LIFE-CYCLE IMPACT ANALYSIS OF GREEN SHIP DESIGN / OPERATION ALTERNATIVES BASED ON ENVIRONMENTAL AND MONETARY ASPECTS

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ABSTRACT

The increase in the clampdown of emissions due to the maritime sector has been on the top of the international maritime agenda in recent years. (IMO, 2009) However the response to the call of curbing the rate of emissions caused by the maritime sector had been rather sluggish. The bulb of the unwillingness to reduce the emission rate by the owners is often due to monetary effects such as the unnecessary cost incurred for the implementation of green technology, duration required to retrofit the green technology to existing ship which hinders freight plans and worst of all the probability of an additional cost incurred over the lifecycle of the ship in order to maintain or combat the possible drawbacks of green technology. Thus, the question at hand isn't to enforce on more rules to reduce the emission rate but to convert the stereotypical thinking of owners over their unwillingness toward environmental conservation. The solution proposed in this paper is the creation of a lifecycle impact analysis of green ship design / operation alternatives based on environmental and monetary aspects. The model would present itself as a comparison study of the fuel consumption of the ship, monetary effects (cost & earnings) and the emissions reduced (CO_2, SO_x, NO_x) by the possible green technology used. Scenarios of different scales could be simulated, from a possible booming economy to an economic downturn will allow owners to have a first-hand estimation to the possibility of monetary gains with the use of green technology and the possible amount of the emissions that could be reduced as a result.

Keywords: Emissions, life-cycle cost and earnings, green solutions, feasibility analysis

1. INTRODUCTION

Global warming, it is a situation worsening by the day with major contributing factors coming from harmful pollutants released one way or another by the act of mankind. From various activities ranging from the basic production of staple food needed for our survival to even the generation of electrical energy needed by mankind, pollutions were generated throughout the process thereby hastening the effect global warming. (Environmental Agency UK, 2010) The result of global warming has already taken its toll on mankind through various aspects such as the increase in global temperature, rise in sea level and even the increase in the occurrences of severe natural disasters that were not expected to occur within the current era. (Molnia, 2005).

The ever growing population puts great pressure in the search of natural resources such as crude oil, gases, fossil fuel, food and water for our daily use and consumption. (Laws, 2000) Based on the survey carried out by "Fairplay", the total numbers of ships that constitutes to world trade amount to a total of 50,054 ships with various roles and usages in the global maritime industry. (Fairplay, 2010).

From the survey, we can understand that the vast amount of ships that participated in the global trade is indeed of a significant amount. (J.Bruce, 1999) Due to the vast amount of ships that are sailing across the globe daily in order to carry out various trades and tasks, it leads to an increase in various pollutions generated as a result of maritime transport business. (Panetta, 2010).

However much the desire to ensure a balance between environmental preservation and the maritime trade is achieved, the common misconception relating the implementation of green technology on ships towards expensive retrofitting or the possibility of a decline in cargo capacity for the ship would always cause the owners to carry out the minimum requirement set by the various classification societies or its governing authorities. (EMEC, 2010).

This leads us to the objective of this research that is to develop a lifecycle impact model that will be based on the airborne emissions (greenhouse gases) and the monetary aspects. In proving the possibility of an increase in revenue over the life cycle of the ship by the use of green technology from the model, it will definitely encourage more ship owners to consider the option of implementing various green technologies on board which will in turn contribute towards environmental preservation.
Following the introduction stage (section 1), this paper will dwell into the detail explanations of the proposed method (section 2), the breakdown of the model (section 3), an actual scenario analysis made by our model considering the various green technology and its constituting effects along with a discussion on the results obtained from the scenario analysis (section 4) and finally the conclusion to summarize the paper and certain possible recommendation for future improvements (section 5).

2. PROPOSED METHOD

The lifecycle impact model that will be based on the emissions (greenhouse gases) and the monetary aspects mentioned will be broken down into three major sections. In addition, all the three different sections are able to conduct different scenario analysis be it in the design stage or during the operation stage of the ship. The first section belongs to the "Ship specification and fuel price". Based on the required ship specification and the current fuel price entered by the user, the first section of the model will present all the fuel consumption results of the heavy fuel oil, marine diesel oil and the lubricating oil consumed per year and their lifecycle cost that will be involved.

The second section of the model is the "Monetary Benefits" section. This section governs the comparison of the ship with and without the consideration of green technology. In addition, this section also allows the user to be able to manipulate a total of three different parameters (percentage fuel inflation per annum, percentage fuel saving per annum and the percentage freight rate per annum) in order to understand the various effects of possible economic behavior. The final result presented will reflect the possible savings incurred by the use of green technology over the life cycle of the ship desired by the user.

Finally the third section of the model leads us to the "Emission Index". This section will reflect the emissions results of the three major elements of greenhouse gases which are the CO_2, NO_x and SO_x. Once again, in this section various comparisons pertaining to the emissions generated will be carried out in order to allow the user to understand the difference between the emissions effect of the ship with and without the presence of green technology. (Kontavas, 2008)

3. BREAKDOWN OF MODEL

In order to understand the effect of greenhouse gases generated from ships, it is important to understand the constituting factor that give rise to the greenhouse gases which is basically the fuel consumption over time.

3.1 SHIP SPECIFICATION & FUEL PRICE

The control of fuel consumption would generally be found in terms of the type of main engine, auxiliary equipment, utilization, and the type of fuel used. This section will discuss on the different areas that contribute to the fuel consumption used in the "Ship specification and fuel price" section of the model.
It is important to obtained and understand the amount of fuel consumed per life cycle of the ship in order to generate the total emission and the fuel cost per life cycle of the ship. The steps to calculate the fuel consumption is as follows. The total amount of fuel consumed by a ship will be broken down into three major entity and they are the heavy fuel oil, the marine diesel fuel and finally the lubricating oil.
Figure 1 reflects the graphic model under the ship specification & fuel price section which will be discussed in detail. The major headings that will be discussed are highlighted in red color along with its respective order number.

