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Global optimal vessel capacity for LNG production and transportation

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Abstract: In this paper, developed a linear programming model to determine the volume of vessels that will give an optimal return on investment. The solution to the developed model was carried out using the Interior Point algorithm with the help of the MATLAB package. The analysis observed that the production and transporting of the LNG with a vessel of capacity 178,5006m3 would give an optimal profit of 633,640 million USD. And from the results of the analysis, we observed that the decision to take the maximum modern capacity instead of lower capacities yields the highest profit.

Keywords: natural gas, liquefied natural gas, vessel capacity, transportation, linear programming.

1. Introduction

Investment in the vessels for transportation of Natural gas as a business is the concern of this paper. The paper seeks to determine the vessel capacity that will optimize the profit, the production and transportation of natural gas. Natural gas is the cleanest fossil fuel that is composed of methane, carbon dioxide and some noble gases found in reservoirs beneath the earth surface as an accompanying product of oil (Fpz.unizg.hr, 2018). It is formed as a result of the transformation of organic matter due to heat and pressure of overlaying rocks in the earth's crust (Patin, 1999). During combustion, natural gas, in comparison to the combustion of oil and coal, emit minute amounts of nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon dioxide (CO_2), carbon monoxide (CO) and other reactive hydrocarbons, whereas a higher level of harmful gases such as nitrogen oxides and sulfur dioxide are released during the combustion of oil and coal as a result of the composition of a much more complex molecular structure (Liang et al., 2012). And by cooling natural gas below its liquefaction point of about -163°C at atmospheric pressure, it is converted into liquid form for easy storage and transportation (Peter, 2009). Natural gas is cleaner and cheaper and therefore environmentally friendlier than any other known fossil fuel (BP Statistical Review of World Energy, 2017). When natural gas at atmospheric pressure is cooled

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to temperatures of -163°C, it condenses into colorless, odorless, non-toxic, non-corrosive and non-carcinogenic liquid. Natural gas occupies only 1/600 of the volume of its gaseous state in liquefied state, so it is transported more economically and stored more effectively.

The gas is refined in order to remove impurities according to the consuming market requirements. It can be refined to be in the form of LNG (liquefied natural gas), NGL (Natural gas liquids), LPG (liquefied petroleum gas), CNG (Compressed natural gas), and GTL (Gas to liquids). LNG is the main focus of this paper, though we shall give a little explanation of the other forms of natural gas as they are often used interchangeably.

LNG is made up of about 95% methane and 5% of other gases. In the process of liquefying it, non-methane components, such as carbon dioxide, water, butane, pentane and heavier components are removed. It burns in concentration of 5% to 15% when vaporized and mixed with air. **NGLs** is made up of molecules heavier than methane. These molecules are easier to liquefy than methane. It contains 95% ethane, propane and butane, then 5% of others gases. **LPG** is predominantly a mixture of propane and butane in a liquid state at room temperature when under moderate pressure of less than 200psig (pounds per square inch gauge). It contains 95% butane and propane, then 5% of other gases. It is highly flammable and used heavily for domestic purposes such as cooking and heating. **CNG** is not the same as LNG, it is compressed natural gas, natural gas that is pressurized and stored in welding bottle-like tanks at pressure up to 3600psig. It has the same composition with pipeline quality natural gas, i.e. the gas has been dehydrated and all other elements to trace so that corrosion is prevented. CNG, LPG and LNG are used as common transport fuels. **GTL** refers to the conversion of natural gas to products like methanol, dim ethyl ether (DME), middle distillates (diesel and jet fuel), and specialty chemicals and waxes (Foss, 2007).

LNG is shipped in specialized ocean-going vessels (gas carriers) between the export terminals, where natural gas is converted to liquid form, and import terminals, where LNG is returned to its gaseous state (re-gasification). At an import terminal, it is injected into pipelines for transmission to local distribution companies, industrial consumers for industrial uses, and power plants for electricity generation. The majority of worldwide LNG exports take place between two or more continents, meaning that shipping LNG across the ocean is often required. This is done with the use of an LNG vessel or LNG ship, which transports large quantities of LNG between export and import terminals. The main type of LNG vessel that exists today among several types is referred to as an LNG tanker. The main components of an LNG tanker are the boiler and pump rooms, a double hull for added strength, bow thrusters, and the LNG storage tanks. Typically, an LNG tanker is built with 4 or 5 individual LNG tanks. LNG is shipped around the world in specially constructed seagoing vessels. LNG is transported in specially designed ships with double hulls protecting the cargo systems from damage or leaks.

