Chapter

Selection of the Best Optimal Operational Parameters to Reduce the Fuel Consumption Based on the Clustering Method of Artificial Neural Networks

Tien Anh Tran

Abstract

The international shipping transportation industry becomes gradually important in the field of national economic development. It is explained by means of an increase in a number of ships nowadays, and it also expands the operating routes on international routes including the North of America, Baltic Sea, and emission control areas (ECAs). The energy efficiency of ships is very necessary to respond to the regulations of the International Maritime Organization (IMO). Moreover, the operational parameters have a significant meaning in supervising and monitoring the engines on a ship. They completely depend on the navigation environment condition. So, selecting the optimal operational parameters' component is a target of this study. In this chapter, a study on the energy efficiency of ship by decreasing the fuel consumption of the main engine for a certain ship namely M/V NSU JUSTICE 250,000 DWT of VINIC shipping transportation company in Vietnam is by the method of artificial neural networks (ANNs). In particular, these studies were conducted by the classification and clustering method of artificial neural networks (ANNs) based on the experimental database of M/V NSU JUSTICE 250,000 DWT. The results of this chapter will solve the energy efficiency issue on ships nowadays and contribute the aims in the next studies.

Keywords: energy efficiency, fuel consumption of engines, artificial neural networks, clustering, classification

1. Introduction

The international shipping transportation industry plays an important role in the economic development of each nation. The benefits have been brought dramatically through years. It is adopted that the number of cargoes that have been transported between the ports increases; however, the development of shipping transportation leads to the environmental pollution. This is a reason that the International Maritime Organization (IMO) is adopted and conducted to solve the problems that concern about the ship operation in the field of development of the international shipping transportation industry.

The definition of a sustainable shipping transportation is identified through some fields such as maritime safety, sea environmental protection, ship energy efficiency management, security and ocean resource conservation, so on. Moreover, the ship energy efficiency management is a main part of issue in the field by decreasing the CO_2 gas emissions from the international shipping transportation industry. Hence, it is a big factor that contributes the climate changes and environmental pollution nowadays.

Following the data statistic, the harmful gases emit into the environment about 900 million tons of carbon dioxide in 2018. Amount of this gas gradually increases comparing each year [1]. Moreover, the CO_2 gas emission is the main cause to make the greenhouse gas (GHG) emission. The global warming phenomenon and climate changes are the serious effects that the world is facing today (**Figure 1**).

The International Maritime Organization (IMO) has made some progress, and the current debate is addressing how much the sector can be expected to reduce emissions and should be obliged to reduce, as well as in what manner these diminutions can be achieved [2]. On the other hand, the energy efficiency issue plays a vital role in decreasing the fuel oil consumption of main engine and equipment along with the restricting greenhouse gas emission, especially the carbon dioxide gas. This is leading to the energy efficiency issue, which becomes a mandatory for countries obeying the IMO's regulations and rules about the environmental protection. Especially, the main cause that makes this phenomenon is generated from the combustion chamber of engines on board. Marine diesel engines are self-ignition engines in heavy-duty vehicles, but they are generally larger in size, equipped with more complex system and operated with higher efficiency.

As an alternative, a simulation model can be developed to predict the actual condition of engine performance through the fuel consumption level of engines and navigation environmental condition impacts. Moreover, there are also a lot of recent researches about energy efficiency of ships by reducing the fuel consumption of main engine and equipment by applying the modern control theory, machine learning, or artificial neural networks. The artificial neural network method is used as an alternative method comparing with other traditional methods [3]. On the other hand, the input signal will be trained when admitting the artificial neural network. After that, the appropriate data and method will be used to obtain the best prediction. Finally, the output signal will be given out into result part.

On another side, the artificial neural network (ANN) method has been developed during many years with the aim of dealing the complex issues. Hence, the model is applied by ANNs and is possible to deal with other analytical and statistical methods [4]. Especially, the capability of forecast is approached by ANNs [3]. Besides that, the ANNs could fit the great adaptability, robustness, and major fault tolerance in case of highly processing factors [5]. Moreover, the surface fitting of ANNs will be applied in the study and favor the method in the field of establishing the prediction model [6].

