LNG Supply Chain Design and Optimization at Qatargas:

A showcase of industry-leading collaboration

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As LNG trade becomes more dynamic and responsive to market changes, LNG producing companies must ensure that their supply chains enable them to simultaneously meet contractual obligations and seize opportunities for spot cargoes, while all the time striving to minimize operational costs and using all assets as effectively as possible.

This paper describes a state-of-the-art LNG supply chain planning and optimization model jointly developed by Shell and Qatargas. It is a result of a joint research collaboration project which combined Shell's latest technological developments in the LNG design domain and LNG supply chain modelling tools with Qatargas' experience of operating the world's largest and most complex LNG supply chain. The modelling tool is designed for supply chain and risk analysis and can also support tactical level decision making. It captures supply chain dynamics and impact of decisions over time and therefore can provide a powerful insight into Qatargas' supply chain operation that is well calibrated against reality.

Since the model takes into account every aspect of delivering LNG from Qatargas' facilities in Ras Laffan to customers all over the world, it has been used to evaluate the reliability of Qatargas' supply chains and to gauge potential risks. It has been used to find answers to questions such as what fleet configuration and speed requirements would logistically be most effective for various marketing scenarios, and to also make recommendations regarding long term fleet acquisition strategy. This paper provides an overview of the research collaboration, features of the tool, and its practical application at Qatargas. It also highlights critical success factors for enabling similar intercompany collaboration endeavours.

[Note – The detailed methodology including business rules and logic implemented as algorithms in the software this paper is based on are confidential and deliberately not included. Neither are the detailed results of the simulation analysis and the managerial insights thereof.]

1. Background

The increased use of natural gas in the world's energy mix has enabled the global LNG trade to grow in volume and strategic importance. Having doubled in trade volume between 2006 and 2010, LNG has become increasingly important for transporting natural gas across borders. Countries which used to be small LNG importers have now emerged as major buyers, while several others have joined the list of LNG importers. This trend is driven by robust demand, as natural gas is in many countries becoming the fuel of choice to supply electricity, provide heating and cooling, and support economic growth.

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In the last two decades growth in LNG volume has been accompanied by an on-going transformation in its business character. Traditionally, LNG has been delivered under long-term arrangements between buyers and sellers and was only marginally traded on a spot basis. For instance up till 2005 the spot trade accounted for only 10% of total LNG traded, but has since grown to more than a fifth (21% or 47 MTPA) in 2010. While long-term contracts will continue to underpin new investments, they are being supplemented by growing short-term and spot trade that is made possible partly by destination flexibility in LNG contracts. According to International Gas Union (IGU) this trend is going to continue [1].

The LNG trade has been evolving continually to accommodate this increasingly complex web of buyers and sellers, as new players continually enter the market and increased responsiveness is demanded due to unplanned natural events in the world. A case in point is the 2011 Tōhoku earthquake and tsunami that prompted a change in the Japanese Energy import mix with LNG as a substitute source for nuclear energy at least in the short and medium term.

The shift towards more flexibility in the LNG trade has presented challenges to major LNG players like Qatargas and Shell to optimize the use of their supply chain assets. Recognizing that this challenge can only be addressed by developing and deploying state-of-the-art LNG supply chain decision support tools, QG and Shell joined forces through a joint research project to develop a flexible model as support tool for logistics planning and optimization. In the project the Qatargas rich (QG1) and lean (QG234) LNG supply chains have been modelled and evaluated using ADGENT and SALSA, Shell's proprietary LNG supply chain design and evaluation tools. This paper discusses the collaboration, the features of the model, and recommendations for future collaborations.

2. The Project Collaborators

2.1 Qatargas – largest LNG producer & journey towards a Premier LNG Company

Qatargas is responsible for production and export of about 42 MTPA LNG and other associated products, making it the largest LNG producer in the world. It was formed in 1984 and now operates and maintains the assets of four LNG joint ventures, the Laffan Refinery and supporting assets on behalf of the shareholders. A summary of the LNG joint ventures is given in Table 1.

Joint Venture	Shareholders	Capacity (MTPA)	Ships	Start-up
Qatargas 1 (QG1)	QP, ExxonMobil, Total, Mitsui, Marunbeni	10 (3 trains)	14 conventional LNG carriers	1996
Qatargas 2 (QG2)	QP, ExxonMobil, Total	15.6 (2 trains)	8 Q-flex, 6 Q-max	2009
Qatargas 3 (QG3)	QP, ConocoPhillips, Mitsui	7.8 (1 train)	7 Q-flex, 3 Q-max	2010
Qatargas 4 (QG4)	QP, Shell	7.8 (1 train)	4 Q-flex, 4 Q-max	2011
Qatargas Operating Company (QG OpCo)	QP, ExxonMobil, Total, ConocoPhillips, Shell, Marunbeni, Mitsui, Idemitsu, Cosmo	Operator	n/a	1984

Table 1. Qatargas LNG joint ventures.

