

ENVIRONMENTAL BENEFITS AND ENERGY EFFICIENCY ARISING FROM OPTIMIZATION OF VESSEL'S VOYAGE

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ABSTRACT

The number and size of vessels are increasing every day, and the maritime industry is becoming one of the leading factors of global pollution. This paper will present the basic methods and simulations which will show that significant environmental and energy efficiency benefits can be achieved by optimizing the vessel's route. A detailed description of the reduction of harmful gases emission, which is resulting from the reduction of the ship's speed, will also be presented. In addition to the presentation of the current existing results on this topic, the results obtained from the analysis carried out on the ship machine and engine simulator from the Maritime Faculty in Kotor, by the authors of the paper, will also be given. By optimization of the voyage, which comes from more effective tasks performing at all organizational levels, the vessel is able to adjust its speed in such a way to arrive at the port exactly on time for the berthing operations. This would allow the vessel to reduce its speed, which would lead to the ultimate goal of minimizing air pollution by reducing the emission of harmful gases from vessels.

Keywords: marine pollution, harmful gases emission, vessel's speed, vessel's voyage.

INTRODUCTION

The implementation of environmentally sustainable practices in shipping is becoming increasingly important due to growing concerns for the environment and the need to reduce energy consumption (Watson et al., 2015.). This paper aims to study the environmental benefits and energy efficiency that arise from the optimization of a ship's voyage. Organization of ship's voyage presented in this paper consists of calculating a reduced speed which will affect harmful gases emission and will minimize or eliminate time spent at anchor while waiting for berthing operations. The calculated speed will allow the vessel to arrive at port precisely on time for berthing and cargo operations and will also lower the harmful gas emission (Heaver, 2021). Existing examples and results will be given through analysis of simulation performed on engine room simulator at the Maritime Faculty Kotor. Simulator exercises gave results of fuel consumption and harmful gas emission at different levels of speed performed on two types of vessels by using different speed adjustments. In addition to this method, this paper is based on a literature review of the application of different methods for optimizing a ship's voyage and their effects on the environment and energy consumption. Literature sources include scientific papers, conference papers, technical reports, and related publications published in the recent years. Figure 1 shows the increase in the capacity of container fleet ships over a period of 40 years (IHS, 2019).

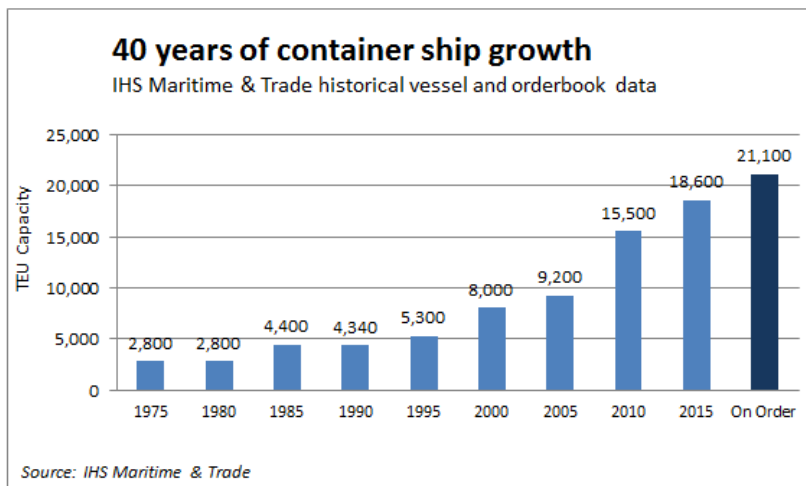


Figure 1. The increase in the capacity of container fleet ships over a period of 40 years (IHS, 2019).

