Simulation Information Paper

The Use of Computer Simulation in LNG Shipping and Terminal Applications

Introduction

As computer memory and processing speeds have increased over the years at seemingly exponential rates, so has the ability to carry out complex simulation of many different facets of our every day life. Flight Simulator packages are just one example where a sophisticated package has been developed for the domestic market and has spawned a large number of aircraft models that developers have made freely available.

Shipping simulation has not captured the imagination of the public in quite the same way as flight simulation and remains the preserve of the specialist software developer and modeller. It is also true to say that shipping simulation carried out in real time can be tedious for those with only a passing interest.

The purpose of this paper is to look at the application of simulation in the LNG shipping and terminal interface areas of operations, to discuss the types of simulation programmes available, their application and to make some general recommendations on their use, expanding on the general statement;

> *"Before LNG operations begin at a port with no previous history of the trade, it is prudent for simulator training to be provided for pilots and, perhaps, tug masters. Such training would aim to ensure all involved parties are thoroughly au fait with the proposed operation and are practised in handling emergency procedures and deviations from the plan"*

from the SIGTTO publication ***"LNG Operations in Port Areas"***.

This paper will not make recommendations in respect of specialist simulation service providers (although it will list many of those with which SIGTTO Members have worked) nor will it cover the basic STCW type Bridge Resource Management or Bridge Team Training simulators that are prevalent amongst the many nautical colleges world-wide. Neither does this document seek to address the use of simulators in port channel design which is extensively covered in the PIANC document ***"Approach Channels – A Guide for Design".***

Computer Simulation in LNG Shipping and Terminal Applications

A ship manoeuvring simulation model is a complex mathematical model of the behaviour of a ship under the influences of a number of modelled parameters reflecting the environment in which it is operating. These modelled parameters extend to sea state, weather conditions, bathymetry and any other external influence that may affect the behaviour of the vessel.

Such ship manoeuvring simulators are available in many different forms and each may have a particular application as discussed below.

Project Feasibility

In the early days of any intended LNG project, the focus of any calculation is on feasibility, fleet size for the intended route and terminal storage requirements. Once these parameters have been established, certain aspects of the project may be modelled in much greater detail.

Fleet size can be modelled effectively on a simple spreadsheet package using variables such as vessel size, speed, boil off rates, voyage distance, port time, required delivered quantities and a range of other factors or a more complex simulation package can be used. The answers derived from such modelling are reasonably accurate even with fairly simplistic assumptions. Greater complexity in respect of inputs and variables in the spreadsheet model perhaps only result in marginal improvements in the results and potential “spurious accuracy”. Nevertheless, for the initial stages of a project, these results may be sufficient to confirm assumptions and to get a ‘feel’ for the viability of the project.

The first key part of ship modelling comes into effect when looking at potential export and import terminal locations if these are “greenfield” sites or located in ports which have not, hitherto, handled LNG ships.

The Fast Time Simulator

For such studies looking at the entry of an LNG ship into a potential LNG terminal location, the best way to model this is to use a simulator package which may be capable of fast time simulation on a laptop or desktop computer, usually providing a plan view of the port. An experienced mariner attached to the project should be able to carry out a detailed simulation of the port entry using an LNG ship model and a geographic database of the port approaches. The models provided with such a simulator are usually selected by the purchaser from a library of LNG and other ship models. The geographic database usually has to be modelled by the software manufacturer – a process that may take several weeks – and is based on existing charts and information available in the public domain.

The mariner will then perform a number of entry and departure runs using different tug configurations (tug models of varying bollard pull are built into the model) and different weather and current conditions to determine the suitability of the port location. At this stage, other shipping movements within the port area are not taken into consideration – these would need to be the subject of a separate Quantified Risk Assessment carried out in conjunction with, or at least shared with, the relevant Port Authority.

This modelling is carried out by one person controlling all inputs and can be "made to work" through repetition, fine tuning the use of tugs and the other external forces but does not guarantee safe port entry and exit over a wider range of variable parameters, nor does it generally model any interaction with other shipping. Furthermore, fast time simulation has the ability to distort the findings as fast time motion is perceived differently to real time. Fast time simulation may also provide "instantaneous" vector tug inputs rather than making due allowance for the time operations take in reality.