Only QG1 produces rich LNG, the other ventures produce lean LNG. A high level supply chain view of Qatargas at Ras Laffan is given in Figure 1. The lean LNG is exported via a common shared storage and loading facility, which has been developed under the common Lean LNG Storage and Loading Project (CLLNG) with sister company RasGas. According to the CLLNG operating agreement each of Qatargas lean ventures is nominated for a portion of the eight-tank storage facility. To capture the synergy of a common storage facility the venture groups are allowed to exceed their nominations occasionally at the cost of excess usage fees. All the lean LNG production from Qatargas and RasGas (total 56 MTPA) is exported through CLLNG, making it the world's largest and most complex LNG storage and loading terminal [2].

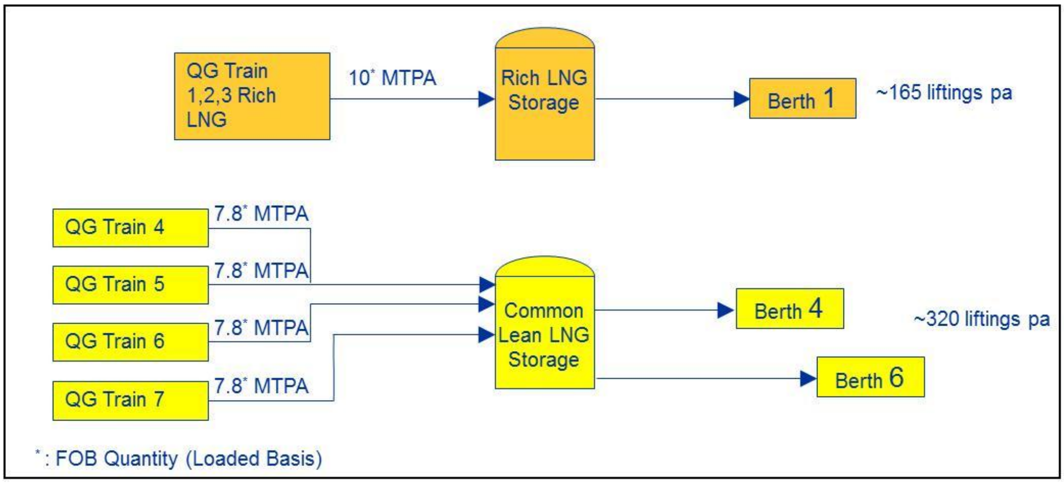


Figure 1. Qatargas LNG supply chain, a high level view.

Qatargas currently owns and operates a supply chain that consists of 7 trains with 42 MTPA of LNG production, delivery to 17 import terminals through a fleet of 14 conventional ships and 32 state-of-the-art Q-flex and Q-max vessels. The complexity is increasing by the day as QG grows and expands into almost every LNG market in the world.

Qatargas is committed to innovation and operational excellence and the company is well on its way to become the premier LNG Company by 2015.

2.2 Shell – technological advancement and innovation

Shell helped pioneer the LNG sector, providing the technology for the world's first commercial liquefaction plant at Arzew, Algeria, in 1964. Since then the company has continued to play a leading role in improving the technology behind LNG production. Shell has a leading position among IOCs in the LNG business, with a diverse, large and growing LNG production portfolio across the world. With the Qatargas 4 venture, Qatar has become the seventh country in which Shell has an LNG equity position. Moreover Shell is technical adviser to LNG operations in six countries and Shell joint ventures supplied more than 30% of global LNG volumes in 2010.

With over 45 years experience designing, building and operating LNG plants around the world, Shell is able to apply decades of construction and operational learning to the projects it is involved with. This has also resulted in, among others, a suite of LNG/Gas supply chain design and optimization tools that are used across the entire spectrum of the LNG business. An overview of the portfolio of these tools is given in Table 2. Each of these tools is employed during different stages of an LNG project.

No.	Tool	Main focus	Areas addressed			
			Gas Supply	LNG Production	Transport & Delivery	LNG Demand
1	SPARC	Reliability and availability modelling	✓	✓		
2	GFPT	Timing and expenditures of gas field developments	✓	✓		
3	PRO	Field and plant optimization	✓	✓		
4	SALSA (and predecessor ADGENT)	Integrated supply chain, master-planning	✓	✓	✓	✓
6	COMPASS	Detailed annual planning & daily scheduling	✓	✓	✓	✓

Table 2. Shell's robust suite of decision support solutions for the LNG business.

The table depicts overlapping functionality among the various decision support systems. In some instances the overlap is inherent in design to allow complementary use. In other instances, the need to respond to the requirements of specific business environments and/or organizational structures has also created overlap.

3. The Joint Qatargas-Shell LNG Logistics Research Project

The need to partner when optimizing LNG supply chains to for global markets has long been felt by both Qatargas and Shell. While various areas of collaboration were identified and discussed during joint consultative meetings, it was agreed to prioritize and focus on high-impact initiatives that would deliver immediate and sustained value.