There are a large number of studies that are applied in the field of designing the fuel oil consumption model of diesel engine by the ANN method [7–10]. ANN has been found to be the domain for many successful applications of prediction tasks, in modeling and prediction of energy-engineering system [11], prediction of the energy consumption of passive solar buildings [12], and analysis of the reduction in emissions [13]. In this study, the author has investigated the artificial neural network in particular the clustering data method in the field by reducing fuel consumption of main engine for bulk carriers when considering the navigation environment condition impacts. On the other hand, the data clustering method is carried out using big data from experimental data, then the research results are compared with the actual experimental data with the aim of regulating the

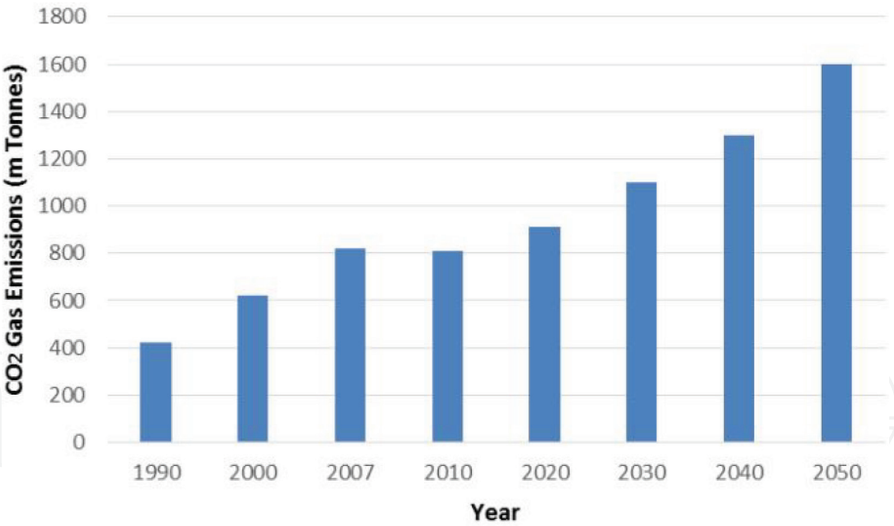

Figure 1.
The carbon dioxide (CO_2) emission the following years [1].

proper operation of ship and gaining the low fuel consumption of main engine on bulk carriers. Moreover, the study object is applied and verified throughout the certain bulk carrier, namely, M/V NSU JUSTICE 250,000 DWT of VINIC Shipping Transportation Company in Vietnam.

2. Literature review

2.1 Fuel oil consumption of diesel engine

Each kind of diesel engine has the specific fuel oil consumption. The fuel consumption of diesel engine will decide the working characteristics of each diesel engine and be able to generate the power and performance to the screw propeller. Almost diesel engines are equipped on ships that are two-stroke low-speed, large-size diesel engine of MAN B&W, Sulzer manufacturers. They are served as marine main diesel engine on ships and set-up on bulk carriers. Recently, there are some researches of scientist and researchers which investigate the fuel oil consumption of main diesel engine. Tran has proposed fuel oil consumption model of diesel engine when sailing on emission control areas (ECAs) by the artificial neural network [14]. The evaluation of ship engine effective power fuel consumption as well as gas emissions has been carried out by Borkowski et al. through ship's speed [15].

2.2 EEOI measure

EEOI—energy efficiency operational indicator—is a main parameter in operational energy efficiency measure of ships. The regulations of EEOI are defined in Chapter IV, Annex VI, MARPOL 73/78. Furthermore, there are some recent researches which concentrate on this index through their studies. A tool of EEOI calculation for bulk carriers of VINIC shipping transportation is carried out by Tran [16]. Hence, the optimization of this index is also conducted by him [17]. Consequently, the energy efficiency management of ships plays an important role in key policy strategy nowadays. The study of barriers in the field of ship's energy efficiency management has been conducted by Rehmatulla and Smith [18]. The study of the uncertainty hull form optimization method has been investigated by Hou with the aim of lowering the EEOI index [19].