Use of fast time simulation requires the mariner to use his experience and judgement to determine whether any inability to perform the manoeuvre is based on his own inability in respect of shiphandling or the external influences of the conditions being modelled. If the port approach/departure calls for manoeuvring where there are very small margins of error, it will be necessary to perform a number of runs to ensure repeatability and it may be beneficial to get another experienced mariner to perform the same manoeuvre to verify that it is feasible.

Reliance on fast time simulation alone is not sufficient and full mission bridge simulation should be employed to ensure that the same manoeuvres can be carried out in a full situational display (rather than in the plan view mode) and using a bridge team approach.

Project Simulation Models

As some of the initial "unknown" concepts in an LNG project are firmed up, it is usual for the Pre-FEED (Front End Engineering Design) contractor or the project team themselves to commission a detailed project model which will look at a large number of variables such as gas and LNG production rates, plant maintenance downtime, export terminal tankage requirements and fleet size (number of ships and volumetric capacity). In some cases, the receiving terminal(s) may also be modelled to identify any storage or scheduling constraints that may apply at the import end with the potential to impact on the export terminal. This model will also factor in dry docking of the fleet and weather conditions where these will have an impact on the ability to maintain regularity of supply.

Once again, the complexity modelled can vary considerably. If the terminal location at either end of the supply chain is in a Tropical Revolving Storm belt, random shutdowns or vessel delays due to bad weather may be built in. Daytime or 24 hour berthing rules may apply, routes involving ice may include algorithms for ice breaking performance, the use of leads in ice and pressure events. Weather conditions may be modelled for the entire route, particularly if the weather can be extreme such as crossing the North Pacific.

In one particular case, a simulation model used 6 years of real weather data and the simulation determined each vessel's performance based on where it was, what weather it was seeing and direction relative to the ship's head such that two passing ships seeing the same weather would return different simulation speeds for the next 12 hour period. This obviously needed vessel hull performance algorithms to be built into the simulation model.

From such simulation results, decisions can then be made on the optimal plant size and tankage at the production terminal, fleet size based on weather, vessel inter-arrival time, dry docking and other external influences and, if required, tankage at an import terminal.

It is essential that when performing model runs, only one parameter is changed at a time to enable the effect of that parameter to be understood. Changing more than one parameter at a time can result in masking of individual component contributions to the simulation outcome and may either negate each other or act in conjunction, thus greatly affecting (and devaluing) the output.

Introducing the Human Factor

With the exception of the feasibility study using a fast-time simulator, almost all the simulation carried out in our LNG project has been based on assumptions but there comes a time when the human element has to be brought in. This may identify additional port dredging requirements or navigational aids but will also be used to set certain parameters such as the number and size of tugs, terminal operating limits and also act as a training tool.

At this point, simulation is carried out in real time, using real people in a variety of roles in a full mission bridge simulator. Due to timing considerations, certain factors may have already been set at this point in the project, such as the required tug bollard pull if the project is to build its own tugs. If tugs are available from marine service providers, the actual bollard pull requirements may be established at this stage.

Modelling the LNG terminal for use in a full mission bridge simulator should be carried out at least 9 months before the terminal becomes operational. In general, it will take 2 months to build the port geographical database and carry out the necessary validation of the port model. Those companies that are able to carry out the necessary port modelling required at this stage generally have a library of validated LNG ship models – if a specific ship model has to be built, consideration needs to be given to how this may be validated, particularly if sea trial performance data is not available for a class of vessel still under construction.

Full Mission Bridge Simulation

Full mission bridge simulation has been in use for over 30 years as a training tool for ships' officers and Radar training using simulation is a requirement under STCW although specific Bridge Resource Management training is not. Over this time, simulators have progressed from basic night time simulators showing light points only to daylight simulators with full graphics representing the area being considered. Apart from this STCW training requirement, the use of such simulators has expanded to cover Bridge Team Management, Bridge Resource Management, Dynamic Positioning simulation (manoeuvring to, from and at FPSOs), lightening and other general marine operations. Casualty reconstruction and research projects are also increasingly being carried out on bridge simulators.

It should be noted that the more basic "STCW type" simulator will generally be unsuitable for the detailed and complex LNG port manoeuvring and training that is required to be carried out. Very careful consideration is required to be given to the selection of facilities commissioned to undertake this work and they should have a proven track record of performing such work, including establishing weather limitations, determination of tug power and pilot/tug master training.