LNG supply chain logistics was chosen because it can draw on the synergies between both companies' strengths and was found to be a good fit with their aspirations. After thoroughly scoping the work and activities, a Memorandum of Understanding (MOU) was signed on March 15, 2009 with the objective to "create a state-of-the-art LNG logistics model as a planning and optimisation tool, for the benefit of Qatargas and Shell using Shell's tools, experience and modelling best practices."

The research has been conducted at the Qatar Shell Research & Technology Centre located in the Qatar Science & Technology Park. The project plan and milestones are shown in Figure 2. Immediately after the signing of the MOU, relevant personnel from the Qatargas Business Scheduling department were identified and nominated. The Shell Logistics Engineer in charge of the project was relocated to Doha. This ensured early engagement of participants and enabled a close collaboration in advancing the project and successfully tackling issues arising in the course of the project.

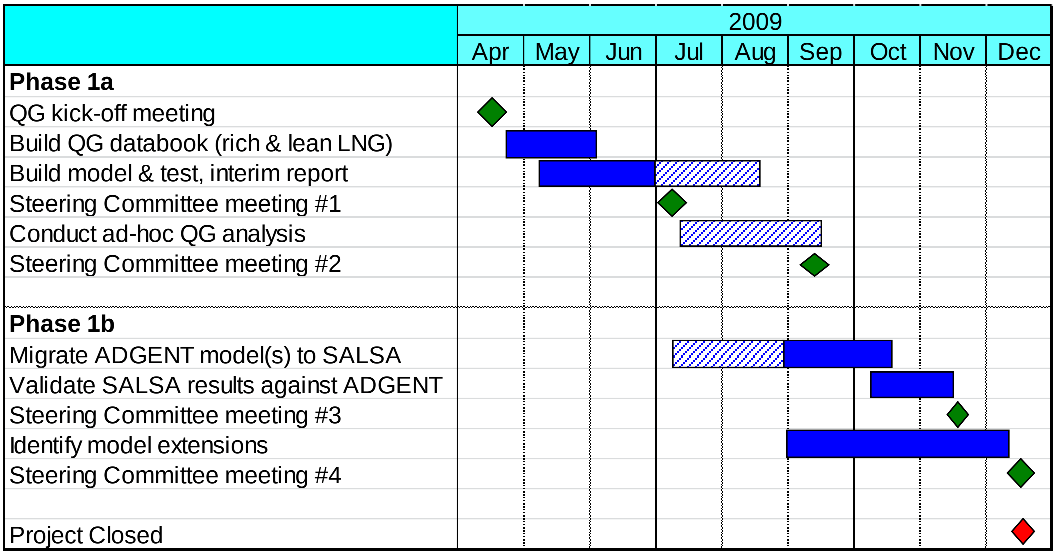


Figure 2. Project plan and implementation schedule.

Project meetings were held on a weekly basis. A steering committee that consists of 2 senior executives from each of the two companies met approximately every 2 months to review progress, sign off key deliverables, discuss plan forward and resolve any issues.

Two tools from Shell's portfolio – initially ADGENT and later transition to SALSA - were selected for use in this project. They were selected because their scope and detail were found to be appropriate to realise the project's objective of long term planning. A brief description of the tools is provided in Section 4. A more detailed description within the context of modelling the QG supply chain is given in section 5.

4. LNG Supply Chain Design and Deployed Technologies

Due to the inherent time-based dynamics and complexity associated with modelling and analysing Gas/LNG supply chains, many of the design tools are based on discrete event simulation methodology. This in contrast to analytical methods such as optimization that usually need to make simplifications to the model. Discrete event simulation technology enables the LNG supply chain designer to deal with more details and variability in the supply chain and extract more comprehensive results. Moreover, simulation tools usually have a strong visualization capability to monitor the dynamics of the supply chain.

4.1. LNG/Gas Supply Chain Logistics – Design and Optimisation

Design and optimization of LNG/gas supply chains is a key activity that is carried out throughout the project life time. Generally, prediction of overall LNG supply chain capacity occurs by modelling and simulating particular configurations of assets including upstream gas supply, processing plants, LNG export plants, LNG shipping and LNG import facilities. Within the boundaries of the simulated world, different configurations of the chain can be tested in a 'what-if' integrated manner to determine an optimum mix of assets and their operations required to meet various anticipated market scenarios.

Depending on the project phase, the supply chain investigations focus on different aspects. In an export plant design phase, optimization of plant infrastructure including storage berths and production capacity can be simulated. And in a shipping restricted supply chain, analysing the impact of LNG carrier capabilities or speeds can be emphasized in conjunction with the marketing mix driving transportation requirement. The simulation approach adopted by Shell's tools is flexible enough to encompass all these different types of analysis.

