The Game of Making Decisions in LNG Projects

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Multi-objective optimization of LNG processes

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Experimental and modeling study of two-phase flow instabilities in single channel

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Modeling multiphase flow in downhole valves

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Modeling and simulation of anomalous transport phenomena
The Game of Making Decisions in LNG Projects
Frame of Reference
Decision Making (DM) on LNG Projects
Implementation
Results
Closure
Global energy demand is increasing. According to Oilfield Review, Natural Gas (NG) consumption will increase more than oil consumption by 2025.

Liquefied Natural Gas (LNG) is a suitable alternative to transport (overseas) of NG.

Main Issues:
- High investment
- High Operational Costs
- Many actors (Joint Venture)
- Complex decision-making process
Currently…

The optimization of LNG processes is focused on:
- LNG processes during their operation
- Equipment design
- One part of the LNG value chain

Optimization processes have been based on power consumption and/or UA and/or Minimum Approach Temperature

Optimization processes are achieved by assignation of some weights

The Decision-Making process has not been included
Game Theory

- Game theory is the formal study of decision-making (conflict and cooperation).
- A game consists of a set of players, a set of moves (or strategies) available to those players, and a specification of playoffs for each combination of strategies.
- The concepts of game theory provide a language to formulate, structure, analyze, and understand strategic scenarios.
Game Theory: The Prisoners’ Dilemma

A simple game that has become the dominant paradigm for social scientists since it was invented about 1960

Two suspects of a crime are found near the scene...

Dave

Henry

They are quickly separated for questioning...

Each one is confronted by three choices: admit to the crime, tell on the accomplice, or do not cooperate with police... Each prisoner is told the following:
Prisoners’ Dilemma

- If you both confess: 2 years in prison
- If you confess, and the other person does not: go free; and 10 years in prison
- If neither of you confess: 30 days in prison
- If you do not confess, and the other person does: 10 years in prison; go free
- Each of you is being given the same deal

Think about it…
Prisoners’ Dilemma

What strategies are "rational" if both men want to minimize the time they spend in jail?

From Dave point of the view:
“Henry can confess or not”

Henry confesses: I get **10 years** if I don't confess, **2 years** if I do
It's best to confess

If Henry does not confess, and I don't either, I get **30 days** but if I confess I can go **free**.
It's best to confess

**They both confess…**

Source: Investopedia
Frame of Reference

Game Theory: The Prisoners’ Dilemma

Cooperative Nash

There are not (without collaboration or communication with any of the others)

Existence of Equilibrium Points

Players are supposed to be able to discuss and agree on a rational joint plan

The agreement should be assumed to be enforceable by an outside party (e.g., police, etc.)

Source: Investopedia
Market Behavior

\[ \text{Profit}_1 = p \cdot \text{Quantity}_n \cdot \text{Quantity}_1 - \text{Cost} \]

Frame of Reference

Nash Equilibrium (Non Cooperative)

Best Reply Correspondence of Company 1

Best Reply Correspondence of Company 2
\[ f_1(x, y) \leftrightarrow f_2(x, y) \]

**MOO**

**Frame of Reference**

**Optimal Pareto: non dominated solutions**

**Operation Point??**

**DM on LNG Projects**

**Implementation**

**Results**

**Closure**
Frame of Reference

Process Behavior

Nash Equilibrium
(Non Cooperative)

Cooperative
Nash Bargaining

Minimum loss

Frame of Reference
DM on LNG Projects
Implementation
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Not Confess
Confess

Confess
Not Confess

30 Days
10 Years
Free

2 Years
10 Years
Free

10 Years
Free
2 Years
Stackelberg game (leader-follower) (1953): preplay announcement

- Leader and followers
- Leader announces a strategy before implementing it - can induce the follower-player to behave in a desired way
  - Announcements have a coordinating effect, even though the signaling act is not a strategy
  - Announcements look to obtain a favorable play-off for both, but the leader dominates the game
Decision-Making on LNG projects

Integrated concept

Hierarchical structure
Using Genetic Algorithms
Based on Game Theory

Leader-Follower Game

Non Cooperative Nash Game

Input

Upper Level

n-Medium level

n-Lower Level

Highest decision makers in the structure of the project (i.e. shareholders)

Decision makers in the middle grades of the project structure (i.e. Pre-treatment manager)

Relative lower level of decision making (i.e. HX, compressor design team)
Assumptions

**Objective:** Evaluation of DM framework in a project which uses Simple Mixed Refrigerant (SMR) process

**Focused on:** Cost reduction

**Scenario:** Decision makers are in different places and times and have different preferences

**Economic model:** based on CAPEX, OPEX, Revenues and “Market Cost “

Why should we use a Market Cost Model?
LNG application...