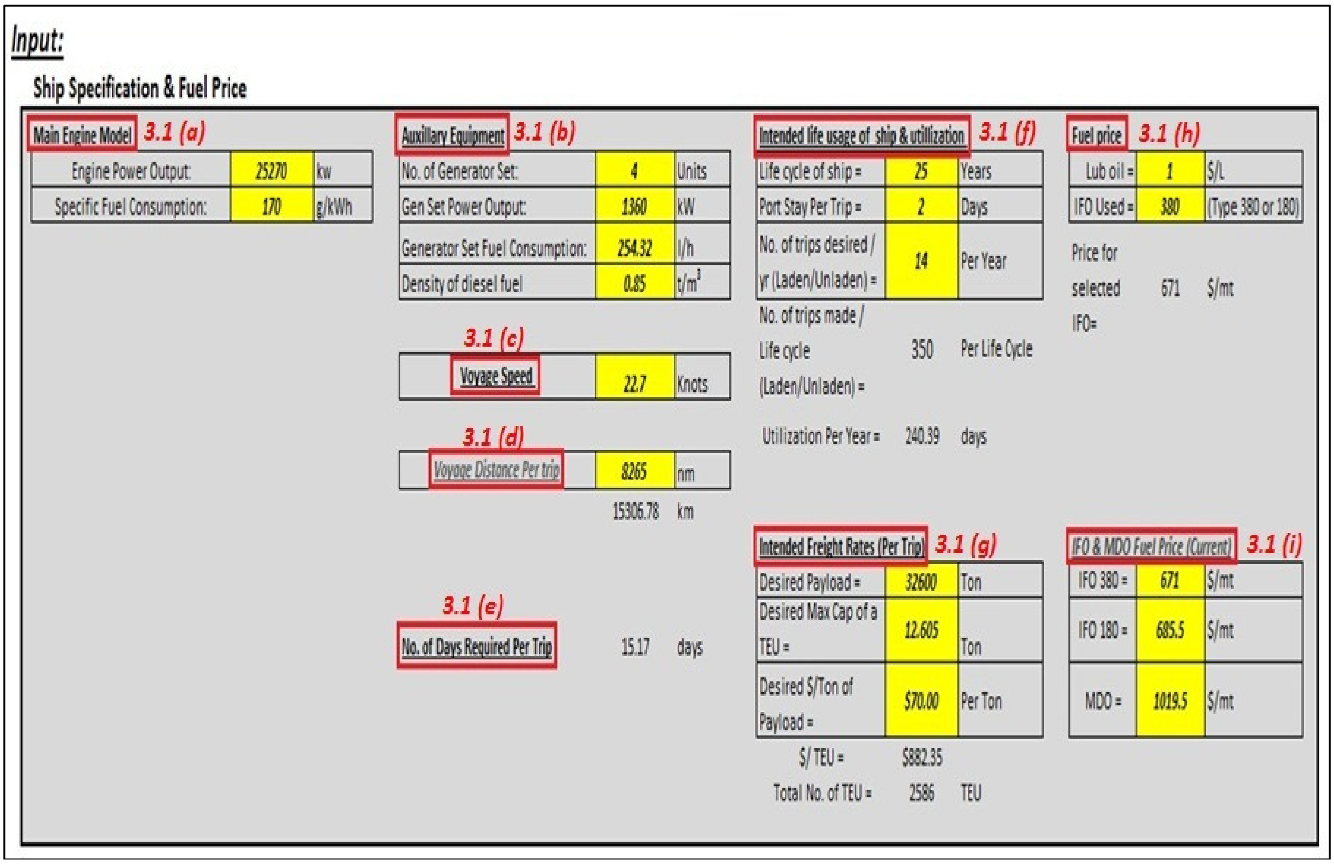

Figure1 : Ship specification & fuel price

3.1 (a) Main Engine

Under the main engine model tab we have the engine power output and the specific fuel consumption required from the user. The purpose of the engine power output and the specific fuel consumption is required for the calculation of the fuel consumption of the intermediate fuel oil and part of it in the calculation of the lubricating oil consumption (Fig 1, “3.1 (a)”).

3.1 (b) Auxiliary Equipment

Under the auxiliary equipment tab we have the number of auxiliary engine, the generator set power output, the auxiliary fuel consumption and finally the density of the fuel required. The auxiliary equipment tab not only contributes to the calculation of the lubricating oil consumed but also to the marine diesel oil consumed. In the generator set fuel consumption tab the users can enter the generator set fuel consumption of their generator used. The generator set fuel consumption is then multiplied against the density of the diesel fuel used in the generator set and finally multiplied by the total number of generator set required (Fig 1, “3.1 (b)”).

3.1 (c) Voyage Speed

Under the voyage speed tab the user can enter its desired voyage speed required for the vessel. The voyage speed is required to obtain the number of days that would be required per trip and is divided by the voyage distance required. The voyage speed is an important parameter that would help to determine the utilization of the ship per year (Fig 1, “3.1 (c)”).

3.1 (d) Voyage Distance

Under the voyage distance tab the users can enter their required voyage distance required per trip. The voyage distance, together with the voyage speed is required to obtain the total number of days required per trip. Finally in having the number of days required per trip we can obtain the utilization of the ship per year. There is also an additional web link in the voyage distance tab to allow users to find out the actual distance that would be required for their voyage from different ports in the world (Fig 1, “3.1 (d)”).

3.1 (e) Number of Days Required / Trip

The number of days required per trip tap reflects the results of the possible days that would be required given the voyage distance against the voyage speed. Finally the presence of the number of days required per trip is necessary in order to obtain the utilization of the ship made per year (Fig 1, “3.1 (e)”).

3.1 (f) Intended Life Usage of Ship & Utilization

The intended life usage of ship & utilization tab consists of three main inputs and they are the life cycle of the ship, the required port stay required per trip and finally the number of trips made per year (be it loaded or unloaded condition) (Fig 1, "3.1 (f)").

The life cycle of the ship is dependent on the user's preferences. However it is good to note that an average life cycle of a ship would usually be up to twenty five years. In addition to the life cycle of the ship, the life cycle limit in this model could be calculated up to a maximum of one hundred years. In multiplying the life cycle of the ship against the number of trips desired per year will affect the total number of trips made per life cycle (Laden or un-laden).

In order to simulate real life shipping duration required per trip, it is important to consider the effect of the additional time for loading and unloading of goods that would be required by the ship made per trip, in short the effect of the port stay made per trip. The port stay tab allows the user to decide the number of days that would be required per trip.

The number of trips desired per year (laden or un-laden) is an iterative tab for the users to decide the optimum number of trips that the users would like to have for each year. This iterative tab allows the user to maximize the number of possible trips for a given parameters such as the voyage speed, voyage distance and the number of port stay required per trip. In addition should the users wishes to increase the number of trips desired per year, the users could manipulate parameters such as the voyage speed, voyage distance and the number of port stay required per trip. However it is important for the users to understand that the results (utilization per year) for the iterative boundary of the numbers of trips made should not exceed a maximum of 365 days / year. In the case whereby the boundary limit is reached, an error message stating "ERROR (No. of Days Exceeded 365 / Yr)" will be reflected in the model.

3.1 (g) Intended Freight Rate / Trip

The intended freight rates per trip tap consist of the desired payload (tons), the desired maximum capacities of a twenty foot equivalent unit container (TEU) and the desired dollar per ton of the payload. The desired payload enables the user to enter their desired payload according to the respective size of their ship. The desired payload will be divided by the desired maximum capacities of a TEU to obtain the total number of TEU that the ship is capable of carrying. Due to the effect of the desired payload tab, it enables the model to be able to consider the bulk cargo ships besides the container ships (Fig 1, "3.1 (g)").

