sciendo

DOI: 10.1515/aon-2018-0006

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CONCEPT OF LNG TRANSFER AND BUNKERING MODEL OF VESSELS AT SOUTH BALTIC SEA AREA

ABSTRACT

At first part of the article methods of SOx (sulphur oxides) emission reduction is presented along with the description of LNG (Liquefied Natural Gas) as a bunker fuel for vessel. Assumptions for the methods of bunkering between different LNG driven vessel and bunker means is presented. Last part presents assumptions for optimization method and detailed factors to be used in the further work. Optimization of Location-Route Planning (LRP) model with dynamics is presented as starting idea for next steps.

Keywords:
LNG, bunkering of gas, supply chain

1. INTRODUCTION

Dynamic implementation of SECA zones at Baltic Sea (where sulphur content emitted to atmosphere will be limited) forces ship owners to seek for other solutions than traditional HFO (heavy fuel oil). It can be expected that switch to MDO (marine diesel oil) with low sulphur content is temporary and based on:

- very easy implementation to existing engines;
- low emission of SOx (sulphur oxides);
- easily available.

This kind of fuel is more expensive than HFO and traditional MDO but recent, moderate prices (around 515 $/MT) still encourages ship owners to use it (for the fall of 2016). Largest improvements that are taken into consideration could be described as:

1. switching to gaseous fuels (liquefied or compressed natural gas - LNG, CNG(compressed natural gas));
2. using HFO/MDO with water scrubbers;
3. electric driven vessels/other means (MeOH, ethane, hydrogen, LPG, di-methylether, ethanol).

All of these can reach 0.1% sulphur emission (SECA Zones) limits where electrical driven (and other mentioned means) vessels doesn't seem to applicable in the close future. Also development of scrubbers at existing vessels show that this technology generate lots of contamination in water used inside the system – scrubber waste. This wastes must be treated properly according to MARPOL Convention and reception facilities are not available in many ports. According to (EMSA 2013) and other papers this technology is extremely limited. In authors opinion it is not promising technology, along with the recent advances vs. emission control.

Most promising technology is using liquefied/compressed gases for vessels propulsion. There are three most important factors influencing it:

1. gas is more and more available in Europe;
2. existing engines can be driven by gas or easily adopted to it;
3. dual fuel operation in normal conditions for 2 or 4 stroke engines (also generators) is possible.

According to LR Bunkering Infrastructure Survey 2014 (Luis Benito 2014), carried out in 22 major seaports in Europe, Asia and North America it can be ruled that:

1. 59% of ports either have in site or have plan to provide LNG bunkering infrastructure for local shipping;
2. 86% consider LNG as likely or very likely to be an important bunker fuel for sea shipping;
3. 76% of them have a project in period of 0 to 5 years for LNG bunkering operations to commence; for the others ports the time frame is no more than 10 years.

This trend is now surveyed by EMSA [1] and several agencies or private bodies (to mention LR, DNV GL etc.). It shall be expected that most of the ports are planning to set up LNG infrastructure.

Recent implementations and developments in small scale LNG (as for fall 2016) are focused at:

1. Fjord Line opened second loading-arm-based LNG bunkering station (first was in Stavanger's Risavika harbor) for its gas-powered cruise ferries Stavangerfjord and Bergensfjord, at Hirtshals in northern Denmark. Ferry berth at Hirtshals has a 500m^3 LNG storage tank (cylindrical), filled by trucks [4],
2. Authority of Port of Hirtshals is building a small liquefaction plant and storage tanks for LNG capacity of 5,000m^3. Gas will be sourced from the Danish sector of the North Sea and the terminal is expected to be in operation by 2017 [4],
3. Fjord Line's jetty-mounted loading arm at Risvika is linked to the Skangas liquefaction plant by a 750m LNG pipeline. Skangas expects to make 35,000 tonnes of LNG available as marine bunkers in Risavika this year, most for Fjord Line. Risavika harbour authority and Skangas are developing a second quay in the port for LNG bunkering [2],
4. Estonia plans to build the terminal for small scale operations in Muuga.