2.3 Data analysis methods

2.3.1 Artificial neural networks (ANNs)

In recent times, the artificial neural networks (ANNs) have been studied and applied in many fields of science and technology. Especially, it has been used in the field of the data clustering method through analyzing the architecture and pattern recognition. In case of pattern recognition, this method has presented the input and output nodes in which they are linked each other with differential weights. The proposed model will have a mission, which creates the relationship between input node and output node. This relationship will be adjusted until a termination criterion is satisfied. This process of weight adjustment, called learning, lends continuous learning or artificial learning capability to the system, which can be either supervised or unsupervised learning capability to the system, which can be either supervised or unsupervised learning in ANN. The supervised learning demands an output class declaration for each of the inputs. The unsupervised learning network itself recognizes the features of the input and self organizes the inputs. The parametric and nonparametric approach will be reached. The parametric approach will be combined between classification and parameterization. The nonparametric approach will include the unclassified data that used the adaptive resonance theory (ART) method. This combination will be based on neurophysiology including prior knowledge and adaptive resonance theory (ART) method. Hence, this one will be known as stability plasticity dilemma.

The basic block of artificial neural network model is an artificial neuron. Each artificial neuron has three sets of rule including multiplication, summation, and activation. Each input node of artificial neural network will have multiple weight values. The weight value has gained the separate function of artificial neural network. The definition of transfer function is known as the weighted sum of previous input nodes and bias (**Figure 2**) [20]. A simple neural network is known as a real power when it is connected with other neurons in the same network. The progress of dealing will be reviewed all neurons through transferring information between nodes each other. The equation of transferring information will be represented as [20]:

$$y(k) = F\left(\sum_{i=0}^{m} w_i(k).x_i(k) + b\right) \quad (1)$$

where $x_i(k)$ is the input value in discrete time k, and i ranges from 0 to m; w_i (k) is the weight value in discrete time k, and i ranges from 0 to m; b is the bias; F is the transfer function; and y (k) is the output value in discrete time k.

Competitive learning exists in biological neural networks. Competitive or winner-take-all neural networks [21] are used often to cluster input data. The characteristic of the same pattern is grouped, which is represented by a single unit. This group will be hanged automatically on the same basis data. The process of weight update will be carried out and divided into a certain group. The Kohonen's Learning Vector Quantization (LVQ) and Self-Organizing Map (SOM) use for familiar artificial neural networks [22] and adaptive resonance theory models [23]. The two-dimensional map of multidimensional data has been used for vector quantization and speech recognition [22]. In addition, the learning rate and a neighborhood of win node have been studied and controlled. Carpenter and Grossberg [23] use ART model in order to support more stably and more plastic. The partitions are approached for different ones. Moreover, the ART net will be made up of the number and size of clusters. The pattern will be classified into different groups by vigilance threshold. Hence, the hyper spherical cluster is fit for both SOM and ART [24].

2.3.2 Data clustering method

The data analysis technique has been investigated in this research. This technique is useful in the field of big data. The research key of the data clustering method is a classification of big data into a separate group in which each group will contain the data that is the same characteristic together. Even though there is an increasing interest in the use of clustering methods in pattern recognition [16], image processing [17], and information retrieval [18, 19], clustering has a rich history in other disciplines [20] such as biology, geography, geology, archeology, psychology, psychiatry, marketing, and finance.

The data clustering method is analyzed through input data. Krenker and his colleague [20] had the debate section between the data clustering methods that includes pattern recognition, classification, and clustering data. The study of the fuzzy set theory technique has been carried out in the process of classification and robust approach. The machine learning technique includes the artificial neural network (ANN), the nonlinear characteristics of data, and the classification of data.

2.3.3 Data analysis through ANNs

The data analysis is a complex subject in the field of machine learning. This field is used in the complex structure models. Normally, the data usually have a certain rule. So, the clustering method is used as an effective method in the field of controlling data. This tool includes an unsupervised classification technique. It presents some inherent structures in data set. All the classification steps will look up from an appropriate function with data groups in the proposed method [25, 26]. In addition, a neural network is a nonlinear control model that is based on the real complex process. This model provides the basic classification rule and statistical data analysis [27]. The neural network has been used as a potential alternative method in the field of the classification method. This method has been confirmed as a useful technique for data clustering. So, the output layers have been considered as a competition layer. The competition layer will be connected together along with the input layers [22, 23].

