

Statistical Analysis and Proposed Formulae for Preliminary Design of Inland Passenger-Car LNG Fuelled Ferries

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Abstract: The potential benefits of LNG as fuel with regard to technical adaptability, compliance with emission regulations and reduced operating costs in ships have attracted the attention of stakeholders in the marine industry, and have recently experienced a significant rise in ship applications. Statistically, it was found that the most dominant types of LNG fuelled ships are passenger/car ferries, followed by supply vessels and tugs operating within the coastal domain of inland waterways. A statistical survey of the raw data of the recent passenger-car ferries powered by LNG fuel was carried out, wherein the data of approximately 40 vessels was gathered from reliable sources. The data was tabulated, analyzed and plotted to demonstrate the different relationships between the main ship dimensions and other essential ship parameters. This data takes the form of charts and formulae for determining the length of a new ship in relation to other ship particulars such as the breadth, depth, draft, speed and engine power. Similar charts and formulae were plotted and created for determining the relationship and trends between the dead weights and breadth, depth and draft of the same type of ships. Further, charts and formulae were designed depicting the relation between the LNG fuel tank volume and the tank diameter, the relation between tank volume and tank length, the relation between tank volume and tank weight in empty and full conditions, and the relation between tank volume and the total installed power. A chart illustrates the relation between the natural gas consumption and the ship installed power. The overall outcome of the plotted charts and given formulae can serve as trend guidance in the preliminary design phase for passenger/car ferries.

Keywords: LNG Fuel applications in Inland and Seagoing ships-Passenger-Car LNG Fuelled Ferries-Statistical Analysis of LNG Fuelled Ships.

NOMENCLATURE:

B: Breadth in (m)

D: Depth in (m)

DWT: Deadweight (tones)

D_t: LNG tank diameter

G_c: The natural gas consumption

LNG: Liquefied Natural Gas

L: Length Overall (m)

L_k: LNG tank length

MAGALOG: Maritime Gas Fuel Logistic

P: Ship Power (in kW)

RO-RO/RO-Pax: Roll On/Roll Off-Passenger Ship

T: Draught in (m)

v: Ship speed (knots)

V_t: LNG Fuel tank volume

W_{te}: LNG tank weight in empty condition

W_{tf}: Tank weight in full condition

1. INTRODUCTION

According to the statistical information collected from a survey of the recent passenger/car ferries powered by LNG fuel, data is presented here showing the different relationships between the main dimensions and other essential parameters in the form of charts and formulae for determining the length overall of a new ship (L) as a function of other ship particulars.

For this purpose, the main particulars of approximately forty (40) modern existing LNG Fuelled ships (mostly inland passenger-car ferries) were gathered from many different reliable sources and subsequently analyzed and plotted.

The dimensions of this group of LNG fuelled passenger- car ferries include the ship’s length overall ranging from 49.80 m up to 170m, the breadth from 8m up to 28.80m and the draught from 2.20m up to 6.80m. Additionally, the total engine power ranging from 722 to 10,060KW, with LNG fuel tank size ranging from about 20 m3 to 586 m3.

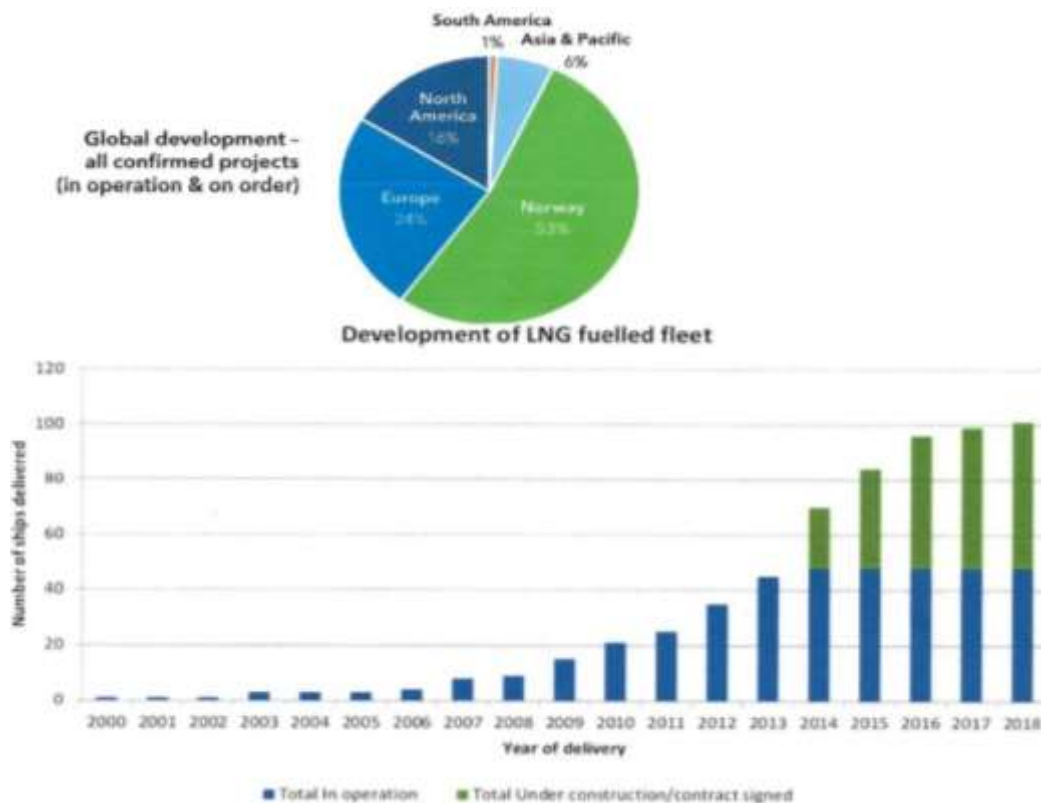
Based on the data parsed from these recent statistics, new trend charts and formulae were developed for determining preliminary principal dimensions such as breadth (B), depth (D), and draft (T) of LNG fuelled passenger- car ferries. Further formulae were composed for determining the relationship and trends between the dead weights and the breadth (B), depth (D) and draft (T) of LNG fuelled passenger- car ferries.

Charts have been plotted and formulae derived showing: the relation between the LNG fuel tank volume (V_t) and the tank diameter (D_t), the relation between tank volume (V_t) and tank length (L_k), the relation between tank volume (V_t) and tank weight in empty (W_{te}) and full (W_{tf}) conditions, and LNG fuel tank volume and the total installed power. Additionally, a chart illustrates the relation between the natural gas consumption (G_c) and the ship installed power (P).