At the large size terminal market of LNG at the Baltic Sea it can be seen that:

1. Largest LNG receiving plant in Świnoujście, Poland is commissioned and operation has been commenced (04. 2016),
2. Second largest terminal (Klaipeda, Lithuania) is operative basing on the FSRU LNG storage tanker,
3. Largest production plant is St Petersburg able to produce 0.42 million tons of LNG per year (Gorskaya, Russia).

From the vessel perspective market is developing really fast and for our point of research it must be seen that:

1. The Russian company has ordered three 7,300m^3 LNG bunkering and coastal distribution tankers at United Shipbuilding Corp (USC), the first LNG carriers of any type ordered at a Russian shipyard. The first is due to enter service in early 2017 [2],
2. Polish based company PGNiG – leader in gas production and LNG whole sale - is considering building the LNG tanker/bunker vessel,
3. Positive tests of new US based company TOTE propelled by LNG container with innovative storage can be an impulse to whole industry [10].

2. BUNKERING OF LNG

Bunkering is defined as supply of fuel to the vessel for propulsion, power generation, heat production or any other issues. It is not limited to supply by the means of other vessels (called bunker vessel or barge) and can be set up as a:

1. Ship to ship - STS,
2. Truck to ship – TTS,
3. Fixed facility Shore to Ship – FF,
4. Removable tank or container – CONT.

These are the 4 types that will be implemented to build the model of bunkering LNG as a fuel in the possible means of bunker transport to the fueled ship.

2.1 Ship To Ship

Typical vessels serving as a bunkering means can be divided into significant sizes:

Tab. 1. Significant types of vessels serving as bunkering means.

No	Type	Gross capacity of liquid gas Q(m^3)	Est length overall Loa (m)
1	LNG barge	200 – 1000	Up to 85
2	Bunker barge/feeder	1000 – 10 000	100 – 120
3	Large feeder	10 000 – 75 000	120 - 215

Source: Authors.

Typical bunker barge/vessel is in fact small LPG carrier with all installation on board required by international law, and some sort of representative vessel is presented at fig. 1. (feeder of capacity 30k m^3) and smaller one (Q= 7k m^3) at fig. 2. Barge (or properly bunker barge) of capacity around Q=2k m^3 is presented at fig. 3.

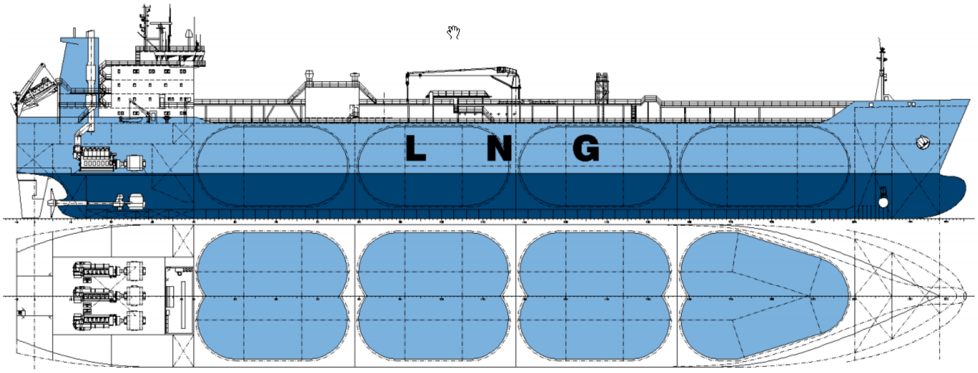

Figure 1. Feeder Q=30 000 m3 LNG (LOA 180m).
(Source: http://www.tge-marine.com/158-0-TGE-Marine-signs-contract-for-30000-cbm-LNG-Carrier.html (10.09.2018).

