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ELECTRICAL POWER ENGINEERING

Development of Transport Efficiency of Merchant Vessels by the Research on Historical Change of Specific Power Output and Engine Trend

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Abstract **- The object of this paper is to provide how technological innovation makes advantageous to shipping industry by the concept of transport efficiency showing the historical change of the specific power output versus the product of speed and payload (P/W_PV). In this paper, research on LNG carriers, Tankers and Container ships within 1970-2008 are carried out and the data, fleet size, Dead Weight Tonnage (DWT), speed, power output and engine trend for each type of vessels are retrieved from Fairplay Encyclopaedia online data base.**

Keywords: **transport efficiency, power output, speed, payload, LNG, Tanker, Container, engine trend**

I. INTRODUCTION

The maritime commercial shipping industry moves more than 90 percent of the world trade [21]. According to the energy use (kW-hr/t-km), shipping is the most efficient mean to move cargo over long distances by comparing other transportations. This high efficiency level can reduce transportation costs and greenhouse gas emissions per tonne-mile of cargo moved [16]. Aiming at supporting the maritime transport to be efficient, technological innovation is essential requirement for shipping industry to cope both qualitative demands, regarding reliability of transport, and quantitative demand, regarding the volume of cargoes [15].

To get better transport efficiency, the relationship between economy and technology, innovation of ship design according to the speed merit and size merit aiming at faster and cheaper [15], the important factors are designed speed, route length, vessel's size; and payload/displacement ratio [7] and also trading volume is included [9]. For being matched higher levels, both the size and the speed of the vessels have to be emerged in designing the ships [10] from engineering point of view and also economical aspects [6].

Aiming at future innovation for shipping industry that has to be carried on, research on past experiences should be done. Therefore, to know how transport efficiency has developed due to technological innovation in merchant ships, the historical change of specific power output (P/W_PV) within 1970-2008 was researched.

For transporting people, raw materials and manufactured goods, merchant ships which are different in shapes and sizes, are used [14]. Cargo ships, ocean liners, ferries, sailboats, and many other types are included in merchant ships. Nevertheless, only LNG carriers, Tankers and Container ships are under study in this paper.

Because of different functions and carrying different cargoes, the ship's characteristics such as speed, design and size are also different. For these differences, in this research paper, the development of each type of ship is analyzed for the period of 1970 to 2008.

According to the function, a ship which is designed for transporting liquefied natural gas (LNG) is known as LNG carrier while the purpose of a tanker is to transport liquids in bulk and a container is intended to carry the cargo in truck-size containers by the use of containerization technique [11]. Because of different functions, and ship particulars, different development of transportation efficiency for each vessel is analyzed to know how innovation was brought and put into practice to add value for the existing market.

In this paper, the analysis of the development of ship particulars such as ship numbers, speed, engine output, dead weight tonnage, and engine trend between 1970 to 2008 are retrieved from Fairplay Encyclopedia online data base [3]-[4]-[5] and for the purpose of clear comparison to know the change of each data, data from 1970 to 1979 is used as a base and all changes or growths are shown as per unit value.

II. TRANSPORT EFFICIENCY FOR VESSELS

Transport efficiency, the energy efficiency used for transport facilities; depend on the type and size of the vessels and also type of cargoes carried, therefore different types of vessels give different levels of transport efficiency[7]. However, the basic concept of transport efficiency is dependent on the speed and size of the ship.

$$\eta_{TP} = W_P \times \frac{L}{E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where η_{TP} = Transport efficiency; W_P = Payload

L = Distance; E = Energy used for transport

$E = H_f \times$ fuel consumption ………………………………… (a)

Where, H_f = Heat value of fuel

Fuel Consumption = (S_{foc}) × Output (P) × (t) ……… . (b)

S_{foc} = Specific Fuel Consumption

P = Output Power and t = time

But speed V = Distance (L) /Time (t)………………... (c) i.e $t = \frac{V}{L}$ ………………………………… (d)

By substituting (a) (b) (c) and (d) into (1), it becomes,

$$\eta_{TP} = \frac{1}{H_f S_{foc}} \times \frac{W_P V}{P} \quad \text{……………………………… (2)}$$

Assuming H_f and S_{foc} are the same for any vessel Eq: (2) becomes,

$$\eta_{TP} \propto \frac{W_P V}{P} \quad \text{……………………………… (3)}$$

Regarding equation (3), the basic concept of transport efficiency distinctly depends on payload, the speed and engine power output of the ship [14]. For this reason, in this paper, the transport efficiency for each type of vessel is analysed by the change of $P/W_P V$ (kW/ton-km/h). In here, another assumption is that the payload is the same as dead weight tonnage (DWT) although the dead weight tonnage is the sum of the weights or masses of cargo, fuel, fresh water, ballast water, provisions, passengers and crew [2].

