Supply Chain Decarbonisation – A Cost-Based Decision Support Model in Slow Steaming Maritime Operations

Eugene Y. C. Wong, Henry Y. K. Lau, Mardjuki Raman

Abstract**—**CO_2 emissions from maritime transport operations represent a substantial part of the total greenhouse gas emission. Vessels are designed with better energy efficiency. Minimizing CO_2 emission in maritime operations plays an important role in supply chain decarbonisation. This paper reviews the initiatives on slow steaming operations towards the reduction of carbon emission. It investigates the relationship and impact among slow steaming cost reduction, carbon emission reduction, and shipment delay. A scenario-based cost-driven decision support model is developed to facilitate the selection of the optimal slow steaming options, considering the cost on bunker fuel consumption, available speed, carbon emission, and shipment delay. The incorporation of the social cost of cargo is reviewed and suggested. Additional measures on the effect of vessels sizes, routing, and type of fuels towards decarbonisation are discussed.

Keywords**—**Slow steaming, carbon emission, maritime logistics, sustainability, green supply chain.

I. Introduction

AMONG the greenhouse gases emitted by human activities, 77% of them are Carbon dioxide (CO_2). Over 70% of the CO_2 are primarily from the use of fossil fuel. The volume is much higher than the rest of the GHG: Methane (CH_4) with 14%, Nitrous oxide (N_2O) with 8%, and Fluorinated gases (F-gases) having 1% [1], [2]. Over the years, the global carbon emissions from fossil fuels have increased significantly, over 16 times from 1900 to 2008 [3]. Transportation, including road rail, air, and marine transportation, is the third largest global emission sector, constituting 13% of the global emission sectors, following Energy supply sector of 26% and Industrial sector with 19% [1], [4]. The United States Environmental Protection Agency (EPA) revealed that carbon emission in transportation accounts for 31% of the total U.S. emissions in 2011 [5]. International Maritime Organization (IMO) conducted a comprehensive and authoritative assessment of the level of GHG emitted in the global shipping industry in 2009. Shipping is estimated to have emitted 1,046 million tons of CO_2 in 2007, corresponding to 3.3% of the global emissions during 2007. International shipping is estimated to have emitted 870 million tons, which is 2.7% of the global emissions of CO_2 in the same year [6].

The design of vessel incorporating the objective of decarbonisation would bring tremendous effect on minimizing greenhouse gas emission. The fuel-cell technology and shore side electric power unit are one of the targets in Nippon Yusen Kabushiki Kaisha (NYK Line) to achieve zero emissions. NYK Line has designed the concept of ship NYK Super Eco Ship 2030 by using an alternative energy source – fuel cells. Hetland and Mulder assessed the role of natural gas as a real option in transport and reviewed the new generation LNG-fuelled platform support vessel operating in the North Sea by Eidesvik in Norway. The vessel is quoted with emission reductions of 84% less NO_x and 20% less CO_2 than conventional diesel engines [7].

Professional organizations and government bodies launch measurements, guidelines and reports as initiatives to reduce CO_2 emissions. IMO has developed technical and operational measures to control the CO_2 emissions from ships. The organization has introduced the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Plan (SEEMP) regulating the energy efficiency and carbon emission from ships during the design and operation stages. Clean Cargo Working Group (CCWG) derived comprehensive reports and methodologies on carbon emission reductions.

Initiatives of slow steaming started less than a decade ago. Driven by the soared fuel prices and low carbon emission pressures, Maersk is one of the earliest shipping lines that successfully implemented slow steaming with fuel savings and carbon reduction in 2009. With adjusted network and engine settings, Maersk saved 22% bunker fuel in 2010. Literature on the speed, schedule and cost of container shipping have evolved. And that on slow steaming has also come to attention. Cariou measured the rate at which CO_2 emissions had been reduced in different trades. Cariou further estimated the bunker break-even price for long-term shipping operations [8]. Psaraftis and Kontovas investigated the implications of various maritime emission reductions policies for maritime logistics [9]. Further research has been started on the evaluation of the relationship between the speed and carbon emission in a vessel. Lindstad et al. explored the potential for reducing CO_2 emission in shipping through investigations on the effects of speed reductions on the direct emissions and costs of maritime transport [10]. Psaraftis and Kontovas reviewed in detail the changes in speed, as a decision variable,

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towards the CO_2 emission, fuel consumption, and the vessel size-type, through a taxonomy and survey [11].