Guidance charts and formulae are presented for identifying trends of LNG fuel tank parameters, one of the important characteristics of this type of ship.

2. THE DEVELOPMENT TREND OF LNG FUELLED-SHIPS

The Global Development of LNG Fuelled ships in operation and on order from 2014 until 2018 is shown in Figure (1) [1][2]



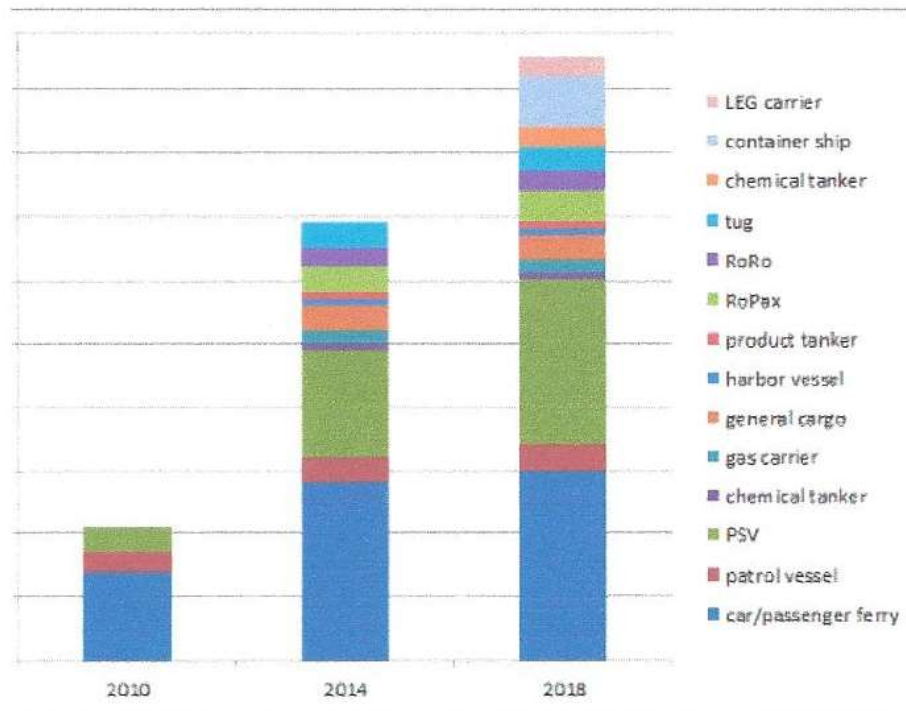


Figure 1: The Global Development of LNG Fuelled Fleet in Operation and New Construction By Segment (2014-2018) ^{[1][2]}

The Figure shows that the most dominant types of LNG fuelled ships are car/passenger ferries, followed by supply vessels and tugs within the coastal operations and the domain of inland waterway ships.

As evidenced by the Figure, gas burning engines are desirable and, in fact, are currently operating in a broader range of ships, in particular ferries (RO-RO/RO-Pax), cargo and offshore support ships, coastal ferries, patrol vessels, and chemical tankers. Natural gas is also being seriously considered for other vessel types, such as container vessels and ships involved in “short sea shipping”, both from a new construction and from a retro-fit perspective. The number of ships using LNG as fuel is rapidly increasing, and more and more infrastructure projects are planned or proposed along the main shipping lanes. Over 50 LNG-fuelled ships (excluding LNG carriers) have been built and currently operate worldwide, while more than 100 new buildings are confirmed.

Recently a number of forward-thinking companies have been paving the way by pioneering the use of LNG as a fuel, especially for ships engaged on regular coastal or short sea shipping services.

The Future Perspective of LNG Fuelled Ships:

Although challenges and some economic uncertainties exist, the development of LNG fuelled fleet shows an increasing trend. Many experts have claimed that LNG is coming of age and has the potential to become the fuel of choice for all shipping segments, provided the infrastructure is in place, and its market share is expected to double between 2020 and 2030. Other fuels, such as renewable fuel cells and biofuels, are expected to hold only small market shares in 2030. ^[4]

Some scholars still argue that liquefied natural gas (LNG) has a strong future as a marine fuel, but its environmental and economic benefits are not as clearly evidenced as sometimes suggested.

A recent study was carried out by MAGALOG (Maritime Gas Fuel Logistic) in 2014 for LNG as a clean fuel. It is believed that in 5 to 10 years, the majority of ships contracted for short sea trades will use LNG as marine fuel oil and RO-RO ships and container-feeders have been identified as potential candidates for LNG propulsion systems. ^[5]

The decision of whether to build a new ship or to convert an existing one to LNG fuelled is not simple, due to the current limited bunkering infrastructure, the uncertainty of LNG price advantage worldwide, and the many technical challenges faced during the design of all the associated systems, especially in the absence of finalized International Codes and Standards.

The wider adoption of LNG as a marine fuel will rely on rigorous oversight of design, and safety and regulatory compliance.

Numbers of existing LNG fuelled fleet are still relatively small, and very limited deep-sea LNG fuelled ships are in service as of yet, partially due to the fact that the comparatively high capital cost of the system installation can be a barrier in some cases. However, some key players are expecting that, the demand for LNG powered ships, including deep-sea, is expected to grow rapidly in the next decade.

LNG uptake is anticipated to expand quickly in the next 5 to 10 years, initially on relatively small ships operating in areas with developed gas bunkering infrastructure. [6]

For instance, “DNV GL expects the LNG powered fleet to grow to 3,200 ships by the year 2025. However, a number of unresolved issues remain”. [7][8][9]

The reality is that there are limited companies that have yet fully committed to LNG as a fuel for deep sea going ships. An illustration graph for the forecast for the expected number of deep sea LNG new building fuelled ships and bunker consumption by 2025 from Lloyd’s Register is shown in Figure 2. [10]