The desired maximum capacity of a TEU allows the users to place a limit of each TEU allowable on board the ship. In having this constraint, it allows the users to have a flexible control of the total maximum number of TEU containers that the users could carry. However it is good to note that different ranges of the number of TEU that a ship could carry would cause the ship to fall into different categories of ship sizes (VLBC, Panamax, Handy, and Feeder etc.). Due to the different ship sizes, there are certain routes in specific parts of the world that places limits on the weight or size of the ship to allow entry (Panama Canal, Suez Canal etc.). Therefore users must ensure that a reasonable size of ship is selected and capable crossing over their selected routes in accordance with the specified entry criteria limit.

The desired dollar per ton of payload tab allows the users to enter their desired cost for each ton of payload. In addition the users will have flexible control over the cost of each trip and the users can manipulate this tab to attain the required amount of revenue that would be required per trip to ensure their profit margin is met.

In order to allow the users to have a clear understanding of the cost per TEU carried. An additional tab of dollar per TEU is created to reflect the cost in terms of TEU.

3.1 (h) Fuel Cost

The fuel price tab consists of the current lubricating oil price tab in dollar per litres and the intermediate fuel oil used tab (IFO 380 or 180). The presence of the lubricating oil price is to allow the users to enter the current lubricating oil price in dollar per litres so as to obtain the latest cost of the total lubricating oil per year. (Fig 1, "3.1 (h)")

In this model it is assumed that bunkering of the intermediate fuel oil will be the main source of fuel for the main engine. Therefore in the "IFO Used" tab the users can select the different types of IFO (380 or 180) to be bunkered in for their ship. Following the selection made by the user, the model will select the respective fuel price of the selected fuel type which will be reflected on the "Price for selected IFO" tab. In order to ensure that the users would have a clear view for the price of their selected intermediate fuel oil used, an additional price for the selected IFO (dollars per metric ton) tab is introduced. In the price for the selected IFO tab the users can have a clear picture of the price for the respective type of IFO selected (380 or 180).

3.1 (i) Intermediate Fuel Oil & Marine Diesel Oil Cost

The intermediate fuel oil (IFO) and the marine diesel oil (MDO) tab consist of the current fuel price tab for the different IFO (380 and 180) in dollar per metric tons and the MDO in dollar per metric tons. The purpose in having the different varieties of current fuel price is provide the model with a fuel price data base for the model which will be updated by the users.

In order to provide the users with the necessary information of the different fuel price update, a link to the world bunker prices is being provided on the "IFO & MDO Fuel Price (Current)" tab. Finally, an additional point to note of in this model is that the fuel price selected will be considered as a constant variable throughout the selected number of years of life cycle of the ship, or on a simpler term the fuel price selected will be the same for the life cycle of the ship.

The intermediate fuel oil 380 and the intermediate fuel oil 180 fuel price tab will provide the latest fuel prices of the respective intermediate fuel oil. Upon the selection of the types of intermediate fuel oil from the fuel price tab, the green technology feasibility model will automatically select the respective intermediate fuel oil from the intermediate fuel oil tabs. Similar to the IFO tab the marine diesel oil (dollar per metric ton) tab will provide the latest current marine diesel oil updated by the users (Fig 1, "3.1 (i)").

3.2 MONETARY BENEFITS

Some of major difficulties in enticing owners to invest or implement in the different types of green technology into their ship is often due to the high initial installation cost of the green technology, the extended duration needed for the installation of green technology, the possibility of a decrease in revenue for the owners (increase maintenance, deteriorate original hull form etc.) and the difficulty of retrofitting existing ships with the green technology.

On the whole the most crucial problem among all of the above mentioned problems would always be the monetary factor. Thus one of the possible ways to "entice" the owners to invest in any possible green technology is to ensure that an increase in revenue by the use of green technology is a reality.

The projected amount of fuel saved for "n" number of years at "n" percentage of speed reduction page allows the users to create various scenarios of possible situations, be it in terms of fuel reduction that the possible green technology might reap, to the varying economic factors that the owner might face (inflation effects) and lastly the possible solution that the owner could do to rectify the possible economic factors (freight rate increment). In having this "feasibility" model the owners could conduct various scenarios simulation in order to understand if there is a possible risk or long term monetary gains involved just by implementing the specific green technology to their ship.

