Combined Simulation for improving Operations in
LNG Logistics: a Case Study

* DIPTEM, Università degli Studi di Genova, Via all’Opera Pia, 15– Genova, Italy
* DIMP, Università degli Studi di Napoli – Federico II, Piazzale Tecchio 80– Napoli, Italy
piero@itim.unige.it, g.guizzi@unina.it; murino@unina.it; elromano@unina.it;
roberto.revetria@unige.it, Alessandro.testa@unige.it;

Abstract: - This paper presents a logistic simulation study in order to evaluate technical feasibility and
operative costs (demurrage hours) associated to several operating strategies of transshipments in remote sites in
order to assure a certain regasification rate of LNG to the network. In particular two scenarios were evaluated
(A and B) within which searching for best operating strategies and evaluation of associated costs. The
suggested approach uses a hybrid system dynamics simulation that combines typical elements of Discrete-
Event Simulation with the characteristics of a dynamic model.

Key-Words: - Simulation, System Dynamics, LNG, Discrete Event Simulation

1 Introduction

Discrete-Event Simulation (DES) and System
Dynamics (SD) are two established simulation
approaches in transportation and logistics problems.
DES models systems as a network of queues and
activities, where state changes occur at discrete
points of time, whereas SD models consist of a
system of stocks and flows where continuous state
changes occur over time [1].

In DES state changes occur at discrete points of
time, while in SD state changes happen
continuously at small lapses of time (Δt) [6].

In logistics, unpredictable events can affect the
system, forcing to change in real time the standard
flow of activities and events that had been
previously scheduled. In this case SD is more
suitable for modeling purposes, considering that
interruptions in the chain of events are not possible
in the DES, because it considers the starting event
and the final one but not what is going on between
the two [6].

Moreover, SD methodology has proved to be
very reliable when solving traffic flows
problem or transportation problem, because traffic
conditions constantly change in a dynamic way and
they are significantly affected by previous
conditions and by temporal delays [3]. However, the
“pure” SD is not an effective methodology when the
level of detail of the system must be very high or
when the number of variables is noteworthy, so that
the model becomes very complex and onerous in
terms of computational effort and speed. In these
cases the DES is the most appropriate simulation
approach.

In order to overcome these issues, the authors
propose an innovative methodological approach
able to effectively address particular kind of
logistics and transportation problems by utilizing a
hybrid System Dynamics simulation[2][3]. More
specifically the simulation framework here proposed
is composed of two main parts:

1. the “discrete event simulation” part, which
   provides the chain of events that
   characterize the system;

2. the “pure System Dynamics” part, that
   accomplishes two main goals: continuous
   processes and unpredictable events to be
   properly managed.

This approach has numerous advantages:

• the capability, typical of the DES, of
  providing detailed analysis of a particular
  system;

• this new methodology can address the
  modeling of continuous processes, can
  deal with systems where behavior changes
  in a non-linear fashion and/or where
  extensive feedback occurs within the
  system, or can take into consideration
  “fuzzy” qualitative aspects of behavior
  that, while difficult to quantify, might
  significantly affect the performance of a
  system - these last features are typical of
  the SD [4][5].

The paper presents one real life application were
such innovative approach has been extensively
tested and used in order to evaluate technical
feasibility and operative costs (demurrage hours)
associated to several operating strategies of
transshipments in remote sites in order to assure a
certain regasification rate of GNL to the network.

2 Project Background
Liquid Natural Gas (LNG) network connection is located at an offshore platform in northern Adriatic Sea. The simulated configuration foresees that the Floating Storage and Regasification Unit (FSRU) shall move toward a seaport to be fed by an LNG carrier, than move back to the offshore platform to unload gas in the network.

Two scenarios are examined: the former without interaction with crude oil tankers at the offloading point (hereafter named scenario A) and the latter in presence of crude oil tankers (hereafter named scenario B). In scenario B the priority is given according to the following scheme:

- while both disconnected, the crude oil tanker has priority over the FSRU
- the arrival of a crude oil tanker does not imply a disconnection of the FSRU when offloading

Figure 1 shows the supply scheme.

Some definitions/ boundary conditions are hereafter provided.

**FSRU.** Is a floating storage and regasification system, which receives LNG from offloading LNG carriers, and the onboard regasification system provides natural gas send-out through flexible risers and pipeline to shore (figura 2)

**Maximum regasification rate.** Annual network demand: 4 BScm/year.

**Arrivals schedule.** The time lapse between two arrivals is the significant parameter to validate the ship-arrival generation routine (NOR). By comparing real data with simulated values (considering oil tankers only, since no LNG carriers are currently in use), the K (10) value of the Erlang distribution has been defined so as to generate the schedule. Similarly the average return period of the time- chartered ships has been optimized. The so obtained K value is assumed to be applicable to LNG carriers’ arrivals as well.