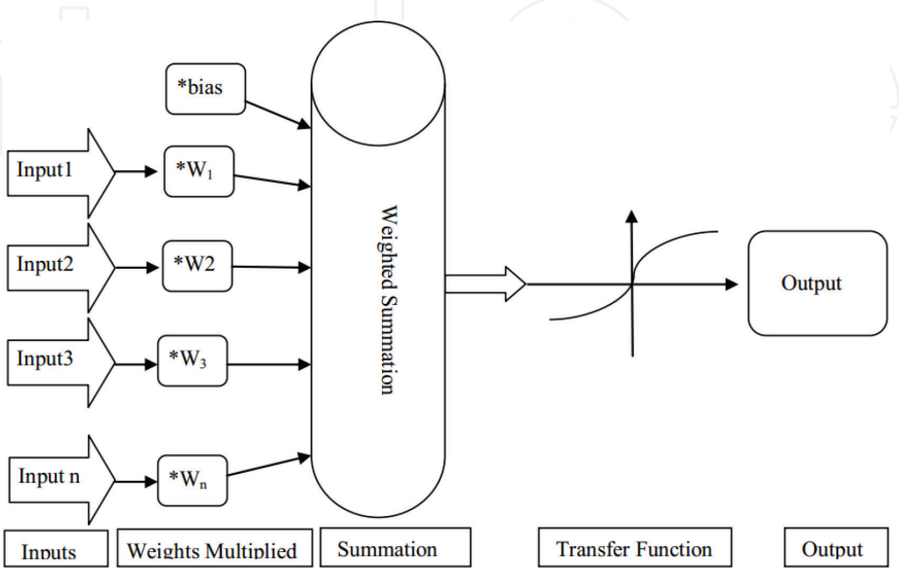

Figure 2.
Artificial neural network simple model.

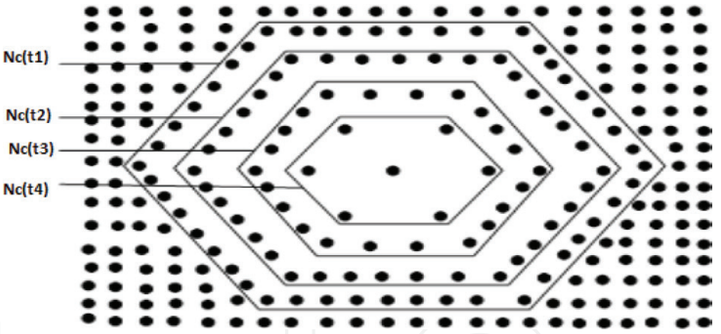

Figure 3.
Topological neighborhood of Kohonen's net Nc(t).

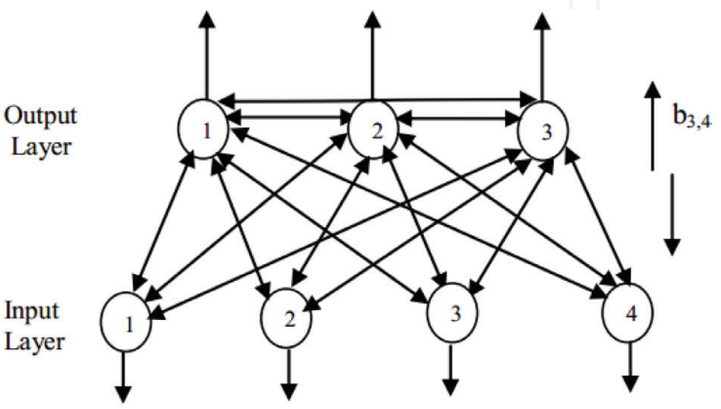

Figure 4.
ART1 networks.

2.3.4 Self-organizing feature maps (SOFMs)

Self-organizing feature maps (SOFMs) also called Kohonen feature maps [22] are laid on the category of learning clustering. The nodes of artificial neural network become various input nodes. It concludes two layers of neuron: input layer and competition layer. The winner neuron is determined into competition layer. The competition process is based on the clustering method not only the weight of winner neuron but also its neighborhood Nc(t) (with t1 < t2 < t3 < t4), which is defined in terms of some proximity relation. This neighborhood relation is usually represented as a grid (usually two dimensional) in **Figure 3**.

