SIMULATING ECONOMICAL IMPACTS OF SLOW&ULTRA SLOW STEAMING STRATEGIES ON A BULK CARRIER FLEET

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RESUMO
Navios porta-contêineres atualmente utilizam em suas frotas a navegação lenta (slow steaming) para obter uma redução das emissões ao meio ambiente e para obter ganhos mediante a redução dos custos operacionais. No entanto os armadores ainda não estão convencidos dessa pratica porque o tempo de navegação aumenta. Também se conhece que empresas que fazem transportes de linhas regulares utilizam a "navegação lenta" em seus fretes, embora esta condição de navegação e seus efeitos não tem sido estudados em navios graneleiros porque as velocidades de operação são mais baixos do que navios porta-contêineres. Este trabalho propõe um modelo de simulação de uma frota de navios graneleiros implementado em três condições: a condição atual de navegação, a navegação lenta e a navegação ultralenta. Foi desenvolvido um modelo de simulação de eventos discretos com uma base de dados real de uma frota de navios graneleiros. Como resultados da simulação se tiveram os dados de consumo total de combustível e de carga máxima transportada em um ano. Os valores achados mostram a economia nos custos de combustíveis refletindo diretamente na diminuição dos custos operacionais.

ABSTRACT
Operators of container ships have recently implemented slow steaming strategies to reduce the emissions and raise the profit margins by reducing operational costs. However, some ship owners are not yet convinced of this practice because the navigation time is increasing. Liner shipping enterprises use slow steaming in their fleets, but this effect has not been studied in bulk carriers because they are navigating slower than container ships. This paper proposes a simulation model of a bulk carriers fleet in three conditions: the actual condition of navigation, the slow steaming and ultra-slow steaming. We developed a Discrete Event Simulation model with a real database of a bulk carrier fleet. The results obtained are the total fuel consumption and the cargo transported for one year. These values are showing the saving in fuel cost, reflecting the reduction of operational costs.

1. INTRODUCTION

Standard contracts stipulate an 'utmost dispatch' about load delivery time using a speed as fast as possible, even if the vessel have to anchor for several days before being admitted to a berth (Alvarez, Longva and Engebrethsen 2010). Hence, these contracts do not consider the availability of the ports, the operational costs (fuel costs), and the Green House Gas (GHG) emissions.

Due to fuel cost, the practice of slow steaming (decreasing of navigation speed) has become more common in cargo fleets especially for container ships (Cariou 2011). Positives effects to use this reduction in speed are: lower CO_2 emissions and savings of mUSD in fuel annually (Maloni, Paul and Gligor 2013).

Although some industries criticize the Slow Steaming (SS) because it is necessary to build more ships to transport the same quantity of product, SS guarantee a win-win situation to industry and environment (Cameron 2010). Nevertheless, this practice is currently used for container ships because they are generally designed for higher navigational speed. For bulk carriers it is not yet proved that SS is a good strategic choice for navigation.

Recently a research presented by (Tai and Lin 2013) analyzed emissions from international container ships finding a reduction in pollutant emissions of 22.7% when ship speed is reduced from 22 to 18 knots, and 23.3% when speed falls from 18 to 15 knots. Another study conduced by (Cariou 2011) analyzed the impact of SS in container shipping and proved an emissions reduction of about 11% in the last two years. (Psaraftis 2010) examined the case of a Panamax container vessel when SS is used and concluded that emissions can be reduced compared to other types of transport. Therefore, SS is more profitable economically if Cost, Insurance and Freight (CIF) price of the cargo is lower.

Another line of research relates to vessel routing to minimize transportation cost, which is a relevant problem due to high fuel prices. (Fagerholt, Laporte and Norstad 2010) proposed an alternative solution methodology that studies an optimization model based on a shortest path problem on a directed acyclic graph for minimizing fuel consumption and emissions on a shipping route subject to the constraint that deliveries at each port on a predetermined service route must be made within certain time windows.

Moreover, (Notteboom e Vernimmen 2009) studied how shipping liners adapted their liner service schedules (in terms of commercial speed, the number of vessels deployed per loop, etc.) to deal with increasing bunker costs. A cost model was used to simulate the impact of bunker cost changes on operating costs in liner services, demonstrating that bunker prices have a significant impact on the costs per TEU.