**Demurrage.** Demurrage time has been calculated for LNG offloading operations to the FSRU and for crude oil to the hub. In the former case the contractual time is 2 days for all operations. The counting begins at supply tankers arrival from remote site to offshore and finishes at the end of offloading operations to the FSRU. Operating hours exceeding the contractual ones are counted as demurrage hours. Such time is influenced only by the availability of the FSRU at the transshipment location.

According to the contractual terms, the crude oil offloading time is 36 hours.
<table>
<thead>
<tr>
<th>Ship type</th>
<th>Croatian harbor</th>
<th>Offshore platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas tanker</td>
<td>2 days</td>
<td></td>
</tr>
<tr>
<td>Crude oil tanker</td>
<td></td>
<td>36 hours</td>
</tr>
</tbody>
</table>

Figure 5. Contractual schedule.

3 Model Specification

The model presents several chains of events representing simulated objects states. In particular are defined:

1. The FSRU logical status chain within the LNG offloading cycle to the offshore platform (Figure 1 – from starting event “Available” at the offshore platform in full-loaded condition to “Ready to Leave” after completion of gas offloading.

2. The FSRU logical status chain within the journey cycle. The green links are related to the sub-cycles “LNG Loading” and “Gas Offloading”.

3. The FSRU logical status chain within the LNG loading cycle.

4 Input Data

The identified parameters for the study can be grouped as follows.

Handled volumes: significant parameters bounded to LNG movement.

Operative limits: operative limits to perform mooring operations, ability to perform commercial operations and emergency unmooring if it is necessary under weather conditions.

These limits depend on ship and mooring system types.

Loading and offloading rate: variability range of LNG and crude oil loading and offloading rate.

Time requirement: time requirement for gas tankers and crude oil tankers mooring and unmooring from offshore platform, and time requirement for operations at harbor.
4.2 Operative limits

The simulation model has been planned assuming the following operative limits.

<table>
<thead>
<tr>
<th>Limit type</th>
<th>Parameter</th>
<th>Unit</th>
<th>HUB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mooring</td>
<td>wave</td>
<td>m</td>
<td>Hs=1,25</td>
</tr>
<tr>
<td></td>
<td>wind</td>
<td>m/s</td>
<td>V=6</td>
</tr>
<tr>
<td>Operating</td>
<td>wave</td>
<td>m</td>
<td>Hs=2</td>
</tr>
<tr>
<td></td>
<td>wind</td>
<td>m/s</td>
<td>V=12,5</td>
</tr>
<tr>
<td>Emergency Unmooring</td>
<td>wave</td>
<td>m</td>
<td>Hs=2,6</td>
</tr>
<tr>
<td></td>
<td>wind</td>
<td>m/s</td>
<td>V=12,5</td>
</tr>
</tbody>
</table>

Figure 10 Operative limits.

4.3 Loading and offloading rate

Variability range among loading and offloading rates observed are showed in table 3, hereafter illustrated.

<table>
<thead>
<tr>
<th>Rate type</th>
<th>Rate</th>
<th>HUB/Croatia</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSRU offloading rate</td>
<td>mc/h</td>
<td>1.650</td>
</tr>
<tr>
<td>All the operations at transshipment site</td>
<td>da</td>
<td>2</td>
</tr>
<tr>
<td>Crude oil offloading rate</td>
<td>t/h</td>
<td>2,900 -4,000</td>
</tr>
</tbody>
</table>

Figure 11. Maximum and minimum loading and offloading rate.

4.4 Time requirement

Time requirement assumed for ship type simulated in the logistic model are hereafter summarized.

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Time requirement (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mooring</td>
</tr>
<tr>
<td>Gas tanker</td>
<td>120</td>
</tr>
<tr>
<td>Crude oil tanker</td>
<td>120</td>
</tr>
</tbody>
</table>

Figure 12. Time requirement assumed in simulation model.

4.5 Light conditions (dawn and sunset).

The ship can enter the hub with daylight only. Thus, dawn and sunset times at site have been calculated for every month.

5 Model Validation

Walk-through methodology has been adopted in order to verify the congruity of the model with the real system. This method describes the validation process of the algorithm and source code.

The aim of this procedure is to guarantee the fitness for purpose of the algorithm and to evaluate the completeness of the model. The validation has been performed in deterministic scheme in order to correctly evaluate the model avoiding that potential code errors are hidden by model stochastic behavior.

Such simplification has been overcome by implementing a stochastic regimen upon validation.

Mean Square Pure Error (MSPE) assessment

MSPE progress has been studied in order to define simulation period optimal duration and identify significant statistic parameters of the model (output and relative error).

