaluate how the system is functioning in today’s situation, and how it will function over time. The results found in the case gave an indication of limited capacity on one of the installations evaluated, a result that is found to be of great interest to a user.

The ability to produce results not possible with any other methods was the second success factor mentioned by Strandhagen. In chapter 4 on supply chain management several other methods within the field of Operational research were described with their benefits and limitations. The best results would be found if it was possible to implement the changes on the real world system and evaluate, but this is naturally not possible due to the cost and risk involved in a failure. The result of this is that the system has to be modelled in some way. Creating a physical scaled model would be possible, but the time and cost it would take to model such a complex system is assumed to be too large. The model would also be extremely limited to this one case if a physical model was to be used. The result of this is that some sort of mathematical model was the only feasible solution to evaluate the problem. And the different methods that could be used were:

- Spread sheet cost models
- Decision trees
- Queuing theory
- Discrete-event simulation
- Inventory theory
- Mathematical programming(optimisation)

A spread sheet cost model is a static model, which would not allow for changes to occur over time. There were no cost data gathered for the analysis, and this model would be more suited for a later stage where different improvement options were to be evaluated, and not for the problem evaluated in this case. Decision tree as a method has its strength in evaluating the flexibility of a supply chain, and could perhaps be used if the probability for an increase was known as well as the cost of having stock out. The way such a method could be used is not clear, and based on the data found in the field studies this was not an option. Queuing theory could be used to evaluated the problem, this method is able to find the time an entity spends in the system, how the system resources are utilized and waiting times which is very relevant to the problem evaluated in this work. This is not surprising since the simulation model that was built is largely based on queuing theory. The limitation of ordinary queuing theory is that it is unable to handle complex systems, then simulation is preferred. Inventory theory is used in the work conducted together with the simulation and helps to find some of the answers that was searched for, but would not be able to find a good value for the amount of stock outs by itself. The best option to the simulation model would perhaps be mathematical programming, using algorithms and heuristics to model the problem. This method is often called optimization since it is able to give a recommended optimal solution to the problem it is evaluating. For such an optimization to be a good choice of method the problem would have to be formulated as a max-min problem. This could be done as minimize the time without chemicals available offshore, or maximize the utilization of the tanks offshore. The main drawback of this method is the complexity; the method is described as both time consuming and advanced where external experts often are needed. Based on the limited experience of the author with mathematically programing this method was not selected for the case study. Based on this it is possible that using mathematically programing could attain the same results as the simulation model, with the possibility of optimisation, and this success factor was not achieved to the highest grade. There is at least a limited amount of methods that could produce the same result, but as stated above perhaps the optimisation method should also be tested.

Resemblance between the model and the real world system is an important factor to discuss when evaluating the simulation model. During the modelling assumptions were made, each of these assumptions could distance the model from the real world system. To limit this validation of the models results based on historical values form the real world system was used. It was found to be a good resemblance between the real world system and the model, there are however some factors that could improve the model. The first is a delay at the base due to bad weather, which could be modelled in the same way as the delay for waiting on platform offshore. There are cases where the vessels are not leaving the base at the scheduled day due to bad weather, but no statistical data on this was available at the time of this study. This would give an effect on the lead time and standard deviation of this value again influencing the ROP and could influence the final results. The second part that could get an improved resemblance to the real world would be the part of the model that represents the sailing and sailing options. As the model stands the sailing for different chemicals, and installations are not dependent on each other, which is not the case in the real world since one vessel is carrying all the goods to the installations on its route. If this part of the model somehow could be linked to the routing program by Fagerholdt and Lindstad and the load manager by Marintek, there could be much more depth and realism added to this part of the model. On the other hand, the model as it stands does in some manor take the dependency of routing into consideration since the delays in this section of the model is based on a routing scheduled where the installations are visited in a given order. And as for the independent loading of chemicals to the vessel, it was found that the vessel capacities were so large that there would not be a problem due to limited space on the ship, which was also supported by the experience at supplier, base and vessel, that this simplification would not differ the model results from the real world results. Increasing the resemblance to the real world system, would mean that the model would have to become more advanced, which could open for more errors than benefits due to the increased complexity. This would also make the running of the model more time consuming, perhaps decreasing the usage of such a model. All in all it is found that the model developed is a good although not perfect resemblance of the real world system;

- The system has chemicals available onshore as stated by the supplier, due to the large amount of items created in the exponential distribution in the beginning, and the delay in the onshore process is within the 48 hour limit with the given normal distribution.

- The routing emulates the system by using the shutdown function to replicate that vessels leave the base. And the selection of routing option is based on statistical data.
- The consumption is normal distributed with a mean set to the average of historical demand values, which seems like a reasonable assumption.
- When the model was given the as-is data the results were similar to what was expected based on the experience given by personnel at Statoil.
- For cases where the capacity was good, the graph retrieved from the model showed the same situation as figure 7.

The fourth success factor relates to the time an inexperienced user would have to spend from the time he starts using the tool until he has the model running. A good user interface where the most important parameters that separates one installation from another, such as capacities and consumption could be entered would make it easy for new users to benefit from the model. This is unfortunately not the case for the model built for this project. A user interface place on top of the model has not been created, the user would therefore have to go manually into each of the blocks and alternate the values for each new case that is to be investigated. This gives an experienced user good flexibility in alternating the model, but would possibly significantly increase the time it would take an inexperienced user to get a new model running.