Considering that world cargo ships are consuming more than 200 million tons of fuel per year (Corbett and Winebrake 2008), and the influence of the SS and the Ultra-Slow Steaming (USS) on a bulk carrier fleet has still not been tested as a good strategic choice for navigation. Therefore, this study propose to the viability of SS and USS strategies in terms of minimizing cost (fuel consumption) for bulk carrier.

In this paper, we analyze the influence of the SS and USS on one fleet of 15 bulk carrier ships. Then, the results of a simulation model suggest that SS implementation is a possible solution to turn navigation more profitable for bulk carriers.

2. METHODOLOGY

Tools to analyze Dynamic Systems (DS) have been implemented for almost 50 years to allow the study of some systems such as: manufacturing, communication, transportation, and others. (Fishman 2001) describes a Discrete Event Simulation (DES) as a procedure, where one or more variables change their value or state at discrete points in time, rather than continuously with time.

DES methodologies consist in several steps: modeling, programming, input data analysis, pseudo-random variety generation, output data analysis, and presentation of results. Various DES software's with user friendly Graphical User Interface (GUI) are becoming available (Fishman 2001).

DES models can replicate an existing system very close of the reality; it is becoming real-time tool orient the daily work of decision makers. A good accuracy in data, based on estimates or in statistics of the past, are vital for this methodology. The use of graphs, numerical displays, and computer animation of the proposed systems is beneficial to understanding the real process. (Sweetser 1999).

DES is useful for applications in manufacturing and service industries. Generally used in queuing situations and, especially when stochastic distributions can be used (Siebers, et al. 2010). Also DES is considered adequate for modeling problems at an operational/tactical level (Antuela and Stewar 2012).
Researchers are using DES to develop models that represents transport in different scenarios. For example, a model to simulate the traffic within the Istanbul Strait is representing the behavior of traffic according to different ship arrival, bad weather conditions and waiting times, (Kose, Basar and Demirci 2003). In addition, simulation has been extensively used for solving container terminal planning and scheduling problems (Lin, Gao and Zhang 2014). According to (Steenken, Voß and Stahlbock 2004) and (Stahlbock and Voß 2008) the last decade shown a considerable growth in worldwide container transportation, an indispensable need for optimization, and fiercer competition among seaports.

Furthermore, DES is used for evaluating new concepts due to a number of advantages obtained, for example (Dulebenets, Golias and Mishra 2015) a floater concept terminal container where a simulation model is evaluating and determining if it can improve terminal productivity.

Using DES (Alvarez, Longva and Engebrethsen 2010) were able to evaluate the performance of terminal operations using simulation to represent the progression of planning activities at the terminal operations under various policies: first-come, first-served (FCFS), standardized estimated arrival time (SETA), and global optimization of speed berth, and equipment allocations (GOSBEA).

ARENA is a graphical transaction-oriented language for the DES. In the ARENA software, the language functionality is incorporated in the building blocks, called modules, with which simulation models can be implemented. Systems are described from the point of view of the entities that flow through them using the available resources. These models are structured in a hierarchical and modular way. They are defined by means of a flowchart diagram and static data (Kelton, Sadowski and Sadowski 2003) (Law 2015). Simulation by a software model as ARENA is one of the most frequently used techniques for the analysis and design of manufacturing and other systems.

In order to achieve the objectives, we model various studied scenarios by DES in ARENA software. The steps to obtain the results in the current model are: input data analysis, modeling, programming, output data analysis, and presentation of results. The model has been implemented to represent the round trip of a bulk carrier fleet composed by 15 ships. The description of the model will be described in the following subsections.

3. DATABASE

This paper is focusing the study of a ship fleet of 15 bulk carriers (see Table 1) that completed a total of 230 one-way voyages (individual journeys). Each voyage is composed of daily records (mean value of the day, i.e. the noon report) of the navigational data. The most relevant information is: Ship identification (ID number), Ship displacement in tons (laden and ballast), Average daily speed in knots, Total consumption of fuel in tons (IFO), Distance in nautical miles, Condition of cargo (laden or ballast), and Cargo transported in tons.

Table 1. Ship Fleet Description (15 vessels)

Description	Mean	Standard Deviation

Total Length (m)	295.1	21.5
Design speed (Knots)	14.2	0.7
DWT (Tons)	195 319	52 127
Breadth (m)	48.2	5.2
Depth (m)	25.4	2.6
Draught (m)	18.5	1.5
Max. displacement (Tons)	220 160	58 459

Three ship types have been created based on their relative displacement in laden condition. Table 2 is showing the mean of the displacement range of each ship type based on their past voyages. Last row gives the relative percentage of ship quantity in each ship type. Both laden and ballast condition have been considered separately for the next part of the study.