The evaluation and study on the modeling and optimization of slow steaming operations came to attention. Miola and Ciuffo analyzed various modes of ship emission modeling and compared the results of each model [12]. Meyer et al. provided a detailed review over the main financial effects of slow steaming in order to evaluate the economic aspects of this operation mode. Suggestion has been put forward as a potential development on a decision support system for container shipping line on slow steaming, considering the main influencing technical and economic factors, including vessel characteristics, freight rates, emissions, weather conditions, etc. [13]. Brouer et al. reviewed slow steaming as one of the options in the identified Vessel Schedule Recovery Problem (VSRP). This paper evaluates this problem as a given disruption scenario and selects a recovery action balancing the tradeoff between increased bunker consumption and the impact on cargo in the remaining network and the customer service level. It is achieved by a model developed for handling disruptions in liner shipping that aims to reduce cost and carbon emission [14].

Carbon costing should be included in the slow steaming decision, after the carbon footprint has been well established in the marine transportation. Carbon footprint has been used commonly in the freight forwarding and transportation industry. The volume of carbon emission from an origin to a destination is estimated. The relationship between the volume emitted and the costs impacted by the emission is seldom reviewed. Johnson and Hope (2012) evaluated the overall cost of carbon emission through climate change [15]. The Social Cost of Carbon (SCC) evolved as an estimation on the direct effects of carbon emissions on the economy. It estimates the possible damage on the emission and costs required to compensate the loss caused via climate change. The major factors considered in the SCC include net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem service. The SCC is first estimated with a central value of USD21 per metric ton of carbon dioxide (CO_2) by the U.S. Interagency Working Group in 2010. The estimated central value increases to USD24 per ton of CO_2 in 2015 and USD26 per ton of CO_2 in 2020 [16]. Other estimations can be found in Holladay and Schwartz [17], Tol [18], and Tallis et al. [19].

II. Slow Steaming Operations and Scenarios

Opportunities of slow steaming to save bunker costs are continuously being explored in the industry. Cariou indicates an analysis conducted by Alphaliner in 2010 on the impact of slow steaming by trade. A total of 2,051 vessels serving various trades in the period of 2007 to 2010 are reviewed. The vessel size ranges from 1,000 to 8,000+ Twenty-footer Equivalent Unit (TEU) [8]. Taking the bunker costs, cargo nature, transit time, speed, and CO_2 emission into consideration, initiatives on slow steaming have a higher percentage in Asia/North America and Europe/Far East trades than other trades. With longer distance and less sensitive cargo in the weak leg of trade imbalance in both trades, the chances of saving bunker costs by slow steaming are higher.

With slow steaming as an action of ship operators to deliberately reduce vessel cruising speed to cut fuel costs, Faber et al. suggested that when the speed of a vessel is reduced by 10%, its engine power is reduced by 27% [20]. This results in less fuel consumption. The emissions from the vessel are indirectly reduced. Vessel speed is monitored by marine planners and executed by the ship master. The reduction of vessel speed allows a saving in bunker costs. Carriers thus adjust the proforma by adding vessels into the proforma of a regular service but extending the transit time for shipments from the port of loading to the port of discharge. This reduces the competitiveness of the shipping line. Major parameters on the cost-benefit analysis, including speed, bunker cost, and extended number of days, are required to be reviewed to determine the optimal trade-off point.

When the number of vessels and the proforma are fixed, overnight speed reduction on a 5,000 TEU size vessel could still initiate a saving of bunker prices by nearly USD100k with one day delay. A scenario cost-based analysis is proposed as a decision support for selecting the optimal choice of available speed with consideration of impacted cost on bunker, carbon emission, and shipment delay. If a vessel with a gross tonnage of 66,300 TON and total capacity of 5,560 TEU, it is generally designed with a maximum speed of 25 knots, subject to the vessel specifications and engine design. A speed of 20.5 knots could be under 76 revolutions per minute (RPM) consuming 125 metric tons (MT) fuel consumption per day. Reducing the speed to 16.2 knots will be having 60 RPM consuming 75 MT fuel consumptions per day, with the saving of 50 MT fuel consumptions. In the recent market and bunker situation, the cost saving would be about USD50 per metric tons. The scenarios on various speeds resulting on different performances are shown in Table I.

TABLE I
Scenarios for the Performance of a Vessel Upon Changes in Speed

Scenario	Performance (RPM)	Fuel consumptions per day (MT)	Speed (Knots)
Scenario 1	76	125	20.5
Scenario 2	60	75	16.2

The major adverse impact of the speed reduction is the delay of shipment delivery. The cost reduction initiation though slow steaming is usually driven by the operations and marine section. The initiation is sometimes further evaluated commercially considering substantial number of factors, including cargo volume, cargo nature, delivery schedule, contract of carriage, customer priorities, etc. The overall decision could be selected and balanced among the scenarios on the extent of slow steaming and impact on cargo delivery.

Besides bunker cost saving, decarbonisation is often included as one of the initiatives of slow steaming. The emission reduction and the environmental benefits are seldom quantified and incorporated into the cost impact consideration. The decision making process should include the reduced volume of carbon emission as well as the social cost of carbon emission.