Full mission bridge simulation should be used for setting the terminal operating limits (as opposed to the engineering limits established at the time of design) and as a training tool, bringing in external parties such as tug masters and pilots. Ideally the officers designated to serve on board the ships using the port should also take part in this training but they may not be available (or even identified) at this point. This simulation can also be used to determine optimum tug power, numbers and usage, taking into account potential failures such that may occur during the berthing/unberthing manoeuvres.

Preferably, the full mission bridge simulator used should provide an "own ship" bridge interfaced with at least 2 separate tug simulators to provide suitable training for the tug masters who will operate with the pilots and officers of the LNG vessel. Additional tug input to the manoeuvres will normally be fed in through the simulation control station. The purpose of the training carried out at this stage is to provide the Pilot and tug masters with the opportunity to practice handling the LNG carrier in weather and tidal conditions close to the limits of operability, giving them the opportunity to practice emergency situations and to make sure that all manoeuvres are carried out safely and in full control of the LNG vessel at all times.

Simulation of this type will typically take two weeks – the first few days ensuring the geographic model is validated by the Pilots and giving them the "feel" of the simulator and the LNG vessel model(s) being used. Operational limits are then determined through a sequence of simulations starting close to the berth and involving the landing of the LNG carrier alongside the berth, or taking the vessel off the berth until safely headed out through the port. During these exercises, the failure of the most critical tug may be applied to ensure that the weather criteria arrived at always ensures that the LNG vessel is maintained under strict control. It is best if this work is carried out with a recognised tug expert in attendance to provide help and guidance on the placing and realistic operation of the available tugs.

Having established the operational limits of wind, current and visibility, pilots, tug masters and, if possible, senior ship's officers are then put in the simulators to carry out a range of arrival and departure scenarios aimed at testing their interaction and effectiveness in the operations. At this stage it is normal to introduce emergencies into the simulation through the failing of a critical tug, the vessel's engines or steering gear in such a way that pilots are tested to ensure that full control of the LNG carrier is always maintained. For this reason, operational limits for the terminal are always established at conservative levels.

When looking at a long pilotage to the berth or an area with heavy traffic, it is likely that random traffic movements will be introduced, particularly at choke points or areas where manoeuvres are required to take place to inject more realism into the exercises. This can assist in the determination of safe speed in particular parts of the port and the application of reduced visibility can further test the safety of the inbound or outbound transit, together with the reaction of pilots in a high stress situation. It may also highlight the requirement for positive management of other traffic movements when an LNG carrier is moving within a port area, especially if a Vessel Traffic Management System is not currently in use.

Factors to consider in Simulation

Use of bow thrusters

Most LNG carriers built in recent years have a bow thruster. The tendency of some projects and operators is to see this as an alternative to an additional tug. The perceived wisdom is that the bow thruster remains available for immediate use in the event that there is a failure of a tug or the vessel's steering or main engines such that the bow thruster can be brought into service to counteract the failure. Reliance on the bow thruster in place of an additional tug or reducing the power of tugs available because a bow thruster is available is a dangerous practice and is to be discouraged. Thrusters usually are less powerful than any tug, are less flexible as they create thrust only along one axis, and are historically prone to unreliability.

Over-reliance on a bow thruster can result in tugs not being in the right place or having adequate weight on their lines in the event of a failure of part of the total manoeuvring "package" available. Furthermore, if pilots handle ships both with and without bow thrusters, it is only a matter of time before they call for the use of a thrusters when one is not fitted with resultant embarrassment all round.

Berthing in the simulator

It is not generally necessary to place the ship exactly alongside the berth when carrying out simulator runs. Usually it will be sufficient to place the ship parallel to the berth, stationary over the ground and under the full control of the tugs, about 5 metres off the berth. Where a ship is put alongside the berth, the rate of closing and landing on the fenders should not exceed 0.2 m/s which is normally the maximum design load for the fenders.