Table 2. Classification of the Ship Type in the fleet

Ship Type	Type 1	Type 2	Type 3
Ship Code	SHIP 1 to 3	SHIP 4 to 11	SHIP 12 to 15
Displacement Average [ton]	135 685 to 147 219	147 219 to 194 577	229 600 to 246 104
Ship Type Percent	20%	53.3%	26.7%

4. MODEL

The aim of the study is to evaluate the potential economic benefits of new navigation condition: SS and USS. The proposed framework consists of a DES model to represent the voyage process. We describe this below.

The model developed is using ARENA at the one-way voyages level, for both ballast and laden conditions. The flowchart diagram is composed by instantiating and connecting predefined components named flowchart modules, this has an interface and an internal behavior. Interface is used to connect with other modules, thus describing the path for the entities. Internal behavior describes the actions performed by the entities while in the component, e.g., delay a certain amount of time, seize and release resources, and record statistics. The simulation results are usually presented in the form of statistical indicators that are calculated during the simulation. The static data allow specifying component characteristics, such as the characteristics of the entity arrival processes, resources and queues (Sanz, et al. 2013).

In the simulation, time parameter could be a fixed value, statistical distributions, or a calculation involving entity attributes and variables. Furthermore, the software provides a range of distribution functions for modeling arrival times, process times, etc. We use a database to define distributions to be applied as input data.

The inputs parameters of DES model for both laden and ballast conditions are: Average daily speed in knots, Total consumption of fuel (IFO) in tons, Distance in nautical miles, and Cargo in tons. Output parameters in this model are: Total Cargo Transported in tons, and Total Consumption of fuel (IFO) in tons.

Information of distance (log-normal distribution) and cargo transported (normal distribution) are shown in the Table 3 for the laden condition. Distance information is the same for ballast condition, and cargo transported is zero.

Table 3. Parameters used with their corresponding distribution

Parameter	Type of ship	Mean	Standard Deviation
Distance	Type 1	5 338	4 479
Distance	Type 2	4 640	3 774
Distance	Type 3	6 474	3 816
Cargo	Type 1	161 459	2 381
Cargo	Type 2	194 413	17 388
Cargo	Type 3	259 766	21 734

The above information is used to develop the models explained below. Three models are proposed:

- Model 1: Original conditions.
- Model 2: SS; speed is decreased by 2 knots compared with the original model.
- Model 3: USS; speed is decreased by 4 knots compared with the original model.

Distance and cargo transported parameters are fixed for both conditions as well as for original, SS and USS strategies. Total consumption parameter is modified due to speed effect. Distributions for each parameter is calculated, see Table 4 and Table 5.

Table 4. Total consumption of fuel (IFO) log-normal distributions in both conditions for each ship type, in tons

Type of ship	Condition	Cargo State	Mean	Standard Deviation
Type 1	Original	Ballast	675.9	529.1
Type 1	Original	Load	912.6	741.3
Type 2	Original	Ballast	675.9	529.1
Type 2	Original	Load	953.4	928.7
Type 3	Original	Ballast	1 108.8	828.8
Type 3	Original	Load	1 261.2	716.1
Type 1	SS	Ballast	419.5	496.3
Type 1	SS	Load	467.4	566.5
Type 2	SS	Ballast	426.7	584.9
Type 2	SS	Load	532.4	660.1
Type 3	SS	Ballast	646.2	665.2
Type 3	SS	Load	681.3	601.9
Type 1	USS	Ballast	154.4	265.4
Type 1	USS	Load	137.9	237.0
Type 2	USS	Ballast	185.0	317.9
Type 2	USS	Load	199.8	343.5
Type 3	USS	Ballast	283.1	486.5
Type 3	USS	Load	257.9	443.1

Table 5. Average daily speed normal distributions in both conditions for each ship type, in knots

Type of ship	Condition	Cargo state	Mean	Standard Deviation
Type 1	Original	Ballast	12.2	0.8057