III. DEVELOPMENT OF FLEET SIZE, SHIP SIZE (DWT), SPEED, POWER AND TRANSPORT EFFICIENCY FOR LNG CARRIERS (1970-2008)

Depending on market growth, ship size (DWT) for LNG carrier is increased as shown in Table I, because the larger the size of the vessels the lower the transportation costs, consequently, the better the transport efficiency is [9].

According to Table I, number of vessels and DWT for LNG carriers is decreased by 40% during 1980s and increased in DWT by 23% proving that small LNG carriers are not too much constructed.

During 1990s, the fleet size and the DWT were increased by almost the same percentage. But during 2000s, LNG ship fleet size was increased drastically and DWT was also increased showing the large LNG carriers for international trade were built according to the market demand.

By applying theoretical concept of $P \alpha V_s^3$ [15], during 80s, when the speed is increased by 3% , the growth of power should be 8% but in practice, regarding Table I, the actual data shows that the power is increased by 20%. It shows that development of engine was not effective to reduce required power for specific speed during this decade.

During 90s, although the speed is the same as the base value, the engine power is reduced by 7% because of the development of small sized, high-powered, energy-saving type medium-speed diesel engines, namely, DK-20 and DK-28 which give increased fuel efficiency and cargo capacity [13].

Furthermore, in 1987, Wärtsilä dual-fuel gas engine was introduced and in 1996, development of the lean-burn dual-fuel engines, having efficiency more than 47%, was started [22].

Again in 2000s, the speed is increased by 3% but the power used is increased about 12% which is approximately equal to the real increment by applying $P \alpha V_s^3$ [15] concept.

During these years, the analysis of the development of engine shows that dual fuel electric in 2003 was initiated [22], having efficiency 43% [19], Wärtsilä 32DF was introduced, again, in 2004, lean-burn dual-fuel engines Wärtsilä 6L50DF [22] and the dual fuel diesel engine (DF) which has about 47% efficiency [1] were also developed.

This development of propulsion system can give a great fuel economy benefit for LNG shipping and as the result high level of WV/P ratio gives the high transport efficiency.

The data from Table I. proves that transport efficiency of LNG carriers has been improved since 1980.

For the decades of 1990s and 2000s, the transport efficiency is higher and higher by the aid of technological innovation.

TABLE I

FLEET SIZE, DWT, P, V AND WV/P FOR LNG CARRIER (1970-2008)

Period	No. of Vessels (Fleet Size)		DWT (Tonne) × 10^3 (Payload) W_P		Output Power P (kW) × 10^3		Speed V(km/h)		$W_P V/P$(ton-km/h/kW) (Transport Efficiency)	
	Average	Growth	Average	Growth	Average	Growth	Average	Growth	Average	Growth
70s	39	1.00	56.28	1.00	23.42	1.00	35.20	1.00	85	1.00
80s	23	0.59	69.46	1.23	28.09	1.20	36.08	1.03	89	1.05
90s	46	1.18	64.00	1.14	21.71	0.93	35.18	1.00	104	1.22
00s	135	3.46	74.84	1.33	26.23	1.12	36.43	1.03	104	1.22

Source: [4]

IV. DEVELOPMENT OF FLEET SIZE, SHIP SIZE (DWT), SPEED, POWER AND TRANSPORT EFFICIENCY FOR TANKERS (1970-2008)

There are different types of tankers like chemical tanker; oil tanker and product taker due to the cargo. Due to the need of market, cargo capacity of oil Tanker is increased decades by decades and also the oil demand and supply is increased from 1970 to over 2000[8].

For these reasons, the fleet size and DWT of Tanker is gradually increased as in Table II.

By comparing base data in 1970s, the fleet size in 1980s is dramatically increased but the size of vessel (DWT) is increased by only 28% while in 1990s, the fleet size becomes 9 times and the DWT becomes 2.2 times. However, in 2000s, there is not too much changed. It shows that tanker market has been increased since 70s up to now.

Oil Tanker trade is more international than other trades [23] and increase in oil demand and supply worldwide, crude oil tankers are needed for transportation.

Because of low value of the cargo and not time sensitive characteristic, the tanker speed is almost flat at slow speed therefore, the fuel consumption is saved.

However, engine power depends on the resistance of the water contact surface so special hull design was developed to reduce that resistance.

From Table II, during 1980s, the speed is the same in 1970s but power consumption is reduced by 10% because of the advantage of the shifting Steam power plant from Diesel Motor [11].

During 1990s, the speed is increased by 3% and as a result, the power is distinctly increased and also, during 2000s, the speed is increased by 7%, the power is also increased. During these periods, development of the slow speed diesel and dual fuel diesel-electric give economic advantages [11].

To save fuel, engines for propulsion are selected according to the size of the vessel, for instance, four-stroke and two-stroke diesel engines for small tankers and diesel engines like 6S50MC-C/ME-C are installed in 95% of handymax tankers and, 5S60MC-C/ME-C and 6S60MC-C/ME-C for Panamax and so on. However, to be efficient, reliable and low cost of maintenance of the main engine, only the two-stroke diesel engines can be applied for aiming at the long run [18].