Figure 2. Feeder A Q=7000 m^3 LNG (LOA 117m).
(Source: https://www.anthonyveder.com/wp-content/uploads/2012/07/methane-varend-1024x409.jpg (10.09.2018).

Bunker vessel/barge capable to fill other ships with LNG bunker must be equipped with:

1. isolated cargo LNG grade tanks pressurized class C or composite;
2. deep well pumps;
3. compressors;
4. safety valves etc.;
5. manifold with quick release system;
6. cryogenic hoses, flanges etc.;
7. firefighting system.

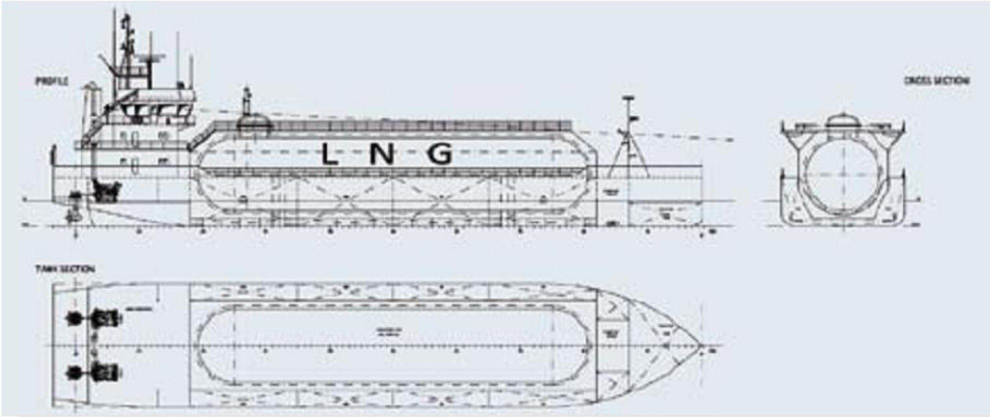

Figure 3. Barge/bunker barge Q=2000 m3 LNG (LOA 48m) (Source: http://tge-marine.com/37-0-Small-Scale-LNG.html (10.09.2018).

2.2 Truck to ship

Trucks are dedicated trailer based cryogenic tank systems with standardized saddle for truck hauling. Tanks are insulated in different manner (depending on producer) from loses due to external heating. Typical parameters of auto LNG truck trailer are:

1. Capacity: 45- 48 m^3;
2. LNG storage for 0.48 MPa: 17.5 t;
3. Allowable maximum pressure: 0,483 MPa;
4. Length without trailer: 14.6m;
5. Breadth: 2.6 m;
6. Height: 3.74 m;
7. Net weight: 11.5 t.

Auto trailers are self-unloading (all required devices and systems are taken always on) and following devices must be available for this purpose:

1. Centrifugal pumps;
2. Vapor return valve;
3. Earthing circuit;
4. Cryogenic hoses (LNG);
5. Mass flow meters;
6. Vapor and liquid level monitoring.

2.3. Shore to Ship

This kind of facility comprises of some kind fixed tank at shore, hoses, arms and couplings to connect vessel and as such is applicable in the lines where constant service is provided to mention:

1. Ro-Ro vessels;
2. Ro-Pax vessels;
3. Cruisers on line service;
4. Containers and general cargo on line services.

2.4. Container with LNG

One of latest conception is container with LNG, which technically is similar to truck type tank with proper insulation and some devices enabling its connecting, filling and monitoring. Tank is usually one or two sided semi pressure tank in form of cylinder inside the typical container (20’’ or 40’’ size) frame isolated from outer world with special foam and housing. Some companies has designed and produced such containers working at pressure P=0.5 MPa and with outer insulation can holds up to 50m3 of LNG with self-cooling time for around 1 month. Container of 20 feet equivalent is presented at fig. 4.

Fig. 4. LNG container. Source: https://www.karbonsan.com.tr/ (22.06.2018).