Type 1	Original	Load	10.8	0.6171
Type 2	Original	Ballast	14.3	0.7658
Type 2	Original	Load	12.58	0.8091
Type 3	Original	Ballast	13.2	0.3954
Type 3	Original	Load	11.5	0.5082
Type 1	SS	Ballast	10.2	0.8057
Type 1	SS	Load	8.82	0.6171
Type 2	SS	Ballast	12.3	0.7658
Type 2	SS	Load	10.5	0.8091
Type 3	SS	Ballast	11.2	0.3954
Type 3	SS	Load	9.54	0.5082
Type 1	USS	Ballast	8.2	0.8057
Type 1	USS	Load	6.8	0.6171
Type 2	USS	Ballast	10.3	0.7658
Type 2	USS	Load	8.5	0.8091
Type 3	USS	Ballast	9.2	0.3954
Type 3	USS	Load	7.5	0.5082

The same simulation workflow has been used for Original, SS, and USS as shown in Figure 1. All ships would be created and initialized here according to some specific rules. It has been calculated based on the average travel time per year of whole ship fleet and the number of ships. The average time between arrivals is about one every four days. Three sub-processes have been created to map the three ship types defined in Table 2. Each of them is respecting the assignments sequence shown in Figure 2.

The voyages implemented in each sub-process correspond to equation 1:

$$Tv = D/S \qquad (1)$$

Where Tv Voyage time distribution in days
D Distance distribution in nautical miles
S Average daily speed distribution in nautical miles per day

The equations to estimate the information above mentioned are:

$$L_{tT} = L_{tT} + C \qquad (2)$$
$$L_T = L_T + C \qquad (3)$$
$$T_{FC} = T_{FC} + FC \qquad (4)$$

Where L_{tT} : Load to Transport
L_T : Load Transported
C : Cargo
T_{FC} : Total Fuel Consumption
FC : Fuel Consumption

As a result, *total cargo transported* and *total fuel consumption* is calculated.

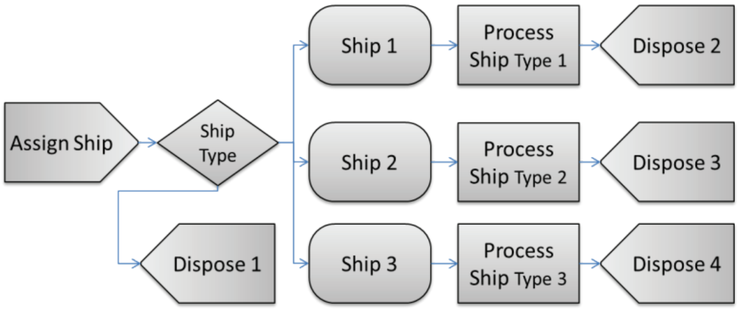

Figure 1. Simulation workflow of bulk carrier's fleet

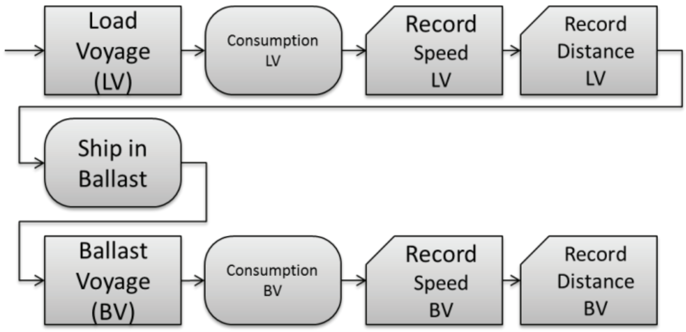

Figure 2. Sub-process for each ship type

The variables calculated in the simulation are shown in real time included total transported cargo and total consumption. Each model, i.e. one for original conditions, one for SS and one fore USS, are run for 200 iterations, each of them representing 360 days (one calendar year). The convergence is verified for each model, e.g. fuel consumption convergence after 200 iterations is shown in Figure 3. Between each iteration, semi-random numbers have been altered.