LNG-fuelled Deep Sea Shipping – 653 Ships by 2025

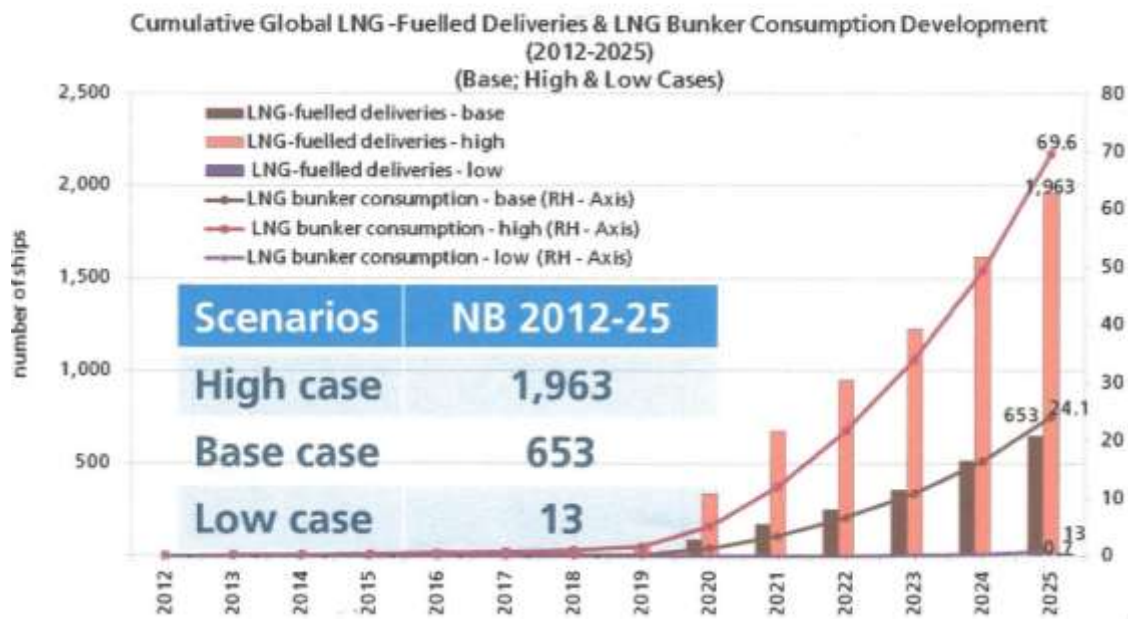


Figure 2: Cumulative Global LNG-Fuelled Ships New Building Deliveries and LNG Bunker Consumption Development [10]

The study reveals that it is expected for the base case that there will be 653 new built LNG fuelled vessels by 2025, and the best case of approximately 1963 new vessels and a worst case was only a growth of 13 new vessels. [10]

Some industry key players have said they expect LNG to gain much wider adoption as the construction of infrastructure for the fuel moves forward. However, many market players have the perception that the commercial risk of choosing LNG as ship fuel is still too high. But, on the other hand, what might the risks be of not considering LNG?

Wartsila predicts that this is just tip of the iceberg. During the next ten years, LNG will find its way to a thousand new ships. The estimated new building market (contracting) is shown in Figure (3). [11]

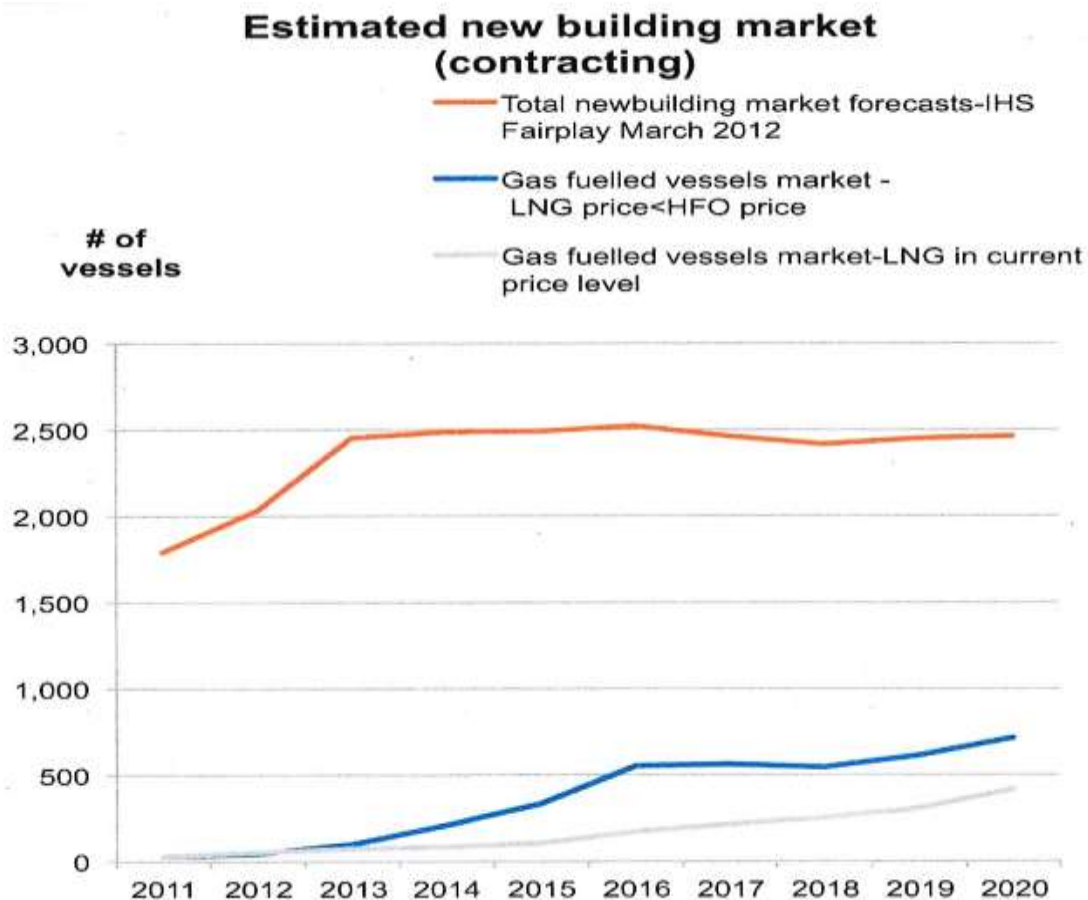


Figure 3: Estimated new building market (contracting) ^[11]

Shell also believes LNG is a competitive future fuel, with the proper applications. ^[12]

3. PROPOSED PRELIMINARY DESIGN CHARTS AND FORMULAE FOR LNG FUELLED PASSENGER –CAR FERRIES

Based on recent statistical data for existing LNG fuelled passenger - car ferries, we aim to develop new formulas for determining the length as well as estimating the other principal dimensions for new inland LNG fuelled ships. For this purpose, the main particulars of about forty (40) modern existing LNG fuelled ships (mainly inland passenger-car ferries) were gathered from several reliable sources and subsequently analyzed and plotted by the author.

