FRAMEWORK FOR SIMULATING LNG PORTS

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ABSTRACT

LNG ports are often located at very remote locations and have a dedicated function of exporting product to markets worldwide. Vessels are dedicated to routes between ports and often are part of the investment. These are just a couple of the characteristics of a LNG exporting port. Due to these specific characteristics the design and simulation of such a port is different from a normal maritime port. In this paper we identify a set of attention points that need to be considered and help to perform a simulation study for a LNG port. We have applied these attention points to a new LNG port in Yemen and describe the results and the advantages of following these additional processes in an early stage of the simulation study..

Keywords: port design, LNG vessels, discrete event simulation

1. INTRODUCTION

With the cost of oil increasing, it becomes more worthwhile to invest in alternative sources of energy. LNG is one of the fuels rapidly gaining interest, but LNG is only available at very remote locations. Further LNG is expensive and hazardous to transport from these remote locations to ports that can handle and have storage facilities. With the requirements for LNG products in the Western world, three types of investments can be spotted in news papers more often:

- Port Authorities preparing their port for the import of the product
- Vessels being build and put to use
- New LNG train production facilities with ports for exporting

In this paper we discuss the complexity and the special elements in design studies for the third point of the list above. Compared to a normal export terminal the following things appear to be of great importance in a design study for LNG port operation:

- The locations of LNG ports are remote, most often due to the difficult wind and wave conditions
- LNG vessels require large safety distances from other vessels
- LNG vessels can not be loaded partially, but due to the bad weather the loading process could be interrupted
- Production of the LNG is a continuous process, stopping the process due to lack of storage space is unacceptable
- Production and throughput flows must not be stopped due to financial requirements

Several researchers have described how ports and marine traffic should be simulated (Kidston and Kunz 2008, Thiers 1998, Fu and Fang 1998). Some have even developed generic toolsets for the modeling of maritime traffic in a port, for example POSEIDON (Carbone et al 1998). Over the years the generic work has specialized for container terminals (Mayer et al 2004, Nam et al 2002), but no work has been done specifically for LNG terminals to the knowledge of the authors.

We believe that the items which are crucial in LNG port design also have crucial effects to the way a simulation study for a LNG port must be executed. The specific elements should be included in the simulation model and put in the correct perspective in performing the scenarios for design evaluations. This paper describes a list of attention points with common options that are specific in a simulation model for LNG terminal design.

The second section describes in more detail the consequences and background of the LNG specific requirements. The third section describes the attention points for development of the simulation model for LNG ports. We applied these attention points successfully for LNG operations at a port in Yemen and Russia, which we describe in section 4. We end this paper with some remarks and conclusions for further improvement of the framework.

2. SPECIFIC IN LNG SIMULATION STUDY

Vessels that come to a LNG port to be loaded are often dedicated vessels making a round trip to a market and back to the port. These vessels will arrive according to a schedule that is reasonable well adjusted to the nominal production of the facility. However, the exact arrival cannot be predicted and is influenced by other events the vessel has encountered, for example the waiting time in the port of unloading or weather conditions at the ocean. The majority of the vessels will arrive, but a minor set of vessels will arrive between 24 and 56 hours later then desired based on the levels in the storage.

Once the vessel is arriving, it cannot just go to the berth. Several conditions need to be met for the vessel, of which the weather conditions are probably the most fluctuating. LNG is found at remote areas such as Middle East, the Pacific or the North pole. At all these places the weather can be terrible, resulting in high waves coming from different directions. The design of the berth layout can reduce the effect of the wave conditions, but still quite some disturbance can be encountered by vessels during connection to the berth, loading or departure to open sea. Correct representation of these events either requires a historical data file of the weather, wind and waves in the region or information from meteocean models.

Additional complexity in the process of vessel handling is that once a vessel starts with a process, it cannot stop. The vessel needs to be able to travel without interruptions to the berth, the vessel cannot leave the berth half way the loading process and vessel travel cannot be interrupted during the travel to open sea.

While the vessel movements are very variable, the production of the LNG trains is not. It is a constant flow of product into LNG tanks. The only interferences are the scheduled maintenance period or breakdowns somewhere in the train. The maintenance schedule for LNG trains is a long cycle of up to 5 to 7 years.