The final success factor is the accuracy and validity of the results. As the model was validated during the building, it is assumed that the result s would be valid. The results that was gained by the case study was that there was a shortage in the capacity at one of the installations, and that implementing automatic tank level readings and increased capacity would improve the situation. Based on this the results are accurate given that the model is valid. If it is also taken into consideration that for the installation where capacity problems were found a “worst case” consumption that was higher than the 50% increased consumption evaluated was given by Statoil, the result that this installation has to low capacity is further strengthened. Now the demand/consumption increases that was used in the simulation case was limited to a maximum of 50% increase which may not be the case, as the only statement received from Statoil was that it was expected that future demand would be higher. This could affect results on installation A and B where the findings where satisfactory capacities. Nevertheless the result found for the consumptions evaluated provide an indication on how the system reacts to changes, which in itself is a result. Since there are no cost values evaluated, the only value that suggests changes to the system is the improvement in tank utilization, the result being that no suggested solution is provided. The results are therefore only to be used as an indication on how the system performs given the different setups, and for the cases where the results are that the system is not working in an acceptable way, a thorough evaluation of the possible improvements should perhaps be made. This evaluation could include optimisation of tank capacities given actual forecasts of future demand, available space offshore, and cost of implementation.

7 Conclusion

The main objective of this report was to conduct an analysis of the supply of production chemicals to offshore installations. The problem given by Statoil was that the current system was out dated since manual tank readings were necessary, that the capacities were insufficient and that this would get worse as the demand is predicted to rise. The method chosen for this analysis was discreet simulation modelling, which was selected on the basis of supply chain management theory and the data collected in the field studies. The paper give a description of the supply of production chemicals and based on this description of the system a model was created. The analysis also included results relating to how ideas from the field of Integrated Operations would affect the systems performance, with automatic tank level readings.

The model built in the case provided a good "what-if" analysis of the system which could be useful when investigating if modifications are needed, and provide an overall image of the supply chain for the four different scenarios in the case. In the discussion the list on what makes a successful simulation study was used to discuss the work. The following is a conclusion based on this discussion:

1. Ability to produce results not possible with any other methods: The model evaluates how a system is able to handle future challenges, with different alterations. This would best be investigated by changing the real system, but since this is impossible due to the cost, simulation modelling was found to be the best method.
2. Could other methods have been used: During the discussion it was found that the best option to the simulation method that was chosen would be mathematically programing. This option would allow for optimisation, and could provide a suggested improvement to the existing system. It was also found that this method would probably be more time consuming, and that it would require external experts, but again the question was whether or not other methods could be used, and the answer is therefore yes.
3. Resemblance between the model and the real world system: The approximation made in the modelling is found to be good, and the results were validated by historical data. Assumptions were however made and improvements could always be made for a closer resemblance.
4. The time an inexperienced user has to spend from the time he starts using the tool and till he has the model running: In this part there are room for improvement as no overlaying user interface has been made in the model. The explanations given in the report and appendix would allow an inexperienced user to alternate the model, but no attempts to find the time it would take has been conducted during this work.
5. The validity of the result: Based on the historical data and experience provided by Statoil the As-is model is giving a result that is reasonable when looking at the throughput, lead time, and amount of times there is a need to make priority calls due to lack of production chemicals. Given that the assumptions made in the other scenarios are not too far from what would be the real case, the results are found to be accurate and valid.

Given the assumptions made in the modelling, it was found that there was sufficient capacity on both installation A and B to handle the average demand based on data from the last three years. Installation C did show some weaknesses in this first scenario, and it was concluded that this installation did not have sufficient capacity. Whether or not the installations had sufficient capacity in today's situation was the first problem addressed when building the model. The next step was to see what would happen if the demand increased. For installation A and B the results were still good, and it is assumed that problems would not arise before the demand increased even more than the 50% increase used in the model. For installation C, which struggled with the original demand, the situation naturally got worse. Both these questions were addressed in the first scenario of the simulation case. The next question that was asked to be evaluated by the model was which changes to the system would prove to be the most efficient. This was done in scenario 2-4. Since the results in the first scenario was so good for installation A and B it was found unnecessary to see how increasing the capacities would affect these installations, the improvement of adding automatic readings of tank levels to the system was however done for all the installations. This was done since one of the main questions was how IO ideas could improve the situation. It was found to be true for all the installations that such an implementation of automatic tank level readings would give an improvement. The size of the improvement was larger the “worse” the original situation was. The largest improvements found by implementing one improvement was found when the capacities on the offshore tanks at installation C was increased to last for the minimum amount of days given by Statoil, 10 days. This gave an almost perfect result for the demands used in the model. The last scenario in the simulation case would be the one giving the best result, as this case was the combination of both the improvements on installation C. There was no amount of time where the possibility of stock–out was found during this run of the simulation. This option would also be the most likely improvement in the real world since there would be no reason not to include automatic tank readings if the tanks offshore were to be replaced by new larger tanks. The results given from the model indicate that such a simulation program could become a valuable decision support tool.