Bridge Team and Resource Management

The use of full mission bridge simulators and interactive tug simulators by pilots and tug masters alone can often result in the loss of a very important component, namely bridge resource management. The tendency is for the Pilot (or pilots) under training to get the job done as quickly as possible and many aspects of bridge team and resource management are conveniently ignored. It is crucial that simulator staff insist on proper "Master/Pilot" exchange of information to ensure a shared understanding of the intended port transit, that the passage through the port be properly planned and monitored by others on the bridge and that challenge be issued where a pilot is considered to be taking an incorrect course of action. This is of particular importance where orders may be given in a language not understood by the simulator instructors and operators, or by any ship's officers attending the simulation.

The other aspect of Bridge Resource Management is to acquaint the Pilot with the back-up that he should be receiving when going on board any well run vessel. It is his duty to integrate himself into the bridge team and not to act as an individual in total isolation to those around him.

Management of Simulation

One of the most critical requirements for any simulation is that the people behind the scenes actually operating, managing and running the simulation understand why it is being carried out and for what purpose.

In some respects, simulation packages have been commoditised and are quite widely available from a number of suppliers whereas previously, each was a bespoke package built for specific purposes. This has meant that a number of entities now have in-house simulation capabilities but sometimes they do not have the breadth of experience necessary to fully understand the capabilities (and more importantly limitations) of the software. Alternatively, some of the software manufacturers have sought to increase the appeal of their software by providing scaleable ship models which can cover a range of simulation requirements. Unfortunately, these models are generic approximations and have not been properly validated for the handling characteristics of any particular sized vessel within the scaleable range other than perhaps the base vessel. This means that whilst it reduces the cost of ship model production, handling characteristics and idiosyncrasies of individual vessels may not be accurately reflected. This could result in Masters or Pilots being "caught out" by a vessel's behaviour in certain conditions, or the simulation outcomes being flawed.

In some cases, the personnel running simulation programmes are systems operators and lack the marine experience that can enable them to draw the maximum learnings from a given situation. The most effective simulation centres are perhaps those where the training is done by experienced Master Mariners who are able to structure the simulation training or operability assessment to bring out critical learnings. Such facilities should also have the ability to draw on current serving Pilots and Tug Masters to ensure that practices put forward during training remain current and valid.

Use of Simulators as a research tool

It is not intended that this paper should investigate the use of simulators as a research tool into the human factor but they can certainly be used to investigate the siting of additional berths to determine the impact these may have on vessel manoeuvrability on departure. In one particular case, a second berth was being investigated and it became apparent that an emergency departure was practically impossible with a given wind speed and direction as the LNG vessel effectively "stalled" and was unable to make a modest turn to port from the berth into the departure channel. This was tested using a variety of different LNG ship models, all with the same outcome. Moving the berth back by about one ship's length in the simulation model enabled the ship to build up sufficient forward momentum on departure to safely make the required turn.

Other Applications of Simulation in LNG Operations and Training

There are a number of other specialist areas of LNG operations where simulation and simulation training plays an important part in ensuring that personnel are adequately prepared for their roles in LNG operations.

Mooring

Safety and security of the ship shore interface is crucial in LNG operations and although terminal hard arms can accommodate a certain amount of movement, excessive movement beyond pre-defined limits, initiates an Emergency Shut Down (ESD) sequence. When designing a berth or send an LNG carrier to a new of different berth, it is necessary to carry out a detailed mooring analysis to ensure that the moorings remain secure within certain industry specified wind and current limits. Where excessive forces are generated that may jeopardise the integrity of the mooring system, lower environmental conditions criteria may be applied for cargo operations.

There are several mooring analysis programmes available but the best known and most widely used within the LNG industry is OPTIMOOR. TERMSIM produced by MARIN is capable of doing offshore and jetty mooring analyses and will produce similar results.

Mooring analysis may also take into account any required speed restrictions imposed on passing traffic and simulation can be used to assess the impact of this on other traffic using that port.

Use of manned models for pre-command experience

The handling of large ships is sometimes a daunting challenge for Chief Officers as they face promotion to Master and although computer simulation can prepare them for the port entry and departure, it does not give them the full feel of a vessel's behaviour. Using manned models, operating at scale speed on a lake allows a range of different effects to be realistically modelled – narrow channels, bank effect, squat, blocking effect and the effects of interaction when vessels are passing close to each other.