3. FRAMEWORK WHAT SHOULD MODEL CONTAIN

The processes in the simulation model for LNG can be separated into two parts:

- Production of LNG
- Vessel operation

The simulation model need to contain the items that are specific for LNG port operations, further specified to the actual port or production facilities. We identify attention points that should be incorporated into the simulation model. These attention points combined result in the framework for LNG port simulation models.

The production of the LNG might seem simple, because it is a constant flow of product into tanks, but it is affected by three major items:

- Availability of storage space in a tank
- Maintenance cycle
- Breakdown occurrences

Availability of storage space in a tank means that the production will stop if no space is available. It also means that the LNG production trains have to evaluate from a set of tanks which tank to fill. The selection mechanism will evaluate the tanks that are available for storage and based on the correct state of the tank. For example, if two tanks are available, the mechanism will select the largest tank or the tank with the most available space still to be filled. Once the LNG production has filled a tank, a new tank needs to be selected and this process needs to be triggered.

Attention point 1: Selection mechanism for a tank to fill be evaluated every time that a tank is filled.

The production process needs to be stopped when all tanks are full. A restart of the production facilities, even if the stoppage is only half an hour, requires a couple of hours before the restart of the production reaches full speed. The effect of a stoppage of production is thus larger then just the hours until a vessel starts to empty the tanks. For example if a vessel is only 1 hour too late, then the stoppage of production easily takes 10 hours. Unnecessary long stoppages can be avoided by reducing the rate of production at the moment that the storage capacity is nearly fully utilized. A reduction of the production rates for as little as 1 hour can avoid a complete stoppage of the LNG production facilities.

Attention point 2: Production rate might change when tanks are about to be full.

In simulation is a rule of thumb that the length of a simulation replication is approximately three times as long as the longest effective cycle. The longest cycle in the LNG production facilities is the scheduled maintenance cycle of 5 to 7 years. As a result, the cycle for a simulation should be around 15 to 21 years. If we also consider the need for multiple replications, then we might have a total run time of several centuries for valid results. A trade off might be to focus only on the months with the maintenance or months with specific weather to reduce the run time.

Attention point 3: Trade off to handle maintenance of production facilities in short separate simulation experiments.

A final point of attention in the shipping study is to consider the effect of breakdowns to the overall system. Murphy’s law claims that breakdowns occur when you least want them, but in a simulation model for shipping it is much worse if the breakdowns do not occur at all. The effect of a breakdown is that the storage gets less filled then would occur given a normal production. Therefore, a breakdown of production units might cause that less storage capacity is required and that less stoppages occur due to overloading the available tanks. Thus a trade off needs to be made whether it is worthwhile to consider breakdowns of production trains in the simulation model.

Attention point 4: Trade off to include the effect of breakdowns of the production trains.

The vessel operation is a more complex process that consists of items shown in the process flow underneath: Vessel arrival at port can be triggered by different processes. Vessels are part of a network serving mechanism and the network is designed in such a way that the vessels should arrive when sufficient product is in the storage. In normal maritime simulation projects the vessels that arrive are highly random in number, size and type. A LNG port does not have this randomness, only LNG vessels will arrive and the size of LNG vessels is almost always the same type. There are different ways to handle the lack of randomness. One option is to include the complete network of the vessel and allow vessels to move from the port where the vessel is loaded to the market port and back. This requires some more data collection, but has the advantage of also providing insight in the requirements for vessels. Vessels can also be generated new into the system at the moment that they are expected. A schedule could be defined ahead of the simulation experiment to define exactly when a vessel is expected to come based on a constant production or put some sensors in the tanks that evaluate and trigger a new vessel to arrive at the moment that sufficient product is in stock.

Attention point 5: Select a mechanism to handle arrival of vessels.