MATERIAL AND METHODS OF WORK

Nowadays, vessels spend a lot of time anchored in the areas in front of the port, waiting for the mooring and the start of the planned operations. In most cases, the ship's journey lasts several days or weeks, and ships spend a few hours or days at anchor. By optimizing the ship's journey, that is analyzed by the authors (Dražković, & Bošnjak, 2023), the conclusion is reached that with more effective and organized communication between all involved factors (ships, companies, ports, terminals, coastal stations), ship's journey could be optimized in such a way that ship arrives at the port exactly on time for mooring operations, which would avoid the negative impacts that anchoring brings with it. Also, from this comes the possibility of speed reduction, which significantly reduces fuel consumption and exhaust gas emissions, which is the main topic of this work. Table 1 shows a case study from the aforementioned paper, which presents the port of departure, time spent sailing to that port, as well as time spent at anchor, of vessel Agnes Victory (Call Sign:LAEM8, IMO: 9258600, Bergen, Norway, year 2021).

Table 1. Port of departure, time spent sailing to that port, as well as time spent at anchor.

Port of Call	Time spent on anchorage	Length of voyage (full ahead)
Evyap Port, Izmit, Turkey	16 hours	4 days
Tartous, Syria	8 hours	2 days
Dneprobugskiy, Ukraine	9 hours	5 days
Kakinada, India	1 hour 30 minutes	7 days
Pasir Gudang, Malaysia	18 hours	6 days

The table is taken from the case study of one of the authors of the paper (B. Drašković), during the time he spent working on the given ship.

RESULTS AND DISCUSSION

Andersson, & Ivehammar, 2017 analyzed how it is possible to optimize the ship's voyage, in order to avoid anchoring, so that ships would arrive at the port exactly on time for mooring and commence of operations that were planned in specific port. Table 2 shows the fuel savings per 1000 kg on an annual basis, taking into account the percentage of speed reduction, as well as the time period in which this reduction was made. For example, if the speed is reduced by 25%, 12 hours before arriving at the port, the fuel savings will be 20979000 kg (annually) (Andersson, & Ivehammar, 2017).

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Table 2. The fuel savings per 1000 kg on an annual basis, taking into account the percentage of speed reduction, as well as the time period in which this reduction was made (Andersson and Ivehammar, 2017.)

Speed reduction	The time before arrival in which the necessary information is provided			
	1h	4h	12h	24h
5%	402	1609	4826	9 640
10%	784	3135	9376	18 638
25%	1805	7163	20 979	41 249
50%	3094	11 602	32 670	61 586

Table 3 shows the financial savings per 1000 kg on an annual basis, taking into account the percentage of speed reduction, as well as the time period in which this reduction was made. For example, if the speed is reduced by 10%, 12 hours before arriving at the port, the fuel savings will be 12089000 kg (annually) (Andersson, & Ivehammar, 2017).

Table 3. The financial savings per 1000 kg on an annual basis, taking into account the percentage of speed reduction, as well as the time period in which this reduction was made (Andersson, & Ivehammar, 2017).

Speed reduction	The time before arrival in which the necessary information is provided			
	1h	4h	12h	24h
5%	519	2074	6223	12 429
10%	1011	4042	12 089	24 032
25%	2327	9236	27 050	53 187
50%	3989	14 959	42 127	79 418

Table 4 shows reduction of emissions of harmful gases (CO₂, NO_x, SO₂, PM_{2.5}) per 1000 kg on an annual basis, taking into account the percentage of speed reduction, as well as the time period in which this reduction was made. For example, if the speed is reduced by 10%, 12 hours before arriving at the port, the reduction of harmful gas emission (NO_x) will be 681000 kg (annually) (Andersson, & Ivehammar, 2017).

Table 4. Reduction of emissions of harmful gases (CO₂, NO_x, SO₂, PM_{2.5}) per 1000 kg on an annual basis, taking into account the percentage of speed reduction, as well as the time period in which this reduction was made (Andersson, & Ivehammar, 2017).