Specialized simulation software is required to design and optimize the LNG supply chain, especially for:

- Fleet & storage definition for new projects, debottlenecking or plant expansions
- Ultimate delivery capacity for existing plants
- Impact of changes in market mix or fleet composition for existing plants
- Annual Delivery Program (ADP) reliability assessment & selection of voyage and production margins
- Upstream/downstream integration & selection of upstream spare capacity requirements
- Fine-tuning of ADP (scheduling)
- Planning & testing of spot-cargoes
- Impact of events at receiving terminal harbour facilities and storage requirements

4.2. Deployed Technologies

4.2.1 ADGENT

ADGENT (ADP Generator and Tester) was developed in the eighties to facilitate design optimization of the LNG value chain from well-head to end user. It was continually upgraded over the years and its latest release ADGENT 2006 has been available since June 2006.

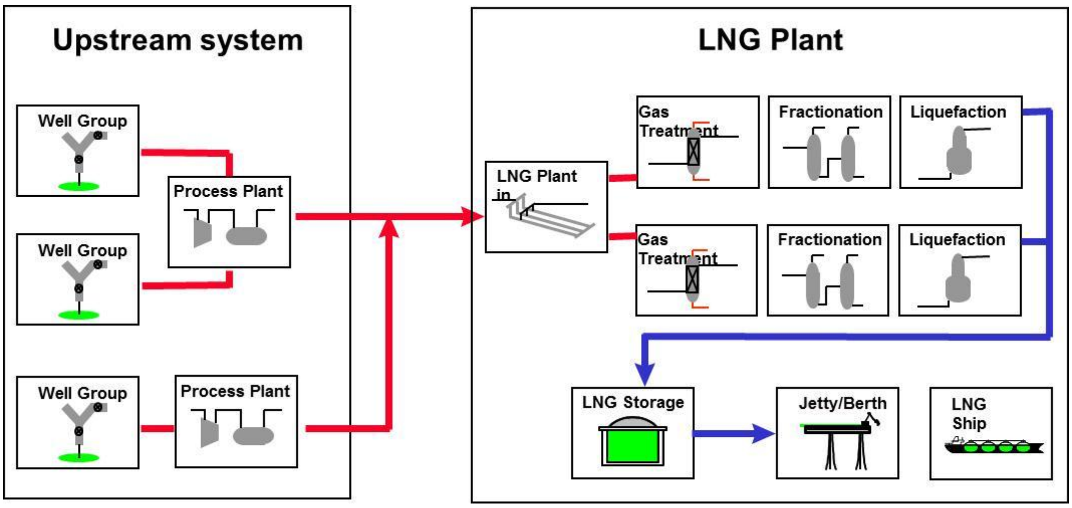


Figure 3. ADGENT production and loading port system model elements.

ADGENT models can be configured in a flexible manner. Specific or unique characteristics of a supply chain can either be incorporated, or worked around in ADGENT. Moreover a scenario manager is available that can be used to manage a number of simulation scenarios. Figure 3 shows the modelling elements for the loading port that are built as element icons and that can be dragged across the screen to build the system to be modelled.

As the model elements have previously been validated, the validation/verification effort for the newly created models for a specific supply chain configuration is less. Editing ship delivery programs can be done using a Gantt Chart and matrix style ADP editor. The software gives some visualization of ships and can also dynamically chart many of the problem variables during a simulation run.

Although ADGENT showed to be a reliable tool applicable for many supply chain investigations, it appeared not easy to adapt it to the currently changing LNG trade conditions that demand detailed modelling, among others, of spot cargoes and diversions. A transition to a new tool has become apparent to overcome the limitations and as a result SALSA (described below) has been developed.

4.2.2 SALSA

SALSA is an acronym for Shell Advanced LNG Supply chain Application. It has been developed following Shell's recent strategic decision to consolidate and rationalize the platform of LNG decision support tools and to make use of the recent advances in simulation technology that have improved run speed, ease of use, and flexibility.

A thorough and exhaustive assessment was carried out to select the platform on which the new supply chain simulation software would be built. Flexsim was chosen to be the best fit for Shell's strategic aspirations and technological requirements. It is a general-purpose and an object-oriented software environment used to develop, model, simulate, visualize, and monitor dynamic-flow process activities and systems.

SALSA comprises 2 libraries that are built on the top of the Flexsim simulation platform. It essentially retains the well-proven ADGENT functionalities but significantly improves the user interaction and the ability to model specific characteristics of any LNG logistics chain. The additional features and benefits of SALSA can be summarized as follows.

- Simulation 3-D graphics which are an integral part of the software design and extremely powerful for analysis
- Standard and configurable LNG value chain building blocks
- Comprehensive two-step ADP generation & testing
- Selective user access to adapt the core functionality and user add-ins
- Enhanced communication with databases and other software tools (e.g. SPARC,COMPASS)
- Combining user defined add-ins with generic functionality in a single model
- Interactive scenario development (operator intervention)
- Customized Graphical User Interface GUI
- Options for:
    - Product definition based on molar composition
    - Heating value calculation using ISO6976 and GPA2145
    - Gas quality tracking along the supply chain; N_2 injection possibility
    - Detailed modelling and analysis of fuel consumption, bunkering, and dry docking

5. Qatargas Supply Chain Modelling

Both ADGENT and SALSA were used to model rich (QG1) and lean (QG234) supply chains with very similar results. The SALSA models are discussed in the following sections. The models' elements include ships, production, tanks, berths, loading, offloading and port operations at import and export terminals. Performance indicators are calculated over the simulation years but reported on a per year basis.