2.3.5 Adaptive resonance theory (ART)

Adaptive resonance theory is presented as the ART method in which it stands for the input vector with an active code vector. The first ART model, ART1, given by Carpenter and Grossberg [28] is shown in **Figure 4**.

ART networks are based on Stephen Grossberg's stability plasticity dilemma and are supposed to be stable and plastic [23].

2.3.6 Learning vector quantization (LVQ)

Learning vector quantization (LVQ) is known as an effective method for training the competition layers of neural network artificial. An LVQ has also the same architecture which is expected into classical membership function. Each LVQ network will have competition layer and linear layer. Both competition layer and

linear layer will have one neuron per class. In case of two categories of LVQ models, the supervised mode will consist of LVQ1, LVQ2, and LVQ3 [22] and unsupervised like LVQ4 and incremental c means [29].

3. The case study

3.1 M/V NSU JUSTICE 250,000 DWT

The target ship is chosen in this study, a kind of bulk carrier with certain name M/V NSU JUSTICE 250,000 DWT. This is the largest ship of VINIC shipping transportation company, Haiphong, Vietnam. The main routes of this vessel concentrate on the international routes such as Japan-Australia-Brazil-the United States-emission control areas (ECAs; **Figures 5** and **6**).

In **Table 1**, the technical parameters of the main propulsion plant on M/V NSU JUSTICE 250,000 DWT are shown. They definitely concern about the fuel consumption level of the main engine and operational working condition of ship.

3.2 Data clustering method for bulk carrier

From the above theoretical research, the data clustering method based on artificial neural networks (ANNs) plays a vital role in data mining, and it is applied effectively for the ships with large size and complex routes. In this research, the author carried out researching the clustering method with applied object is a certain vessel of VINIC shipping transportation company in Vietnam. M/V NSU JUSTICE 250,000 DWT is the largest size of company equipped with nine cargo holds. This is a kind of bulk carrier, and it usually operates on Japan, Australia, and Brazil. The experimental data were collected from completed voyages at certain different ports in 1 month. **Table 2** shows the separate voyages of M/V NSU JUSTICE 250,000 DWT. The order item is corresponding to the in turn of the voyage number 16, 17, 18, 19, and 20.

In **Table 2**, the input parameters including the average draft of M/V NSU JUSTICE have conducted the voyage from the departure port to the destination one. Each port has different drafts depending on the density of water and water temperature and weather condition at certain time. The working hours and propeller hours under water also referred as the input parameters. Voyage distance is also listed. On the other hand, the speed of the ship, main shaft revolution, and ship speed slip degree are also included in the input parameter component. Especially, the fuel

Figure 5.
M/V NSU JUSTICE 250,000 DWT.

Figure 6.
Main diesel engine (MAN B&W 7S80MC-C).

Ship name	NSU JUSTICE	Type of main engine	MAN B&W 7S80MC-C
IMO N°	9,441,922	Maximum continue rating (MCR)	21,910 kW
Flag	PANAMA	Revolution per minute (100% MCR)	74.5 rpm
Built year	2012	Fuel oil consumption	160.9 g/kWh
Dead weight tons (DWT)	250,000	Number of cylinders	7
Length (m)	329.95	Cylinder bore (mm)	800
Width (m)	57.00	Piston stroke (mm)	3200
Draft (m)	18.00	Turbocharger	Axial flow

Table 1.
The specification of M/V NSU JUSTICE and main diesel engine.

No.	Voyage no.	Draft	Working hours (Hrs)	Propeller hours (Hrs)	Distance (Knots)	Ship speed (Knots/h)	Speed slip	Shaft revolution (rpm)	FOC (MT)
1	16	9.95	270.25	264.5	3458	13.1	−0.2	59.7	512.2
2	17	9.67	271.75	268.5	4053	15.3	−1.2	69.8	747.7
3	18	9.82	826.5	809.5	12,194	15.1	0.1	69.7	2256.6
4	19	9.71	234.75	230	3463	15	0.2	69.7	645.7
5	20	9.68	233.18	229.8	3431	15	−0.8	69.1	629.3

FOC = fuel oil consumption.