Once a vessel arrives near the terminal it is not allowed directly to go to berth and get loaded. Depending on the port one or more checks need to be performed before a vessel is granted permission. The most common permissions for LNG vessels are the following:

- Capacity in storage - sufficient product should be available in the storage tanks before the LNG vessel can move to the berth
- Berth - the berth is available for the LNG vessel
- Wave height - the wave height is not above a threshold for berthing operations
- Predicted wave height - the predicted wave height to be expected for the duration of the loading operation is not exceeding the threshold for vessels being located at berth
- Channel - the channel to be used to travel to the berth is available
- Tugs - tugs to support the vessel to move to the berth are available
- Pilots - pilots to support the vessel to navigate to the berth are available
- Time period - the vessel arrival applies to time periods that need to be considered

In addition to the wave height it might also be required to consider the direction of the waves. For example, waves coming from the South have hardly any effect to a vessel, due to the position of the berth and thus the waves of the South have a higher threshold then waves coming from the East. The same applies for the future wave height resulting in thresholds during the loading process.

Attention point 6: Decide which conditions need to be met before a vessel is allowed to travel to the berth of the port.

The LNG vessel that is allowed to move to the berth and is ready to perform the operational steps will first require one or more resources for traveling to the berth. These resources can be the tugs and pilots, but also might be the channel and reservations in the future to have access over crossing points with other waterways. The conditions mentioned in attention point 6 are all matched, but still the physical claim to the resources in the port need to be performed.

Attention point 7: Claim physical resources required for traveling to the berth

The LNG vessel at the berth will be subject to one or more processes before the actual loading can start. These processes are connection to the loading arms, verifying custom papers etcetera. The actual loading process will consume LNG from one or more storage tanks. The LNG vessel will perform comparable decisions as have been made by the selection for a tank to fill from the production trains. The correct tank needs to be allocated and available to be emptied. When the selected tank is emptied into a vessel another tank is selected, until the vessel is loaded ready to leave or until some kind of disturbance occurs. In some designs of storage tanks and pipes is decided to empty several tanks simultaneously to fill a vessel. This includes additional complexity to the selection mechanism and to the decisions made to design the number of tanks and options to consume LNG from a tank to load a vessel.

Attention point 8: Selection mechanism for a tank to be emptied to load the LNG vessel

Loading operation of a vessel is vulnerable for disturbances that occur in reality. The most common disturbances are:

- Breakdown of one or more loading arms
- Waves above threshold that require stoppage of loading
- Insufficient product in storage tanks to continue loading

In the simulation model these disturbances should be included and also handled. For example, a breakdown can result in a slower loading rate or it can stop the loading completely. The high waves can enforce loading to be temporarily stopped, but it can also mean that a vessel needs to leave the berth completely and reconnect to the berth in a later stage.

Attention point 9: Evaluate the applicable disturbances to the loading process with their effects.

Finally, when the loading is completed, the full LNG vessel can be prepared to depart to open sea. Again a range of permissions needs to be verified for applicability to the specific LNG port. The most common permissions for LNG vessels leaving the berth are the following:

- Wave height - the wave height is not above a threshold for berthing operations
- Channel - the channel to be used to travel to the berth is available
- Tugs - tugs to support the vessel to move to the berth are available
- Pilots - pilots to support the vessel to navigate to the berth are available
- Time period - the vessel arrival applies to time periods that need to be considered

Attention point 10: Decide which conditions need to be met before a vessel is allowed to leave the berth to travel to open sea

The LNG vessel that is allowed to leave the berth will first require most likely the same resources as it required to get to the berth for attention point 7.

Attention point 11: Claim physical resources required for traveling from the berth to open sea

4. EVALUATION OF APPLICABILITY FRAMEWORK

The applicability of the framework and attention points are underneath demonstrated using two different simulation studies performed by Sogreah and Systems Navigator for Total. The first simulation study is a LNG terminal for a LNG production of 32 million ton annual in Yemen, the second simulation is a LNG terminal for production growing from 39 million ton to 117 million ton annual in Russia. The two simulation studies followed the same process steps as described underneath:

- Define the requirements of the simulation model based on the attention points mentioned in section 3
- Develop the simulation model in Arena 11.0
- Interface the simulation model using Scenario Navigator
- Perform convergence tests for the base design with weather data from historical files using different number of replications
- Perform sensitivity scenarios for different constraints and designs
- Report on outcome of sensitivities with overview reports and detailed reports of individual vessel movements and events in production process

4.1. LNG Terminal in Yemen

Total is developing a new terminal in Yemen in which 2 LNG production trains will feed 2 tanks. The LNG will be exported via vessels at one berth. The berth will not contain break waters, thus different thresholds apply to the berthing, loading process and forced departures. In the region especially in June, July and August high waves affect the vessel movements due to the monsoon.