5.1 QG1 (Rich LNG) Model

A snapshot of the SALSA model is given in Figure 4. This is the main window in 2D with Ras Laffan and the import terminals in Japan and Spain are shown. Moreover vessels and the shipping legs are also shown. At this instance of the simulation 5 ships are on laden voyage and 3 ships are on ballast voyage. The opening/closing status of the Suez canal for laden and ballast voyages are shown in different colours.

Model validation and testing has been done based on historical data going back as far as 1996 when QG1 started operating. The results generated from the models are consistent with actual performance and behaviour of the QG1 supply chain. This demonstrated the correctness of the simulation methodology implemented in the tools.

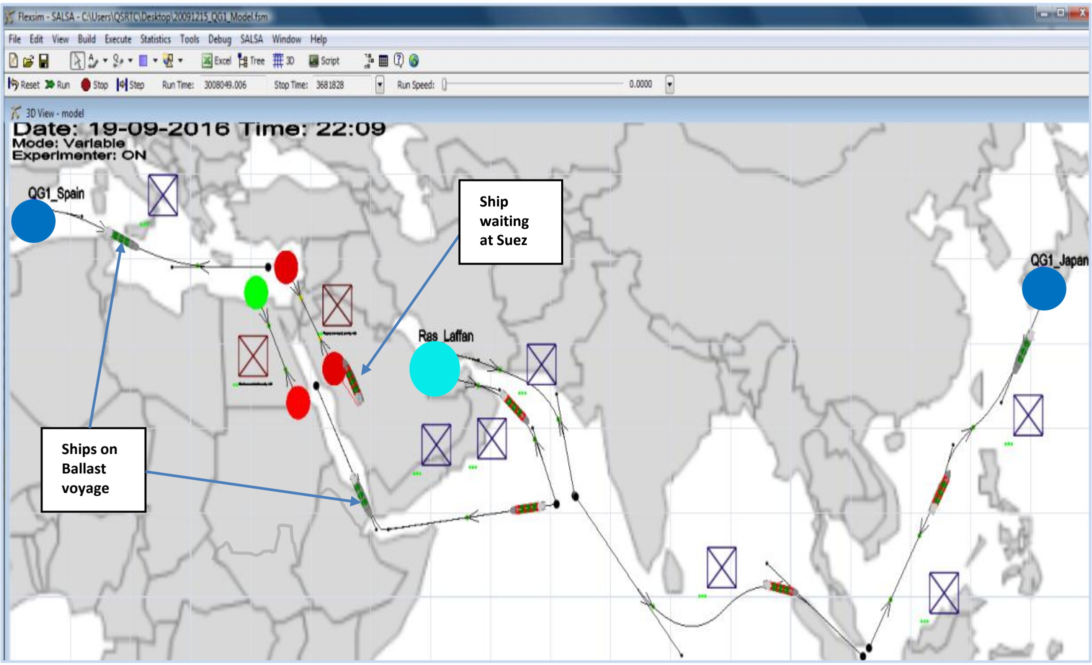


Figure 4. Snapshot of QG1 SALSA model.

Most of the work on QG1 looked at fine tuning the current planning margin, running the supply chain with reduced fleet capacity, and generating and quantifying spot cargoes. An extensive number of experiments using given constraints were performed to determine the number and timing of spot cargoes that can be delivered on the top of existing contracted commitments. This insight has been found to be invaluable when advising Qatargas on securing LNG spot deals that maximize value to its shareholders.

The results of analyses as well as recommendations are documented and communicated through a set of diagrams. An example graph is given in Figure 5, which depicts the relationship between production and ADP robustness for a set of production planning margins. For a particular scenario it was decided to study the impact of testing different production planning margins. The initial planning margin considered by QG doesn't result in a robust ADP, since the delay profiles of ships at the import terminals has been found to be higher than the acceptable threshold. The planning margin has been increased progressively until a robust supply chain that ensures the delivery of firm commitments is obtained. This is shown and recommended as the new operating point for the supply chain. The spot volumes for the old and new operating points are also shown in the figure. The new operating point corresponds to the one that maximizes spot volumes, from all feasible points of robust ADP. The results of such analyses have provided a valuable understanding of the complexities of the supply chain.