For this simulation model to become a decision support tool there are much work to be done. An overlying user interface must be made so that the model would become easy to use for personnel with no experience in the model. The presentation of the result reports could also be improved so that there is no need, for the operator running the simulation, to do extra spread sheet calculation in order to receive the result they look for. Furthermore the model should be linked to other work done on the subject of offshore logistics, modelling and simulation. Creating a link to the rout planer made by Fagerholt and Lindstad and the load manager created by Marintek, could give a new dimension to the routing part of the model both for the delay, and the available capacity of the vessel. If there is a possibility to link the results found in some of these studies together, provided an easy user interface is made, the result could become a good decision tool for the logistic management of offshore supply. A cost benefit analysis must, as mentioned previously, be conducted on the different improvements to evaluate if they are could be implemented in the real system. The model in this report does not take cost or the fact that the improvements of a given scenario could be impossible to conduct. Finally to get a more realistic result, Statoil’s forecast for the future demand should be used in the model. This problem was briefly mentioned in the discussion chapter, and if there are no such forecasts available they should be made. Since the demand has such an important effect on the result, it is therefore of the utmost importance that the simulation is run again with these values.

Bibliography

Birkeland, B. M. (u.d.). *Dok.no.SO0268 Kjemikaliebehandling AE Statfjord C version 2.01.* Staoil internal document.

Chang, Y., & Makatsoris, H. (2001). *Supply chani modeling using simulation.* Cambridge: Institute for Manufacturing, University of Cambridge.

Chopra, S., & Meindl, P. (2010). Supply Chain Management. I S. Chopra, & P. Meindl, *Supply Chain Management fourth edition* (ss. 198-201;264-333). New Jersy: Pearson.

Fagerholt, K., & Lindstad, H. (2000). *Optimal policies for maintaining a supply service in the.* Omega The international Journal of management science.

Fjørtoft, K. (2004). *cargo management for offshore installations.* Trondheim: Marintek.

Forbes. (n.d.). *Website for Forbes* . Retrieved May 30, 2011, from List: Worlds biggest companies: http://www.forbes.com/global2000/#p_11_s_acompanyRankOverall_All_All_All

Law, A. M. (2007). *Simulation modeling&analysis.* New York: McGraw-Hill.

Law, A. M. (2007). Ways to study a system. In A. M. Law, *Simulation modeling and analysis 4th edition* (p. 4). New York: McGraw-Hill.

Law, A. M., & McComas, M. G. (2001). *How to build valid and credible simulation models.* Winter Simulation Conference.

Longo, F. (n.d.). *Supply Chain Management Based on Modeling & Simulation: State of the Art and Application Examples in Inventory and Warehouse Management.* University of Calabria.

Nilsen, E. G. (2009). *Robust supply chain design.* Trondheim: NTNU.

Shapiro, J. F. (2001). Modeling the Supply Chain. In J. F. Shapiro, *Modeling the Supply Chain* (pp. 477-512). Pacific Grove: Duxbury Thomson learning.

Shapiro, J. F. (2001). Modeling the Supply Chain. In J. F. Shapiro, *Modeling the Supply Chain* (p. 19). Pacific Grove: Duxbury Thomson Learning.

Statoil. (2010). *Logistikkportalen*. Hentet September 30, 2010 fra http://logistikkportalen.no/

Statoil. (2011). *Website for Statoil*. Retrieved May 30, 2011, from http://www.statoil.com/no/about/pages/default.aspx

Statoil. (2011). *Website for Statoils activities*. Retrieved May 30, 2011, from http://www.statoil.com/no/ouroperations/pages/default.aspx

Statoil. (n.d.). *Statoil News*. Retrieved Aipril 2011, from Using fewer harmful chemicals: http://www.statoil.com/en/NewsAndMedia/News/2003/Pages/UsingFewerHarmfulChemicals.aspx

Statoil. (n.d.). *Statoil technology and innovation*. Retrieved Aipril 2011, from Handeling Scale in oil production:

http://www.statoil.com/en/technologyinnovation/fielddevelopment/flowassurance/scale/pages/default.aspx

Strandhagen, J. O. (1994). *Operativesimulation in production management.* Trondheim: NTNU/Sintef.

Swire Oil Field Services. (u.d.). *Swire Oil Field Services.* Hentet Aipril 2011 fra Products and services, Chemical tanks: http://www.swireos.com/ProductsandServices/ChemicalTanks/tabid/150/Default.aspx

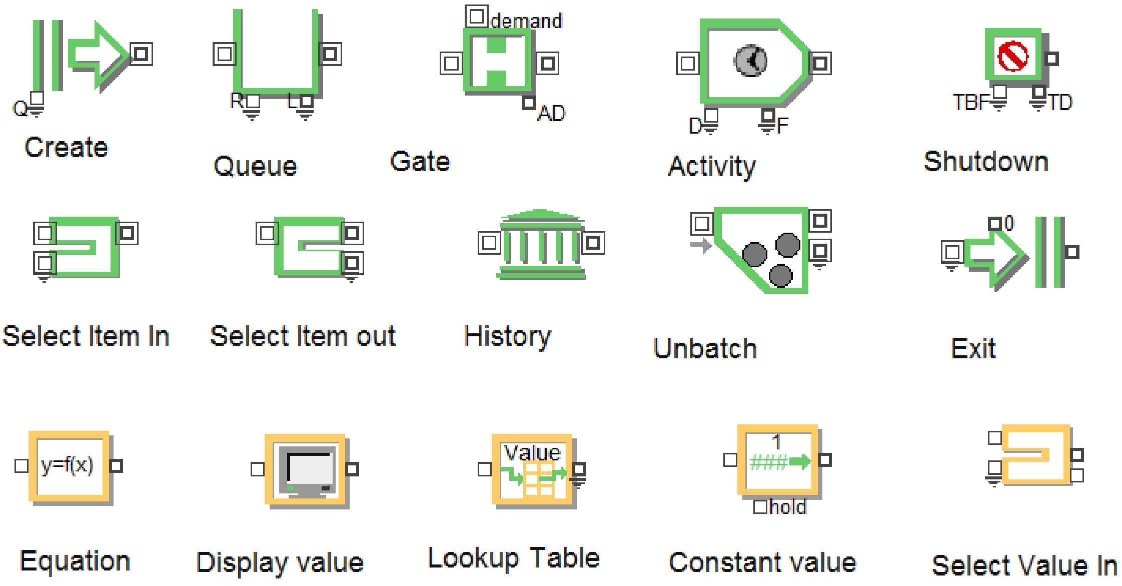
Tayur, S., Ram, G., & Michael, M. (1999). Quantative models for supply chain management. I R. Kapuscinski, & S. Tayur, *Optimal policies and simulation based optimization for capacitated production inventory system* (ss. 7-41). Kluwer Academic Publisher.

