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An Evaluation of Energy Saving Measures for Ocean Going Vessels

Yong-Wong Kim[*] · † *Dal-Won Kang* · *Ki-Chan Nam*[**] · *Hyung-sik Nam*[***]

, †, Department of logistics system, Korea maritime and ocean university, Busan, Korea*
**** Department of Shipping Management, Korea maritime and ocean university, Busan, Korea*

Abstract : *This paper analyzes and evaluates the importance of energy saving measures based on qualitative survey. Through literature review and group interviews with specialists, 4 factors, 13 measures for energy savings, and 4 evaluation criteria were selected to carry out an Analytic Hierarchy Process (AHP) analysis. At the first stage of AHP analysis, the importance of factors was derived, and then the importance of 13 measures. Lastly, the cross examination of 4 factors was carried out in order to evaluate the best possible qualitative considerations. The result revealed that 'choosing the best course weather', is the most important factor with the highest value on applicability and operational complexity criteria. These results may imply that operational considerations are regarded as a main factor to be taken into account when considering appropriate energy saving measures.*

Key words : *Energy Saving Measures, Ocean Going Vessels, CO2 Emission, AHP analysis, Evaluation of energy saving measures*

1. Introduction

Since the late 2000, due to the global economic crisis which has also heavily affected the maritime industry, a new common core strategy of cost-reduction and cost control has spread among major companies in the shipping arena, in order to survive in a very competitive and depressed market.

In the operations of a ship, the fuel cost is identified as the second largest cost after the labor cost and it is the area in which shipping companies are trying to improve its cost efficiency. In fact, presently due to recent technological development on ship building, an increasing number of sea going vessels have been able to use LNG, which has proved to be more cost efficient and more environmental friendly. This seems to have some impact on the perception of the importance of the measures.

This paper aims at assessing the importance of energy saving measures for ocean going vessels through the analysis of users' preferences for various energy saving measures. The paper is divided into three parts. Firstly, several marine energy savings and CO2 reduction measures are discussed through literature review. Secondly, based on the literature a list of the measures is derived, and both an alternative energy saving measure and evaluation criteria are selected through an interview with specialists of the industry. Finally, the importance of measures selected is evaluated by applying an Analytic Hierarchy Process (AHP) analysis technique.

2. Literature review

2.1 Major literature review

Jung (2014) introduced the result of the research carried out in collaboration with a shipping company and a major shipyard in Korea. The study categorized technology into three main areas namely improvement of ships design, ship maintenance/operations and improvement of machinery efficiency. Based on the technical analysis carried out by a shipyard the author explained the energy saving effect of each measure considered. In conclusion it was suggested that shipping companies need proactive response in order to be able to effectively implement new technology to achieve

† Corresponding author : kangdw@kmou.ac.kr 051)410-4912
* ywkim386@gmail.com 051)410-4912
** namchan@kmou.ac.kr 051)410-4336
*** hsnam0215@gmail.com 051)410-4381

better fuel efficiency.

Balland et al (2014) in their study introduced the Multi-Criteria Optimization Model aimed at selecting suitable control measures for reducing harmful emissions to air. The model was applied to a shipping company called Grieg Shipping considering subjective and qualitative factors. A survey among internal Grieg Shipping stakeholders identified the most important criteria to consider, their relative importance, and the scoring of controls. This empirical data was used as parameters in the model and the model was then applied on a vessel of the Grieg Shipping fleet. The result suggested that non-financial factors also play a fundamental role in the selection process for air emission control in the maritime industry.

Doudnikoff and Lacoste (2014) explored the possible consequences of the future low-Sulphur fuel requirements in Sulphur Emission Control Areas (SECA). They proposed a cost model that estimates the cost-minimizing effect, with variable vessel's speed inside and outside SECA, and the resulting CO2 emissions of the liner service. Applying this model to representative liner services serving North Europe, the authors found that differentiating speed accordingly, slightly decreases total costs and increases CO2 emissions.

Shuaian and Meng (2012) developed a model which shows a relationship between bunker consumption and ships' speed. The authors also analyzed the optimal speed of a container vessel on different legs for each route, considering transshipment operations and routing through a mixed-integer nonlinear programming model. The model was being applied practically with real data from the shipping industry.