Appendix (A) presents the characteristics of LNG fuelled passenger - car ferries. ^{[13] [14] [15]}

The dimensions of this group of LNG fuelled ships include the ship's length overall ranging from 49.80 m up to 170m, the breadth from 8m up to 28.80m and the draught from 2.20m up to 6.80m. Additionally, the total engine power ranging from 722 to 10,060KW, with LNG fuel tanks size ranging from about 20 m³ to 586 m³.

According to the above survey for the LNG fuelled ships, the statistical data can be presented illustrating the different relationships between the main dimensions and other essential parameters of inland LNG-fuelled ships in the form of charts and formulas for determining the length between perpendiculars of a new ship (L) as a function of other ship particulars.

The results of this investigation are presented as follows: Figure (4) shows the relation between the breadth (B) and the length overall (L), Figure (5) illustrates the relation between the depth (D) and the length(L), Figure (6) presents the relation between the draft (T) and the length (L), Figure (7) shows the relation between the speed (v) in knots and the length (L) and finally, Figure (8) shows the relation between the engine power (P) and the length (L).

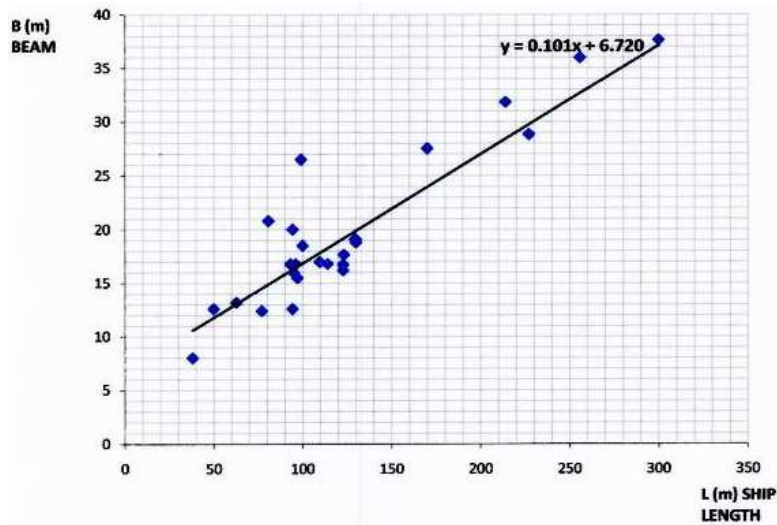


Figure 4: Breadth (B) and Length (L) Trend Guidance chart

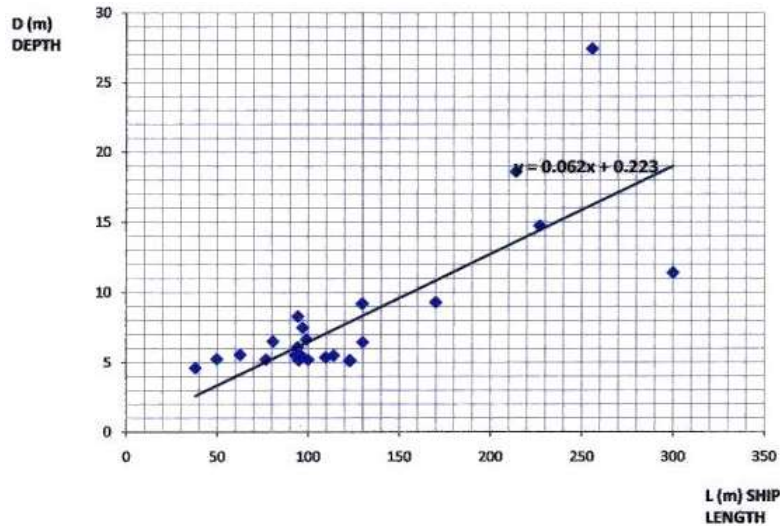


Figure 5: Depth (D) and Length (L) Trend Guidance chart

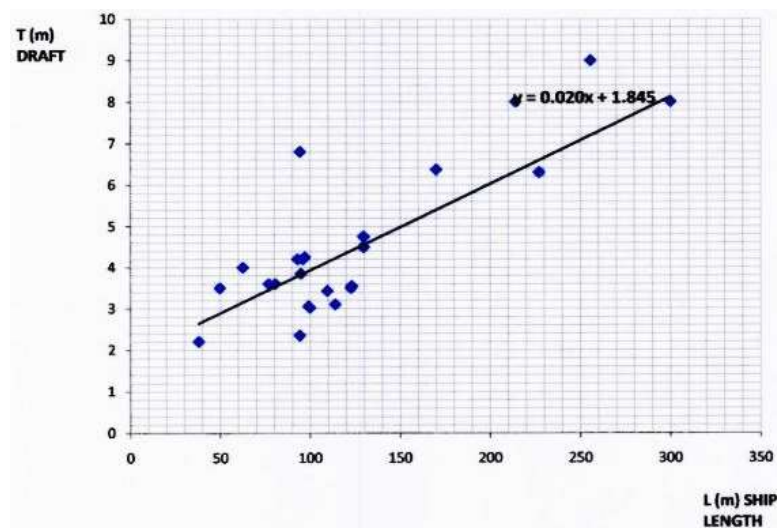


Figure 6: Draft (T) and Length (L) Trend Guidance chart

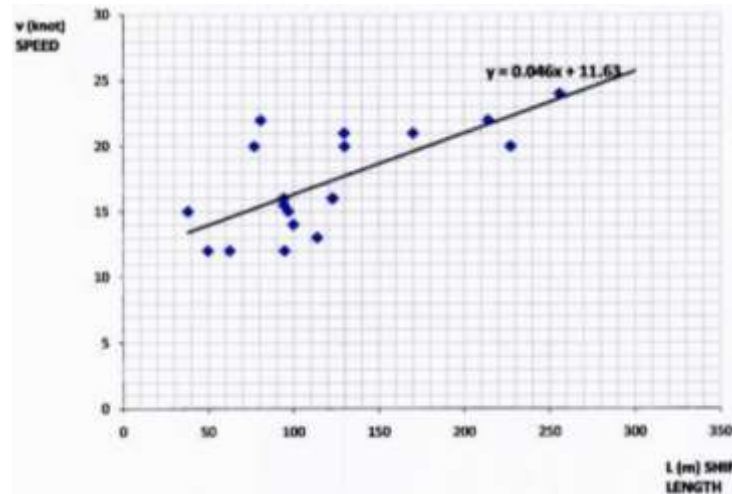


Figure 7: Speed (v) and Length (L) Trend Guidance chart

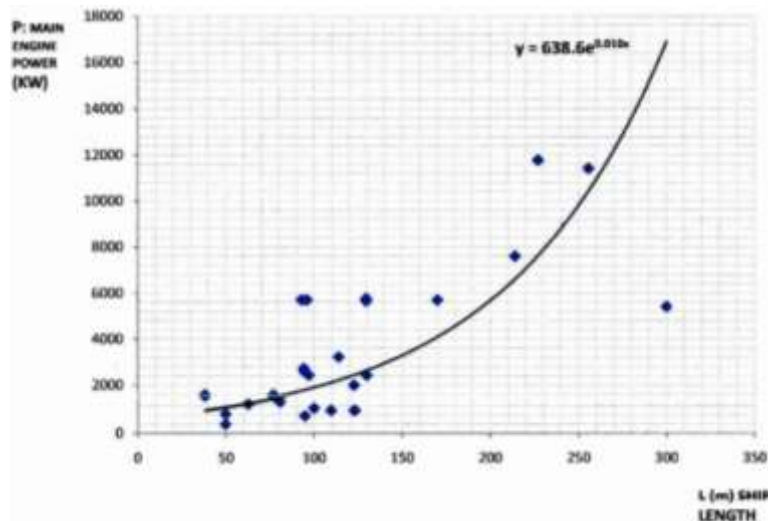


Figure 8: Main Engine Power (P) and Length (L) Trend Guidance chart