Table 2.
Operational data of M/V NSU JUSTICE 250,000 DWT.

consumption of main engine is the target input that needs to reduce with the aim of solving the energy efficiency of ships. In this research, the energy efficiency of ship proposes to the bulk carriers, particularly M/V NSU JUSTICE 250,000 DWT of VINIC shipping transportation company in Vietnam.

4. Results and discussion

Throughout the neural network toolbox on MATLAB program, the working of data clustering was completely conducted based on the artificial neural networks (ANNs). The algorithm of data clustering is self-organizing map (SOM), and it is explained that the same characters will be classified at the same cluster. The benefit of data clustering method will give out the proper values in series of the experimental data of this vessel, M/V NSU JUSTICE 250,000 DWT.

The self-organizing map topology in the clustering method based on the artificial neural network toolbox is shown in **Figure 7**.

In **Figure 8**, the SOM neighbor connections are indicated based on the self-organizing map data clustering. In this figure, each node has the connection together. Following this, the SOM neighbor connection that will be represented through each node will have a certain connection. This connection has been explained clearly according to the data clustering method of artificial neural network theory. The material data will be added into this model and analyzed the following certain rules.

On another side, the distance of weights in self-organizing map (SOM) data clustering is also shown in **Figure 9**. It helps the users to recognize the weight position in grid map along with the distance of different weights.

Each weight is distributed in different positions corresponding to **Figures 10–14**. Based on the proposed method, the operational data of M/V NSU JUSTICE 250,000 DWT have been analyzed and clustered into a certain group. From the operational data of M/V NSU JUSTICE 250,000 DWT, these data have been divided into a certain group through the data clustering method of artificial neural network in MATLAB program. In particular, the operational data have been divided into five inputs through **Figures 10–14**.

In a result, the best optimal operational parameters for the energy efficiency of M/V NSU JUSTICE 250,000 DWT laid on weights 1 and 2 corresponding to the minimum of the main engine fuel consumption level. It means that the operators need to remain the ship's speed at a certain level, and then the fuel consumption is lower when changing the main engine working conditions. The optimal value has been selected according to the initial condition and certain rule of data clustering method of artificial neural networks. There are five voyages, and then, there are two voyages, which are selected as a specific example of the data clustering method in the field of data analysis.

In **Table 3**, the best parameters on M/V NSU JUSTICE 250,000 DWT are shown.

It is suggested that for the bulk carriers in general should remain the ship's speed in the range of 13–15 knots/h then assuring the navigation elements (i.e., just in time, a weight of cargoes carried, etc.) and the energy efficiency of ships (**Figure 15**).

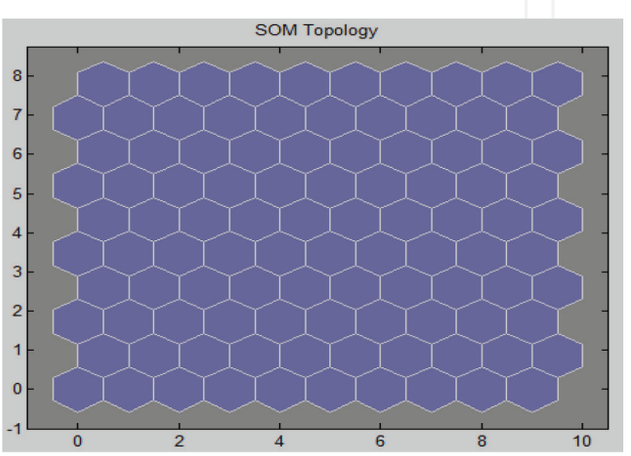

Figure 7.
SOM topology for experimental data.

In order to identify this effective proposed method, the author has conducted to compare the data clustering method of artificial neural network with the fuzzy clustering method same operational data of M/V NSU JUSTICE 250,000 DWT. The results of data clustering are shown in **Figure 16** [30].