Uses of natural gas

Natural gas is one of the cheapest forms of energy. It is readily available to residential consumers for usage. It also has a number of uses such as natural gas heating and cooking. Using natural gas for cooking by residential customers is safer because it is characterized by its easy temperature control, self-ignition and self-cleaning.

The Commercial uses involve the use of natural gas in places such as public and private enterprises, place of worship, schools, office buildings, hotels, eateries and government structures. The main uses of natural gas include water heating, space heating and cooling.

Natural gas is used for the production of products like plastic, fertilizer, anti-freeze, fabrics, etc. Industrial users of natural gas are the largest consumers of natural gas as they account for about 35% of natural gas use across all sectors. After electricity, the second most used energy source in industry is natural gas.

Natural gas is also used as a fuel for transportation. This has mainly been through the firm emissions regulation and often in the form of public transportation systems like buses. A lot of advantages are obtainable with regards to emissions control especially in large cities where car congestions causes serious emission problem. When compared to oil, natural gas has lower harmful emission and can be used in cars with similar engines to today's average petrol cars (EIA, 2018).

Challenges in handling of LNG

The challenges of liquefied natural gas include:

a. Storage/Transportation: Natural gas is difficult to store or be transported because of its physical nature and needs high pressures and low temperatures to increase the bulk density. Due to the difficulty of natural gas storage, natural gas needs to be transported immediately to its destination after production from a reservoir (Cranmore, 2000).

b. Transportation Cost: The cost of transporting natural gas per unit of energy to distant markets is much higher compared to oil because of its volume–pressure behavior. LNG production at present costs around US$ 15/bbl oil equivalent (i.e. $ 2.5/thousand scf of gas) but many importing countries do not have the capital to build the huge storage and regasification facilities (Cranmore, 2000).

c. Economics of LNG: LNG projects are very much capital intensive. The entire chain from surface of the oil well (wellhead) to the receiving terminal can cost around US$4 billion. Economies of scale are very significant as in the case of pipelines: liquefaction plants typically comprise one or two processing trains of about 3 to 3.5 million tonnes per year. Normally a single-train plant costs around $1 billion, although actual costs vary geographically according to environmental and safety regulations, other local market conditions, labor costs and land costs (Moryadee & Gabriel, 2017). Thanks to economies of scale, substantial reductions in cost have been achieved over the past decades. The sizes of tanker vessels have now increased from some 40,000 m^3 for the first generation to a range of 150,000 to 180,000 m^3 nowadays.

d. Environmental Concern: The issue of global warming has dominated all discussion relating to human existence on earth today. Huge quantities of natural gas exist in the form of natural gas hydrates, which are reservoirs in which natural gas is trapped within ice cages. These materials have strong links with climate change; they have the potential to magnify or remedy climate change depending on how they are handled. These materials are only stable at low temperatures and methane (95% natural gas) is twenty times worse than carbon dioxide as a greenhouse gas. Non-exploitation is thus not an option because with the present increase in atmospheric temperature due to climate change, these materials will soon start melting and methane will be released uncontrollably into the atmosphere (Igboanusi, 2007).

This work is divided into five sections; section one is devoted to introduction of natural gas with special interest in the LNG. Section two deals with literature review. Section three treats Materials and Method. Section four treats data presentation and analysis, and section five treats conclusion and discussions.

2. Literature review

The LNG shipping is done with specially designed ships with cryogenic containment system. They are double-hulled tanker ships specially designed and insulated to prevent leakage or rupture in an accident. The LNG is stored in a special containment system with the inner hull where it is kept at atmospheric pressure and cryogenic temperature, (Foss, 2007). The typical LNG carrier can transport about 125,000 – 138,000 cubic meters of LNG although lately more LNG ships with containment system with a capacity of up to 260,000 cubic meters are on order (Clarkson's research institute, 2008).

The transportation system for natural gas consists of a complex network of pipelines, designed to quickly and efficiently transport natural gas from its origin, to areas of high natural gas demand. Natural gas flows efficiently through pipelines so it was a more preferred method of transporting natural gas but more costly compared to shipping through vessels. Most natural gas pipeline infrastructure takes the natural gas between liquefaction facilities and storage facilities, from storage facilities to tankers, and from tankers to re-gasification facilities. By this means much higher amounts of gas are able to be transported for the same volume flow (Gate Terminal, 2011), important insulation must be combined into liquefied natural gas pipelines in order to maintain this low temperature and ensure that it does not return to its gaseous form. This normally includes a combination of mechanical insulation like glass foam and a vacuum layer (PHPK Technologies, 2008). This complex insulation system makes LNG pipelines significantly more difficult and expensive to manufacture the standard natural gas pipelines.

Since the first LNG carrier methane pioneer was built in the late 1950s; the LNG shipping industry has grown rapidly and has increased in size; with the largest carriers today shipping more than 200,000 m^3 capacity. Approximately, 300 meters (m) (975 feet) long, 43m wide (140 feet) wide and has a draft of about 12 m (39 feet) is the dimension of a typical modern LNG ship. The cargo capacity of LNG ships varies, from 1,000 cubic meters to approximately 267,000 cubic meters, but the majority of modern vessels are between 150,000 m^3 and 200,000 m^3 capacity (or 180,000 m^3capacity for the case of the new Panama Canal). In some areas, such as Norway and Japan smaller LNG ships (1,000 – 25,000 cubic meters' capacity) also operate. LNG carriers are capable of speeds of up to 21 knots (oil tankers operate at 15-20 knots) in open waters. In the 2008, the cost of the largest LNG carriers was up to $280 million but in 2009, the same size cost less than $200 million today due to the fact that the LNG industry was been driven by both competition and innovation of new technology, to become more cost- efficient (DNVGL, 2018).

At the end of 2015, total LNG fleet consist of 416 LNG carriers (IGU, 2018), considering only those above 30,000m^3 in payload. Most young vessels are built with a design speed of 19.5 knots plus a sea margin, which is because of the initial design of vessel Hilli and her sister vessels built in 1970s (DNVGL, 2018) and the design speed was optimized because of their high boil-off on a long contract and the storage capabilities. The relatively high speed is capable of being retained without corresponding high external fuel consumption because the boil-off was used directly in the machinery for propulsion. The standard speed of 19.5 knots plus a sea margin which has been since used was pointless because advancement in technology has lowered the boil-off, which makes around 16-18 knots a more suitable speed. This is also the speed most LNG carriers sail in today.

According to the volume of tanker plus four-day production capacity of LNG, storage is expensive for LNG plant. During the year 2000-2010 majority of LNG tankers having capacity of approximately 140,000 m^3 were built. They carry the gas of 3.1 Bscf (87 million m^3) or 512,000 BOE. Super LNG tankers having capacity of 265,000 m^3 were designed for long trade from Qatar to United States of America. In order to meet the requirement of tanker load, most of the LNG plants are having two or more storage tanks (Choi, 2010). Long distance transport from one country to another by ship across ocean to markets and its local distributions is facilitated by the LNG physical properties. An advantage over the construction of long-distance pipeline is the reduction of the LNG transportation costs using cargo ships (Mokhatab & Economides, 2006).

In this work, we are concerned with the determination of the vessel capacity (Volume) that will optimize return on investment for Vessel investors. We intend to develop a linear programming model that will maximize profit on LNG production, required vessel volume that will yield optimal profit for vessel investors.

3. Materials and method

3.1. Method of data collection

The data used in this work was a secondary data obtained from BP Statistical Review of World natural gas production and LNG fleet carrier sizes, 2018.

3.2. Method of data analysis

We are concerned with the development of linear programming model for the LNG production; and the objective function is to maximize the profit from shipping the product subject to vessel volume (the constraints). From the model, we determine the optimal vessel size that is needed to maximize profit. It may not be economical to use or invest in under sized or oversized vessels to avoid wastages. This will help investors in vessels to determine the vessel size that will bring maximum returns on investment.

3.3. Development of the model for the production and vessel capacity

We used optimization technique to develop a Linear programming model for the LNG production and shipping to maximize profit. The developed model is solved using the Interior Point Algorithm technique to find optimal and feasible solution to the problem. Interior Point algorithm is employed here because of large number of variables and parameters involved; otherwise, we use the Simplex method for the solution. We shall find the contributions of each of the decision variables to the optimal profit, this yield the optimal vessel size. To achieve these, we follow the steps below, (Arua et al., 2000);

$$Minimize\ Z = \sum_{j=1}^{n} C_j X_j \tag{1}$$

Subject to

$$\sum_{i=1}^{m}\sum_{j=1}^{n} a_j X_j \le b_i$$

$$X_j \ge 0; \quad b_i \ge 0 \tag{2}$$

Where Z is the objective function, C_j is the cost coefficients and X_j is the decision variables, decision variables can either be basic or non-basic variables; a_{ij} is the resources available and b_i is the total constrains (vessel volume).Since the problem is large, we use the interior point algorithm to solve the problem. We shall employ MATLAB to solve the modeled problem.