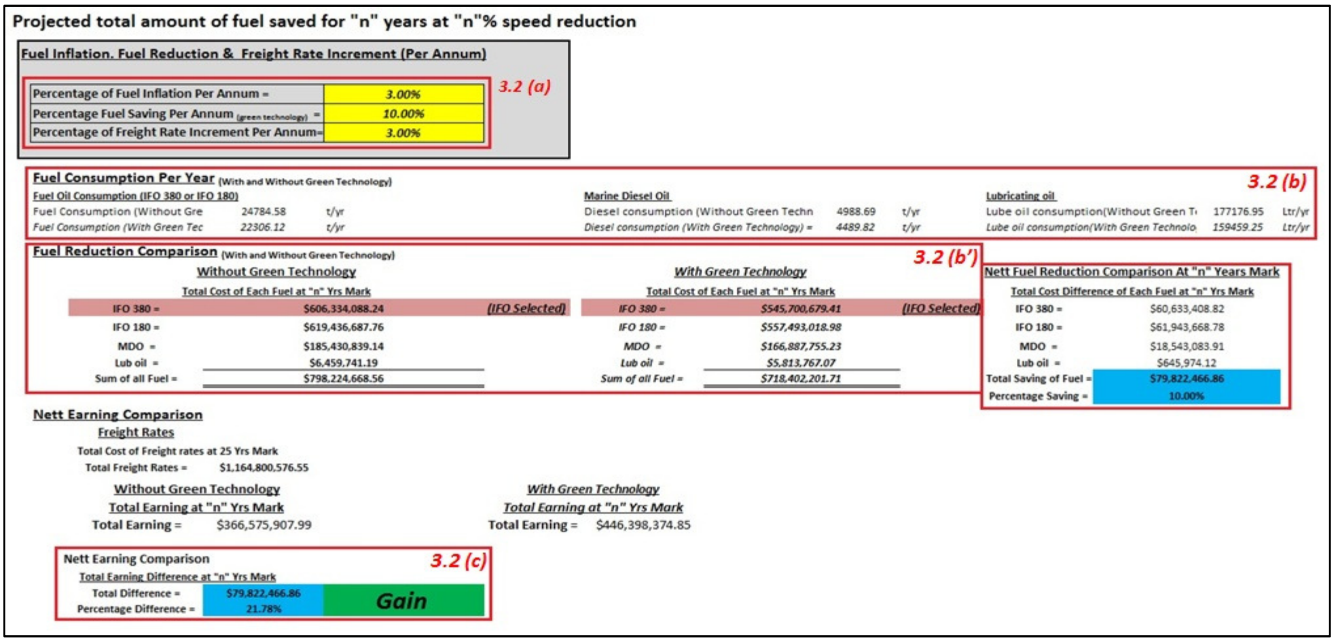

Figure 2: Fuel inflation, fuel reduction and freight rate increment / annum

3.2 (a) Fuel Inflation, Fuel Reduction and Freight Rate Increment / Annum

The fuel inflation, fuel reduction and freight rate increment per annum tab consists of the percentage of fuel inflation per annum tab, the percentage of fuel reduction per annum tab and the percentage of freight rate increment per annum tab. The purpose of these three major tabs is to allow users to manipulate the different possible scenarios that they desired. From a booming economy to the possibility of a recession period which affects the total revenue could be applied by the users to analyze the feasibility of implementing any possible green ship technology in various economy conditions (Fig 3, “3.2 (a)”).

Due to the increasing demand for the need of fossil fuel there will high likely be a constant increment in the cost of fossil fuel. This effect is especially true as the search for the remaining fossil fuel in world spread into deeper and harsher environment which result in a great increase in terms of the exploration and production cost of extracting fossil fuel from these environment. As a result the cost of fuel price will constantly be increasing annually in order to ensure profit is made for the fuel companies. In the percentage of fuel inflation per annum tab the users can alter the different economic condition possible such a constant annual inflation, a stagnant economic condition (zero inflation) to even the possibility of a decrease in the rate of an inflation just to name a few. In having considered the fuel inflation rate, it will definitely aid the users to have a more accurate prediction and consideration of the effect of fuel inflation

3.2 (b) Percentage of Fuel Reduction / Annum

Similar to the percentage of fuel inflation per annum tab, the presence of the percentage of fuel reduction per annum tab is to allow users to manipulate the different ranges of fuel reduction percentage due to the effect of implementing the green ship technology on the user’s ship. In enabling the users to generate the different scenarios making capabilities, the users will be able to foresee the possible positive effect (monetary gains), stagnant effect (zero monetary gains) to even the possibility of a negative effects (monetary loses) that the users might face with the implementation of the green technology.

In order to ensure that the users will have a clear view of comparison between the effect of fuel consumption before and after the implementation of the green ship technology, an additional fuel consumption tab (with green technology) is introduced just below the original fuel consumption tab (without green technology) (Fig 3, “3.2 (b)”).

Under the fuel reduction comparison tab, a detail comparison table reflecting the different types of fuel selected by the users is being shown. The very first column reflects the cost of all the different types of fuel used such as the Intermediate fuel oil 380 (IFO380), intermediate fuel oil 180 (IFO180), marine diesel oil (MDO), and the lubricating oil better picture before considering the effect of green technology. Similar to the first column, the second column reflects the respective types of fuel however in this column the effect of green technology is being considered (Fig 3, “3.2 (b’)”).

The third column or the nett fuel reduction comparison at “n” years mark reflect the monetary difference of the total fuel cost between the effects in using the green technology and without the use of the green technology. The results are shown in two ways; the first results reflect the actual monetary difference between the use of green technology and without. The second results act as a checking device to ensure that the monetary difference when calculated in terms of percentage is exactly the same as the results entered by the users in the percentage fuel reduction per annum tab (Fig 3, “3.2 (b’)”).

3.2 (c) Percentage of Freight Rate Increment / Annum

Due to the constant surge in fuel price all around the world, a very common practice taken to reduce the effect of incurring expenditure by the owners is to increase the freight rate charged. (Stopford, 2009) Thus in order to achieve positive simulation of the marine transport business, the percentage of freight rate increment per annum tab is created. In creating this tab the users could manipulate the desired percentage of freight rate increment per annum to overcome or even to strike a balance against the impending annual fuel inflation.

Finally under the last section of the nett earning comparison, we have the total earning difference at “n” years mark. This section is created to reflect the total monetary difference by considering between the effect of green technology and without. Similar to nett fuel reduction comparison at “n” years mark, the total earning difference at “n” years mark reflect the exact monetary difference and the percentage difference (Fig 3, “3.2 (c)”).

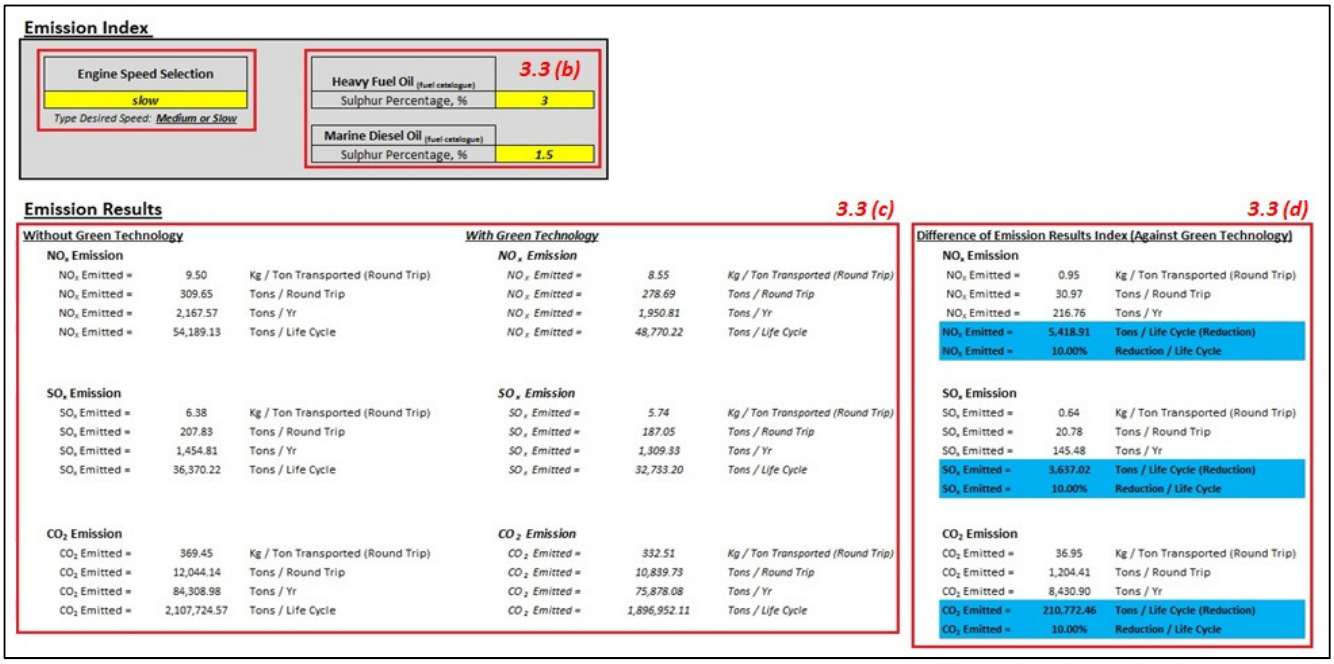

Figure 3: Emission index

3.3 EMISSION INDEX

Finally in this "Emission Index" section, detail results of the emission generated will be reflected. Besides presenting the emissions results, a comparison between the use of green ship technology and without will also be shown to allow the users to understand the possible environmental contribution of the green ship technology used.