Kim et al. (2012) tried to identify the relationship between the fuel consumption and vessel speed based on the data of engine trial tests and the AB Log data. It has been identified that the amount of fuel consumption is directly proportional to the load of the main engine, and the load of main engine has sharply increased at 150 RPM. With regard to vessel speed the fuel consumption had increased rapidly beyond 14 knots. Based on these, the authors suggested that the optimal ship's speed was 14-15 knots and the optimum RPM was 140-150 under specific sea conditions.

Hoffman et al. (2012) analyzed the investment cost and the CO2 emissions reduction potential taking into account 25 CO2 emission reduction measures. In order to analyze the cost implications, 59 ships segments were selected over new ships and vessels to be built between 2010 and 2030, and over those existing ships built before 2010 and expected to be still operational by 2030. In order to cost efficiently implement CO2 reduction measures over each ship segment considered, the additional capital cost was estimated. The result shows that by 2030 a vast percentage (93 %) of the reduction potential will be connected with new buildings. Another implication is that emission reduction measures will most likely affect the price of building new ships resulting in more expensive vessels and more capital required.

Balland at al. (2012) conducted a study focused on the suitable control measure to reduce harmful air emission of vessels through an optimization model. The model selected air emission control for a specific vessel taking into account the interactions between costs and emissions reduction potential by minimizing the cost while being able to comply with the current legislation and able to meet the emissions reduction target.

Lee and Doo (2011) examined the issue of greenhouse emission from ships in terms of international legislation reviewing, in particular, UNFCCC and Kyoto Protocol principals along with IMO new regulations and UNCLOS basic framework. In addition, the paper focused on proposing a fundamental theory and implementation methods in order to comply with latest IMO regulations and the principles found in UNCLOS.

Im and Yi (2010) proposed a study regarding the marine vessel emissions analysis called LCA (Life Cycle Assessment). The authors analyzed greenhouse emissions on merchant ships. In a time range of a few years, data from one bulk carrier and one tanker were collected through inventory of exhaust greenhouse gas emissions during ships' operations. Through the analysis, the authors attempted to measure how much exhausted gas was produced for transporting 1 ton of cargo at a speed of 1 nautical mile.

Corbett et al. (2009) evaluated whether vessel speed reduction can result in being a cost effective CO2 reduction measure for vessels calling on US ports, or not. A profit maximization equation is applied to evaluate the impact of a fuel tax policy and a speed reduction mandate on CO2 emissions. The profit maximization function encompasses opportunity cost associated with speed reduction. The findings of the paper suggested that a fuel tax of about $ 150/Ton would reduce CO2 emissions by about 20%. In addition, should a speed reduction mandate target a 20%

CO_2 reduction, it would result in an additional cost estimated between \$ 30 and \$ 200 per Ton CO_2 abated.

The literature review discussed in the paper can be broadly summarized as:

Firstly, previous papers have focused on two main areas of studies: to reduce fuel consumption and reduce CO_2 emission on air. Most studies revealed some limitations on the range of energy saving measures considered even though some studies described extensive measures. Secondly, previous papers have been extensively using optimization methods and quantitative analysis but qualitative tools have been rarely applied.

Therefore, this paper tried to investigate the different measures and implications of energy saving in the shipping industry through AHP (Analytical Hierarchy Process) analysis. Additionally, considering previous study recommendations and findings, the paper has intended broadening the concept of energy saving measures through the application of qualitative methods and through interview of experts.

2.2 Ship Energy Saving Measures

Table 1 identifies the factors regarding energy saving measure which have been selected from previous studies. It includes 26 measures selected from 4 literature reviews. The measures listed on the Table 1 have some limitations. Particularly, some constraints are identified in terms of application and expression during discussion with experts.

Therefore, this study has focused on surveying and targeting shipping companies operating in the market for over 10 or more years. The survey has been carried out through pre interview and has analyzed the major factors selected regarding energy saving measures. When conducting the survey, duplication, addition and configuration of individual element were considered. Finally, for the purpose of the research, 4 factors and 13 measures were taken into account as shown in Table 2.