The Norwegian Oil Industry Association. (n.d.). *Website for The Norwegian Oil Industry Association*. Retrieved May 30, 2011, from Facts abaout Norwegian Oil and Gas Industry: http://olf.no/en/Facts/

Tysseland, B. E. (2010, September). *Supply chain of Gullfaks.* Bergen, Hordaland, Norway.

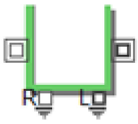
Appendix

A: Simulation Block description



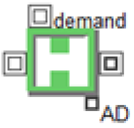
Create

This block is used to create “Items” in the simulation model. The items in the model made in this paper represent a quantity of a given chemical. The block creates the item based on an exponential distribution, and it is possible to alternate the distribution and the mean time between creation in this block.



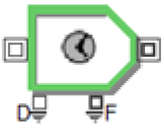
Queue

The queuing blocks are used throughout the model and are places where items are “stored”. The queuing block is used to emulate the tanks offshore in the simulation made for this paper. It has many possible features, but in this paper it is used as an infinite queue in the first parts and as a queue whit limited capacity when emulating the tanks. All the queues in the simulation is set to the first in first out setting. From the “tank queues” the level is monitored and ploted.



Gate

The gate block is used to route items into the system at given times. The simulation uses two gates one which is value driven and a second which is item driven. The difference is that the value gate will open when it receives a given value, which in the model is the order quantity. The second gate is a safety gate that makes sure that there is not to many items released into the system. This gate needs to register that an item has actually left the system before it opens.

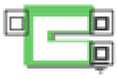


Activity

The activity blocks are used to ad delays to the items and simulate different stages of the supply chain in the model. This block can have a constant delay, or a distributed delay with a mean and standard deviation. In the model this is used to simulate the delivery time, the sailing from base offshore, the delays offshore due to waiting, and also the draining of the tanks or demand.

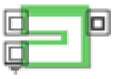
Shutdown

These blocks work in close relations to the activity blocks and are used to simulate that the supply vessels are unavailable for loading when they are offshore. This is done by connecting them to the different activity blocks emulating vessels. The shutdown block will send a signal at a given interval making the activity block unavailable for this period. The items already in the activity block will not be affected, which is the real world case of them being transported.



Select Item out

This block is used in situations where there are several options for the item regarding routing. These blocks use probability to select the output for an item, and thus the different routings. The probabilities used in these blocks in the model are based on historical data.

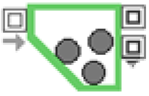


Select Item In

When it is possible to get items from several activities it is a need to gather the items on the same path again. This is done whit the select item in block.

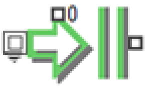
History

The history block register an item as it pass through. This block does not give any extra delays and is used in the beginning of the supply chain and the end of the supply chain to find the average lead time and the standard deviation for the lead time. Two blocks are needed in the chain to do so.



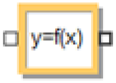
Unbatch

This block receives one item in and divides them in to several items, in the model it is used to duplicate the item as it leaves the system in order to activate the item gate, as the item exits.



Exit

The opposite of the create block, removes items from the system as they arrive and register the amount. Works like a sink.

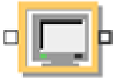


Equation

The Equation block is a value block. Value blocks don’t send items, but values. In the model this block is connected to the tank queues and has a function that will send out a value for some tank levels. In the model this is programed as an IF sentence which differs from system to system. The equation block is used in the part of the model that simulates reorders, and the value generated in this block opens the value gate. Exampel of an equation in this block could be:

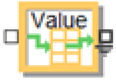
```
If (inCon0<=1)
outCon0=10-InCon0
else
ouCon0=0
```

where inCon0 and outCon0 is the incoming and outgoing conectors.



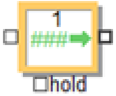
Display value

The display block does just that, displays values as they pass through. Does not ad any attributes to the system.



Lookup Table

The look up table value can be used to select different values from a given table, or as in the case of this simulation to release a value based on the time in the system. This is used together with a select value in block, where it for some given periods will release the value 1, chaiging the routing of the select value in block.



Constant value

The constant value block is self-explanatory, and in the model it is constantly producing zero values. This is to ensure that the value gate is closed when except from when orders are to be sent. The constant value block and the equation block send the values through the select value in block which is governed by the lookup table value block.