In the emission index tab we have the types of engine speed selection tab, the percentage of sulphur content in the heavy fuel oil tab and the percentage of sulphur content in the marine diesel oil tab.

Unlike the calculation of CO_2, the calculation NO_x and SO_x revolves around a set of variable emission factors that would be required in order to obtain the emission index. This explains the presence of the engine speed selection tab, the sulphur content in the heavy fuel oil tab and the sulphur content of the marine diesel oil tab.

3.3 (a) Engine Speed Selection

In the engine speed selection tab the users can choose between two different speed ranges for their desired engine type. Due to the fact that the main target of the green technology feasibility model revolves around container ships and bulk cargoes ship, the available speed selection ranges would therefore fall between slow and medium speed engine types in this model. (Fig 3)

As mentioned in the earlier paragraph, the calculation of the NOx index would depend on a set of variable emission data. The first emission data or emission factor in this case belongs to the medium speed engine group which is an empirical factor of 0.057. The second emission factor belongs to the slow speed engine group which is an empirical factor of 0.078 (CORINAIR, 2002).

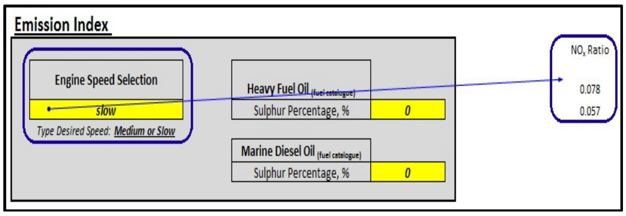

Figure 4: Engine speed selection

3.3 (b) Heavy Fuel Oil, Marine Diesel Oil

Due to the fact that sulphur exist in both the content of the heavy fuel oil and the marine diesel oil, in the model we decided to take into consideration of the possible SOx emission which exist in both the heavy fuel oil and the marine diesel oil.

Under the heavy fuel oil and marine diesel oil tab the users could enter their desired percentage of sulphur content which is commonly listed in their respective fuel catalogue. The sulphur content would usually depend on the quality of the fuel used and its level of sulphur content in it. (Fig 3, "3.3 (b)") Similar to the calculation of the NOx emission, the SOx emission depend on a variable emission data too, however in this case the variable emission data for the calculation of SOx emission would depend on the sulphur percentage specified by the user. Nevertheless the calculation of the emission index of the SOx depends on an additional SOx emission factor of 0.02 which is obtained from the chemical reaction of sulphur and oxygen. (CORINAIR, 2002)

Even though there is no required input which would affect the CO_2 emission by the users in the emission tab section, it doesn't means that the emission of CO_2 is being neglected in this model. In actual fact according to the relevant environmental authorities (green peace, marpol, IMO etc.) the emission of CO_2 is one of the most serious and urgent problem at hand.

Unlike the calculation of the NO_x and SO_x emission index which would depend on the user's inputs, the calculation for the CO_2 index is considered to be a much simpler procedure than compared to the other emission index. Similar to the NO_x and SO_x emission, the CO_2 index requires an empirical emission factor of 3.17 which is a common emission factors used widely in many emission literatures (CORINAIR, 2002).

3.3 (c) Emissions Results

The emissions results are broken down into three major columns they are the emission result without the use of green technology, the emission result with the use of green technology and finally the difference of the emission index to present a clear view to the users of the difference in terms of the emission index. The first and second columns of the emission results reflect the NO_x, SO_x and the CO_2 emission index. A total of four different types of results are shown in each of the respective emission index column (Fig 3, "3.3 (c)").

Moving on to the third column of the emission result index, we have the difference of the emission results index. As stated in the earlier paragraph, the presence of emission result index serve as a visual guide of comparison to the users to understand the effect of the emission emitted with the use of green technology. The third column consist of the four similar types of results as the first two columns, however an additional results reflecting the percentage of reduction per life cycle is being introduced in the third column making the total different types of results to five (Fig 3, "3.3 (d)").

4. SCENARIO ANALYSIS

Having completed the generalized model we shall now put our generalized model to use by creating various scenarios simulating the effects of the selected green technology into an existing ship. A total of three scenarios shall be created and the three scenarios were made considering the following possibilities consisting of the optimistic, the most probable and the pessimistic scenarios.
Each of the three scenarios made shall consist of four different considerations of the green technology. The first consideration considers the effect of the ship without the presence of green technology this consideration is required so as to achieve a basis line of comparison to understand the monetary effect and the emissions generated. The second consideration considers the monetary effect and the emissions generated with the presence of a randomly selected green technology (skysail). The third consideration considers the monetary effect and the emissions generated with the presence of slow steaming. The fourth and last consideration considers the monetary effect and the emissions generated with the presence of both the skysail technology and slow steaming effect. (Fig 6)
Having explained the various considerations that will be taken into account into the model, the next paragraph will touch on some of the assumptions used in this scenario analysis section.

Pessimistic Scenario

- The freight rate increment per annum would be assumed at a constant increment of 3% for the pessimistic scenario. The basis for a 3% increment rate per annum is required in order to ensure minimum profit is made.
- It shall be assumed that in the case of the pessimistic scenario, zero percentage of fuel will be saved by the use of skysail technology.
- It shall be assumed that in the case of the pessimistic scenario, the percentage of speed reduction shall be set at 10% and main engine power output reduction shall be set at 20% for slow steaming condition.
- In the event where combination of green technologies is to be considered, the various percentage reduction of the various green technology shall remain as per mentioned in the pessimistic scenario.

Most Probable Scenario

- The freight rate increment per annum would be assumed at a constant increment of 6% for the most probable scenario. The basis for a 6% increment rate per annum is required to simulate the probability of a higher profit margin made in an average recovering economy.
- It shall be assumed that in the case of the most probable scenario the percentage of fuel that will be saved by the use of skysail technology shall be set a total of 10%.
- It shall be assumed that in the case of the most probable scenario, the percentage of speed reduction shall be set at 20% and main engine power output reduction shall be set at 30% in the case of slow steaming.
- In the event where combination of green technologies is to be considered, the various percentage reduction of the various green technology shall remain as per mentioned in the most probable scenario

Optimistic Scenario

- The freight rate increment per annum would be assumed at a constant increment of 9% for the most probable scenario. The basis for a 9% increment rate per annum is required to simulate the probability of an even higher profit margin made in a booming economy.