By analyzing these charts, the following formulae may be obtained:

$$B = 0.1013 L + 6.7205 \quad (1)$$

$$D = 0.0626 L + 0.2235 \quad (2)$$

$$T = 0.0209 L + 1.8456 \quad (3)$$

$$v = 0.0469 L + 11.635 \quad (4)$$

$$P = 638.60 e^{0.010L} \quad (5)$$

Where:

B= Breadth in (m), D= Depth in (m), T = Draught in (m), v= Speed in (knots), and P= Power in (kW).

Similarly, Figure (9), Figure (10) and Figure (11) illustrate the relationship between the breadth (B), depth (D) and draft (T) of passenger/car LNG fuelled ferries and the dead weights. From these plotted charts empirical formulas were derived for determining these relationships and trends in LNG fuelled ships.

The breadth, depth, draught and dead weight formulas are as follows:

$$B = 4.9205 DWT^{0.194} \quad (6)$$

$$D = 1.2265 DWT^{0.2561} \quad (7)$$

$$T = 1.1514 DWT^{0.1913} \quad (8)$$

Where:

DWT: deadweight (tones)

Guidance formulae for definitive trends of LNG fuel tank parameters, one of the important characteristics of this type of ship, were also derived.

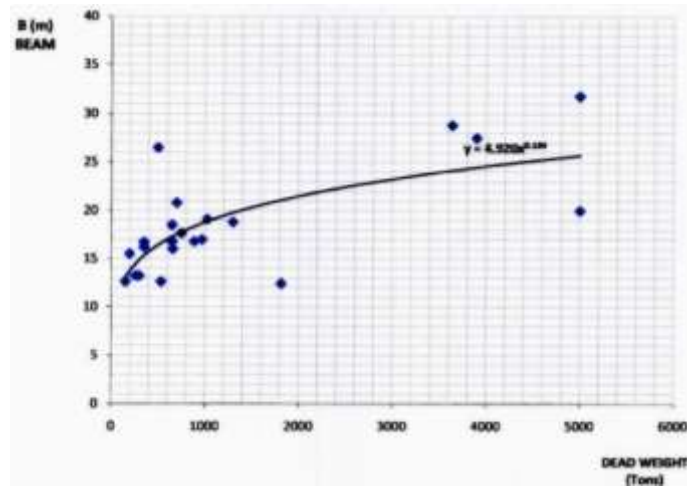


Figure 9: Dead Weight and Breadth Trend Guidance Chart

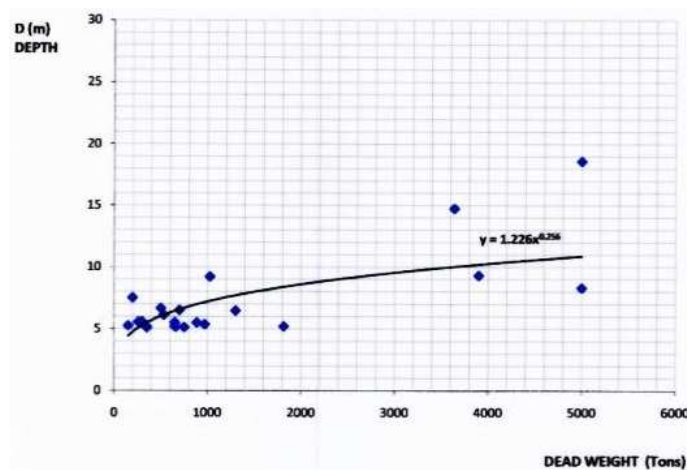


Figure 10: Dead Weight and Depth Trend Guidance Chart

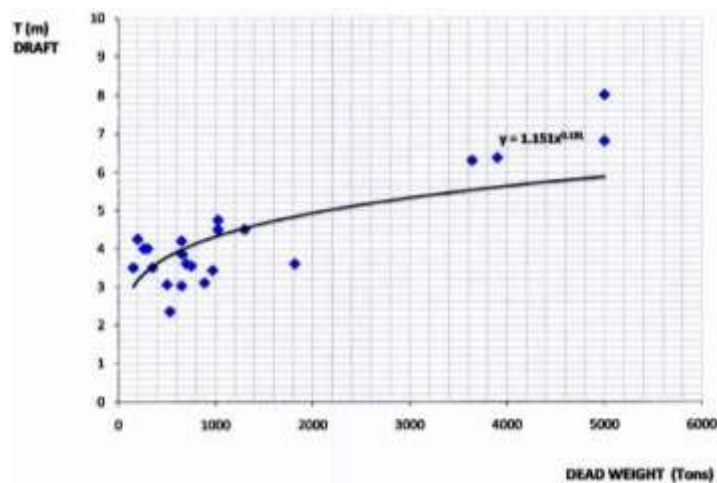


Figure 11: Dead Weight and Draft Trend Guidance Chart

Figure (12) shows the relation between LNG fuel tank volume (V_t) and tank diameter (D_t), Figure (13) shows the relation between tank volume (V_t) and tank length (L_k), Figure (14) shows the relation between tank volume (V_t) and tank weight in empty (W_{te}) and full (W_{tf}) conditions, Figure (15) shows LNG fuel tank volume and total installed power, and Figure (16) illustrates the relation between the natural gas consumption (G_c) and the ship installed power (P).

$$D_t = 0.139 V_t + 3.7346 \dots\dots\dots (9)$$

$$L_k = 1.8503 V_t + 11.558 \dots\dots\dots (10)$$

$$l_c = 1.6985 V_t + 9.9187 \dots\dots\dots (11)$$

$$l_c = 0.1519 V_t + 1.6396 \dots\dots\dots (12)$$

$$W_{te} = 0.2746 V_t + 23.817 \dots\dots\dots (13)$$

$$W_{tf} = 0.7197 V_t + 21.969 \dots\dots\dots (14)$$

$$V_t = 41.94 e^{0.000P} \dots\dots\dots (15)$$

$$G_c = 0.0084 P + 5.7377 \dots\dots\dots (16)$$

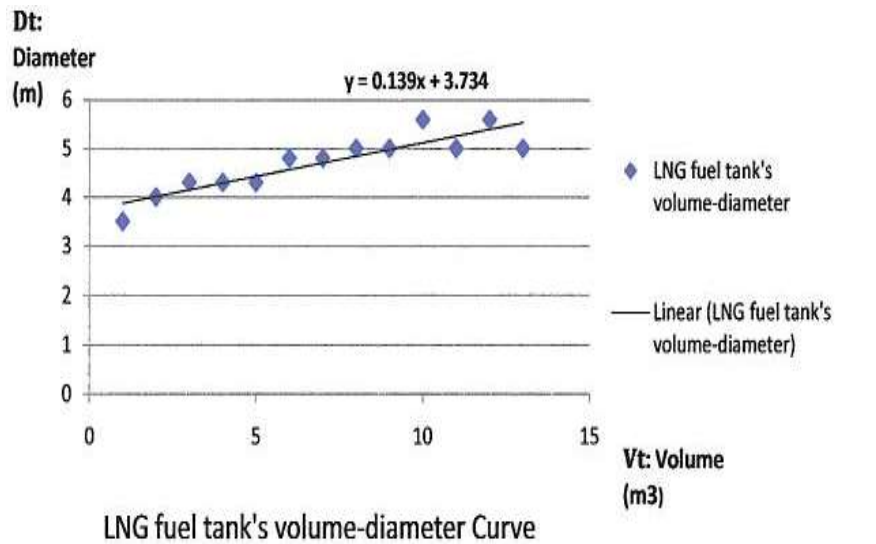


Figure 12: LNG Fuel Tank Volume and Tank Diameter

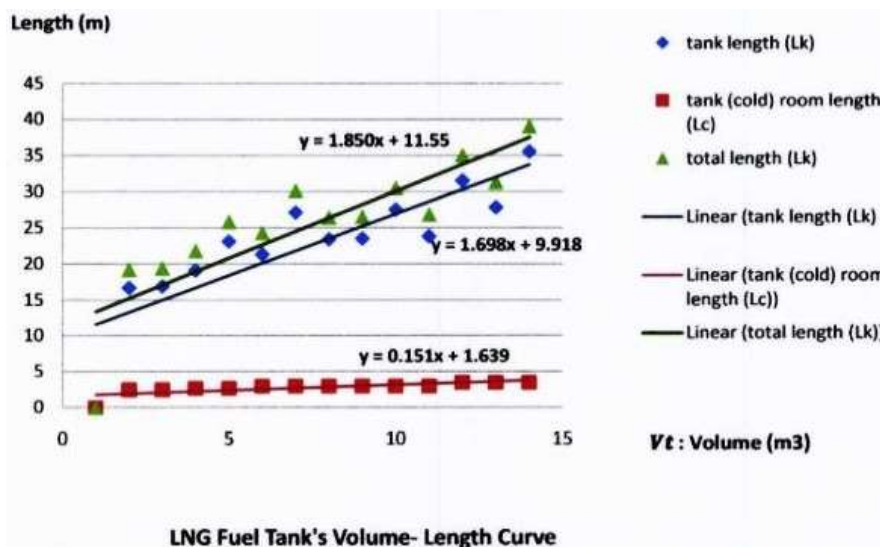


Figure 13: LNG Fuel Tank Volume and Tank Length

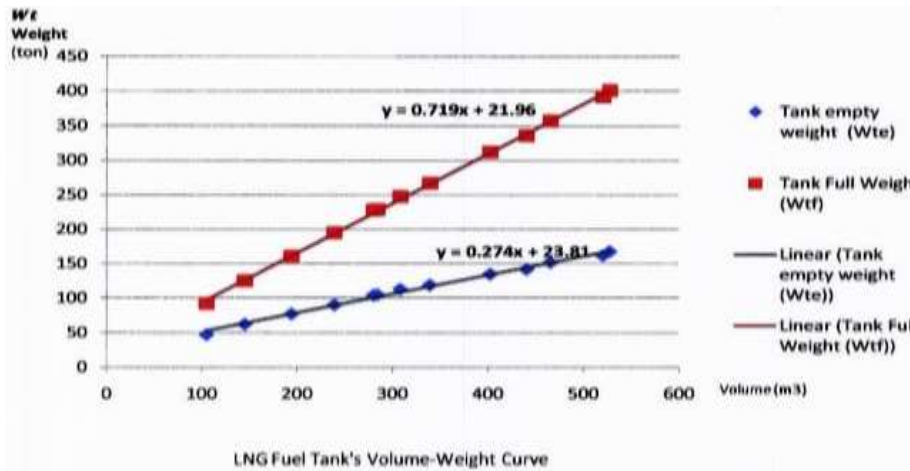


Figure 14: Tank Volume and Tank Weight in empty and full conditions

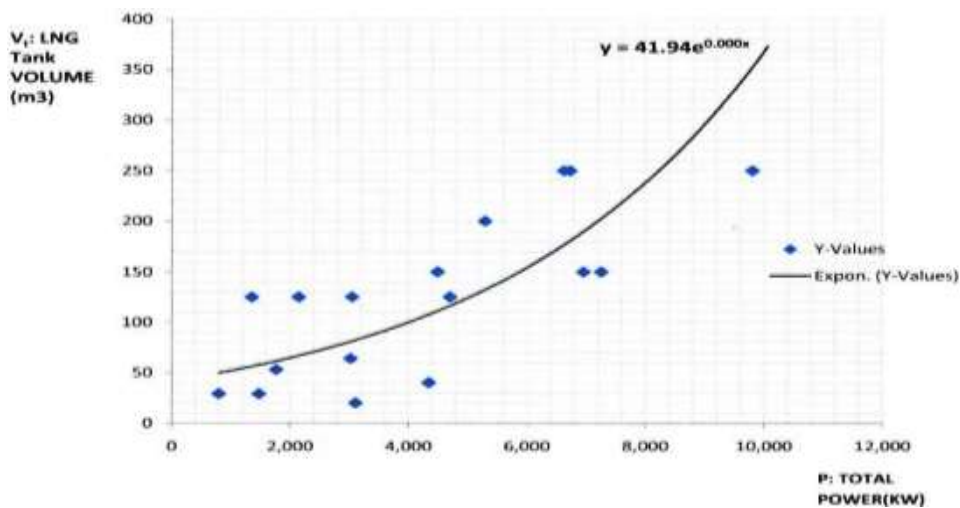


Figure 15: LNG Fuel Tank Volume and Ship Power

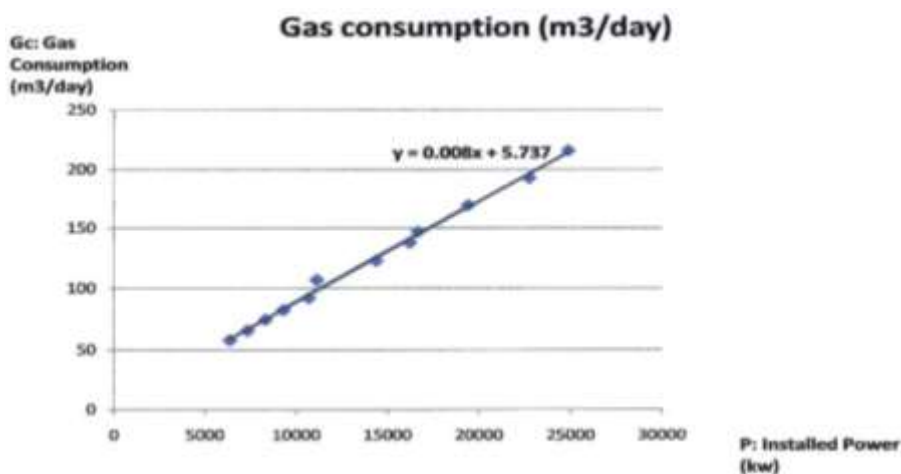


Figure 16: Natural gas consumption and Ship Installed Power

It should be noted that the above obtained formulas and the estimated ship dimensions are preliminary values for trend indications and are intended to be re-evaluated and updated on case by case basis during the early design phase in order to cope with the fast development of maritime industry. As experience in the field grows, this initial trend might undergo change and adjustments may be necessary.

4. CONCLUSIONS

This paper studied the “statistical analysis and proposed formulae for preliminary design of inland passenger/car LNG fuelled ferries”.

From the analysis given in this paper, the following conclusions can be reached:

- 1- Passenger- car ferries represent the majority percentage of LNG fuelled ships, followed by offshore supply vessels.
- 2- The resulting plotted charts and generated formulae show that the relationship between ship’s length and ship’s breadth, depth, draught and speed is a linearly proportional trend; while the relationship between ship’s length and main engine is a non-linear increasingly proportional trend.
- 3- The relationship between ship’s deadweight and ship’s breadth, depth and draught is also a non-linear increasingly proportional trend.
- 4- The LNG tank diameter is a linearly proportional trend with the tank’s length and weight, while it is an exponential trend with the installed engine power.
- 5- The natural gas consumption is linearly proportional with the installed ship’s power.
- 6- The overall results of the plotted charts and given formulae can serve as approximate trend guidance in the preliminary design phase for passenger/car ferries.

5. RECOMMENDATIONS

- 1- It should be noted that the above obtained formulae and the estimated ship dimensions are preliminary values for trend indications and to be re-evaluated and updated on a case by case basis during the early design phase in order to cope with rapid development in maritime industry.
- 2- As experience and knowledge in this field grow, the proposed preliminary design charts, formulae and trend patterns might change and a need for updating and adjusting may be necessary.
- 3- Offshore Supply Vessels, which are considered statistically the second most common ship type to use LNG as fuel, should be dealt with in a future separate study.

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APPENDIX - A

 Main Particulars and Characteristics of LNG Fuelled Inland Passenger-Car Ferries. ^{[13] [14] [15]}
Main Particulars and characteristics of Existing LNG Fuelled Inland Passenger/car Ferries^{[13][14][15]}

NO	Ship Name& (IMO number)	Year Of Built	L.O.A. m (LBP)	Beam B (m)	Depth D (m)	Draft T (m)	Speed V (knot)	(Dead Weight) & Gross Tonnage GT (tons)	No. of LNG tanks	Maker of LNG Tank	LNG Fuel Tank capacities (m ³)	Main Engine Power (KW)	Aux.Engines power (KW)	Total Power (KW)
1	GLUTRA (*/**) (9208461)	2000	94.8 (78)	16	5.15	3.85	12	(659) 1,651	2	Cryo AB	64 (2X32)	722	2,300	3,022
2	STAVANGER (9263758)	2003	80.63 (76.8)	20.8	6.5	3.6	22	(699) 2942	?***	?	?	1,320	?	?
3	BERGENSFJORD (9343091)	2006	129.5 (122.40)	19.1	9.2	4.75	21	(1,025) 4,325	2	?	250 (2X125)	5,760	962	6,722
4	STAVANGERFJORD (9344746)	2007	129.5 (122.40)	19.1	9.2	4.75	21	(1,025) 4,325	2	Cryo AB	250 (2X125)	5,760	962	6,722
5	FANAFJORD (9344758)	2007	129.8 (122.4)	19.10	9.2	4.75	21	(1,025) 6,904	2	Cryo AB	250 (2X125)	5,660	962	6,622
6	MASTRAFJORD (9344760)	2007	129.8 (122.4)	19.10	9.2	4.5	21	(1,025) 6,994	2	Cryo AB	(2X125)	5,660	962	6,622
7	RAUNEFJORD (9344772)	2007	129.5 (122.4)	19.10	9.2	4.5	21	(1,025) 6,904	2	Cryo AB	250 (2X125)	5,660	962	6,622
8	TRESFJORD (9008794)	2007 (Initial 1991)	96.94 (79.60)	15.50	7.50	4.25	15	(197) 3,423	1	Cryo AB	50	2,430	?	?
9	DRONNINGEN (9481192)	2009	49.80 (48.60)	12.60	5.25	3.5	12	(150) 1,125	1	?	29	800	676	1,476
10	KONGEN (9481166)	2009	49.80 (48.60)	12.60	5.25	3.5	12	(150) 1,200	1	?	29	361	439	800
11	MOLDEFJORD (9477115)	2009	122.68 (116.27)	16.2	5.10	3.5	16	(350) 2,971	1	Cryo AB	125	959	2,090	3,049
12	PRINSEN (9481207)	2009	49.80 (48.60)	12.60	5.25	3.5	12	(150) 1,200	1	?	29	361	439	800
13	FANNEFJORD (9477127)	2010	122.69 (116.31)	16.73	5.12	3.5	16	(350) 2,971	1	Cryo AB	125	2,000	2,700	4,700

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14	KORSFIORD (9534860)	2010	122.73 (116.31)	16.73	5.25	3.5	16	(350) 2,971	1	Cryo AB	125	959	1,190	2,149
15	ROMSDALSFIORD (9477139)	2010	122.67 (116.26)	16.73	5.13	3.5	16	(350) 2,971	1	Cryo AB	125	959	2,090	3,049
16	SELBUØMSFIORD (9553335)	2010	113.96 (?)	16.80	5.50	3.10	13	(886) 2,989	1	Cryo AB	150	3,220	1,270	4,490
17	BOKNAFIORD (9599896)	2011	129.90 (123.44)	18.8	6.48	4.5	20	(1,300) 7,536	1	Rolls-Royce	250	2,430	7,370	9,800
18	HJORUNDFIORD (9528471)	2011	109.54 (99.49)	16.99	5.38	3.43	?	(970) 2,967	1	Cryo AB	125	959	399	1,358
19	STORFIORD (9528469)	2011	109.54 (99.49)	16.99	5.36	3.43	?	(970) 2,967	1	Cryo AB	125	959	399	1,358
20	BAROY (9607394)	2012	92.96 (89.96)	16.79	5.51	4.2	?	(650) 5,695	1	Hamworthy	150	5,700	1,250	6,950
21	LANDEGODE (9607370)	2012	96.00 (89.98)	16.79	5.50	4.2	?	(650) 5,695	1	Hamworthy	150	5,700	1,250	7,250
22	LODINGEN (9607409)	2012	93 (90)	16.79	5.51	4.2	?	(650) 5,695	1	Hamworthy	150	5,700	1,250	7,250
23	OLKMPIC ENERGY (9603829)	2012	94.30 (84.90)	20	8.3	6.8	15.5	(5,000) 5,197	1	Cryo AB	200	2,610	2,681	5,291
24	VAEROY (9607382)	2012	95.99 (90.00)	16.79	5.50	4.20	?	(650) 5,695	1	Hamworthy	150	5,700	1,250	6,950
25	HARDANGER (966272)	2013	123.12 (119.92)	17.65	5.12	3.55	16	(750) 3,999	1	Cryomar	125	959	4X???	?
26	RYFYLKE (9662710)	2013	123.20 (199.91)	17.65	5.13	3.55	16	(750) 4,003	1	Cryomar	125	959	2,090	3,049
27	OSTFRIESLAND (8324622)	2014 (Initial -1985)	94.20 (78.72)	12.6	6.30	2.35	16	(531) 1859	1	Wartsila (LNGPac)	?	2,728	2,028	4,756
28	ECONURI (IMO No.?)	2014	38 (34)	8	4.6	2.2	15	(?) 200	1	Samsung HI FU Gas	20	1,584	1521	3,105
29	BERGENSFJORD (9586617)	2014	170 (148)	27.50	9.30	6.37	21	(3,900) 31,678	2	Rolls-Royce	586 (2X293)	5,700	4,360	?
30	BERGSFIORD (9733155)	2015	62.60 (52.60)	13.2	5.58	4	?	(300) 2,203	?	?	?	1,232	1,620	2,852
31	HASVIK (9733143)	2015	62.6 (52.60)	13.20	5.55	4	12	(260) 2,203	?	?	?	1,232	1,620	2,852
32	HELGOLAND (9714862)	2015	76.90 (74.40)	12.4	5.20	3.6	20	(1816) 2,150	1	Wartsila (LNGPac)	53	1,584	182	1,766
33	PRINSESSE ISABELLA (9692806)	2015	99.91 (95.96)	18.50	5.20	3.02	14	(650) 5,478	1	?	40	1,056	3,282	4,338
34	VIKING SUN (9725433)	?	227.2 (195.5)	28.8	14.73	6.3	20	(?) 47,800	?	?	?	?	?	?
35	VIKING SEA (9725421)	2016	227.2 (195.5)	28.8	14.73	6.3	20	(?) 47,800	?	?	?	?	?	?
36	VIKING STAR (9650418)	2015	227.2 (195.5)	28.80	14.73	6.30	20	(?) 47,800	?	?	?	?	?	?
37	VIKING GRACE (9606900)	2013	214 (200)	31.80	18.60	6.80	22	(?) 57,000	2	?	400 (2X200)	?	?	?
38	FINCANTIERI-1 (9796250)	?	227.2 (195.5)	28.8	14.73	6.3	20	(?) 47,800	?	?	?	?	?	?
39	FINCANTIERI-2 (9796262)	?	227.2 (195.5)	28.8	14.73	6.3	20	(?) 47,800	?	?	?	?	?	?
40	VIKING SKY (9650420)	?	227.2 (195.5)	28.8	14.73	6.3	20	(?) 47,800	?	?	?	?	?	?
41	BAROY (9607394)	2012	92.96 (89.96)	16.79	5.51	4.2	?	(?) 5696	1	?	150	5700	1250	?

(*): The first Gas ferry, (**)Ship name is subject to change but IMO number are a fixed reference & (***)?: Unknown data.

The sequence in the table is based on year of built