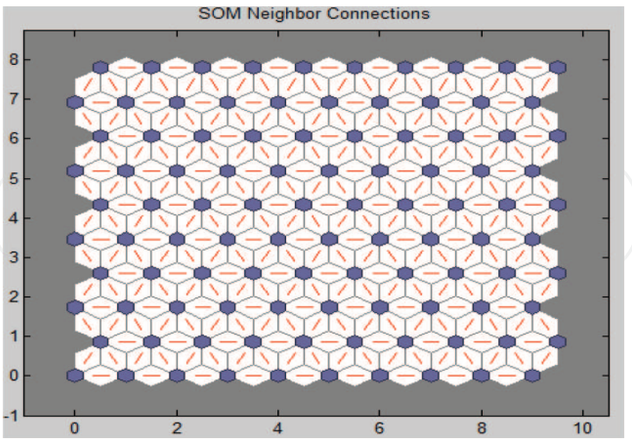

Figure 8.
SOM neighbor connections.

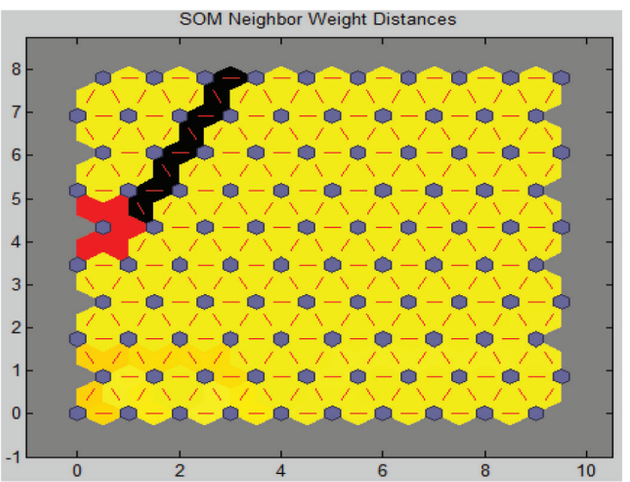

Figure 9.
SOM neighbor weight distances.

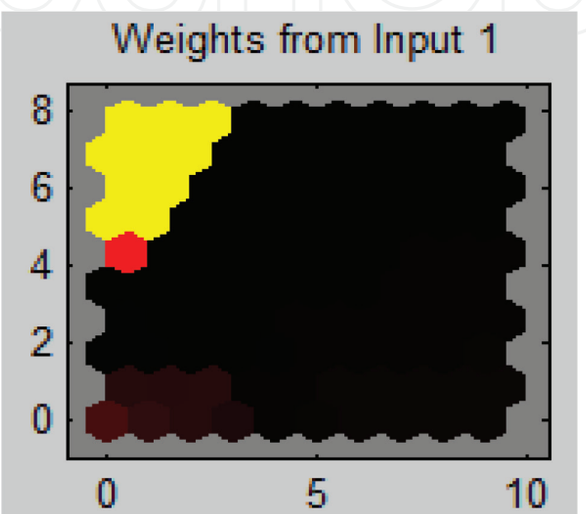

Figure 10.
Weight density of Input 1.

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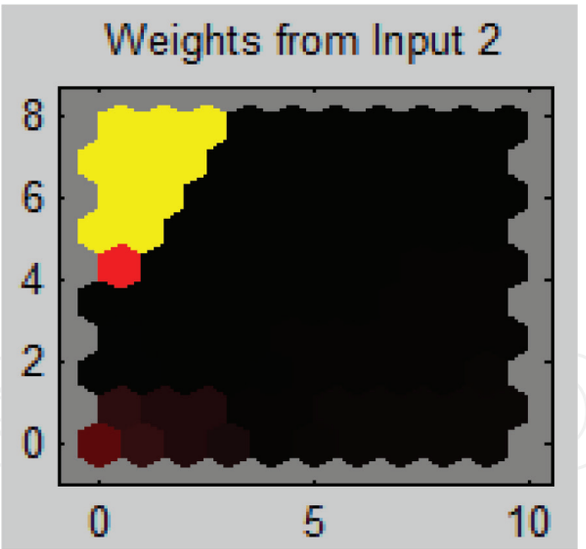

Figure 11.
Weight density of Input 2.