- Cost reduction by improvement in LNG technologies (power consumption/UA) is limited to around 5% (*).
- There is a potential cost reduction as high as 20-30% in other aspects of the LNG project (FEED/EPC) (\(^a\), *).

Market Cost

- Include critical equipment, processes and competition in the economical model.
- Include flexibility in execution of the project phases.
  - ✔ Who/How will FEED and EPC be carried out.

General Model

\[
\text{Cash Flow} = \text{Revenues} - \text{CAPEX} - \text{OPEX} - \text{Cost}_{\text{Market}}
\]

\(^a\) FEED: Front-end Engineering Design. EPC: Engineering, Procurement and Construction
LNG application...

Leader (manager)
Minimize Process Cost
Equipment Suppliers
Competition of EPC Development

Leader-Follower Game

Follower 1:
(design team 1)
Minimize Heat Transfer Area
Availability on the Market

Leader-Follower Game
Non Cooperative Nash Game

Follower 2:
(design team 2)
Minimize Power Consumption
Availability on the Market

Implementation
Going on our particular case...

Leader \[ \text{Cost}_{\text{process}} = \text{Cost}_{HX}(A) + \text{Cost}_C(w) + \text{Cost}_{\text{Market}}(s) \]

Follower 1

Heat Exchanger

Follower 2

Compressor/driver

Cost_{Equipment}(A) +

Cost_{space}(A) +

Cost_{Environment}(NG) +

Cost_{Market1}(s)

Cost_{Equipment}(w) +

Cost_{space}(w) +

Cost_{Environment}(w) +

Cost_{Market2}(s)

\text{Design Variables} \quad A: \text{Heat Transfer Area} \\
\quad w: \text{Power consumption} \\
\quad \text{Market variable} \quad s: \text{market variable}
LNG application…

Formal Problem…

\[
\min \text{Cost}_{\text{process}} \quad \min(\text{Cost}_{\text{Market}}) \quad \min(w) \quad \min(A)
\]

Multiobjective problem

Market models

\[
\begin{align*}
\text{Cost}_{\text{Market}} &= \beta s^2 \\
\text{Cost}_{\text{Market1}} &= (s + A)^2 \\
\text{Cost}_{\text{Market2}} &= (s + w)^{0.5}
\end{align*}
\]

Leader preference

\[
\frac{\delta \text{Cost}_{\text{Process}}}{\delta s} = 0 \quad s = s^*(w, A)
\]

Followers

\[
\begin{align*}
\text{Cost}_C &= f_1(m, P_l, P_h, \text{Compositions}, s^*) \\
\text{Cost}_{HX} &= f_2(m, P_l, P_h, \text{Compositions}, s^*)
\end{align*}
\]
Nash-Genetic Algorithms

Implementation

Optimization of \( t = X^* Y^* \)

Player 1
\( \text{Pop}_1: \text{Initial Population (X)} \)

Player 2
\( \text{Pop}_2: \text{Initial Population (Y)} \)

Initialization of \( \text{Pop}_1 \) and \( \text{Pop}_2 \)

Choose randomly \( X^*_0 Y^*_0 \)

Optimize \( X_1 Y^*_0 \)

Optimize \( X^*_0 Y_1 \)

Optimize \( X_2 Y^*_1 \)

Optimize \( X^*_1 Y_2 \)

Optimize \( X_n Y^*_n \)

Optimize \( X^*_n Y_n \)

Solution
\( X^*_n Y^*_n \)

Source:

LNG application…

Input

Process Configuration

Process Optimization

Output Data

HYSYS database

Implementation
Market Costs might be taken into account from the design and selection of LNG processes.

Integrated models offer more realistic and systematic procedures for decision making.

Optimizations based on thermodynamics parameters might not give the best decision.

Better models of the penalties for the markets are required in order to increase the reliability of the decisions.
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