4.1.1. Attention points in Yemen

Attention point 1: Selection mechanism for a tank to fill be evaluated every time that a tank is filled.

Both tanks are filled simultaneously

Attention point 2: Production rate might change when tanks are about to be full.

Sensitivity studies are performed with reducing the production rate if the tank is above a certain level. In other sensitivity scenarios the production is completely reduced during the monsoon period to reduce the risk of overloading the tank storage.

Attention point 3: Trade off to handle maintenance of production facilities in short separate simulation experiments.

Long maintenance is considered in a planning for 7 years with large maintenance of 30 days and short maintenance of 7 years.

Attention point 4: Trade off to include the effect of breakdowns of the production trains.

Short breakdowns for the production trains are excluded of the simulation.

Attention point 5: Select a mechanism to handle arrival of vessels.

A vessel will be triggered to arrive if the level in the tank is more than 180.000 tons in both tanks. After this trigger there is a 5% chance that the vessel is more up to 12 hours late and a 1% chance that a vessel is 12 to 48 hours later than the moment of the trigger.

If a vessel is at the berth loading and the tank contains more than 180.000 tons, then a new vessel will only be triggered if the total quantity in the tanks is sufficient for both vessels.

Attention point 6: Decide which conditions need to be met before a vessel is allowed to travel to the berth of the port.

The conditions that need to be met are varied in the simulation experiments. The base case scenario contains the following checks:

- Berth is available
- No berthing threshold while traveling to the berth
- No forced departure threshold while loading. The full loading period will be evaluated, including extra time for repair to loading arms or delays due to loading thresholds.
- During the monsoon period vessels only move to the berth between 6 and 12 in the morning

In some scenarios the vessels were allowed to move directly to the berth without considering the possibility of a departure threshold. In these scenarios the number of forced departures was higher than in the base case.

In some other scenarios the forecasting has been adjusted with extra strong thresholds or thresholds that were different for the coming 24 hours and the period after this.

Attention point 7: Claim physical resources required for traveling to the berth

The terminal has only one berth and thus only one vessel at the time needs to be handled. Therefore, restrictions such as a channel or tugs have not been considered. The only restriction is the availability of the berth.

Attention point 8: Selection mechanism for a tank to be emptied to load the LNG vessel

The two tanks will simultaneously fill the vessel. Thanks to the simultaneous loading and the simultaneous filling will the level in tank 1 always be the same as in tank 2.

Attention point 9: Evaluate the applicable disturbances to the loading process with their effects.

The vessels encounter 2 disturbances during the loading process. The first disturbance is the weather. If the waves from a certain direction are above a threshold level the vessels should stop loading or even leave the berth temporarily to return to the berth once the level of waves is safe again. The second disturbance that applies to the vessel is the state of loading arms. The loading arms have irregular breakdowns in small percentage of times that the loading is performed. In some very rare situations even both loading arms are broken down, stopping the filling of the vessels completely. If only one of the loading arms has a breakdown, then the production rate drops from 10 t/hr to 5 t/hr.

Attention point 10: Decide which conditions need to be met before a vessel is allowed to leave the berth to travel to open sea

Vessels are allowed to move to open sea once they are 100% loaded. The vessel does not encounter any physical issues while leaving.

Attention point 11: Claim physical resources required for traveling from the berth to open sea

This is similar as attention point 7: the physical resources are not a restriction.

4.1.2. Simulation model of Yemen

The figure underneath shows the animation of the simulation model in Yemen with the two active LNG production trains, the LNG tank storage and the level of LNG already loaded into the vessel.