Select Value In

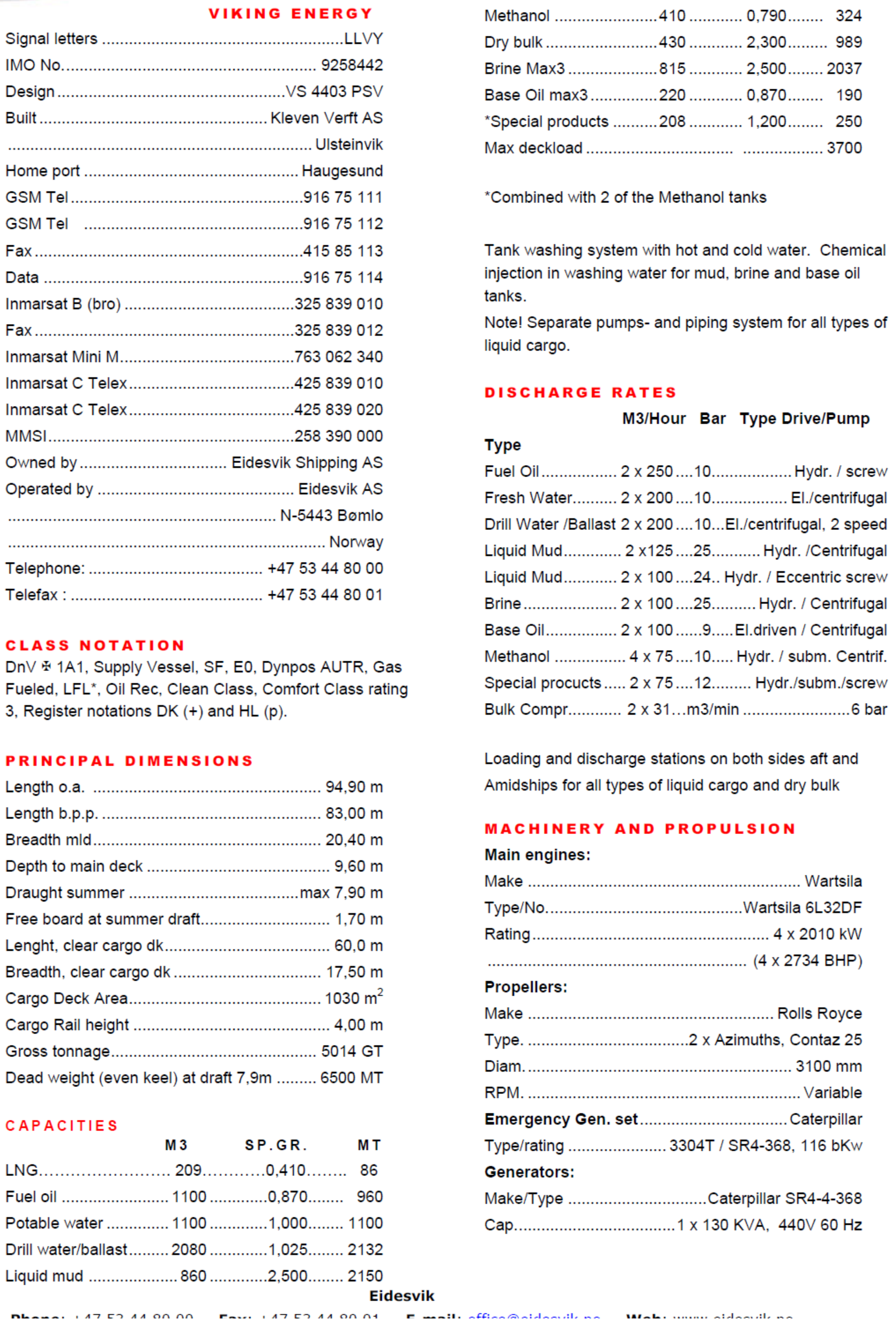
The select value in is, as described earlier, governed by the lookup table value block. As long as it is not receiving the value 1 from this block, the select value in selects the top input. In the model the top input I connected to the constant value block and thus the value that is passed through this block in that situation is zero.

B: Statoil Logistic Statistics-Confidential

C: Statoil Tank Capacities and demand calculations-Confidential

D: Vessel data

Viking Energy



VIKING ENERGY

Signal letters	LLVY
IMO No.	9258442
Design	VS 4403 PSV
Built	Kleven Verft AS
	Ulsteinvik
Home port	Haugesund
GSM Tel	916 75 111
GSM Tel	916 75 112
Fax	415 85 113
Data	916 75 114
Inmarsat B (bro)	325 839 010
Fax	325 839 012
Inmarsat Mini M	763 062 340
Inmarsat C Telex	425 839 010
Inmarsat C Telex	425 839 020
MMSI	258 390 000
Owned by	Eidesvik Shipping AS
Operated by	Eidesvik AS
	N-5443 Bømlo
	Norway
Telephone:	+47 53 44 80 00
Telefax :	+47 53 44 80 01

CLASS NOTATION

DnV ✠ 1A1, Supply Vessel, SF, E0, Dynpos AUTR, Gas Fueled, LFL*, Oil Rec, Clean Class, Comfort Class rating 3, Register notations DK (+) and HL (p).