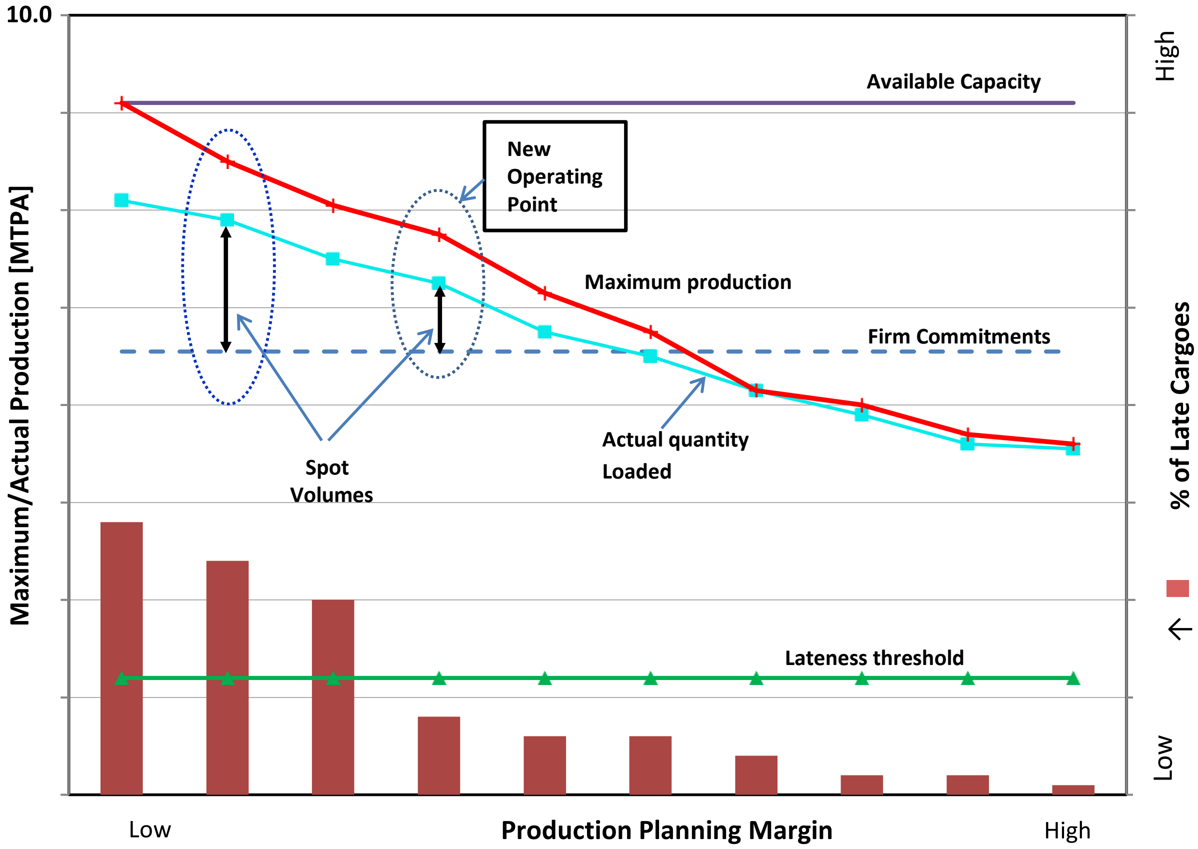


Figure 5. Production and ADP robustness vs. Planning Margin for a particular scenario (figure not to scale).

5.2 QG234 (Lean LNG) - Model

The scope of the QG234 model included the full supply chain from well head to 17 import terminal destinations. The sensitivities studied relate to pooling fleet and storage among ventures, new markets, as well as different storage and fleet capacities. Impacts of bunkering delays and possibility of heeled-out LNG ships arriving in Ras Laffan have also been investigated.

In the course of the project, it appeared that various unique aspects of the Qatargas supply chains were not available in the first issues of SALSA. Accordingly the necessary customization of the SALSA tool was done to accommodate these features.

The SALSA graphical representation of the Ras Laffan production plant and port facilities is given in Figure 6. It shows the 2D view before simulation starts. In the production part of the plant (shown in the left), LNG from the trains runs down to a common storage tank which has the capacity of the total Qatargas storage nomination. The Ras Laffan port (shown in the blue field at the right) contains all the necessary port elements - the jetty with two berths, the channel, port queue and external port processes such as maintenance and bunkering.