Speed reduction	Emission	The time before arrival in which the necessary information is provided			
		1h	4h	12h	24h
5%	CO ₂	1259	5035	15 106	30 173
	NO _x	29	117	351	700
	SO ₂	0.7	2.9	8.6	17
	PM _{2.5}	0.5	2.0	5.9	12
10%	CO ₂	2453	9812	29 346	58 338
	NO _x	57	228	681	1354
	SO ₂	1.4	5.6	17	33
	PM _{2.5}	1.0	3.8	11	23
25%	CO ₂	5649	22 420	65 665	129 110
	NO _x	131	520	1524	2996
	SO ₂	3.2	13	37	73
	PM _{2.5}	2.2	8.7	25	50
50%	CO ₂	9683	56 313	102 256	192 764
	NO _x	225	843	2373	4475
	SO ₂	5.5	21	58	110
	PM _{2.5}	3.8	14	40	75

Table 5 shows the emissions of NO_x, SO₂, and PM_{2.5} per kg of fuel, assuming that all ships are powered by Marine Gas Oil (MGO) with a maximum sulfur content of 0.1%. (Andersson and Ivehammar, 2017.)

Table 5. The emissions of NO_x, SO₂, and PM_{2.5} per kg of fuel, assuming that all ships are powered by Marine Gas Oil (MGO) with a maximum sulfur content of 0.1% (Andersson, & Ivehammar, 2017).

Type and size of vessel	NO _x	SO ₂	PM _{2.5}
Cargo small	0.0731	0.00180	0.00119
Bulk medium	0.0728	0.00170	0.00115
Bulk large	0.0729	0.00172	0.00116
RO-RO	0.0661	0.00191	0.00125
Container medium	0.0733	0.00184	0.00122
Container large	0.0733	0.00184	0.00122
Container very large	0.0722	0.00156	0.00108
Tanker small	0.0731	0.00180	0.00119
Tanker medium	0.0728	0.00170	0.00115
Tanker large	0.0734	0.00181	0.00134
Tanker very large	0.0734	0.00181	0.00134

The price of fuel largely depends on the current state of fuel market, which generally varies significantly. In addition to the spot price (settlement price, i.e. the market where goods are sold at the daily price), two alternatives were given with the average price during the three studied days (624 USD/ton), and a 50 percent higher spot price was also calculated. The results are shown in Table 6 (Andersson, & Ivehammar, 2017).

Table 6. Spot price (settlement price, i.e. the market where goods are sold at the daily price), two alternatives with the average price during the three studied days (624 USD/ton) and a 50 percent higher spot price (Andersson, & Ivehammar, 2017).

	Spot price June 15	Average spot price the 3 studied days	50% higher spot price
Baltic Sea	522.2	588.4	783.3
North Sea	418.3	471.4	627.5
Total	940.5	1059.8	1410.8

Tables 7 and 8 are showing the emission costs calculated with different unit values, as well as the average of their values (Andersson and Ivehammar, 2017.).

Table 7. Annual costs of CO₂ emissions for traffic in the Baltic and North Sea areas, in millions of euros (Andersson, & Ivehammar, 2017).

	ASEK	Stern low	Stern high	EU ETS	Average
Baltic Sea	316.4	184.6	738.2	21.1	413.1
North Sea	253.5	147.9	591.4	16.9	330.9
Total	569.8	332.4	1329.7	38.0	744.0

Table 8. Annual costs for NO_x, SO₂ and PM_{2.5} emissions for traffic in the Baltic and North Sea areas, in millions of euros (Andersson, & Ivehammar, 2017).

	ASEK	CAFE 1	CAFE 2	CAFE 3	CAFE 4	Prosjek
Baltic Sea NO _x	549.6	194.6	299.3	366.4	538.8	390.8
North Sea NO _x	431.7	296.6	459.9	552.9	815.0	511.2
Total NO _x	981.3	491.2	759.2	919.3	1353.8	902.0
Baltic Sea SO ₂	4.6	6.8	10.7	13.6	20.2	11.2
North Sea SO ₂	3.7	10.2	16.2	20.7	28.3	15.8
Total SO ₂	8.3	17.0	26.9	34.3	48.5	27.0
Baltic Sea PM _{2.5}	-	14.7	23.3	29.4	43.0	27.6
North Sea PM _{2.5}	-	27.5	41.3	53.1	78.8	50.2
Total PM _{2.5}	-	42.2	64.6	82.6	121.7	77.9

As a final result, research was conducted on the machine simulator of the Faculty of Maritime Studies in Kotor. Different degrees of speed were taken into consideration, combined with the emission of harmful gases at each of them, which is presented in Table 9.