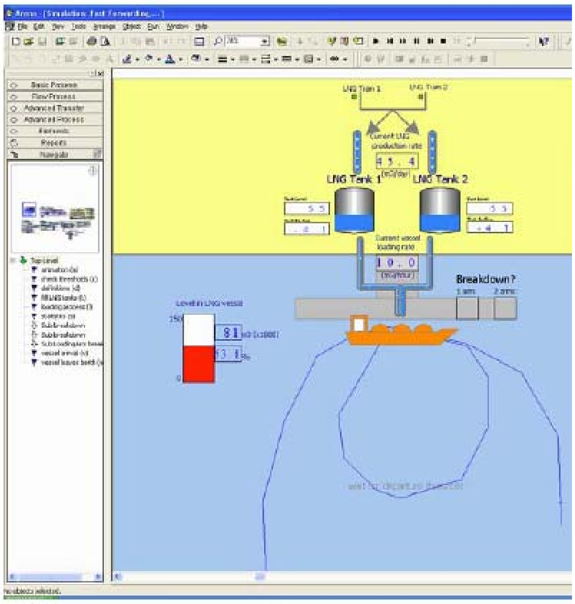

Figure 1: Simulation MODEL in YEMEN

4.1.3. Project conclusions Yemen

The graph underneath shows the waiting time of vessels in different sensitivity studies and allows easy comparison of the best configuration and the effects of different scenarios and tests.

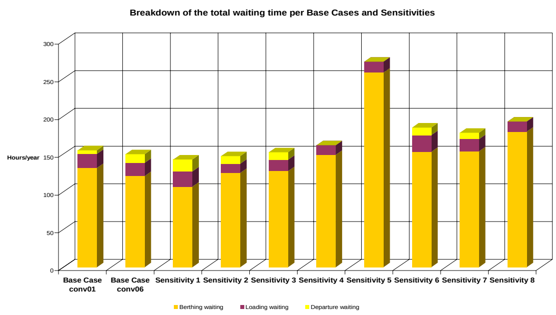

Figure 2: Waiting time of vessels

The graph is only one of the many performance indicators that have been (graphically) represented and provided to the future port operator. Every individual scenario provided almost 700 pages of structured documentation enabling detailed analysis of each aspect of the scenario.

4.2. LNG Terminal in Russia

The Russian authorities have allowed Total and GazProm to exploit the LNG field 300 kms North of Murmansk (the Shtokman fields). A first port design has resulted into 3 different layouts that should physically be possible to export the LNG production in phases. The first phase is two berths for handling export of LNG produced by 1 LNG train. The second phase will double the production capacity and at the end of the third phase 3 berths will be available with 6 tanks and 4 LNG production trains.

Depending on the layout the berth will be protected by break waters or natural riffs, thus different thresholds apply to the berthing, loading process and forced departures. Especially from October to April the weather in this region is bad due to the cold.

4.2.1. Attention points in Russia

Attention point 1: Selection mechanism for a tank to fill be evaluated every time that a tank is filled.

All tanks available in a phase are filled simultaneously

Attention point 2: Production rate might change when tanks are about to be full.

Sensitivity studies are performed with reducing the production rate if the tank level is above the nominal level, but did not reach the geometrical level of the tank yet.

Attention point 3: Trade off to handle maintenance of production facilities in short separate simulation experiments.

Long maintenance is considered yearly for 32 days. This maintenance included the required time for restating the facilities after a stoppage. The LNG trains schedule their maintenance from the first of the month May, June, July or August.

Attention point 4: Trade off to include the effect of breakdowns of the production trains.

Short breakdowns for the production trains are excluded of the simulation.

Attention point 5: Select a mechanism to handle arrival of vessels.

The LNG production will be exported by two types of vessels, Membrane or Spherical vessels. The type of vessel that arrive next depends on a random chance of 90% or 50% in some sensitivies. A vessel will be triggered to arrive if the level in all the tanks is more than the quantity required to load the vessel. Thi includes reservations for liquid by vessels that are already loading at one of the other available vessels. Thanks to the storage capacity and the ability to handle several vessels simultaneously it is possible in this port to have one or more vessels waiting outside in open sea for access to a berth.

After the trigger that sufficient product is in a tank for the vessel a delay applies for late arrivals of vessels. There is a 5% chance that the vessel is more up to 12 hours late and a 1% chance that a vessel is 12 to 48 hours later than the moment of the trigger.

Attention point 6: Decide which conditions need to be met before a vessel is allowed to travel to the berth of the port.