• It shall be assumed that in the case of the most optimistic scenario the percentage of fuel saved by the use of skysail technology will be set a total of 20%.

• It shall be assumed that in the case of the optimistic scenario, the percentage of speed reduction shall be set at 30% and main engine power output reduction will be set at 40% for slow steaming.

• In the event where combination of green technologies is to be considered, the various percentage reduction of the various green technology shall remain as per mentioned in the optimistic scenario.

4.1 FUEL CONSUMPTION COMPARISON

Table 1: Fuel consumption comparison of ship without green technology

Scenarios:		Pessimistic	Most Probable	Optimistic
Ship Without Green Technology	IFO Consumption (mt/Year)	24784.58	24784.58	24784.58
	MDO Oil Consumption (mt/Year)	4988.69	4988.69	4988.69
	Lube Consumption (mt/Year)	150.60	150.60	150.60

Table 2: Fuel consumption comparison of ship with skysail technology

Scenarios:		Pessimistic	Most Probable	Optimistic
Skysail Technology	IFO Consumption (mt/Year)	24784.58	22306.12	19827.66
	MDO Oil Consumption (mt/Year)	4988.69	4489.82	3990.95
	Lube Consumption (mt/Year)	150.60	135.54	120.48

Table 3: Fuel consumption comparison of ship with slow steaming

Scenarios:		Pessimistic	Most Probable	Optimistic
Slow Steaming	IFO Consumption (mt/Year)	21774.13	21181.31	20501.59
	MDO Oil Consumption (mt/Year)	5478.43	6090.60	6877.68
	Lube Consumption (mt/Year)	138.17	138.48	139.29

Table 4: Fuel consumption comparison of ship with skysail technology & slow steaming

Scenarios:		Pessimistic	Most Probable	Optimistic
Best Result				
Skysail Technology & Slow Steaming	IFO Consumption (mt/Year)	21774.13	19063.18	16401.28
	MDO Oil Consumption (mt/Year)	5478.43	5481.54	5502.14
	Lube Consumption (mt/Year)	138.17	124.63	111.43

4.2 MONETARY BENEFITS COMPARISON

Table 5: Monetary benefits comparison of ship without green technology

Scenarios:		Pessimistic	Most Probable	Optimistic
Ship Without Green Technology	Fuel Cost ($/ Life Cycle)	$798,224,668.56	$798,224,668.56	$798,224,668.56
	Total Freight Rates ($/ Life Cycle)	$1,164,800,576.55	$1,752,811,429.24	$2,706,024,232.65
	Total Earning ($/ Life Cycle)	$366,575,907.99	$954,586,760.68	$1,907,799,564.09
	No. of Trips / Yr (Trips)	14	14	14
	Utilization / Yr (Days)	240.4	240.4	240.4

Table 6: Monetary benefits comparison of ship with skysail technology

Scenarios:		Pessimistic	Most Probable	Optimistic
Skysail Technology	Fuel Cost ($/ Life Cycle)	$798,224,668.56	$718,402,201.71	$638,579,734.85
	Total Freight Rates ($/ Life Cycle)	$1,164,800,576.55	$1,752,811,429.24	$2,706,024,232.65
	Total Earning ($/ Life Cycle)	$366,575,907.99	$1,034,409,227.53	$2,067,444,497.80
	No. of Trips / Yr (Trips)	14	14	14
	Utilization / Yr (Days)	240.4	240.4	240.4

Table 7: Monetary benefits comparison of ship with slow steaming

Scenarios:		Pessimistic	Most Probable	Optimistic
Slow Steaming	Fuel Cost ($/ Life Cycle)	$742,246,788.37	$750,511,715.74	$763,173,576.14
	Total Freight Rates ($/ Life Cycle)	$1,164,800,576.55	$1,752,811,429.24	$2,706,024,232.65
	Total Earning ($/ Life Cycle)	$422,553,788.18	$1,002,299,713.50	$1,942,850,656.51
	No. of Trips / Yr (Trips)	14	14	14
	Utilization / Yr (Days)	264.0	293.5	331.4

Table 8: Monetary benefits comparison of ship with skysail technology & slow steaming

Scenarios:		Pessimistic	Most Probable	Optimistic
Best Result				
Skysail Technology & Slow Steaming	Fuel Cost ($/ Life Cycle)	$742,246,788.37	$675,460,544.17	$610,538,860.91
	Total Freight Rates ($/ Life Cycle)	$1,164,800,576.55	$1,752,811,429.24	$2,706,024,232.65
	Total Earning ($/ Life Cycle)	$422,553,788.18	$1,077,350,885.07	$2,095,485,371.74
	No. of Trips / Yr (Trips)	14	14	14
	Utilization / Yr (Days)	264.0	293.4	331.4

4.3 EMISSION INDEX COMPARISON

Table 9: Emission index comparison of ship without green technology

Scenarios:		Pessimistic	Most Probable	Optimistic
Ship Without Green Technology	NO_x Emitted (Tons Per Life Cycle)	54,189.13	54,189.13	54,189.13
	SOx Emitted (Tons Per Life Cycle)	36,370.22	36,370.22	36,370.22
	CO2 Emitted (Tons Per Life Cycle)	2,107,724.57	2,107,724.57	2,107,724.57

Table 10: Emission index comparison of ship with skysail technology

Scenarios:		Pessimistic	Most Probable	Optimistic
Skysail Technology	NO_x Emitted (Tons Per Life Cycle)	54,189.13	48,770.22	43,351.31
	SOx Emitted (Tons Per Life Cycle)	36,370.22	32,733.20	29,096.18
	CO2 Emitted (Tons Per Life Cycle)	2,107,724.57	1,896,952.11	1,686,179.66

Table 11: Emission index comparison of ship with slow steaming

Scenarios:		Pessimistic	Most Probable	Optimistic
Slow Steaming	NO_x Emitted (Tons Per Life Cycle)	50,229.57	50,857.19	51,664.13
	SOx Emitted (Tons Per Life Cycle)	33,087.90	33,090.83	33,094.59
	CO2 Emitted (Tons Per Life Cycle)	1,953,714.42	1,978,126.17	2,009,512.70

Table 12: Emission index comparison of ship with skysail technology & slow steaming

Scenarios:		Pessimistic	Most Probable	Optimistic
Best Result				
Skysail Technology & Slow Steaming	NO_x Emitted (Tons Per Life Cycle)	50,229.57	45,771.47	41,331.30
	SOx Emitted (Tons Per Life Cycle)	33,087.90	29,781.74	26,475.67
	CO2 Emitted (Tons Per Life Cycle)	1,953,714.42	1,780,313.55	1,607,610.16