Table 9. Different degrees of speed, combined with the emission of harmful gases at each of them

Speed	Nav. Full Ahead	Full Ahead	Half Ahead	Slow Ahead	Dead Slow Ahead
NO _x [ppm]	1019	787	515	403	491
CO [ppm]	83	54	28	21	20
SO _x [ppm]	67	61	62	33	30
CO ₂ [%]	4	4	4	2	2
C [mg/m ³]	66	54	48	46	59
Fuel consumption [%]	76	48	30	14	6
Speed [RPM]	105	87	70	53	38

The table is also presented in detail in figure (diagram) 2, which shows the decrease in speed and emission of negative gases in a period of 30 minutes.



Figure 2. Diagram which shows the decrease in speed and emission of negative gases in a period of 30 minutes.

Figure 3 shows the increase in exhaust gas emissions (NO_x, CO, SO_x, CO₂, C) in three speed levels (Dead Slow Ahead, Half Ahead and Full Ahead).

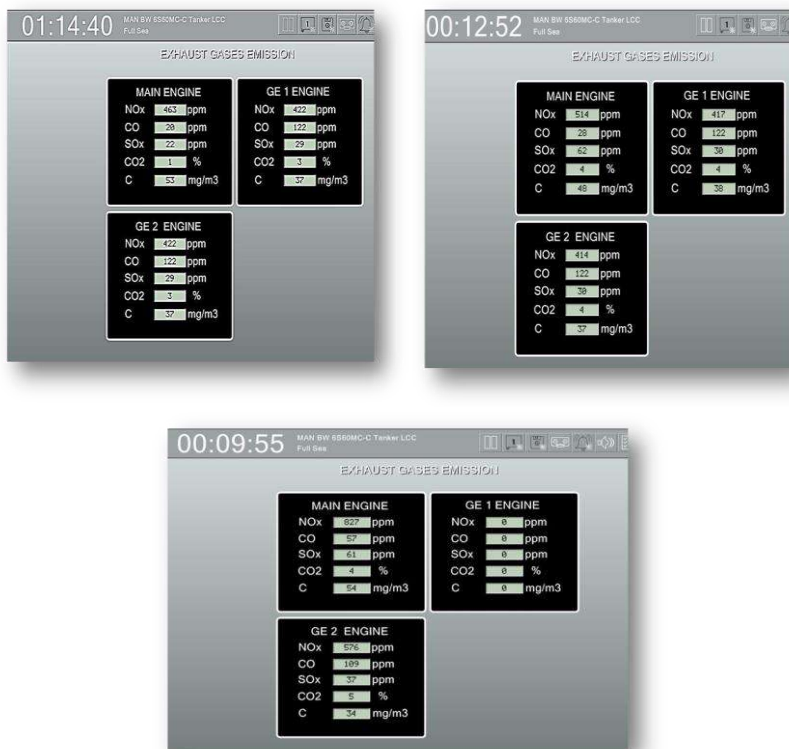


Figure 3. The increase in exhaust gas emissions (NO_x, CO, SO_x, CO₂, C) in three speed levels (Dead Slow Ahead, Half Ahead and Full Ahead).

CONCLUSIONS

In the end, based on the collected results of current research, as well as the test carried out on a machine simulator, the conclusion is reached that it is necessary to establish effective communication at all levels in maritime industry, in order to facilitate the optimization of the ship's journey. Quality optimization would bring a number of benefits, such as: avoiding the anchoring of the ship and its negative impacts, reducing the emission of harmful exhaust gases, reducing fuel consumption and significant financial savings

LITERATURE

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