The manned models use scale hulls (sometimes previously used for towing tank trials) which have the appropriate engine response delays (steam or motor) built in. One trainee acts as the helmsman and operates the telegraph whilst the Master, with his eyes just forward of the bridge gives all helm and engine orders. The vessel is subject to the effects of wind and waves on the lake and behaves in exactly the same way as a full sized vessel.

The training using these models normally takes five days and explores pivot points, the effects of transverse thrust as well as the interaction effects outlined above. Classroom sessions will also cover anchoring and other aspects of ship handling, preparing the candidate for taking command of a large vessel and become confident in the slow speed control of a large ship.

Liquid Cargo Operations Simulators

There are various liquid cargo operations simulators available for membrane and spherical containment systems for LNG carriers. These programmes carefully model the thermodynamics associated with the relevant tank containment system and LNG as a gas and as a liquid. The programmes also usually model nitrogen and glycol systems, ballasting and all associated alarms.

The training course will be conducted in both real and accelerated time and will take a vessel from a aerated condition through inerting, gassing up, cooling down and through load and discharge cycles before returning to an aerated condition at the end of the course. Students will experience the operation of valves and enunciation of alarms through a computer screen interface similar to an Integrated Automation System used on board an LNG carrier.

The complexity of such systems varies according to the manufacturer and although some systems are based on a central server with a number of student stations, the systems can also be configured for use on stand-alone PCs as a self-trainer with a rule-based self assessment capability. One of the dangers of self training is that with some systems, it may not be evident to the student at what point he made an initial error that then was allowed to compound itself before a rule-based error notification was triggered.

Once again, it is essential that those personnel running liquid cargo operations simulator courses have practical experience of cargo operations so that they can effectively monitor students' progress and give corrective guidance where necessary. Needless to say, for this guidance to be effective, the trainer must also have a thorough understanding of the physical properties and thermodynamics of the LNG and associated containment system.

Steam Simulator Training

Everyone involved in LNG is acutely aware that these are the only steam steam propelled merchant ships still being built and in service and that current newbuildings will be with us for at least another 25 years. That being the case, training of engineers in steam plant operation is essential. There are two separate and distinct ways of doing this. One is to set up a training course with the assistance of a power station so that engineers can get experience of a live steam plant. This has been done very successfully by some companies.

The other way of giving engineers steam experience is through the use of a steam simulator which represents bringing a ship's engine room on line from a dead ship condition. This requires all trips and protection devices to be tested and accepted as each part of the engineroom is successively powered up. At the end of the simulation training, the "ship" is fully powered up and full away on passage in a steady state.

These courses are normally run by recently retired Chief Engineers who are able to add far more operational perspective to the simulation, drawing on their years of watchkeeping experience.

Actual steam ship experience is also essential for engineer officers but the steam simulator helps to consolidate knowledge after sailing on a steam ship or as an introduction to steam plant management before such a steam familiarisation trip.

IAS simulation

The heart of the operating system on an LNG carrier is the Integrated Automation System or IAS. This is the system that is used for engine room control, control of the cargo and ballast system and many other functions and may have feeds to subsidiary systems such as planned maintenance system modules for determination of running hours, etc.

Those best placed to explain the purpose and architecture are, quite naturally, the system designers and software engineers (i.e. the manufacturers) – it is essential that staff operating an LNG carrier know and understand what the system is designed to be capable of doing and, equally, what it is not meant to do.

With this knowledge, the main purpose of the training is to familiarise ship's staff with the operation (and maintenance) of the IAS, the data and alarm annunciation so that they are able to readily control systems and recognise and respond to alarms.

It is essential that the training course is carried out by a trainer who has marine operating experience and not a system designer / analyst. This will ensure that students will receive a full understanding of the manner in which it controls the equipment on board the vessel and not just system design philosophy.

Conclusion

This paper seeks to give guidance in the use of LNG simulation tools for a wide variety of applications during the development and operation of an LNG project and also addresses some of the training available to officers serving on the vessels.

Simulation can be expensive, particularly when a geographical database has to be built from scratch for the area of interest. When setting weather limits and training pilots and tug masters you will be paying for the use of multiple integrated simulation facilities. However, it is essential to consider the value of the training rather than the cost. At first glance this may be difficult to justify or to ascertain but suitably trained pilots and tug masters are essential to avoid damage to the export/import facilities. If uncertain, a risk analysis considering the major hazards that can affect the berth (particularly if only one LNG berth) should be carried out to justify the cost.