The conditions that need to be met are varied in the simulation experiments. The base case scenario contains the following checks:

- Berth is available
- No berthing threshold while traveling to the berth
- No forced departure threshold while loading. The full loading period will be evaluated, including extra time for repair to loading arms or delays due to loading thresholds.
- Tugs are available
- No other vessel is traveling through the channel

In some scenarios the vessels were allowed to move directly to the berth without considering the possibility of a departure threshold. In these scenarios the number of forced departures was higher than in the base case.

In some other scenarios the forecasting has been adjusted with extra strong thresholds or thresholds that were different for the coming 24 hours and the period after this, either the full year, or only in the winter period.

Attention point 7: Claim physical resources required for traveling to the berth

The terminal has in phase one only one berth and thus only one vessel at the time needs to be handled. In phase 2 and 3 the number of berths used by LNG vessels will be increased, thus the tugs and the channel availability becomes a limitation.

Attention point 8: Selection mechanism for a tank to be emptied to load the LNG vessel

All the tanks will simultaneously fill the vessel. Thanks to the simultaneous loading and the simultaneous filling will the level in tank 1 always be the same as the level in the other tanks.

Attention point 9: Evaluate the applicable disturbances to the loading process with their effects.

The vessels encounter only disturbances due to the weather. If the waves from a certain direction are above a threshold level the vessels should stop loading or even leave the berth temporarily to return to the berth once the level of waves is safe again.

Attention point 10: Decide which conditions need to be met before a vessel is allowed to leave the berth to travel to open sea

Vessels are allowed to move to open sea once they are 100% loaded, the tugs are available and the channel is not occupied by an other vessel.

Attention point 11: Claim physical resources required for traveling from the berth to open sea

This is similar as attention point 7: the physical resources are restricted for tugs and the channel.

4.2.2. Simulation model of Yemen

The figure underneath shows the animation of the simulation model in Russia with 3 LNG trains, 4 tanks and 2 loading berths. The purple vessel is a membrane vessel ready to leave and the orange vessel is a spherical vessel arriving to be loaded at berth 2.

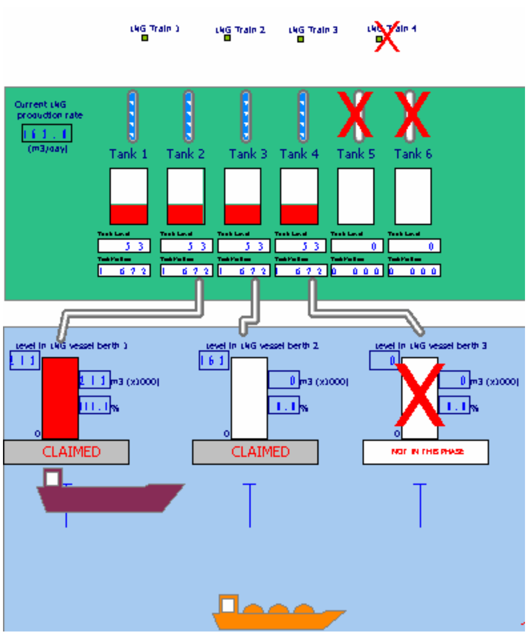

Figure 3: Simulation MODEL in RUSSIA

4.2.3. Project conclusions Russia

The graph underneath shows the waiting time of vessels in different sensitivity studies and allows easy comparison of the best configuration and the effects of different scenarios and tests.

The graph is only one of the many performance indicators that have been (graphically) represented and provided to the future port operator. Every individual scenario provided almost 700 pages of structured documentation enabling detailed analysis of each aspect of the scenario.

5. CONCLUSIONS AND FURTHER RESEARCH

The main use of the framework has been in discussing with the customers the need for modeling their LNG operation and explain them why certain information is needed. We found out that the list of possible conditions to verify permissions require extension. It turned out, mainly in the simulation study of the LNG operations in Yemen, that the time periods that apply are different over the periods of time in the year.

Further we noticed during the model development and the first analysis, that it would have been very useful to also specify a framework for reporting and types of reports to be gained from the simulation model. Early discussion about the content of the reports would have enhanced the understanding and reduced the rework that has been done in final stages.

The framework has helped in the specification for the simulation model, we foresee further research whether we could make dedicated simulation building blocks for the maritime shipping studies like these LNG ports to enable more rapidly implementation of the simulation model.

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