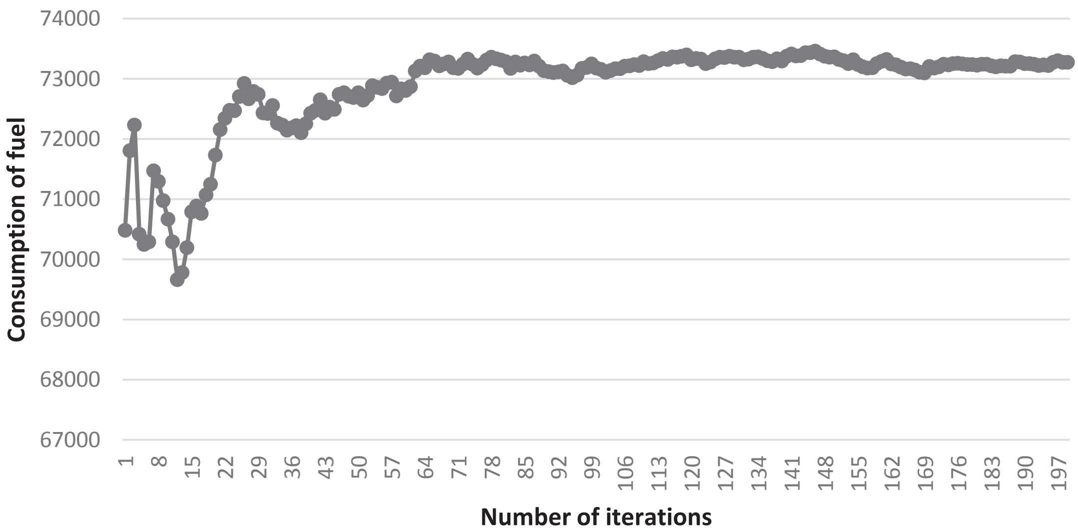

Figure 3. Convergence of total fuel consumption

5. RESULTS AND DISCUSSION

Cost estimation function of ship is based in two factors: cost in port and the cost at sea. If variability of these costs is compared, cost in port must be constant, and the variability is only in cost at sea. In this case the different scenarios of cost at sea are: (a) *original condition of fleet*, (b) *fleet in slow steaming*, and (c) *fleet in ultra-slow steaming*.

Cost at sea is composed of: capital cost, operational cost, and travel cost at sea. The Capital cost and Operational cost are constant in each travel of ship. For analysis of the conditions of slow and ultra-slow steaming only the travel cost at sea varies. This cost is composed of: fuel cost, port charges, channel crossing rates, commissions, cleaning holds and tanks, etc., and other expenses. In fact, if ship takes the same route, only fuel costs could be considered variables (Assis 2014). Therefore, the variations of fuel consumption are enough to map the variation of operating costs.

Another important parameter is the *cargo transported* by each ship in SS and USS. In these conditions due to the speed reduction, the travel days at sea increase for each ship. Consequently, to move *the same amount of load (in same quantity of days)* it would be necessary to use a larger number of vessels at fleet. For this reason is important to record the cargo transported in the simulation time and the number of ships that completed the travels. Therefore, to found eventual savings in model simulation we should consider both *fuel consumption* and *total cargo transported*.

The results show the amount of *cargo transported* (in tons) in each of the proposed alternatives, and *total consumption* (in tons) of the fleet, for a fixed period of one year. These values are presented in Table 6.

Table 6. Cargo transported by the fleet and total consumption of the fleet in the three navigation conditions

Condition	Cargo transported [ton]		Total Consumption [ton]	
Original (O)	18 473 557	100%	148 813	100%
Slow Steaming (SS)	17 695 001	96%	84 040	56%
Ultra-Slow Steaming (USS)	17 204 950	93%	34 105	23%

Using stochastic variables for speed, consumption, load and distance guarantee the robustness of the results. Figure 4 shows that *cargo transported* decreases by 96% and 93% in SS and USS respectively whereas *fuel consumption* decreases by 56% and 23% respectively. The results suggest that speed reduction would be considered since the percentage of reduction of fuel consumption is very high.

The reduction in transported cargo can be carried by new ships in the fleet. The simulation results provide us the average number of ships that are making the round trips for each analyzed alternatives (Table 7). With these data, capital cost of buying new ships can be assessed.

Table 7. Number of ships that leave the round trip in the simulation

Number out	Original	Slow Steaming	U-Slow Steaming
Ship 1	12	16	19
Ship 2	51	46	42
Ship 3	22	20	18
Total	**85**	**82**	**79**

Considering the fuel price about 333 USD for a metric ton (Ship & Bunker 2015), cost savings of SS and USS are assessed respectively to 21 and 38 mUSD annually as shown in Table **8**.

If we consider that the price of a new bulk carrier vessel of the studied size is about 58 mUSD (UNCTAD 2011), we can assess the costs of the extra ships needed to transport total cargo and recalculate if in SS and USS conditions are profitable. **Table 8** shows the annual cost, annual consumption, annual saving in USD and the projection to the next 10 years.