The approach to any LNG project will generally follow the steps outlined above with particular emphasis being placed on any site specific concerns such as narrow channels, tight turns, crossing and passing traffic and local metocean conditions.

Appendix

SIGTTO does not make any recommendations in respect of the models or establishments listed below but Members have experience with one or more of the following (which are in alphabetical order):

BMT (British Maritime Technology)
PC Rembrandt – fast time simulator
http://www.bmt.org/News/?/0/0/208

Force Technology, Copenhagen
Full mission bridge simulation with interactive tug bridges
A number of validated LNG ship models
Towing test tank
Force Technology work closely with Svitzer Towage

Force Technology also has links with Star Cruises in Malaysia (Port Klang) and Fremantle Maritime Simulation Centre, Western Australia.
http://www.forcetechnology.com/en/Menu/Products+and+Concepts/Products/050405_simflex.htm

Fremantle Maritime Simulation Centre
Full mission bridge simulation with interactive tug bridges
http://www.force.dk/en/Header/News/NewsArchive/2007/December/071219_fremantle.htm

Halcrow Engineering
HE35 LNG full lifecycle model
http://www.halcrow.com/html/our_markets/maritime/maritime_portplan.htm

HR Wallingford Ltd
Full mission bridge simulation
A number of validated LNG ship models
http://www.hrwallingford.co.uk

Lanner
Witness – Can be tailored to an LNG full lifecycle model
http://www.lanner.com/en/witness.cfm

Lloyds Register
FLEET – LNG full lifecycle model
AWAITING DETAILS

MARIN, Holland
Full mission bridge simulation with interactive tug bridges
A number of validated LNG ship models
Towing test tank
http://www.marin.nl/web/show/id=44786
http://www.dredgingengineering.com/moorings/mooringsonline/TER/TER.htm

Maritime Institute of Technology and Graduate Studies (MITAGS)
Full mission bridge simulation with interactive tug bridges.
http://www.mitags.org/t-simulationresearch.aspx
http://69.63.139.129/download/documents/Areas&Ships.pdf

Moffat & Nichol International
http://www.moffattnichol.com/practices_port_harbors.php

MPRI (Ship Analytics)
Full mission bridge simulation, Cargo Operations and Steam plant simulators
http://www.shipanalytics.com/MS/SHS.asp
http://www.shipanalytics.com/MS/LGS.asp
http://www.shipanalytics.com/MS/LSS_steam.asp

MSI, Newport RI
Full mission bridge simulation with interactive tug bridges.
A number of validated LNG models
http://www.marinesafety.com/

Sandwell, Vancouver
LNG full lifecycle marine transportation model.
http://www.sandwell.com/en/markets_transport_sim_marine_oilgas.shtml

Simulation, Training, Assessment & Research (STAR) Center
Full mission bridge simulator, cargo operations and steam/diesel engine simulators.
125k m^3 LNG Carrier (spherical) model listed on website
www.star-center.com

Sogreah Consultants, Grenoble, France
Manned Model Course (Port Revel)
http://www.portrevel.com/Contenue/English/Training.html

Star Cruises Ship Simulator
Port Klang
Full mission bridge simulation
http://www.starcruises-scss.com/
http://www.starcruises.com/Investor/Releases/1999/Ar/Ar9907.PDF

Tension Technology International
OPTIMOOR
http://www.tensiontech.com/software/optimoor.html

The Foundation for Safety of Navigation and Environment Protection
Shiphandling Research and Training Centre,
Ilawa, Poland
Manned Model Course
http://www.ilawashiphandling.com.pl/training.html

Transas Group
Full mission bridge simulation
Cargo simulator
Engine Room simulator (motor & steam)
http://www.transas.com/products/simulators/

Warsash Maritime Academy
Bridge Resource Management (several areas relevant to LNG set up)
Manned Model Shiphandling training
Engine Control Room - Steam Simulator
LICOS/WISE
A wide range of other applications associated with LNG and Pilot training are available
(See also MPRI)
http://www.warsashacademy.co.uk/course-details-training-facilities.asp#1

Wartsila
Full mission bridge simulation
Cargo simulator
Engine Room simulator (motor & steam)
https://wlsa.wartsila.com/subicbay.html