4.4 OVERALL FUEL CONSUMPTION, MONETARY BENEFITS AND EMISSION INDEX COMPARISON

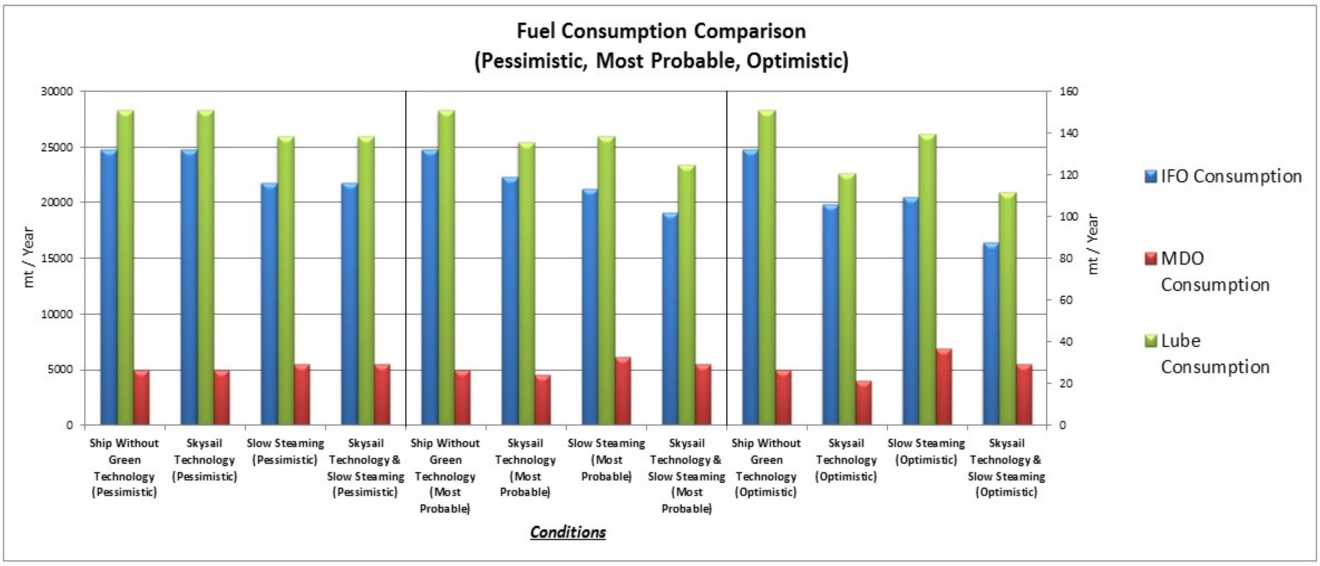

Figure 5: Overall fuel consumption comparison

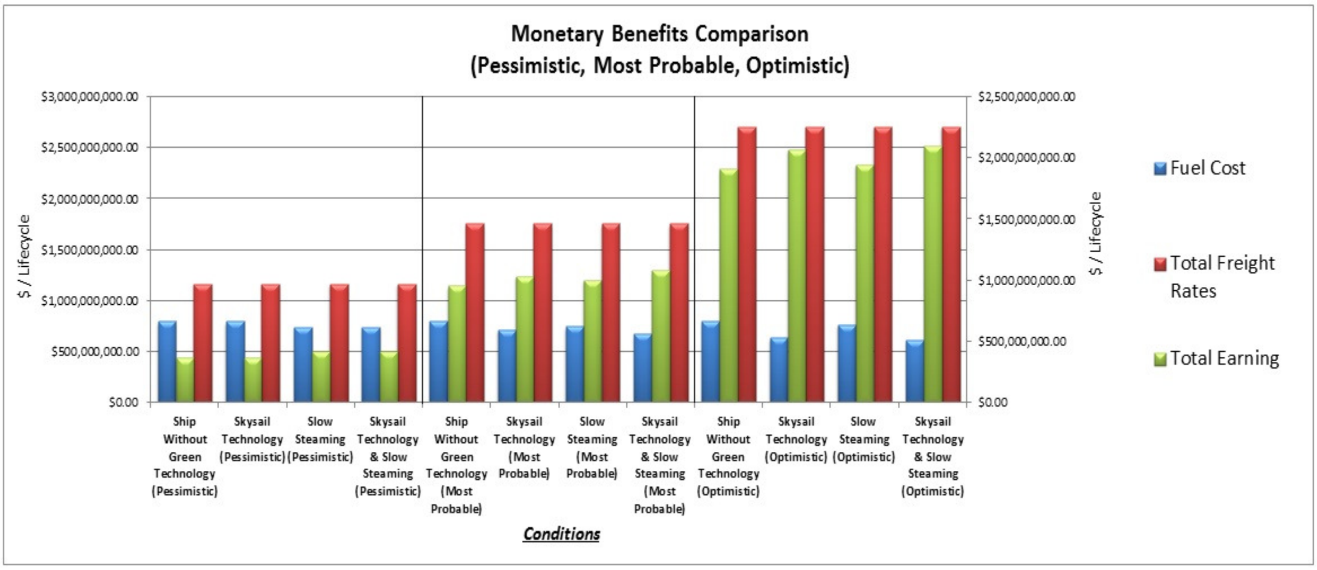

Figure 6: Overall monetary benefits comparison

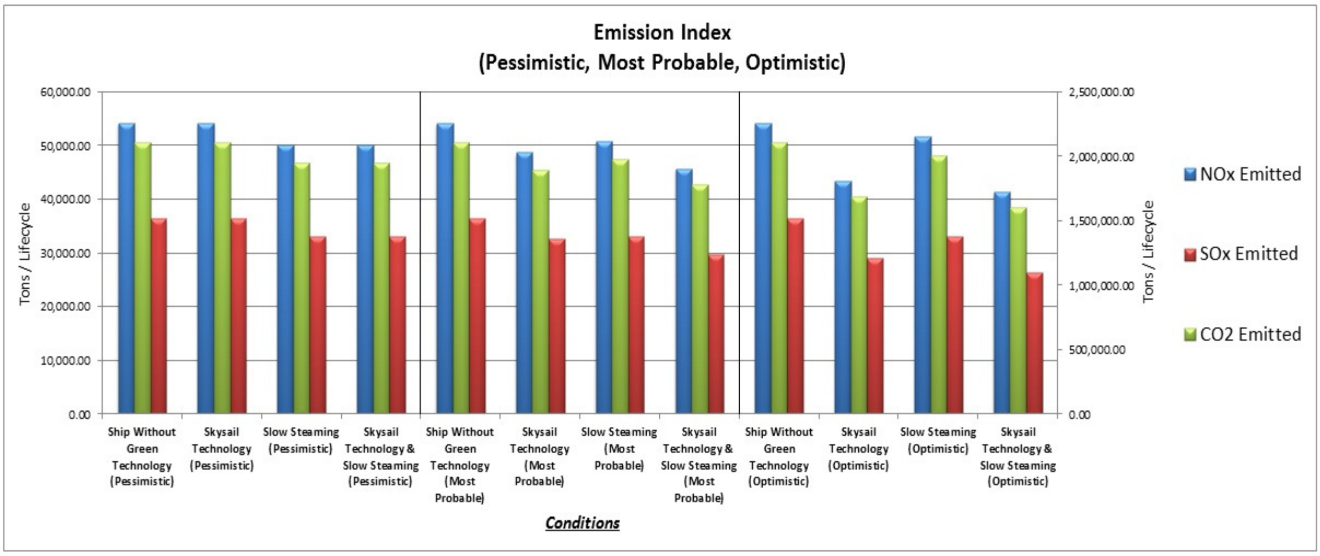

Figure 7: Overall emission index comparison

The third and the last of the scenarios comparison had concluded. Based on the various results obtained, it is clear to us now that the scenarios comparison in terms of the combination of skysail technology along with the slow steaming effect would yield the best results among the four different considerations. Now that we had completed the third and final scenario comparison, let us conclude the scenario analysis section by discussing some of the findings and results gathered through the scenarios analysis carried out by the model created.

Firstly let us discuss on the results obtained from the fuel consumption scenario comparison. As stated in the earlier section, the best result obtained among the four different considerations belongs to the combination of skysail technology along with the slow steaming effect. From the result gathered, we shall assume that the "Most Probable" scenario would most likely be the possible case to happen to the ship in reality. Now that the best combination had been selected let us look into the various positive and negative effects generated by each of the green technology in the next paragraph.

The contributions from the skysail technology constitutes to a constant decrease in the intermediate fuel oil, marine diesel oil and the lubricating oil without reducing the cruising speed of the ship. Based on the contributions and behavior learnt from the skysail technology through the scenarios comparison we can understand that in having the skysail technology retrofitted into the ship, the possibility of fuel reduction could be achieved without hindering the planned utilization required for the ship for each trip. Besides fuel saving this is an important added factor to the ship owners as the possibility in achieving even more trips per year could lead to an increase in the possibility of higher monetary gains within the year.

The contributions from the slow steaming effect constitutes to a constant decrease in the intermediate fuel oil. However due to the nature of the slow steaming effect a decrease in the cruising speed of the ship is experienced. The decrease in the cruising speed of the ship leads to an increase in the duration required for each trip. As a result of the increased duration required for each trip, the fuel consumption of the marine diesel oil required for the generator sets were increased in order to provide the ship with electrical power over the additional duration incurred due to the slow steaming effect. In addition, from the results achieved a marginal increased in the consumption of lubricating oil is experienced. Due to the increased work rate, the main engine and generator sets would experience an increase in the consumption of the lubricating oil to minimize the effect of wear and tear due to the increased work rate caused by the additional duration made per trip.

Having explained the various results gathered from the fuel consumption comparison let us move on to discuss some of the results of the monetary benefits achieved that is contributed by the combination of skysail technology along with the slow steaming effect.

Based on the results obtained, we can understand that the effect of the fuel consumption would directly implicate the results of the monetary benefits gained. In addition to this relationship, we can understand that even though the reduction of fuel consumption could generate an increase in the overall earnings made. The effect of the increased duration made per trip could hinder the overall possibility of an increased earning over the year. Citing an example, an original planned route from point "A" to point "B" taking an average speed of 20 Knots could make a total of 18 trips per year. However by adopting the slow steaming effect the ship speed was reduced to 15 Knots which amounts to a total of 14 possible trips per year.