According to the central limit theorem, the normalized sum of a large number of statistic variables (output) can be tentatively described as a normal standard statistic variable with the following characteristics:

- Average: equal to the sum of the observation averages
- Standard deviation: equal to the square root of the MSPE

Such important property allows determining the maximum variability of the analyzed output (99.7% of the cases):

-3σ ≤ Average(output) ≤ 3σ

Average value and MSPE for LNG “production” per hour and for demurrage days at harbor are showed in the following graphs.

Figure 13. LNG average production per hour.
In both parameters experimental error settles after about 10 years of simulation.

6 Problem Solution

As mentioned above 2 scenarios have been simulated. Scenario A without interactions and scenario B with interactions with crude oil tankers. In particular, in the latter scenario crude oil tankers have priority over gas tankers. Scenario B has resulted to be not satisfactory in terms of gas “production” (it does not guarantee the required BScm/year). Scenario B2 has been hypothesized in order to compensate this deficiency. In this scenario only the 50% of crude oil tankers flow is unloaded at the offshore platform; the other 50% is discharged via a different onshore quay, thus not interfering with the FSRU logistics.

Scenario A

Scenario A does not present particular LNG supply difficulties. Especially, it emerges a low dependence on the transshipment area chosen for gas offloading operations. In the worst situation the gas offloading on FSRU average time lasts (2 days + 83 / 38): 4 days and 3 hours.

Scenario B1

The crude oil presence strongly influences performances of gas supply logistic. In particular the aimed BScm/year cannot be reached. In addition gas ships demurrage strongly increase, due to the fact that FSRU cannot offload and leave (as in the former scenario), but has to stay and wait for crude oil tankers to finish offloading. Gas average discharging time on FSRU becomes (2 days + 110 days/ 37,5): about 5 days.

Scenario B2

By limiting the crude oil tankers interference on the hub the gas supply can be increase again up to the required 4 BScm/yr. Paid demurrage in the transshipment location decrease as well compared to scenario B1. Crude oil tankers demurrage approximately halve.

Figure 15 resumes simulated scenarios results.

<table>
<thead>
<tr>
<th>Scenario A</th>
<th>LNG production [BScm/yr]</th>
<th>Gas tankers demurrage [da/yr]</th>
<th>Crude oil demurrage Hub [da/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Deviation</td>
<td>Mean</td>
<td>Deviation</td>
</tr>
<tr>
<td>Zara</td>
<td>4.01E+09</td>
<td>1.59E+07</td>
<td>8</td>
</tr>
<tr>
<td>Frame</td>
<td>4.01E+09</td>
<td>1.59E+07</td>
<td>8</td>
</tr>
<tr>
<td>Spalato</td>
<td>4.01E+09</td>
<td>1.59E+07</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario B1</th>
<th>LNG production [BScm/yr]</th>
<th>Gas tankers demurrage [da/yr]</th>
<th>Crude oil demurrage Hub [da/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Deviation</td>
<td>Mean</td>
<td>Deviation</td>
</tr>
<tr>
<td>Zara</td>
<td>3.05E+09</td>
<td>1.09E+07</td>
<td>8</td>
</tr>
<tr>
<td>Frame</td>
<td>3.05E+09</td>
<td>1.09E+07</td>
<td>8</td>
</tr>
<tr>
<td>Spalato</td>
<td>3.05E+09</td>
<td>1.09E+07</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
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<td>Mean</td>
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<tr>
<td>Spalato</td>
<td>4.00E+09</td>
<td>1.99E+07</td>
<td>8</td>
</tr>
</tbody>
</table>

6.1 Further results

Given the results above described, the simulator has been used to test the maximum regasification capacity of the logistic system.

In other words gas tankers pressure has been increased (by decreasing arrivals average span time) from remote site to the hub in order to verify how many FSRU cycles can be obtained. The graph illustrated in figure 6 shows results obtained for various scenarios. In particular the graph highlights that by increasing the production rates the costs increase more than linearly. It costs one more day of demurrage for each discharge to pass from 38 ships/year to 44 ships/year (scenario A); instead it costs 2.5 more to pass from 44 to 48. Moreover a threshold value has been identified as 48-49 ships/year. This value represents the maximum limit of the system. However the operative limit is much lower (see figure 16). A configuration in which maximum value of average demurrage/year is 3 days per discharge is considered practicable.
Figure 16. FSRU cycles depending on demurrage days.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Ships/year FSRU</th>
<th>Demurrage[da/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario A (without crude oil)</td>
<td>46</td>
<td>138</td>
</tr>
<tr>
<td>Scenario B1</td>
<td>42</td>
<td>126</td>
</tr>
<tr>
<td>Scenario B2</td>
<td>44</td>
<td>132</td>
</tr>
</tbody>
</table>

Figure 17. Maximum regasification capacity

7 Conclusion

The papers has successfully proposed an innovative approach able to model complex logistics systems. In particular the model was able to provide a credible representation of both continuous and discrete operations reaching a very high level of confidence as stated in the MSPE analysis. A complete case study as been presented and discussed.

References:


