ABSTRACT

"Following its exploitation in submarines and aircraft carriers, nuclear propulsion was introduced into merchant ships in the 1960s. These developments were for the most part successful in their technical achievement, but commercially less so. Notwithstanding this early scenario, there has been a steady, although low level, development of nuclear propulsion in the intervening years, which has mostly centred on icebreakers but has also included some other merchant ship types" (Carlton, Jenkins, & Smart, 2010)

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CHAPTER 1

1.1 What is a cargo ship

"Any kind of a ship or any other vessel that transports heavy goods and materials from one port to another is called a cargo ship" (Marine sight, 2010)

Cargo ships keep evolving in time, increasing year after year their length and capacity to transport volume and weight. Typically, the capacity of a cargo ship is measure in terms of **TEU** and **DWT.**

Twenty-foot equivalent unit (TEU) is an inexact unit of cargo capacity often used to describe the capacity of container ships and container terminals. It is based on the volume of intermodal container, 20 feet (6.1 m) long and 8 feet (2.44 m) wide. There is a lack of standardization in regards to height, ranging between 4.25 and 9.5 feet (1.30 and 2.9 m). However, both 9.5-foot-tall (2.9 m) High cube and 4.25-foot (1.30 m) half height containers are also reckoned as 1 TEU. This gives a volume range of 680 to 1,520 cubic feet (19 to 43 m^3) for one TEU.

Deadweight tonnage (DWT) is a measure of how much weight a ship is carrying or can safely carry. It is the sum of the weights of cargo, fuel, fresh water, ballast water, provisions, passengers, and crew. The term is often used to specify a ship's maximum permissible deadweight.

1.2 Types of cargos

The categorization of the cargo ships can be made depending on the purpose to be analysis. Thus, there are three main classifications that can arise to divide the type of vessels. The division can be made upon:

1. Type of cargo been carried
2. Ship schedule
3. Vessel size group

Before going forward to explain each division is important to understand that each of them include the others, in this sense, different classification rise from the perspective you used to classified the cargo ships.

1.2.1 Type of cargo been carried

There are mainly four different kinds freighters and they are classified on the basis of the cargo that they carry, this groups are:

- General cargo vessels: mostly carry packaged goods like foods, footwear, garments, chemicals, machinery, furniture and motor vehicles.
- Multi-purpose vessels: carry all kinds of goods whether liquid or general cargo. They have separate containers and storage system for all these goods
- Dry-bulk carriers: carriers transport non-packaged loose materials like food grains, coal, and other similar products.
- Tankers: are vessels that have especially designed containers to transport liquid cargo like petroleum products.

1.2.2 Ship schedule

Cargo ships fall into two further categories that reflect the services they offer to industry: liner and tramp services. Those on a fixed published schedule and fixed tariff rates are cargo liners. Tramp ships do not have fixed schedules. Users charter them to haul loads. Generally, the smaller shipping companies and private individuals operate tramp ships. Cargo liners run on fixed schedules published by the shipping companies. Each trip a liner takes is called a voyage. Liners mostly carry general cargo. However, some cargo liners may carry passengers also. A cargo liner that carries 12 or more passengers is called a combination or passenger-cum-cargo line.

1.2.3 Vessel Size grouping

Vessels are categorized by capacity, by weight, and by dimensions (with reference to the various canals and canal locks they fit through). Mainly the types of cargos are classified as shown next:

- Small Handy size: can hold a range between 15,000 - 28,000 DWT.
- Handy size: carriers of 28,000-40,000 DWT. Traditionally the workhorses of the dry bulk market.
- Handymax: typically 40,000 - 50,000 DWT. Operates in a large number of geographically dispersed global trades, mainly carrying grains and minor bulks including steel products, forest products and fertilizers. The vessels are well suited for small ports with length and draft restrictions and also lacking transshipment infrastructure. This category is also used to define small-sized oil tankers.
- Supramax: carriers of 50,000 – 60,000 DWT.
- Panamax: carriers of 60,000 – 80,000 DWT. It was the term used to descrive the larger size of vessels that could cross the Panama channel according to the cannal's lock chamber.
- Post- Panamax: It is the term given to the new ship measures, published by the canal management in 2009. Ships with this size will be accepted when the third lane of locks start to operate in 2014.
- Aframax: Oli tankers between 75,000 - 115,000 DWT.
- VLCC (Very Large Crude Carrier): supertankers between 125,000 – 320,000 DWT.
- ULCC (Ultra Large Crude Carrier): enormous supertankers between 320,000 - 550,000 DWT.

To have an idea of the ship sizes here we provided a comparison **image 1** with the most well know ships. The biggest ever built was the Knock Nevis, fallow by Emma

Maersk. The Knoch Nevis was a constructed between 1979 and 1981. In 2010 was intentionally beached and scrapped.

General vessel sizes

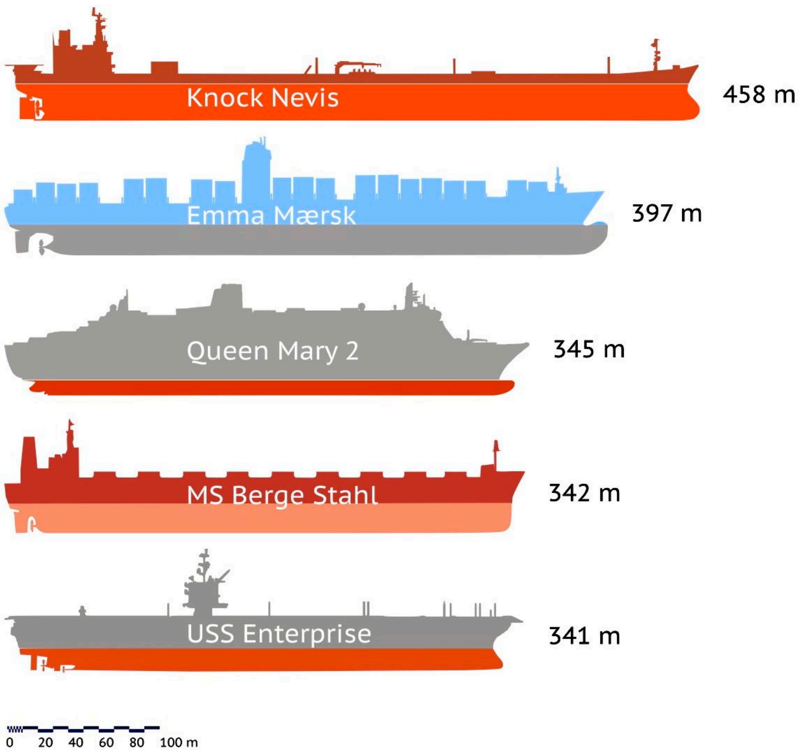

Figure 1. General Vessel size

In particular, this presentation will refer to the vessels according to the classification base on the size of the vessel, which make sense since the cost analysis made depends on the fuel consumption, which is directly dependent upon the DWT carrying, and the size of the ship.

1.2 Evolution of cargo (six generations)

Since the first ship was adapted to be a containership (mid 1950), industry has been growing in the need of bigger vessels with higher capacity of transportation. Over the decades, it was been possible to see this growth mark by what is call “the generations” of cargo ships. So far, six general waves of changes had a generation of containership:

- **The first generation,** the "Ideal-X" born as result of converting World War II T2 tanker into a containership. The container was at the beginning of the 1960s an unproven transport technology and reconverting existing ships proved out to be the least expensive and risky solution. Tankers could transport up 1,000 TEUs with speeds of about 18 to 20 knots.
- **The second generation,** the construction of containerships entirely dedicated for handling containers started at the beginning of the 1970s. These ships were also much faster with speeds of 20-24 knots that would become the speed of reference in containerized shipping.
- **The third generation,** economies of scale rapidly pushed for the construction of larger containerships in the 1980s. The larger the number of containers being carried the lower the costs per TEU. The process became a virtuous circle compounding larger volumes and lower costs. The size limit of the Panama Canal, which came to be known as the panamax standard, was achieved in 1985 with a capacity of about 4,000 TEUs.
- **The fourth generation**, by 1996 capacities reached 6,600 TEUs. This represented a market risk since a ship above the panamax size required a substantial amount of cargo to be used and by the late 1990s the rapid growth of global trade made such a ship class a marketable proposition.
- **The fifth generation**, the panamax threshold was breached, allowing ship size to increase (Post Panamax Plus) with capacities reaching 8,000 TEUs ("S Class"). Each subsequent generation of containership is facing the problems of small number of harbors able to handle them. Containerships above the third generation require deep water ports (at least 43 feet of draft) and highly efficient, but costly, transshipment infrastructures.
- **The sixth generation**, in 2006 the maritime shipper Maersk introduced a new class (E Class) having a capacity in the range of 11,000 to 14,500 TEUs. This generation will take two specifications. The first will take the shape of "New

Panamax", with ships designed to fit exactly in the locks of the expanded Panama Canal, expected to open in 2014, and which confers capacity of up to 12,500 TEU. The second can be dubbed "Post New Panamax" since these ships are bigger than the expanded Panama Canal specifications and can handle up to about 18,000 TEU (Triple E Class). It remains to be seen which routes and ports these ships would service, but they are limited.

The capacity of containership keeps changing by the increase of economies of scale. It has been seen how each generation advance in terms of bigger and higher transport capacity vessels. However, speed has been in average between 20 to 25 knots. *"…it is unlikely that speeds will increase due to energy consumption. The deployment of a class of fast containerships has remained on the drawing boards because the speed advantages they would confer would not compensate for the much higher shipping costs. Supply chains have simply been synchronized with container shipping speeds. Although economies of scale would favor the construction of larger containerships, there are operational limitations to deploy ships bigger than 8,000 TEU. Containerships in the range of 5,500 to 6,500 TEU appear to be the most flexible in terms of number of port calls since using larger ships along trade routes would require fewer calls and thus be less convenient to service specific markets"* (Rodrigue, Comtois, & Slack, 2009)

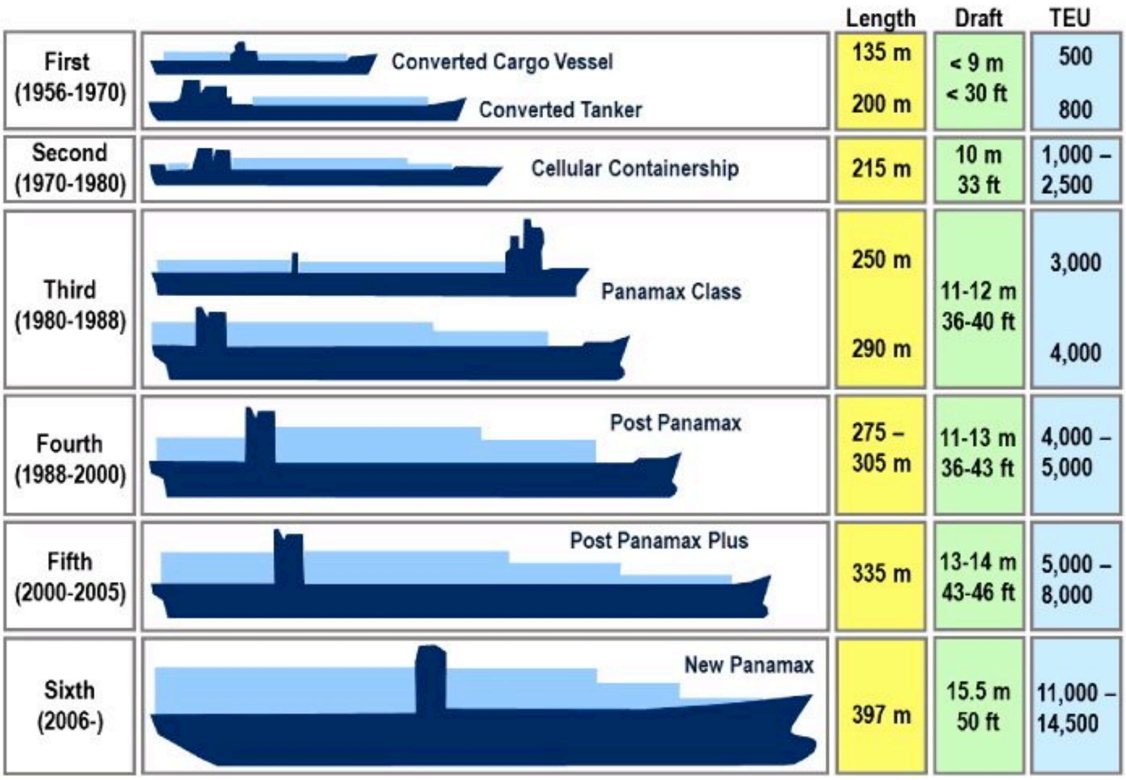

Figure 2. Cargoes generations

(Rodrigue, Comtois, & Slack, 2009)

1.3 Type of Diesel used

In the distillation processing of crude oil, there are four broad product fractions or categories generated: refinery gas (primarily methane, ethane and hydrogen), liquefied petroleum gas, (primarily propane and butane), gasoline, and distillate fuels. Each of these fuel categories boils at higher temperature ranges, until the oil will not boil without thermally decomposing. The non-boiling fraction is called residuum or residual oil.

Distillate fuels are further subdivided into several categories for specific uses. The "lightest," or lowest temperature-boiling fraction (all distillate fuels broadly overlap in boiling range) is called kerosene, and is used for commercial jet turbine engines fuels, for small heaters and for wick-fed illuminating lamps. The next fraction, used during cold weather conditions for automotive or truck fuels in "compression ignition" engines, is called "diesel" fuel. The next higher boiling fraction is used for residential heating furnaces, called "home heating oil." This same boiling range oil is also used in warmer conditions as diesel fuel for larger land-based, on- and off-road engines, such as trucks, busses, earth moving and material lifting and moving equipment, farm equipment and railroad diesel locomotives. The next heavier fraction supplies fuel for industrial heaters and boilers. Finally, the "heaviest," or highest boiling distillate fractions are often blended with residual oil to make fuels for large steam boilers and, with fuel preheating, for very large compression ignition engines, such as ocean-going ships. Small and medium sized marine vessels use distillate fuels in several of these land-based categories.

There are two basic types of marine fuels: distillate and residual. A third type of marine fuel is a mixture of these two basic types, commonly called "intermediate." Distillate fuel, as the name implies, is composed of petroleum fractions of crude oil that are separated in a refinery by a boiling process, called distillation. Residual fuel or "residuum" is the fraction that did not boil, sometimes referred to as "tar" or "petroleum pitch." Diesel fuel for marine use has the following types and grades:

FUEL TYPE	FUEL GRADE	COMMON INDUSTRY NAME
Distillate	DMX, DMA, DMB, DM	Gas Oil or Marine Gas Oil
Intermediate	IFO 180 38, MDO	Marine Diesel Fuel or Intermediate Fuel Oil (IFO), Marine Diesel Oil (MDO)
Residual	RMA-RM, HFO	Fuel oil or Residual Fuel Oil. Heavy fuel Oil (HFO)

Table 1. Type of Diesel fuel for marine

To communicate effectively in a specialty field like "marine fuels" it is necessary to be clear on the definitions and jargon used in this industry. In the marine industry, distillate fuels are commonly called "Gas Oil" or Marine Gas Oil; residual fuels are called Marine Fuel Oil or Residual Fuel Oil; and intermediate types are called "Marine Diesel Fuel," or Intermediate Fuel Oil (IFO). While the term "diesel fuel" for land based automobile and truck use is 100% distillate, in the marine industry Marine Diesel Fuel is the blend of distillate and residual oils, intermediate type. The 100% distillate type fuel in the marine industry is the Marine Gas Oil (implying by this name that it was boiled into a gas, then condensed into a liquid oil).

Fuel Oil, or Residual Fuel Oil, refers to fuels that are primarily non-boiling fractions. Depending on the pressures and temperatures in refinery distillation processes, and the types of crude oils, slightly more or less gas oil that could be boiled off is left in the non-boiling fraction, creating different grades of the distillation process or by blending with distillate. The term "intermediate" is more a colloquial term than a separate fuel type as defined by the American Society of Testing and Materials (ASTM) in the U.S., or in world standards.

1.4 Reference to the type of comercial travel more frecuent.

Principally, one of the strongest arguments for using nuclear reactor to propel vessels is that the speed of the voyage could increase; therefore, the length of the voyage will decrease.

Corporations and traders work on margins and are constantly scouring the regions of the world for cheaper suppliers and new markets where they can sell their products. Distance, speed and the cost of sea transport all play a part in their calculations of the overall cost for transporting their goods.

What is important to recall now, is the understanding of the trade matrix over the world. . With over 3,000 major ports to consider, the trade matrix has, in principle, 4 million elements. Of course in practice some routes predominate, but even in a relatively simple trade such as oil the range of routes is enormous.

Commonly, bulk carrier travel at 13.6 knots. According to due to Maritime Economics, 13.6 knots to 23 knots is the speed range within which merchant ships operate, though to trade efficiently at the opposite ends of this speed band requires significantly different hull and machinery designs.

The average voyage on this journey is 3270 miles. However, there are some much longer trade routes in the bulk shipping business. They include oil from the Arabian Gulf to the North Atlantic via the Cape of Good Hope (12,000 miles or 37 days' steaming), grain from the US Gulf to Japan (9400 miles or 28 days' steaming) and iron ore from Brazil to Japan (11,500 miles or 34 days' steaming). But there are many shorter routes, and in 2005 the oil trade averaged 4989 miles and the major dry bulk trades 5100 miles.

Considering the most important ports, in order to simplify the matters, will be presented three tables which display distance of a voyage (Table 2 from a port to another); the days for a single voyage (Table 3 considering a 13 knots speed) and finally the number of voyages that can be made per year from a port to another (Table 4).

Table 2 shows the distance in nautical miles of a round trip from a port to another. Distance is crucial because it affects cost and journey time. The voyages that has longest nautical miles have been marked in red, thus one can keep the track to those routs. Since nuclear reactors are meant to propel longer distance voyage, the follow cases that are highlight above could be the ones to take in consideration to evaluate the viability change those vessel from diesel engines to nuclear reactors. In particular, the voyage from Arabian Gulf (Ras Tanura port) to UsGulf (New Orleands) has a length of 12,225 nautical miles, been the longest voyage from all the studied in this paper.

		ASIA			EUROPE		UNITED STATES		
		India	**Singapore**	**China**	**North west**	**Med**	**E. Coast**	**Us Gulf**	**W. Coast**
Regions	**Port**	**Mumbai**		**Shanghai**	**Rotterdam**	**Fos**	**N.Y.**	**New Orleans**	**L. A**
Arabian Gulf	Ras Tanura	1,352	2,435	5,852	**11,170**		**11,765**	**12,225**	
Australia	Newcastle	6,095	4,215	4,590	**11,620**	9,915	9,680	9,088	6,456
Canada	Vancouver	9,512	7,071	5,092	8,917	9,105	6,056	5,472	1,144
US Gulf	New Orleans	9,541	**11,514**	**10,080**	4,880	5,300	1,707		4,346
E. Coast South America	N.Y.	9,541	**10,169**	**10,669**	3,270	3,825		1,707	3,780
W. Coast South America	L.A.	**10,308**	7,867	5,810	7,747	7,980	1,707	4,346	
Brazil	Rio	7,863	8,863	**10,877**	5,256	4,900	4,780	5,136	7,245
W. Africa	Lagos	7,188	8,188	**10,202**	4,310	3,810	4,883	5,749	8,006
N. Africa	Algiers	4,570	6,565	8,805	1,791	410	3,545	5,300	7,705
B. Sea	Odessa	4,230	6,214	8,465	3,508	1,720	5,265	6,740	9,450

Europe	Rotterdam	6,337	8,308	**10,590**		2,070	3,270	4,880	7,747
Asia	Osaka	5,112	2,671	790	**10,985**	9,221	9,986	6,348	5,193

Table 2. Distance round voyage (in nautical miles)

Now, an important consideration, as mention before, is that speed range within which merchant ships operate is from 13.6 knots to 23 knots. For a matter of fuel consumption, most traders operate cargoes at 13 knots speed. Therefore, using the information in Table 2, that has the distance of a round voyage and knowing that a knot is equal to 1.15 mph, is presented in Table 3 the days required per single voyage at a 13 knots speed. If the entire time to the round trip wants to be calculated, then it should be considered what is display in Table 3 is just the days required to travel from one port to another, thus, it does not consider that a cargo needs in average two days to load and once it arrives to final destination two other days to discharge the goods.

		ASIA			EUROPE		UNITED STATES		
		India	Singapore	China	North west	Med	E. Coast	Us Gulf	W. Coast
Regions	Port	Mumbai		Shanghai	Rotterdam	Fos	N.Y.	New Orleans	L. A
Arabian Gulf	Ras Tanura	4	8	19	**36**		**38**	**39**	
Australia	Newcastle	20	14	15	**37**	32	31	29	21
Canada	Vancouver	30	23	16	29	29	19	18	4
US Gulf	New Orleans	31	**37**	**32**	16	17	5		14
E. Coast South America	N.Y.	31	**33**	**34**	10	12	0	5	12
W. Coast South America	L.A.	**33**	25	19	25	26	5	14	0
Brazil	Rio	25	28	**35**	17	16	15	16	23
W. Africa	Lagos	23	26	**33**	14	12	16	18	26
N. Africa	Algiers	15	21	28	6	1.3	11	17	25
B. Sea	Odessa	14	20	27	11	6	17	22	30
Europe	Rotterdam	20	27	**34**		7	10	16	25
Asia	Osaka	16	9	3	**35**	30	32	20	17

Table 3. Days per voyage at 13 knots speed

Finally, in Table 4 can be observe how many round voyage can be made in a year. To have this calculated it is consider 350 working days at year, plus the two days required for loading and the other two days required for discharging the goods once it arrive to final destination.

As it is shown in Table 4, a trader that use the rout from Arabian Gulf (Ras Tanura) to Us Gulf (New Orleans) can only operate 4.2 times a year. It is a obvious constrain if the trader has a high demand. Currently, this constrain could be overcome by arranging new logistic agreements with other merchant ships in order to transport the goods, or in case of been a firm that occupies of transport, then a possible solution could be enlarge the number of vessel. There could be more possible solutions, but currently none of them could be increasing the speed of the vessel in order to make faster the round voyage. Why not? Well, the increase of cost consumption would bust the cost of transportation significantly, making the single units of goods more expensive.

		ASIA			EUROPE		UNITED STATES		
		India	Singapore	China	North west	Med	E. Coast	Us Gulf	W. Coast
Regions	**Port**	**Mumbai**		**Shanghai**	**Rotterdam**	**Fos**	**N.Y.**	**New Orleans**	**L. A**
Arabian Gulf	Ras Tanura	27.6	17.8	8.4	**4.6**		**4.4**	**4.2**	
Australia	Newcastle	8.1	11.3	10.5	**4.5**	5.2	5.3	5.6	7.7
Canada	Vancouver	5.4	7.1	9.6	5.7	5.6	8.2	9.0	30.9
US Gulf	New Orleans	5.4	**4.5**	**5.1**	9.9	9.2	23.4		11.0
E. Coast South America	N.Y.	5.4	**5.1**	**4.8**	14.0	12.3	87.5	23.4	12.4
W. Coast South America	L.A.	**5.0**	6.4	8.5	6.5	6.3	23.4	11.0	87.5
Brazil	Rio	6.4	5.8	**4.7**	9.3	9.9	10.1	9.5	6.9
W. Africa	Lagos	7.0	6.2	**5.0**	11.1	12.3	9.9	8.6	6.3
N. Africa	Algiers	10.5	7.6	5.8	22.6	52.8	13.1	9.2	6.6
B. Sea	Odessa	11.2	8.0	6.0	13.2	23.3	9.3	7.4	5.4
Europe	Rotterdam	7.8	6.1	**4.9**		20.3	14.0	9.9	6.5
Asia	Osaka	9.5	16.6	38.6	**4.7**	5.5	5.1	7.8	9.4

Table 4. Number of round voyage a year (350 days trading, 2 days loading, 2 days discharge)

Analyzing the current situation, and time implemented for a round voyage given the speed constrains, it is clear that in the future traders may tend for a faster transport that could decrease cost in the long term.

1.5 Percentage of diesel cost in the overall cost of the trip and variations of velocity for economical reassons (increase of Diesel cost).

Fuel cost represents a high percentage of the voyage cost. Before dig deeply on how much does it represent the cost of fuel, in necessary to have a full understanding of the costs running a ships. A general cost classification, according to Maritime Economics (Stopford, 2009) is as followed:

1. Operating costs 14%
2. Periodic maintenance 4%
3. Voyage cost 40%
4. Cargo-handling cost (not significant with respect to the other cost of running a ship)
5. Capital cost 42%

Those are rough percentages of each cost related to cargoes business, and the wait in the overall cost may vary depending upon ship size, voyage length, speed, type of vessel, etc.

Fuel oil is the single most important item in voyage costs, accounting for 47% of the total. In the early 1970s when oil prices were low, less attention was paid to fuel costs in ship design and many large vessels were fitted with turbines, since the benefits of higher power output and lower maintenance costs outweighed their high fuel consumption. However, when oil prices rose during the 1970s, the whole balance of costs changed. During the period 1970–85, fuel prices increased by 950% (Figure 6.5). Leaving aside changes in the fuel efficiency of vessels, this meant that, if fuel accounted for about 13% of total ship costs in 1970, by 1985 it had increased to 34%, more than any other individual item. As a result, resources were poured into designing more fuel- efficient ships and operating practices were adjusted, so that bunker consumption by the shipping industry fell sharply. In 1986 the price of bunkers fell and the level of interest in this aspect of ship design reduced, but in 2,000 bunker prices started to increase again and the importance of fuel costs increased.

The shipping industry's response to these extreme changes in bunker prices provides a good example of how the design of ships responds to changes in costs. Although shipping companies cannot control fuel prices, they have some influence on the level of fuel consumption. Like any other piece of complex machinery, the fuel a ship burns depends on its design and the care with which it is operated. To appreciate the opportunities for improving the fuel efficiency of ships it is necessary to understand how energy is used in the ship. The extent of the improvement can be judged from the fact that ships built in the 1970s typically consumed 10 tons per day more fuel than ships built in later years to achieve the same speed.

The design of the main engine is the single most important influence on fuel consumption. Following the 1973 oil price rises, and particularly since 1979, there were major improvements in the thermal efficiency of marine diesel engines. Between 1979 and 1983 the efficiency of energy conversion in slow-speed marine diesel engines improved from about 150 grams per brake horsepower per hour to around 127 grams per brake horsepower per hour. In addition to lower fuel consumption, engine operating speeds were reduced to below 100 rpm, making it possible to use more efficient large-diameter, slow-speed propellers without installing a gear box. The ability to burn low-quality fuel was also improved. In some cases the fuel savings achieved were quite spectacular. Diesel-powered 300,000 dwt VLCCs built in 2005 consumed 68 tons of bunkers a day at 15 knots, compared with fuel consumption of 130–150 tons per day by turbine-powered vessels built in the 1970s.

In operation, the ship's fuel consumption depends on its hull condition and the speed at which it is operated. When a ship is designed, naval architects optimize the hull and power plant to a prescribed design speed which. Operation of the vessel at lower speeds results in fuel savings because of the reduced water resistance.

The level of fuel consumption is very sensitive to speed. For example, for a Panamax bulk carrier a reduction in the operating speed of 16 knots to 11 knots results in a two-thirds saving in the tonnage of fuel burnt per day.

As a result of these factors there can be a wide disparity between the fuel consumption of vessels of a similar size and speed. For example, the fuel consumption of two Panamax bulk carriers operating at the same speed could differ by 20–30% depending on age, machinery and hull condition. Obviously the cost importance of this difference in efficiency depends on the price of fuel.

1.6 Brief introduction to USA and Rusia nuclear power ships.

The idea of using nuclear reactors to propel vessels is not at all new. As a matter of fact, this idea goes as far as 1940's when USA started to work on nuclear marine propulsion, been first country in develop the technology, but soon enough followed by Russia.

At the beginning, nuclear reactors were used only for military purpose specially used with submarines, with technological developments it has been also use for navy vessels and icebreakers.

The first nuclear-powered submarine in used was made by US, the *USS Nautilus*. It was put to sea in 1955, after been tested for over two years. The US developed a Pressurized water reactors (PWR), designed to serve as nuclear propulsion for submarines and aircraft carrier.

With the pass of the years, Russia designed four generations of submarine PWRs, the last entering service in 1995 in the *Severodvinsk* class.

Until March 2012, the US Navy registered that over a period of more than 50 years they did not present any accident involve to the usage of 526 nuclear reactor cores over the course of 240 million kilometres, they ensure radiological incident had not occurred. It operated 82 nuclear-powered ships (11 aircraft carriers, 71 submarines - 18 SSBN/SSGN, 53 SSN) with 103 reactors.

The Russian Navy appears to have eight strategic submarines (SSBN/SSGN) in operation and 13 nuclear-powered attack submarines (SSN), plus some diesel subs. Russia has announced that it will build eight new nuclear SSBN submarines in its plan to 2015. Its only nuclear-powered carrier project was cancelled in 1992. It has one nuclear-powered cruiser in operation and three others being overhauled. In 2012 it announced that its third-generation strategic subs would have extended service lives, from 25 to 35 years.

France has a nuclear-powered aircraft carrier and ten nuclear submarines (4 SSBN, 6 Rubis class SSN). The UK has 12 submarines, all nuclear powered (4 SSBN, 8 SSN). China is understood to have about ten nuclear submarines (possibly 3 SSBN, 7 SSN).

Apart from the military purpose, several times over the years nuclear reactors had been used for commercial ends. Although, it has not been economically viable due to high cost related to operate it. It was a fact that Diesel used to be cheaper to propel vessels. Now days, the increasing cost of petroleum has also increase the cost of fuel, thus, this assumption should be re evaluated in order to understand if we have reach the point where nuclear reactors can be feasible as a new and better mechanism to propel vessels.

Over the years several nuclear merchant ships have been commissioned but had not been commercially successful.

In 1962, NS Savannah (US) with 22,000 tonne was commissioned; it had a 74 MWt reactor delivering 16.4 MW to the propeller and it was a technical success. This design was impressive with high safety records; the fuel economy remarkable and the absence of smoke exhaust gases were her undoubted advantages. Eight years later it was decommissioned due to high costs.

The German-built 15,000 tonne *Otto Hahn* cargo ship sailed. It operated for ten years without any technical problems. It had a 36 MWt reactor delivering 8 MW to the propeller. Sailed some 650,000 nautical miles on 126 voyages. However, in 1982 it was converted to diesel since it proved to be too expensive to operate.

The third civil vessel put into service was the 8000 tonne Japanese *Mutsu,* in 1970. It had a 36 MWt reactor delivering 8 MW to the propeller. It was dogged by technical and political problems and was an embarrassing failure.

These three vessels used reactors with low-enriched uranium fuel (3.7 - 4.4% U-235).

In 1988, Russia commissioned the *NS Sevmorput*. It is a 61,900 tonne 260 m long container ship with ice-breaking bow. The same KLT-40 reactor powers it as used in larger icebreakers, delivering 32.5 propeller MW from the 135 MWt reactors. Mainly it was put to serve northern Siberian ports. It has been refuel only once in 2003 since it started to service.

A more powerful Russian icebreaker of 110 MW net and 55,600 dwt is planned, with further dual-draught ones of 32,400 dwt and 60 MW power at propellers. The first of these third-generation icebreakers is expected to be finished in 2015 at a cost of RUB 17 billion.

Russian experience with nuclear powered Arctic ships totals about 300 reactor-years in 2009. In 2008 the Arctic fleet was transferred from the Murmansk Shipping Company under the Ministry of Transport to Atomflot, under Rosatom. This is progressively becoming a commercial enterprise, with the 40% state subsidy of RUR 1262 million in 2011 due to phase out in 2014.ç

In August 2010 two *Arktika*-class icebreakers escorted the 100,000 dwt tanker *Baltika*, carrying 70,000 tonnes of gas condensate, from Murmansk to China via the Arctic route, saving some 8000 km compared with the Suez Canal route. There are plans to ship iron ore and base metals on the northern sea route also.

CHAPTER 2

2.1 Variation of Diesel price over the years.

All the merchant nuclear ships commissioned in the past were not an economical success; due to high initial investment cost related to the nuclear reactor, the operation and maintains, the specific need of crew expertise in the matter.

With time, cost related to merchant ships has fluctuated considerably. For instance, one of the most critical factors is the cost of fuel. Back in 1970's, when the first intent for merchant nuclear ships was made, the price of diesel fuel was very low in comparison to the overall cost related to the merchant ship. Therefore, it was not remarkable when making a economical analysis of investment. Other costs such as capital cost and operative cost had a higher influence in the total cost.

Situation has change; over the past four decades we have witness high fluctuations in the marine fuel. The tendency is towards higher and higher prices with rough changes within months apart. Historical prices of MDO (Marine Diesel Oil) and HFO (Heavy Fuel Oil) from 1973 to 2009 are presented in figure 3. Also, prices vary significantly over short periods of time. For instance, From January 2007 to July 2008, the monthly average price of HFO increased from \$230/tonne to \$670, and then decreased to around \$200 again before the end of the year (Clarkson Shipping intelligence Network).

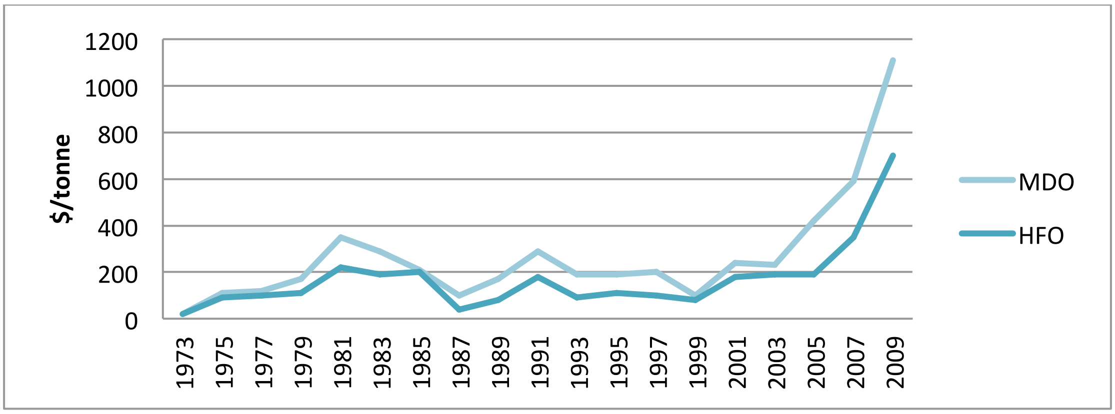

Figure 3. MDO and HFO price from 1973 to 2009 taken fro Rotterdam port.

Shunichiro Namikawa is the Manager of Pre-contract services at DNV (Det Norske Veritas). In his paper *Nuclear powered ships,* he estimate that considering current fuel oil price, the fuel cost is close to 70 % of the total lifecycle cost of a ship. Having this consideration, it is evident that such fluctuations in fuel price, as experienced in the last decade, have a significant impact on the lifecycle costs of a conventionally powered ship.

Bunker world is an online publication with the latest marine fuel news, prices for over 300 ports, analysis, insights from experts; it has a database with historical marine fuel prices. Its presented in the website an index called Bunkerworld Index (BWI). BWI is a weighted daily index made up of 20 key bunkering ports. The main grades IFO380, IFO180, MDO and MGO are all included in the spread proportionate to their importance to the bunker market.

Using the information provided from Bunker world, in figure 4, can be notice the BWI historical from the 3 September 2009 until the 30 of March 2012.

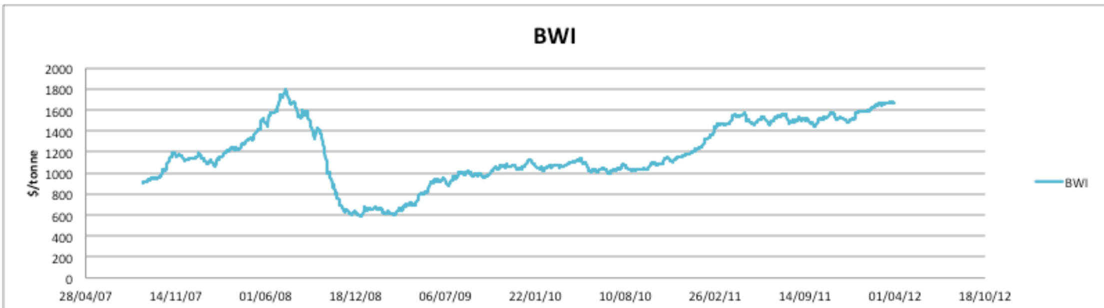

Figure 4. BWI from 03/09/2007 to 30/03/2012

Figure 4 is a corroboration of Mr. Namikawa statement. Indeed, the fluctuation in marine fuel is high. For instance, on 15 July 2008 reached the $ 1799/tonne, this has been his the highest value in the last years, by the end of the year on 31 December 2008 it went down to $ 589/tonne. Rising up again rapidly in 2009. On 30 March 2012 was $1663/tonne, once more with increasing tendency.

An increase in the cost of fossil fuel can also be interpreted as the effect of the adopted Prevention of Air Pollution from Ships, made on 10 October 2008 by the Marine Environment Protection Committee of the International Maritime Organisation (IMO).

IMO set limits on nitrogen oxide and sulphur oxide emissions from ship exhausts. Low sulphur fuel also reduces particulate emissions from ships. The Annex enters into force on 1 July 2010. The aim was to reduce the sulphur content in ship fuel. Started on 1 January 2012 from 4.5% to 3.5% and as of 1 January 2020 to 0.5%. Sulphur content allowed in Sulphur Emission Control Areas (SECA) that currently include the Baltic Sea, the North Sea and the English Channel was expected to on 1 July 2010 from 1.5% to 1.0% and as of 1 January 2015 to 0.1%. The use of exhaust gas cleaning systems will continue to be allowed, which means that vessels equipped with scrubbers may also run on types of fuel that are currently in use.

According to an IMO expert study, the use of heavy fuel oils (HFO) will largely have to be abandoned once the sulphur content limit in fuel decreases to less than 1%. Transfer to low sulphur and thus cleaner fuels (marine diesel and marine gas oil; MDO or MGO) will increase fuel costs considerably, because it is more expensive to produce cleaner fuels than heavy fuels. Fuel price forecasts should be treated with caution because there are so many variables affecting the price.

By 2015 the maximum sulphur content limit will fall to 0.1% in the SECA areas. Then it will be technically impossible to mix fuel grades, and ships will have to switch to gas oil (MGO), which would be the only option among the fuel grades presently available. Because of the way it is manufactured, MGO is far more expensive than heavy fuel oils. Furthermore, as the demand for it increases, it will also presumably go up in price.

As has been said, the prices of fuel grades containing less sulphur are higher than that for the fuel grade more commonly in use at the moment (heavy fuel oil with a sulphur content of 1.5%). This will cause a rise in the fuel costs of vessels. (Kalli, Karvonen, & Makkonen, 2009)

2.2 Impact of fuel price increase in merchant ship industry

Kalli, Karvonen and Makkonen presented in 2009 a report for the ministry of transport and communication from Finland. The report, called *Sulphur content in ships bunker fuel in 2015 A study on the impacts of the new IMO regulations on transportation costs,* has an estimated fuel price calculated through information provided by Finnish Oil and Gas Federation (ÖKKL). Based on it, in table 5 shows new fuel and vessel cost for various vessel types.

In every type of vessel considered in table 5, a significantly increase in price is shown. Is expected to have, in all the type of vessels analysis, an increase around 73%-84% in fuel cost per travel day specifically while using Light fuel oil (0.1%). LFO would be the only one that can be used in proximate future, thus, it means that for a diesel merchant ship will face an increase in its vessel cost travel per day around from 34%-46%. Is important to recall, that those estimates were made with respect the information obtained from ÖKKL, an the prediction made by Kalli, Karvonen and Makkonen, was done using information from 2006-2008. As most predictions, it is not a fact what has been display but a light anticipation of what could be the proximate future.

The expectations are for fuel costs to rise and their share of overall vessel costs will increase. It is worth noting that the switch from heavy fuel oil to light fuel oil will at the same time give rise to a very substantial rise in costs. Light fuel costs will be considerably higher in all vessel types as compared to heavy.