4. Data presentation and analysis

4.1. Data presentation

Table 1: Natural gas production in billion cubic meters

YEAR	North America	S & Cent. America	Europe & Eurasia	Middle East	Africa	Asia	TOTAL
2003	766.6	118.7	1001.9	262.9	144.9	321.6	2616.5
2004	752.8	131.7	1032.3	285.1	154.7	337.4	2694
2005	743.3	138.6	1038	319.9	174.3	363.9	2778
2006	763.9	151.1	1051.7	339.1	191.2	383.7	2880.7
2007	781.6	152.5	1053.2	357.8	203.1	402.2	2950.5
2008	801.5	157.6	1086.5	384.3	211.5	420.7	3062.1
2009	801.8	151.9	969.8	407.1	199.2	446.4	2975.9
2010	826.1	161.2	1043.1	460.7	209	493.2	3193.3
2011	820.5	167.5	1051.8	526.4	202.6	500.1	3269
2012	850.3	173.8	1043.6	552.2	207.8	509.4	3337.1
2013	860.1	176.9	1052.2	569.1	198.3	519.6	3376.2
2014	915.1	179.1	1022.8	589.9	200.6	539.4	3446.9
2015	949.6	180.9	1013.3	608.4	203.6	564	3519.4
2016	944.6	178.8	1008.4	630.8	207	580.3	3549.8
2017	951.5	179	1057.4	659.9	225	607.5	3680.4
2018	761.6	138.5	1035.4	313	173.6	361.8	2783.9
2019	806.3	162.4	1039	466.1	206	474	3167.5
2020	924.2	178.9	1030.8	611.6	206.9	562.2	3514.5

Source: BP Statistical Review of World Energy.

Table 2: LNG Carrier Fleet Development '000 bcm (2013-2017)

YEAR	<40,000	40,000 - 59,999	60,000 - 99,999	100,000 - 139,999	140,000>	TOTAL FLEET
2013	119		983	16,439	35,859	53,400
2014			677	16,489	40,082	57,248
2015			756	16,219	45,468	62,443
2016			756	14,945	49,738	65,439
2017			756	14,583	52,714	68,053

Source: Clarkson research Institute.

4.2. Data analysis

Our interest is to maximize LNG production subject to the vessel capacities. We want to determine the vessel capacity that will maximize the profit from the LNG production. This will help investors in ship business to make informed decision on how to invest in the shipping business.

Formulation of the problem:

Let the LNG production by: North American region = *X1*; South and Central American region = *X2*; Europe and Euro-Asian region = *X3*; Middle East region = *X4*; African region = *X5* and Asian region = *X6*;

Let *Cj* = various yearly productions by different regions, *j; j* = 1, . . . , 6;

aij = various available yearly production from each region, *i; i* = 1, . . ., 18; *j*= 1, . . ., 6 ;

Xij = LNG production per region, this is the decision variable; *Xij* > 0;

bj = the ship volume (capacities);

f(x) = Objective function, which is to maximize the profit from LNG production

Hence, we can now write the model as follows;

$$Maximize\, f(x) = \sum_{j=1}^{n} C_j X_j \quad (1)$$

Subject to

$$\sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} X_{ij} \le b_i$$

$$X_{ij} \ge 0; \quad b_i \ge 0 \quad (2)$$

The restriction is on the vessel capacity and we chose 180,000 bcm.

Therefore, we have;

$$Max\, f(x) = 2616.5x_1 + 2694x_2 + 2778x_3 + \ldots + 2783.9x_{16} + 3167.5x_{17} + 3514.5x_{18}$$

$$\text{Sub. to: } 766.6x_1 + 752.8x_2 + 743.3x_3 + \ldots + 761.6x_{16} + 806.3x_{17} + 9243x_{18} \le 180{,}000$$

$$118.7x_1 + 131.7x_2 + 138.6x_3 + \ldots + 138.5x_{16} + 162.4x_{17} + 178.9x_{18} \le 180{,}000$$

$$1001.9x_1 + 1032.3x_2 + 1038x_3 + \ldots + 1035.4x_{16} + 1139x_{17} + 1030.8x_{18} \le 180{,}000$$

$$262.9x_1 + 285.1x_2 + 319.9x_3 + \ldots + 313x_{16} + 466.1x_{17} + 611.6x_{18} \le 180{,}000$$

$$144.9x_1 + 154.7x_2 + 174.3x_3 + \ldots + 173.6x_{16} + 206x_{17} + 206.9x_{18} \le 180{,}000$$

$$321.6x_1 + 337.4x_2 + 363.9x_3 + \ldots + 361.8x_{16} + 474x_{17} + 562.2x_{18} \le 180{,}000$$