Table 1 Energy saving measures

	Jung (2014)	Balland et al (2014)	SEEMP (2013)	Ministry of land (2010)
Improvement of voyage plan		○	○	○
Adaptation of Micro Bubble technology			○	○
Choosing the best course considering weather	○	○	○	○
Improvement of Propeller Inflow	○	○	○	○
Optimization of ship speed		○	○	○
Propulsion resistance management		○	○	
Rudder Hulb	○			
Minimum Ballast			○	○
Alternative Energy			○	○
Bulbous bow optimization	○		○	○
Enlargement of ships				○
Hull condition optimization	○		○	○
Natural sub-propulsion system			○	○
Just in Time			○	
Optimization of steering equipment and Drag control system		○	○	○
Ballast or Trim	○	○	○	○
Shaft power optimization		○	○	
Engine efficiency improvement		○	○	○
Waste heat recovery improvement system		○	○	○
Slow Steaming	○		○	○
Hull & Propeller maintenance	○			
LED lighting	○			
Disel · Electronic propulsion system		○	○	○
Engine monitoring		○		
Advanced propeller blade sections		○		
Boiler system			○	○

Table 2 Energy saving measures selected

Factor	Details Elements
Operation efficiency	Improvement of voyage plan
	Choosing the best course considering weather
	Optimization of ship speed
Ship Design efficiency	Minimum Ballast
	Bulbous bow optimization
	Hull condition optimization
Ship sailing efficiency	Improvement of Propeller Inflow
	Optimization of steering equipment and Drag control system
	Ballast or Trim
	Engine efficiency improvement
Application of New technologies	Waste heat recovery improvement system
	Alternative Energy
	Disel · Electronic propulsion system

3. Empirical Analysis

3.1 Method

The importance of energy saving measures has been explained through the application of AHP method. The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty (1980), is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process. The procedure for using the AHP can be summarized as follow.

Let's consider the criteria $C_i, \cdots, C_j$, some one level in hierarchy. One wishes to find their weights of importance $w_i, \cdots, w_j$, on some elements in the next level. Allow a_{ij} to be the importance strength of C_i when compared with C_j.. The matrix of these number a_{ij} is denoted A.

$$A\,W = \begin{vmatrix} a_{11} & a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & \vdots & & \vdots & & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nj} & \cdots & a_{nn} \end{vmatrix} \quad (1)$$

An obvious case of a consistent matrix A is its elements

$$a_{ij} = w_i / w_j (ij = 1, 2, \cdots, n) \quad (2)$$

Thus, when matrix A os mulitiplied by the vector formed by each weighting $W = (w_{1,}\ w_{2,} \ldots w_n)^T$.

$$\begin{vmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \cdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{vmatrix} \begin{vmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{vmatrix} = n \begin{vmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{vmatrix} \quad (3)$$

The AHP incorporates an effective technique for checking the consistency of the evaluations made by the decision maker when building each of the pairwise comparison matrices involved in the process.

Consistency Index (CI) is obtained by first computing the $\lambda_{\max}$ as the average of the elements of the vector whose jth element is the ratio of the jth element of the vector A·w to the corresponding element of the vector w.

$$C.I = (\lambda_{\max - n}) / (n-1) \quad (4)$$

A perfectly consistent decision maker should always obtain CI=0, but small values of inconsistency may be tolerated.

$$CI/RI < 0.1 \quad (5)$$

The consistency ratio (CR) can be obtained by dividing CI into RI (that is, CR = CI/RI). The random consistency index (RI) is the values of a mathematical function against the number of elements to be compared. Table 3 presents the values of RI. For example, where the number of elements (n) is 3, the value of a function against the number of elements (RI) is 0.58, or when n is 5, the value of RI can be computed as 1.12.

Table 3 Random Consistency Index Values for Different Matrices

n	3	4	5	6	7	8	9	10
R.I	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.2 Result

In order to obtain the raw data, 50 questionnaires were sent with 29 respondents, employed in major shipping companies in Korea during March 2015. In order to obtain an accurate analysis, this research was conducted verifying the consistency ratio with data provided by individual respondents. Three of the respondents were not considered in the paper because the consistency ratio was found to be higher than 0.2. The calculation of the importance of the energy saving measures was obtained from STEP 1 and it was indicated that a consistency ratio was reasonable equating to 0.006.

The importance of energy saving measures has been explained through the application of AHP method and the hierarchical importance of energy saving measures was indicated as shown in Figure 1.