PRINCIPAL DIMENSIONS

Length o.a.	94,90 m
Length b.p.p.	83,00 m
Breadth mld	20,40 m
Depth to main deck	9,60 m
Draught summer	max 7,90 m
Free board at summer draft	1,70 m
Lenght, clear cargo dk	60,0 m
Breadth, clear cargo dk	17,50 m
Cargo Deck Area	1030 m^2
Cargo Rail height	4,00 m
Gross tonnage	5014 GT
Dead weight (even keel) at draft 7,9m	6500 MT

CAPACITIES

	M3	SP.GR.	MT
LNG	209	0,410	86
Fuel oil	1100	0,870	960
Potable water	1100	1,000	1100
Drill water/ballast	2080	1,025	2132
Liquid mud	860	2,500	2150
Methanol	410	0,790	324
Dry bulk	430	2,300	989
Brine Max3	815	2,500	2037
Base Oil max3	220	0,870	190
*Special products	208	1,200	250
Max deckload			3700

*Combined with 2 of the Methanol tanks

Tank washing system with hot and cold water. Chemical injection in washing water for mud, brine and base oil tanks.

Note! Separate pumps- and piping system for all types of liquid cargo.

DISCHARGE RATES

Type	M3/Hour	Bar	Type Drive/Pump
Fuel Oil	2 x 250	10	Hydr. / screw
Fresh Water	2 x 200	10	El./centrifugal
Drill Water /Ballast	2 x 200	10	El./centrifugal, 2 speed
Liquid Mud	2 x125	25	Hydr. /Centrifugal
Liquid Mud	2 x 100	24	Hydr. / Eccentric screw
Brine	2 x 100	25	Hydr. / Centrifugal
Base Oil	2 x 100	9	El.driven / Centrifugal
Methanol	4 x 75	10	Hydr. / subm. Centrif.
Special procucts	2 x 75	12	Hydr./subm./screw
Bulk Compr	2 x 31…m3/min		6 bar

Loading and discharge stations on both sides aft and Amidships for all types of liquid cargo and dry bulk

MACHINERY AND PROPULSION

Main engines:

Make	Wartsila
Type/No.	Wartsila 6L32DF
Rating	4 x 2010 kW
	(4 x 2734 BHP)

Propellers:

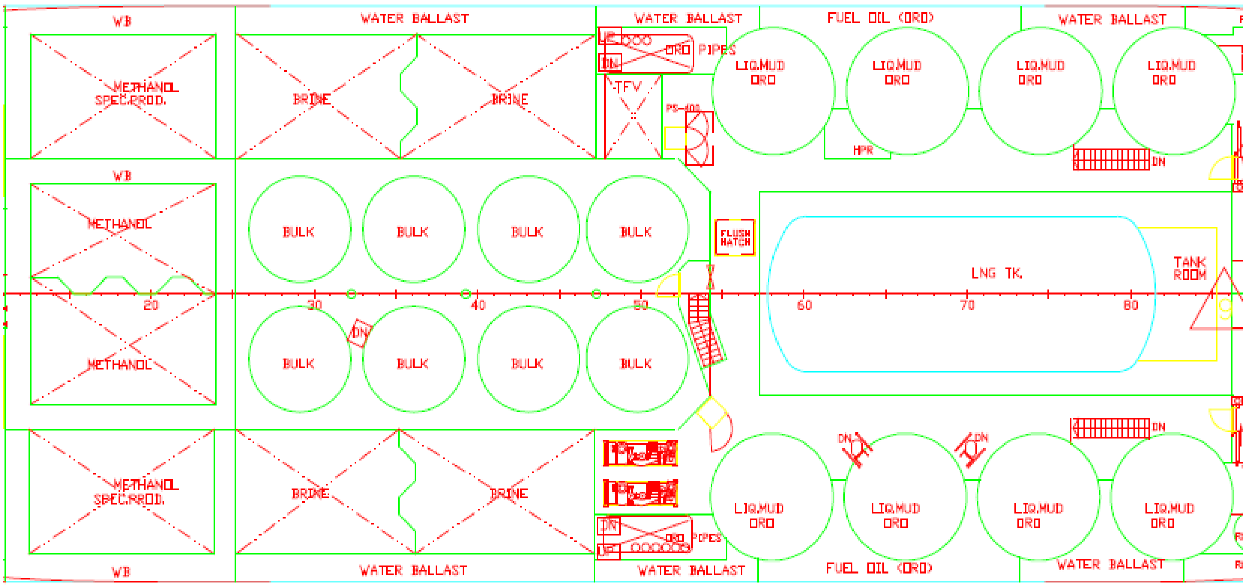
Make	Rolls Royce
Type.	2 x Azimuths, Contaz 25
Diam.	3100 mm
RPM.	Variable
Emergency Gen. set	Caterpillar
Type/rating	3304T / SR4-368, 116 bKw

Generators:

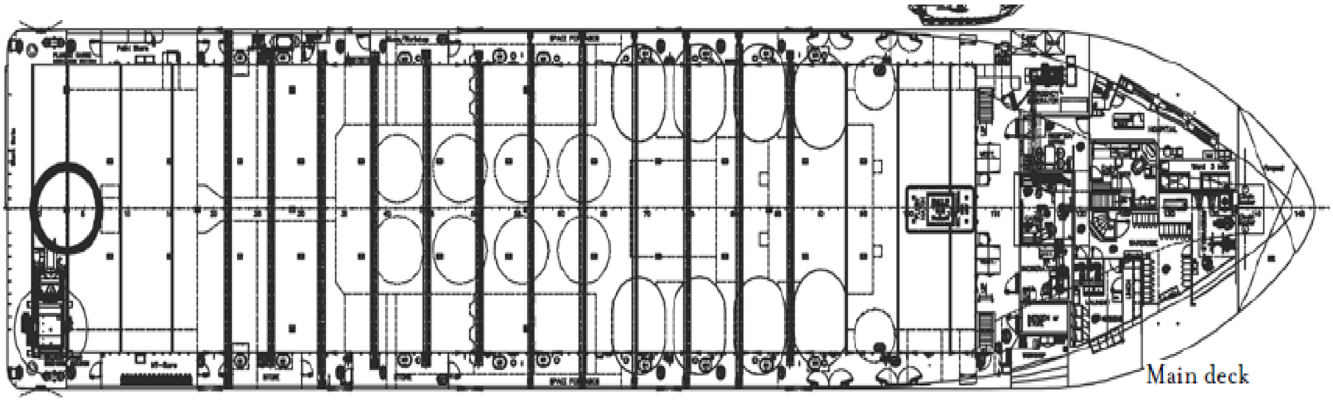
Make/Type	Caterpillar SR4-4-368
Cap.	1 x 130 KVA, 440V 60 Hz

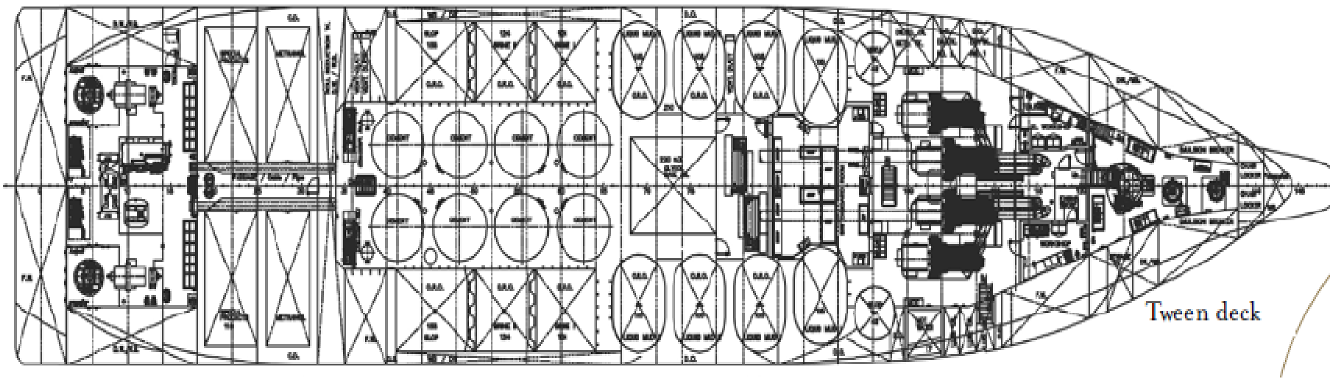
Eidesvik

Viking Energy Tanks



Havilla Foresight





MEASUREMENTS

Length o.a.	93,60 m
Length b.p.p.	86,60 m
Breath moulded	19,70 m
Depth moulded	7,85 m
Draught, max	6,30 m
Freeboard, min	1,56 m
Corresponding DWT	4785 t
Gross tonnage	4309 t
Net tonnage	1520 t
Light ship	3254 t
Displacement	8039 t

CLASSIFICATION

DNV + 1A1, E0-SF, Dynpos AUTR, CLEAN, COMF-V (rating 3), DK(10), hl(2,5 / 2,8),LFL*, OIL REC: Acc. To Nofo 2005 Standard

CARGO CAPACITIES

Deck cargo		
Deck area max		L x B=66mx15,85m = 1046m^2
Deck strength		Main deck from stern to fr. 109 = 10t/m^2
Fuel Oil		1140 m^3 Flow meter with printer
Liquid Mud	SG 2,8	860 m^3 Total 8 tanks
		1 Agitator in each tank (Hyd. Driven)
Brine	SG 2,5	505 m^3
Base oil		245 m^3
Pot water		1020 m^3
Drillwater / ballast		1235 m3 / 1730 m^3
Methanol +		215 m^3
Nitrogen bottle rack system + 1 Nitrogene Comp.		
Special Product		215 m^3
Slop		310 m^3
ORO		1480 m^3
Cement / Barite		400 m^3 8 Vertical tanks each 50 m^3
Emulsion Breaker		100 m^3

DISCHARGE RATES

Fuel Oil	2 x spindle Screw 0-250 m3 9 bar
Liquid Mud	4 x Ecc. Screw 0-100 m3 24 bar
Brine	2 x Ecc. Screw 0-250 m3 24 bar
Mineral oil	1 of 2 spindle Screw 0-150 m3 9 bar
Pot.water	2 x Spindle Screw 0-250 m3 9 bar
Drillwater/ballast	2 x Spindle Screw 0-250 m3 9 bar
Methanol	2 x Centrifugal 0- 100 m3 9 bar
Special Product	2 x Spindle Screw 0- 100 m3 9 bar
Slop	2 x Ecc. Screw 0-100 m3 24 bar
ORO	2 x Ecc. Screw 0-250 m3 24 bar
	3 x Ecc. Screw 0- 100 m3 24 bar
Cement / Barite	2 x Comp. 30 m^3 /min – 5,6 bar
	2 x Cyclone
	2 x Dust Collector
Emulsion Breaker	2 x Spindle Screw 0 – 100 m^3

TANK CLEANING SYSTEM

A total of 14 cleaning machines fitted in: MUD, Brine and Slop tanks

Slop Tank	1 x 40,0 m^3
Hot Water Tank	1 x 14,3 m^3

CARGO MANIFOLDS

ODIM ABCS system midships each side

Manifolds midships each side inside cargo rail and aft starboard side and port side.