Table 8. Annual costs and consumption saving in USD and projection to the next 10 years

	Original	SS	USS
Fleet annual consumption [ton * 1000]	148.8	84.0	34.1
Fleet annual consumption cost [mUSD]	$49.6	$27.0	$11.4
Fleet annual consumption saving [ton * 1000]	-	64.8	114.7
Fleet annual consumption saving cost [mUSD]	-	$21.6	$38.2
Total saving consumption in 10 years [mUSD]	-	$215.7	$382.0
Fleet consumption for 10 years [ton * 1000]	1 488.0	840.4	341.0
Fleet consumption cons. Savings for 10 years [ton * 1000]	-	647.7	1 147.1
Quantity of extra ships to fulfill the total required cargo	0	3	6
Cost of extra ships [mUSD]	-	$174.0	$348.0
Annual consumption of extra ships [mUSD]	-	$1.023	$0.831
Consumption of extra ships in 10 years [mUSD]	-	$10.2	$8.3
Total costs in 10 years [mUSD]	$495.5	$464.1	$469.9
Total costs savings in 10 years [mUSD]	-	$31.5	$25.7
Percentage of total costs in 10 years	100%	94%	95%

Figure 4 shows that SS condition gives better cost savings than USS. This is due to the higher capital cost to be considered in USS conditions.

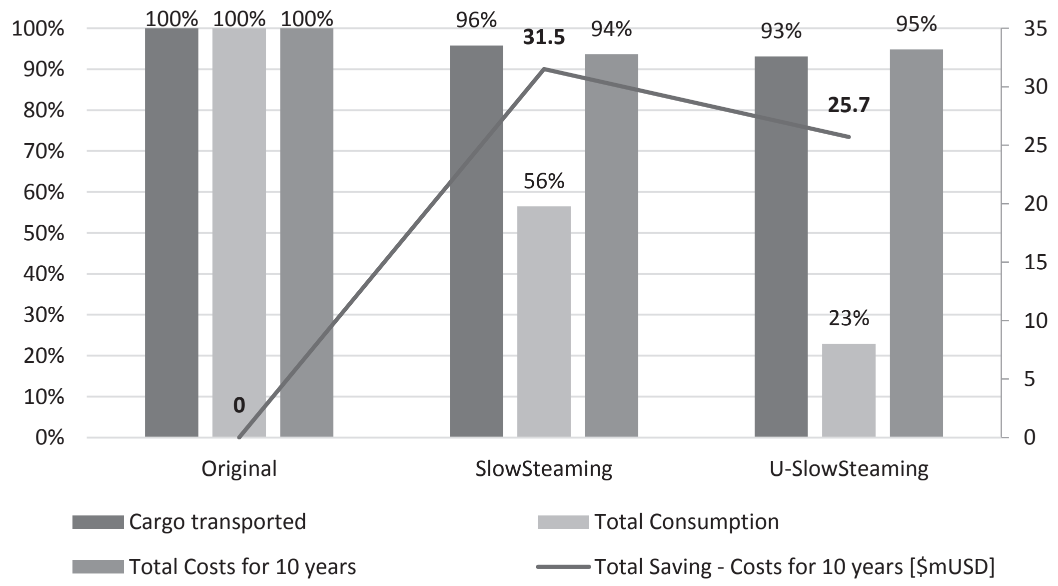

Figure 4. Effectiveness analysis of slow steaming and ultra-slow steaming

6. CONCLUSION

Main results evidenced the reduction of transported cargo by less than 10% for two conditions (SS and USS), while the total consumption decreased by almost 45% and 77%, respectively.

Savings in operating costs, considering only fuel consumption, invites us to reflect on the number of extra vessels required to fulfill the cargo transport objective. Due to the need for increase the number of ships to move the same amount of cargo transported in the same time, SS is more profitable than USS condition to the bulk carrier fleet.

The use of DES can help to simulate scenarios with real historical data, assisting ship-owners in making decisions about the number of ships in their fleet and establishing best operating strategies.

7. FUTURE WORK

The hypothesis of increased new vessels in the fleet should be assessed in more detail about the economic evaluation in future research.

Another possible outcome of this study is the assessment of greenhouse gas emissions (GHGs). In this regard, we propose to improve the model developed in this paper to assess the impact if the deployment of SS on the environment.

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