The factors considered were listed from the most important one to the least important. Ranking first was 'operation efficiency' (35.2%), followed by 'ship design efficiency' (25.9%), 'ship sailing efficiency' (20.4%) and 'application of new technologies' (18.5%).

Table 4 Energy Saving Methods Matrix

Classification		Operation efficiency	Ship Design efficiency	Ship sailing efficiency	Application of new technologies	Importance
Energy Saving Methods	Operation efficiency	1.000	1.542	1.810	1.603	0.352
	Ship Design efficiency	0.648	1.000	1.452	1.384	0.259
	Ship sailing efficiency	0.553	0.689	1.000	1.309	0.204
	Application of new technologies	0.624	0.723	0.764	1.000	0.185
λ_{max} : 4.024 CI : 0.008 CR : 0.006						

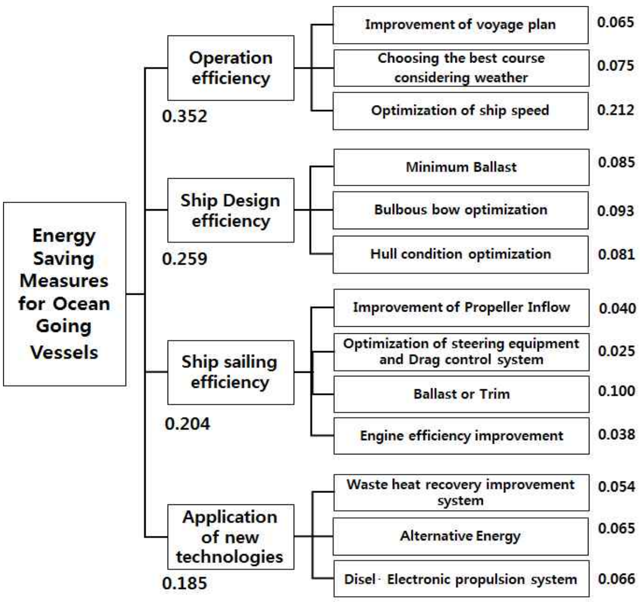

Fig. 1 Hierarchical importance of energy saving measures

The rational for 'operation efficiency' raking first among all other factors can be explained considering that a slight change in operation's system can bring major advantages in terms of cost saving without any additional deep implications.

Among the measures considered the most important one is the 'optimization of ship speed' (21.2 %), followed by 'ballast or trim' (10.0 %), and 'bulbous bow optimization' (9.3%).

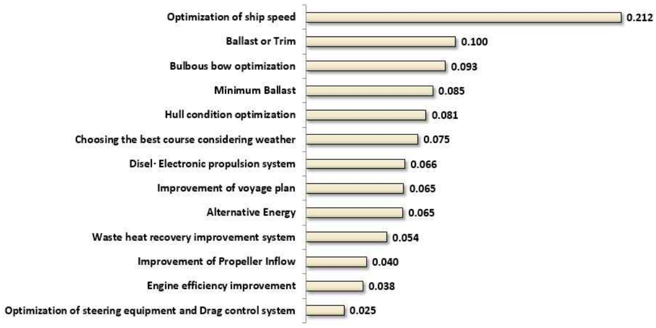

Fig. 2 Importance of energy saving measures

The experts perceived 'optimization of ship' speed' as the most important energy saving measure. This may be generally considered as the measure producing the highest utility with the least input. However, as container vessels are liners providing regular service on fixed routes, ship's speed is closely related to the fleet operational aspect. Therefore, this paper performed a cross evaluation of the measures based on the 4 criteria such as cost, risk, applicability and operational complexity (Table 5).

Table 5 Rank of measures by 4 criteria

Criteria	COST	RISK	Applica-bility	Operational complexity	Rank
Choosing the best course considering weather	3.50	3.12	4.15	3.23	1
Optimization of ship speed	3.81	2.73	3.88	3.15	2
Ballast or Trim	3.23	3.04	3.65	3.38	3
Improvement of voyage plan	3.35	2.73	3.77	3.31	4
Minimum Ballast	3.12	2.92	3.81	3.08	5
Bulbous bow optimization	3.42	2.69	3.23	2.96	6
Optimization of steering equipment and Drag control system	2.92	2.54	3.42	3.27	7
Engine efficiency improvement	3.23	2.50	3.42	2.85	8
Waste heat recovery improvement system	3.46	2.69	2.69	3.15	9
Disel · Electronic propulsion system	3.77	2.65	2.58	2.96	10
Hull condition optimization	3.31	2.42	3.46	2.50	11
Alternative Energy	3.69	2.73	2.38	2.81	12
Improvement of Propeller Inflow	3.27	2.65	2.96	2.69	13