Container of this type can be set up on the vessel deck and connected to the vessels propulsion installation. Typical 40 feet equivalent container has parameters:

1. Max load: 36t.;
2. Capacity 47m^3;
3. Nnet weight: 10 tons;
4. Self-evaporation rate 0.25%;
5. In accordance with: UN T75, ADR, ASME, US DOT, RID, IMO, CSC, IMDG, UN PORTABLE, UIC, TIR, UK DOT, TPED.

For typical TEU container (20'') capacity is around 23m^3. Maximum allowable pressure is around P= 0.6 ~ 1.7 MPa.

2.5 Feeding the bunker barges/vessels

In order to possess cargo as well as bunker fuel (in means of LNG) it is required to fill the bunker barge/vessel at proper jetty/pier or wharf. There are 4 options to obtain LNG grade bunker fuel delivered to fueling ship (with example from Baltic Sea):

1. Produce it on liquefaction train from CH4 (Gorskaya);
2. Transfer LNG from existing tank (either on/off shore i.e. FLNG platform) with LNG from 3rd side (i.e. imported by larger vessel) (Swinoujscie in 2017/8, Klaipeda in 2017);
3. Transfer it from conventional LNG carrier (Q=75-250 km3) or feeder (Q=10-75 km^3) (any roads/anchorages);
4. Transfer LNG from mobile truck (any port).

At the region (whole Baltic Sea) we can observe all 4 types of bunker generation. Position 1 and 2 are strongly preferred and gives best ratios and volumes to be transferred. Number 3 is limited due to the fact that conventional tanker has small margin for delays (time for TTS) and feeders are not in operation yet; though it seems to be very promising mean of LNG bunker delivery for further development. Option 4 is least preferred, though for reasons of availability it is possible to enable it immediately, as far as truck can enter port.

3. MODEL OF LNG DISTRIBUTION CONCEPT

Modeling of distribution and optimal layout of network is not a new problem. Since companies or whole branch has been searching for any kind of network namely: customer-depot-road-means of transport this problem is arising. Set of these problems is generally known as a location-routing problem (LRP). The classical LRP consists in opening a subset of depots, assigning customers to them and determining vehicle routes, to minimize a total cost including the cost of open depots, the fixed costs of vehicles used, and the total cost of the routes [8]. Comprehensive survey on the LRP, published by [6], and followed by [8] presents lot of possible models and techniques in modelling it. New areas of applications for dynamical and static systems emerges very rapidly. For our needs, LRP as such, integrates two areas of decisions; assuming known set of potential ports/wharfs with opening costs, a fleet of vessels and a set of ship-owners (i.e. clients) with known demands; these can be formulated as:

1. Location of port with bunkering possibilities or bunkering means (i.e. location of vessel/barge with bunker);
2. Route for the delivering the bunker from place where it can be obtained (LNG Terminal).

Both factors are not connected to each other and shall be treated independently. From general overview of LRP systems conclusions are that splitting these factor produces significant costs in every transport branch.

Four key constrains in LRP for bunkering network are [6]:

1. Hierarchical structure of problem;
2. Type of input data – deterministic or stochastic;
3. Planning period – single (static) or multi period (dynamic);
4. Solution method – exact or heuristic.

To build the LRP model of LNG distribution for Baltic Sea it can be stated that it requires solving hierarchical, stochastic, dynamic and heuristic problem. And in general it will require following factors to be implemented:

1. Buildup of objective function (basing on economic objectives);
2. Determination of solution space (discreet solution for the LNG supply network);
3. Multiple ports assumption;
4. Number of vessels where non homogenous fleet is concerned;

5. Routing algorithms starting from port of loading the LNG and ending at bunkering place;
6. Application of one to many model where one vessel with bunker can utilize different bunker means, or many to many where different bunker means can bunker more than one vessel at once;
7. Stochastically character of traffic at Baltic routes as well as model of traffic growth;
8. Multiple customer via routes – where for example gas can be delivered to port, transferred to trailers and then from trailers transferred to other vessel;
9. Maximal service path/radius – economical effectiveness of route length with serviceability time (until LNG bunker remains);
10. Complex situations where more incoherent situations can occur.