From the above example made, we can understand that there will be a shortfall of 4 trips made. The shortfall may seems minute by comparing over a year, however by adding up these shortfall over the life cycle of the ship the results gathered would definitely be quite a considerable sum for one to be considered.
Therefore we can understand that the overall effect of slow steaming might reduce the overall possibility of trips made per life cycle which in turn would affect the overall earnings made per lifecycle.

Finally let us move on to the final discussion on the emission index. From the results gathered we can understand that the best results of the scenarios comparison belongs to the combination of skysail technology and slow steaming. Due to the fuel reduction caused by the use of skysail technology, the amount of emissions of the CO2, NOx and SOx were reduced as a result. However in terms of contribution by slow steaming, it is observed from the results achieved that even though there is a modest amount of emissions being reduced when compared to the ship without the effect of any green technology. A marginal increase in emissions between the internal considerations of slow steaming is observed. This phenomenon is likely caused by the extended voyage duration due to the slow steaming effect.

5. CONCLUSION & RECOMMENDATIONS

In using the green technology feasibility model, we were able to obtain the different results reflecting the various combination of green technology. The emissions results that were obtained at the end of the comparison studies were also well validated. Therefore in achieving all the necessary validation the model proves to be a reliable medium for the

users to understand the fuel consumption, monetary benefits and the emission index generated by their ship over the desired life cycle.
In addition to providing the users with a reliable medium to conduct various feasibility analysis of green technology on board their ships, our model was further enhanced by integrating it into a web based model so as to allow even more users / owners all over the world to conduct various analysis studies of green technology. In realizing this, the possibility of bringing across the message in the relationship between environmental conservation in maritime perspectives and the possible revenue gains could be "experienced" by the ship owners all over the world by the use of our model. In completing all these stages draws us to a successful closure of this technical paper.

However much the desire to create a perfect model, the content limit of this technical report could only bring us to a certain juncture that we could had reach within this time frame. Therefore there are definitely certain areas that we could have further improved our model on. Some of the possible ideas for improvement will be listed in this section shown in the next few paragraph.

Firstly, the backbone of our model revolves around a set of linear increment. Taking the percentage of fuel saving per annum for example, the results that were calculated were multiplied by a constant percentage increment per life cycle deemed by the users. Due to this effect, the possibility of a fluctuation rate in term of life cycle analysis is being ignored. In considering the possibility of a fluctuation rate, it will definitely further increase the reliability level of the feasibility model towards real time simulation.

The second idea for improvement requires us to reflect on the system boundary of our model. Currently the applicability of our feasibility model revolves around containers or bulk cargoes types of ship. Therefore the idea of expanding the system boundary to accept other types of ships such as LNG, FPSO, FSO or even a Semi-Submersible could be considered. Thus in expanding the system boundary of our model we are able to exposed more ships to consider the possibility of retrofitting the various types of green technology that are available in the market.

ACKNOWLEDGEMENT

We would like to take this opportunity to thank Dr. Christos Kontavas for his advice and directions rendered in the field of emissions studies.

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