The main point revealed from the result is that the measure 'choosing the best course considering weather' was ranked first but was only ranked sixth applying the AHP analysis. It also had the highest score on the 'applicability' and 'risk' criteria which means that the operational aspect is more importantly considered than the cost in the evaluation of energy saving measures.

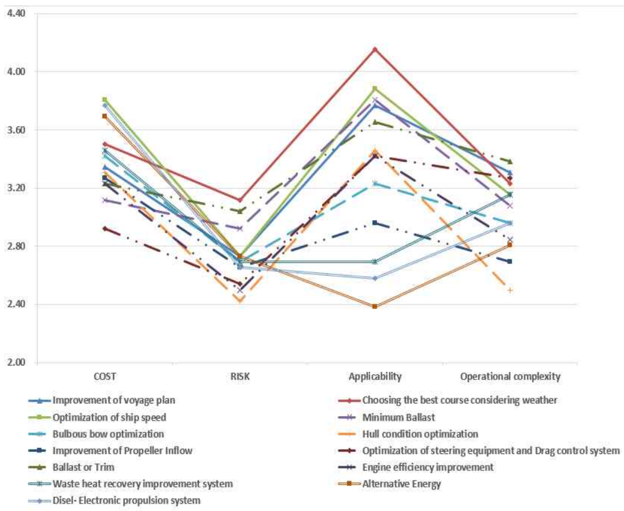

Fig. 3 The evaluation of energy saving measures

4. Conclusion

Since the late 2000, due to the global economic crisis which has also heavily affected the maritime industry, a new common core strategy of cost-reduction and cost control has spread among major companies in the shipping arena, in order to survive in a very competitive and depressed market.

Due to technological development on ship building, an increasing number on sea going vessels have been able to use LNG, which has proved to be more cost efficient and more environmental friendly. Consequently, energy saving methods has been highlighted as an important issue among the shipping lines.

Literature reviews in this research field have been rather limited or fragmented and focused mainly in two main areas: the reduction of fuel consumption and CO2 emission from the shipping lines' point of views. In addition, previous studies in terms of research methodologies have mainly focused on optimization techniques and quantitative method.

Bearing that in mind that this paper tried to analyze and evaluate the importance of energy saving measures based on qualitative survey, 26 energy saving measures have been selected from the literature reviews during the first stage of the study. The study has then carried out group interviews with specialists from the maritime industry, and selected 4 factors (operation efficiency, ship design efficiency, ship sailing efficiency, and application of new technologies) and 13 measures for energy savings. Lastly, analyzing the 26 questionnaires, 4 evaluation criteria (cost, risk, applicability, and operational complexity) were selected to carry out an AHP analysis and find out what the most important factor is.

At the first stage of AHP analysis, the most important factor considered was the 'operational efficiency' which weighted 35.2%. The following was 'ship design efficiency' which weighted 25.9%. 'ship sailing efficiency' ranked third and was weighing 20.4%. Lastly, 'Application of new technologies' weighted 18.5%. The fact that 'operational efficiency' ranked first seems to result from the fact that a small change in a ship's operational system may result in a rather huge impact on energy saving.

As the importance of 13 measures, optimization of ship' speed was identified as the biggest impacting factor which weighted 21.2%. It is followed by ballast or trim weighting 10% and bulbous bow optimization 9.3%.

Lastly, this paper attempted to cross examine 4 factors in order to evaluate the best possible qualitative considerations. The result reveals that choosing the best course considering weather, is the most important factor. However, the best course considering weather ranked sixth when the AHP analysis was applied. In addition, it also ranked in a high position when an applicability and operational complexity criteria was considered. These results may imply that operational considerations are regarded as a main factor to be taken into account when considering appropriate energy saving measures.

This paper attempted to analyze various energy saving measures and rank them in order of importance. The result of the study may provide a guideline for shipping line when considering which measure is the most important in relation with energy savings.

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