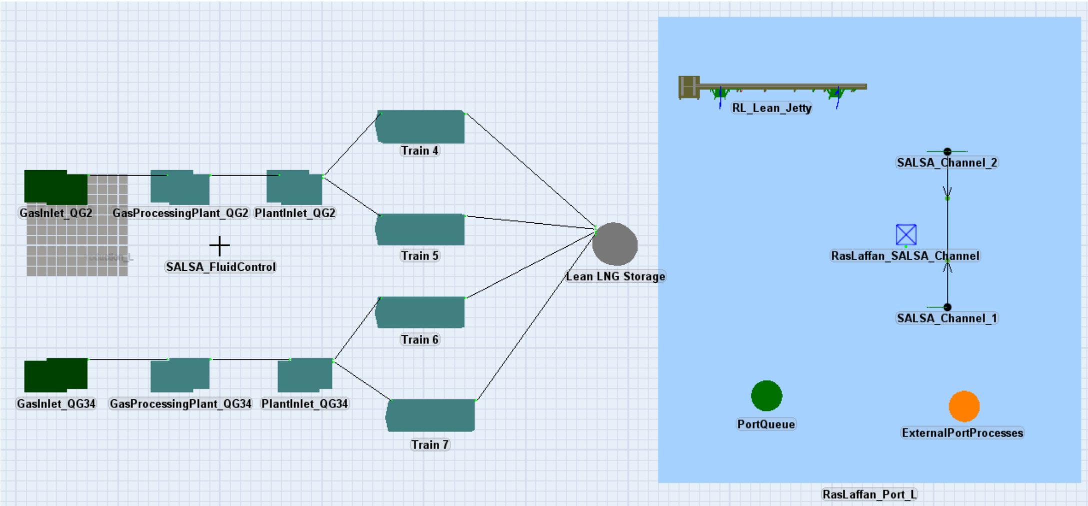


Figure 6. QG234 SALSA model for Ras Laffan - 2D view.

Figure 7 represents a snapshot of the 3D view during the simulation at an instance of simultaneous loading of two vessels. The colours in this view indicate the status of the elements to enable easy visual inspection of simulation progress. For instance the trains showing a red tag are constraining. The tank level is shown in red and can be seen changing over time. As can be seen vessels Mesaimeer and Al Sadd are loading at LNG berths 4 and 6 respectively. The level of loading completion is readily visualized by inspecting the red indicator in the ships themselves.

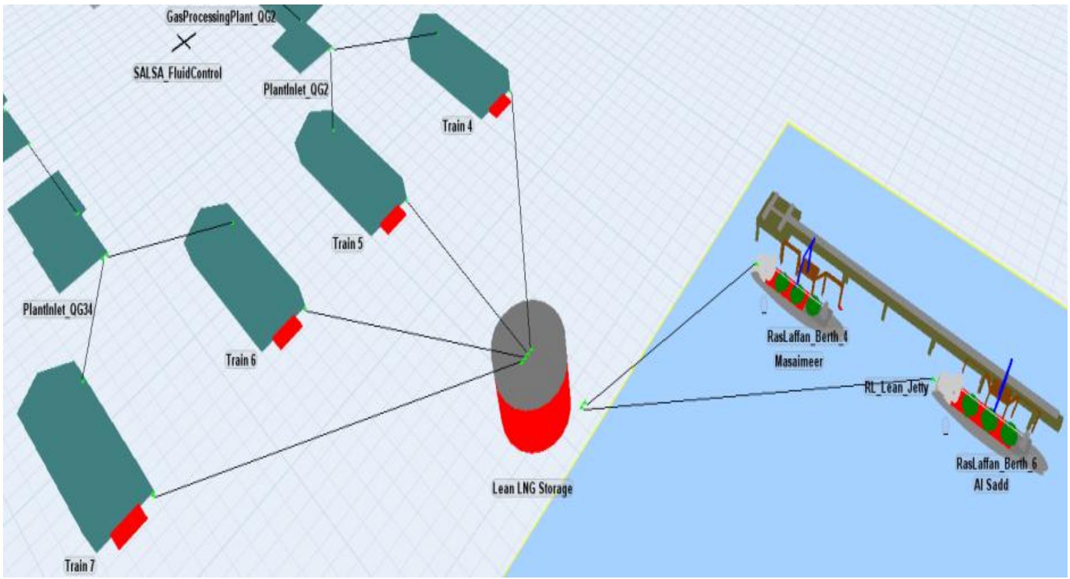
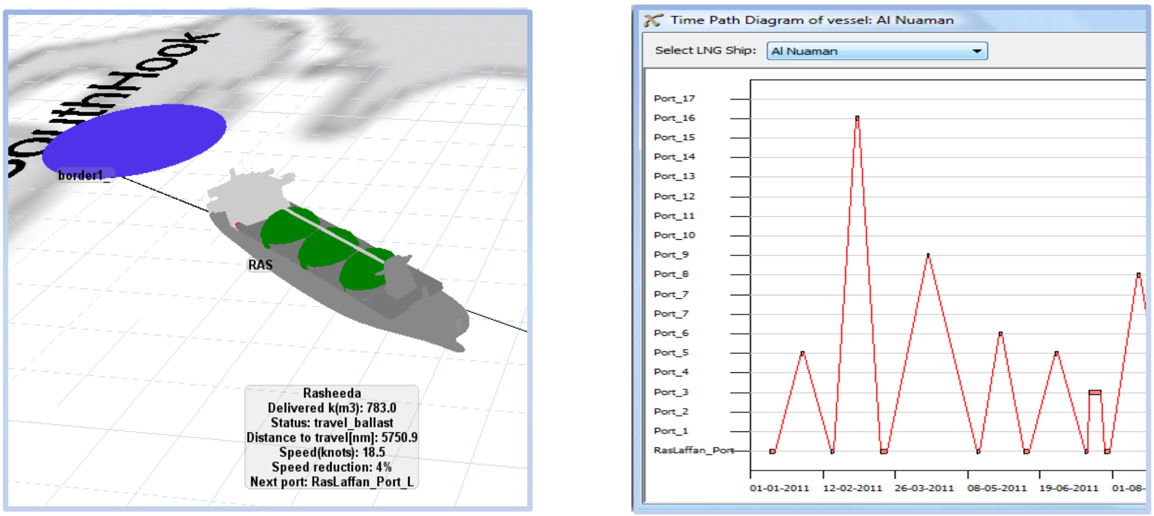


Figure 7. Snapshot of a 3D view during simulation.