In 1970s, because of oil crisis and using steam turbine propulsion which has relatively higher power, the transport efficiency of Tanker is not efficient.

However, in 1980s, the trade was recovered again and because of being increased size of the tanker and diesel engines which have relatively low power are mostly used, the transport efficiency is increased.

In 1990s, the transportation efficiency is much better than that in 1980s because of much bigger ships were built and also the new design to increase beam size to lessen friction can reduce the power required and consequently the fuel consumption is reduced [11].

From 2000 up to now, size of the ship is bigger and bigger, electric power with the podded propeller and other modern propellers are used [20] with slightly increase in speed but still leading higher transportation efficiency.

TABLE II

FLEET SIZE, DWT, P, V AND WV/P FOR TANKER (1970-2008)

Period	No. of Vessels (Fleet Size)		DWT (Tonne) × 10^3 (Payload) W_P		Output Power P (kW) × 10^3		Speed V(km/h)		W_PV/P(ton-km/h/kW) (Transport Efficiency)	
	Average	Growth	Average	Growth	Average	Growth	Average	Growth	Average	Growth
70s	75	1.00	71.34	1.00	11.37	1.00	26.48	1.00	166	1.00
80s	371	4.95	91.02	1.28	10.18	0.90	26.38	1.00	236	1.42
90s	671	8.95	156.18	2.19	14.12	1.24	27.15	1.03	300	1.81
00s	689	9.19	169.87	2.38	17.18	1.51	28.25	1.07	279	1.68

Source: [5]

V. DEVELOPMENT OF FLEET SIZE, SHIP SIZE (DWT), SPEED, POWER AND TRANSPORT EFFICIENCY FOR CONTAINER SHIPS (1970-2008)

The aim of containerization is to ship commodities continuously with higher service standards and lower costs. The concept of the larger the ship size, the better the economies of scale for the container ship fleet, leads the container for being the fastest growth ship fleet[17]. For the requirements of trade, vessels numbers and also DWT for Container ships are very much increased during 1970 to 2008 as shown in Table II.

Worldwide container shipments represent the 90 per cent of the world's traded cargo by volume; the value of container trade is increased steadily. Although it is needed to increase the size of the ship due to increasing demand for the economies of scale, shore side facility, sufficient water depth and appropriate vessel berths limitation control the ship size not to be too large [21].Demand for higher design ship speeds in large container ships is needed, so most of containers use diesel engines [12].

From Table III, speed is gradually increased and the power is also increased but the increment of power does not follow the concept of (P α V^3) [15] because of the development of technology in design of ship, propeller and also engine.

Regarding Table III, transport efficiency is distinctly increased in 1980s because during that decade, turbine was eliminated and diesel-electric propulsion system was started in container ship [12]. But during 1990s, transportation efficiency is decreased by increasing speed which causes power significantly increased. Due to the market demand, ship size is increased and this increment needs large power engines and when the speed is increased to transport timely, the power is again bigger therefore after 2000s, the transportation efficiency is reduced. Hence, to save the energy and to clean the environment, engine innovation from different aspects is stillgoingon.

TABLE III

FLEET SIZE, DWT, P, V AND WV/P FOR CONTAINER SHIPS (1970-2008)

Period	No. of Vessels (Fleet Size)		DWT (Tonne) × 10^3 (Payload) W_P		Output Power P (kW) × 10^3		Speed V(km/h)		W_PV/P(ton-km/h/kW) (Transport Efficiency)	
	Average	Growth	Average	Growth	Average	Growth	Average	Growth	Average	Growth
70s	252	1.00	16.76	1.00	11.68	1.00	31.88	1.00	46	1.00
80s	598	2.37	27.48	1.64	13.79	1.18	33.92	1.06	68	1.48
90s	1,486	5.90	27.90	1.66	16.38	1.40	35.83	1.12	61	1.33
00s	2,171	8.62	43.26	2.58	29.35	2.51	40.48	1.27	60	1.30

VI. CONCLUSION

World economy mainly depends on worldwide transportation and marine transportation is the most effective to get economies of scale comparing with other transportation ways. Therefore, innovation of technology in shipping industry leading to increase transportation efficiency is really needed to cope with the market demand and also getting better economy.

From this research for 1970-2008, it can be seen that the ship size and speed for each vessel are bigger and bigger, consequently, higher engine power is needed and to reduce high fuel consumption of those big engines is the main target for economy and environmental concern, as well. Therefore, innovation for minimum fuel oil consumption engine, modern design propeller, and hull design for reduction of water resistance, have been developed in each type of ship.

Also focusing on future, demand of trade by marine transportation will be never ended for the human well-being; hence, innovation for shipping industry under consideration of "How should we innovate which sector to improve transport efficiency" goes on by continuous analysing the past experiences.

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