III. Cost-Based Decision Support Model on a Trans-Pacific Route

The adoption of slow steaming operations is usually preferred by liners in tradelanes having long haulage and weak leg, considering the time sensitivity of the cargos. In general, recent slow steaming initiations are carried in the Trans-Pacific Trade and Asia-Europe Trade. Considering a Trans-Pacific trade westbound vessel sailing from the east coast of U.S. to Asia Pacific and phasing out in at South East Asia, using the vessel described in the previous section. The vessel, with 1,200 TEU onboard, fully utilizing the allocation of a liner company, is berthing Colombo (CLB), Singapore (SIN), and Vietnam (VND). Among them 100 TEU are to be discharged at Colombo, 700 TEU are to be discharged at Singapore, and 200 TEU are to be discharged at Vietnam as shown in Table II. Besides laden containers, there are 100 units of 40' empty containers moving from U.S. back to Asia Pacific.

TABLE II
Types And Volume of Cargos to Be Discharged at Various Ports

Discharge Ports	Cargo Volume (TEU)	General Cargo (TEU)	Reefer Cargo (TEU)	Empty Containers (TEU)
CLB	100	80	20	10
SIN	700	650	50	170
VND	200	190	10	20

With the initiatives evaluated in Section II, scenarios are suggested for slow steaming considerations on the discussed vessel sailing and phase out at VND. The adverse impact of the speed reduction is needed to be reviewed through various determining factors, including the customer list, cargo description, cargo final destination, etc. Goods that are time sensitive cargos are needed to be of high attention, e.g. reefer cargo with vegetable, seafood, fruits, and other type of time critical foods. Other time sensitive cargos like medicine supplies and critical manufacturing components are required to be analyzed for the extent on shipment delivery schedule.

The scenarios are developed with the estimation on the number of days delay at each port and possible bunker savings on the slow steaming operations. Two of the scenarios are listed in Table III. The cargo impact quantities are assessed and listed in the scenarios. The corresponding carbon emission and social cost of carbon are evaluated, with reference to the discussed central value defined from the Interagency Working Group.

TABLE III
Scenarios of Slow Steaming Operations and Estimated Impacts

Scenarios	Delay at SIN (days)	Delay at VND (days)	Bunker savings (USD)	Cargo impact quantity (TEU)
Scenario 1	4.5	2.5	369,000	100
Scenario 2	3.5	1.5	291,000	60

The scenario-based figures provided facilities the decision making process on directing to the optimal speed of slow steaming proposal, considered the major determinant factors including bunker savings, number of days delay, impacted cargo quantities, and carbon emission reduction, and social cost of carbon.

IV. Additional Decarbonisation Measures

Additional measures are proposed as alternative suggestions on reducing greenhouse gas. The effect of increasing the vessel size could not only save the transport cost but also reduce the carbon emission volume. Lindstad et al. reviewed the current CO_2 emissions in maritime transport and investigated the effects of increasing the vessel size against greenhouse gas emissions and transportation cost [21]. Tai and Lin proposed daily frequency strategies with scheduled ship stopping at only mega-hubs guaranteeing a service at these mega-hubs on a daily basis [22]. It is found that the daily frequency option is an effective way in reducing emission levels when comparing the unit emissions of daily frequency and slow steaming strategies on international container shipping. Armstrong suggested various technical and operational methods as low carbon shipping initiatives, including route optimization, fuel slide valve upgrade, cargo heating management, hull and propeller performance monitoring and engine performance monitoring [23].

Additional rules and protocols should be imposed considering the types of fuels to be used when sailing near to the terminal. The measure could lower the carbon emission so as to minimize the impact on the residents and environment near the terminal. The North American Emissions Control Area (NAECA) took effect on August 2012, mandating the use of 1.0% sulfur Heavy Fuel Oil (HFO) or residual fuel oil for ships within 200 miles of the continent of North America. Low sulfur fuel oil (LSFO) is being used by the vessels when berthing to the terminal.

V. Conclusion

With the initiatives on vessel design and operations towards the reduction of carbon emission being reviewed. The relationship and impact among slow steaming cost reduction, carbon emission reduction, and supply chain delay are analyzed. A scenario-based cost-driven decision support model is developed to facilitate the selection of the optimal slow steaming options, considering the cost on bunker fuel consumption, available speed, carbon emission, and shipment delay. The model assisted the maritime operations as useful decision support tools on selected the optimal choice for slow steaming speed. The considering of social cost of carbon emission is evaluated. The variations and ranges of different estimation methodologies should be further standardized. Further investigation direction is suggested on modeling the cost items with the social cost of carbon emission. Additional decarbonisation measures are supplemented to further reducing greenhouse gas during the vessel operating at sea and berthing at the terminals.

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