Using MATLAB R2007b packages to analyze the above problem, we obtain the following results as presented below;

f = [-2616.5;-2694;-2778;-2880.7;-2950.5;-3062.1;-2975.9;-3193.3;-3269;-3337.1;-3376.2;-3446.9;-3519.4;-3549.8;-3680.4;-2783.9;-3167.5;-3514.5];

A=[766.6,752.8,743.3,763.9,781.6,801.5,801.8,826.1,820.5,850.3,860.1,915.1,949.6,944.6,951.5,761.6,806.3,924.2;118.7,131.7,138.6,151.1,152.5,157.6,151.9,161.2,167.5,173.8,176.9,179.1,180.9,178.8,179,138.5,162.4,178.9;1001.9,1032.3,1038,1051.7,1053.2,1086.5,969.8,1043.1,1051.8,1043.6,1052.2,1022.8,1013.3,1008.4,1057.4,1035.4,1039,1030.8;262.9,285.1,319.9,339.1,357.8,384.3,407.1,460.7,526.4,552.2,569.1,589.9,608.4,630.8,659.9,313,466.1,611.6;144.9,154.7,174.3,191.2,203.1,211.5,199.2,209,202.6,207.8,198.3,200.6,203.6,207,225,173.6,206,206.9;321.6,337.4,363.9,383.7,402.2,420.7,446.4,493.2,500.1,509.4,519.6,539.4,564,580.3,607.5,361.8,474,562.2];

b = [180,000; 180,000; 180,000; 180,000; 180000; 180000];

lb = *zeros*(18,1);

[*x, fval, exitflag, output, lambda*] = *linprog(f, A, b,* [], [], *lb*)

Optimization terminated.

*X** = [0.0000; 0.0000; 0.0000; 0.0000; 0.0000; 0.0000; 0.0000; 0.0000; 0.0000; 0.0000; 0.0000; 0.0000; 0.0000; 178,5006; 0.0000; 0.0000; 0.0000; 0.0000]
fval = f(x)* = 633640
exitflag =1
output = iterations: 10
algorithm: 'large-scale: interior point'
cgiterations: 0
message: 'Optimization terminated.'
lambda =
ineqlin: [6x1 double]
eqlin: [0x1 double]
upper: [18x1 double]
lower: [18x1 double]

4.3. Interpretation of results

Production and transporting the LNG with a vessel of capacity 178,5006 m^3 will give an optimal profit of 633,640 million USD. From the results of the analysis, we observed that the decision to take the maximum modern capacity instead of lower capacities yields the highest profit and hence the policy should be adopted in the shipping industry by vessel investors. We can also observe that the needed capacity was not up to 180,000 m^3 but close to it. There are vessels of other bigger capacities but are demanded on a rare occasions, such vessels are not for regular business and cannot yield optimal profit for the investors. From the analysis, we observed that the policy has a shorter iteration of 10. At this policy, the constraint (vessel capacity) was restrained to 180,000 m^3. Hence, it is advisable that vessel of higher capacity should be invested on for optimal profit to the vessel owners against investing on vessel of lower capacity which yield lower optimal profit.

5. Conclusion and discussions

In this work we develop linear programming model to determine the volume of vessels that will give optimal return on investment. No such work was previously done on LNG using linear programming to determine the optimal profit on production and the volume of vessels required to optimize returns on investment. With this, investors in vessels should be properly guided to maximize profit from their investment. Application of the developed model in the LNG industry should be encouraged because it proffers directions and solutions to both LNG market and investment in vessels as a business. The developed model can handle a large volume of data as we have seen in this work; hence, investors can now make an informed decision on LNG trade and investment in shipping business. Again, we have introduced optimization technique into the LNG industry; with optimization, we have been able to determine the vessel size (volume) that will maximize the return on investing in LNG market.

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