MACHINERY / D/E-PROPULSION Resiliently Moun

Main Engines	4 x 2188 KW Cat: Type
Main generators	4 x 2200 KW Type
Harbour & Emergency Engine	1 x 400 BKW Cat: Typ
Harbour & Emergency generator	1 x 400 KW

PERFORMANCE / CONSUMPTION

Max. speed	16,
Econ. speed	13,
Service speed	12,0 knots / 10,2 m^3 pr
Econ. speed	10.
DP II Average	Draft
DP II Average	Draft
Harbour Mode	0,8 t p

MAIN PROPULSION

Frequency controlled	2 x 2200 KW RR A
Fwd. Tunnel thrusters (S Silent)	2 x 880 KW RR TT 2
	1 x RR
Fwd. Ulstein Aqua master rot table / retractable, el. driven	

BRIDGE DESIGN: NAUT - OSV

1 x Consol forward bridge
3 x Consol aft bridge
1 x Consol each bridge wing
1 x Radio station
1 x Operation Control / office
1 x Survey area

AUTOMATION SYSTEM

RRAS

LOADING COMPUTER

1 x Shipload

DP SYSTEM DYNPOS AUTR

Rolls – Royce RR DP2 AUTR
1 x CySkan Laser
1 x DPS Veripos LHD2 – GG1
1 x DPS Veripos LHD2 – G2
2 x Wind sensors: GILL Ultrasonic
1 x Radius

THRUSTER CONTROL

RR Helikonex

BRIDGE WATCH MONITORING SYSTEM

Ulstein BAS

TANK NR	Volume M³	Fuel	Pot Water	Drill water M³	Ballast water	Mud SG 2.8	Brine SG 2.5	Glycol Base Oil	Methanol	ORO Crude Oil	Emulsion Urea Special product	Anti Heeling Slop	Dry Bulk
1	149,7			149,7	149,7								
2 PS	98,2			98,2	98,2								
2 SB	85,2			85,2	85,2								
3 PS	128,5		128,5										
3 SB	130,5		130,5										
4 PS	82,3	82,3											
4 CL	116,6	116,6											
4 SB	89,7	89,7											
5 PS	139,4	139,4											
5 SB	139,4	139,4											
6 PS	195,6	195,6											
6 CL	102,1	102,1											
6 SB	197,2	197,2											
7 PS	146,7			146,7	146,7								
7 CL	142,6			142,6	142,6								
7 SB	146,7			146,7	146,7								
8 PS	186,6		186,6										
8 SB	189,3		189,3										
9 PS	107,4								107,4				
9 SB	107,4								107,4				
10 PS	109,0										109,0		
10 SB	104,7										104,7		
11 PS	77,5			77,5	77,5								
11 CL	175,5		175,5										
11 SB	83,3			83,3	83,3								
12 PS	105,0		105,0										
12 SB	105,0		105,0										
13PS	51,0										51,0		
13SB	51,0										51,0		
14 PS	40,5										40,5		
14 SB	40,1											40,1	
15 PS	110,5					110,5							
15 SB	110,5					110,5							
16 PS	109,9					109,9				109,9			
16 SB	109,9					109,9				109,9			
17 PS	109,9					109,9				109,9			
17 SB	109,9					109,9				109,9			
18 PS	109,9					109,9				109,9			
18 SB	109,9					109,9				109,9			
19 CL	243,7							243,7					
20 PS	128,6						128,6			128,6			
20 SB	128,6						128,6			128,6			
21 PS	124,8						124,8			124,8			
21 SB	124,8						124,8			124,8			
22 PS	155,9									155,9		155,9	
22 SB	155,9									155,9		155,9	
23 RRT	93,3			93,3	93,3							93,3	
24 RRT	97,4			97,4	97,4							97,4	
25 RRT	116,2			116,2	116,2							116,2	
44 CD	281,6				281,6								
45 CD	212,8				212,8								
BAR 1													50,0
BAR 2													50,0
BAR 3													50,0
BAR 4													50,0
CEM 5													50,0
CEM 6													50,0
CEM 7													50,0
CEM 8													50,0
TOTAL		1062,3	1020,4	1236,8	1731,2	880,4	506,8	0,0	107,4	0,0	356,2	658,8	400,0

E: ROP and Safety Stock calculation-Confidential

F: GFC capacities, max consumption-Confidential

G: Model, reports, images and graphs-Confidential

The size of the model, report and amount of images and graphs generated in the model was found to be too large to given in the print out report. This can be found on the appendix cd. Due to the size of the model files, which all in all accumulated to 16 GB, the only model that is available on the cd is for GFA with the original as-is setting. This will show the general model setup.

H: Master Sailing Schedule-Confidential