Solving such formulated location and routing decisions independently will present solution of suboptimal results and this is particularly important for long term decisions like building bunkering facilities. Modern shipping is highly dependable on the availability of the supplies – in our study only bunker means – and growth of traffic where occupation of route (i.e. intensity of traffic) is certain constrain. Reliability of the network as whole must be calculated with some assumptions for the traffic growth and forecasting; these were presented in the [7], whilst model of supply chain for the reasoning of single companies is shown in [9]. Fast time simulations along with the growth of traffic intensity with modeling of new routes has been done in the [5]. All this data acquired from multiple source will serve as a input to the proposed LRP model.

Having these factors in mind it can be formulated as follows:

1. The LNG bunkering vessel/barge fleet is homogeneous (this simplification can be easily overridden – by adding another loop with another type of vessel/barge);
2. The ports with bunkering capability are multiple (with starting factor=1 it can gives algorithm flexibility);
3. Capacity of each vessel/barge is limited;
4. Total demand served by each vessel/barge cannot exceed its capacity;
5. Working time of each LNG vessel/barge is limited;
6. Service time in each route is given;
7. Every route is visited only once by a single vessel/barge;
8. Availability of each route is probabilistic.

then optimization formula can be stated as:

Minimize

$$Z_1 = \sum_{i=1,\dots,N} \sum_{j=1,\dots,N} \sum_{\vartheta=1,\dots,NV} C_{ij} \tag{1}$$

Maximize

$$Z_2 = \sum_{\vartheta=1,\dots,NV} \left(\prod_{i=1,\dots,N} \prod_{j=1,\dots,N} P_{ij} \right) \tag{2}$$

Where:
N_1, N_2 – optimization function,
i, j – index of demands for LNG at route ($1 \leq I, j \leq N$),
N – number of demand routes/points of bunkering,
NV – number of available vessels/bunker barges,
C_{ij} – cost of bunkering for the route between (I,j),
P_{ij} – availability of route between (i, j).

Model of LNG distribution for Baltic Sea shall include:

1. LRP module for suboptimal allocation;
2. Possibility of modelling different types of LNG barges/vessels with multiple capacities and cruising ranges/from port with bunkering capability;
3. Adding ports with LNG bunkering capability;
4. Adopting ports where operations of bunkering can occur;
5. Cost optimization module;
6. Graphical interface (preferably ECDIS type) for interpretation.

Such defined outline can be modelled in the Microsoft Windows operating system with using Matlab software for algorithm building and .NET environment for GUI and presentation layer.

CONCLUSIONS

Article presents some means of LNG bunkering with respect to Ship and bunker means (barge/vessel, fixed installation, container and trailer)as well as a concept of the model for distribution. Application of LRP methods is presented and described. Factors influencing newly build model is presented and determined and optimization function that can be used for further development has been outlined. Incoming work in this subject are related with building particular elements model in mathematical and algorithmic means.

ACKNOWLEDGEMENTS

This research outcome has been achieved under grant No. S/1/CIRM/2016, financed from a subsidy of the Ministry of Science and Higher Education for statutory activities.

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Received October 2016
Reviewed July 2018
Accepted August 2018

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STRESZCZENIE

W pierwszej części artykułu przedstawiono możliwe metody redukcji emisji SOx dla obszarów SECA oraz szczegółowo opisano wykorzystanie LNG jako paliwo bunkrowe jednostek morskich. Następnie scharakteryzowano metody bunkrowania LNG jakimi są: statek – statek, samochód ciężarowy – statek, terminal LNG – statek oraz wykorzystanie kontenerów LNG. Zaprezentowano również koncepcję modelu dystrybucji LNG na południowej części Morza Bałtyckiego w nawiązaniu do systemów LRP.