Two of SALSA's most powerful debugging aids are presented in Figure 8. These are real-time vessel info during simulation and a time path diagram. The figure in the left shows Rasheeda on its ballast voyage after delivery to the South Hook terminal. Relevant info on its voyage and loading performance is shown in over time if necessary. The time path diagram, shown in the right, dynamically tracks vessel positions in Ras Laffan and import terminals or during voyages. Strange behaviour such as excessive waiting times in one of the ports can enable the modeller to look deeper to that terminal and do the debugging if required.



(a) **(b)**

Figure 8. Two examples of SALSA's powerful verification aids.

Several sensitivities have been conducted on the simulation model to study ways of optimizing the supply chain. One aspect that was examined in detail was the validation of Qatargas' nominated storage. Analysis has shown that with the current nomination (4.6 tanks, 640k m^3), QG will only use Rasgas' storage capacity for relatively short periods of time. Figure 9 depicts the periods of RasGas' storage usage when Qatargas' lifting lags production. The study also reveals that there could be significant potential savings by matching vessel dry docking dates with planned maintenance. This issue was investigated as a follow up item after the project was completed.

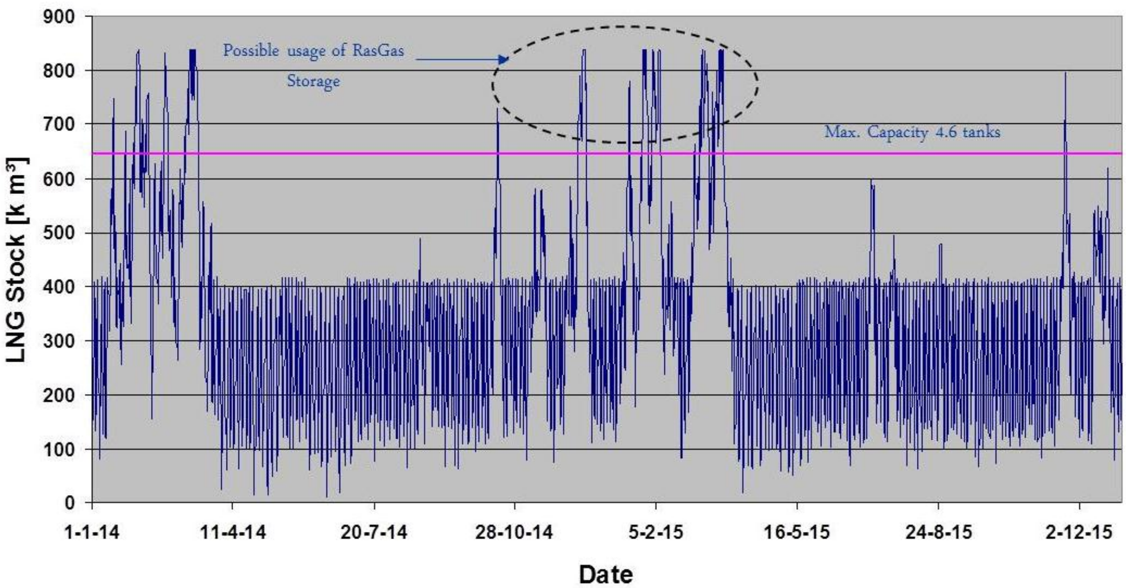


Figure 9. Qatargas' periods of operation above nominated storage in 2014.

6. Current Status and Critical Success Factors

After the project was successfully closed out, the Shell Logistics Engineer was seconded to Qatargas to fine tune the models, implement identified enhancements, and conduct a series of follow-up SALSA-based studies. This enabled maximized use of the collaboration results. The studies were carried out with different themes such as

- Fleet balance
- Long term capacity outlook of Qatargas ventures
- Screening and evaluating marketing opportunities
- Development of a dry-dock planning tool for Qatargas fleet

The successful execution and completion of this joint project is also achieved due to well thought strategies and actions taken by both Qatargas and Shell in the various phases of the project. The following factors have been found to be critical for the success:

- A clear view and guidance from Qatargas to access selected and proven technologies from its partners
- A clearly defined business need for collaboration, with appointed champions to drive it forward
- A project that is tied to specific and critical business processes and goals
- Checking for and clearing legal impediments before commencing a project – Commercially Sensitive Information boundaries, bespoke legal training, and confidentiality agreements
- A well-defined post project and user-deployment plan to maximize value
- Ensuring the product developed meets usability criteria and meets the needs of the intended audience both in Qatargas and Shell

7. References

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