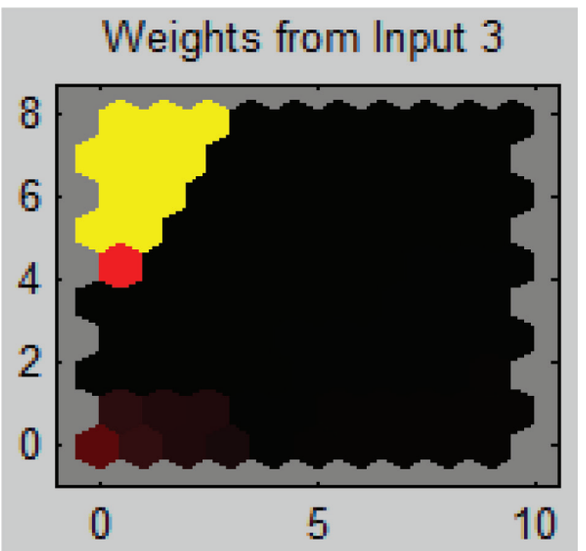

Figure 12.
Weight density of Input 3.

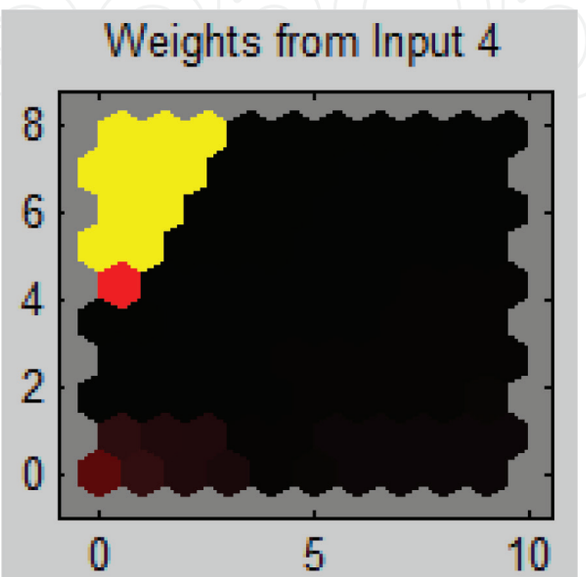

Figure 13.
Weight density of Input 4.

In reality, the data clustering is carried out by the fuzzy clustering method. The operational data of M/V NSU JUSTICE 250,000 DWT have been divided into a certain group. In this case, there are three groups. However, this method is limited with parameters of input values. There are four parameters including wind speed, wave height, fuel oil (FO) consumption, and diesel oil (DO) consumption. And then, the data fuzzy clustering method of artificial neural network can deal with various parameters of navigation environment conditions and selected the optimal voyage of vessel corresponding to the lowest fuel oil consumption of main diesel engine of bulk carriers.

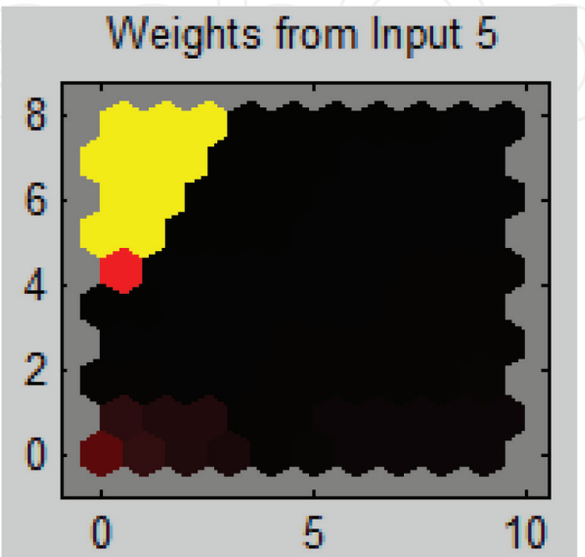

Figure 14.
Weight density of Input 5.

No.	Voyage no.	Draft	Working hours (Hrs)	Propeller hours (Hrs)	Distance (Knots)	Ship speed (Knots/h)	Speed slip	Shaft revolution (rpm)	FOC (MT)
1	16	9.95	270.25	264.5	3458	13.1	−0.2	59.7	512.2
2	17	9.67	271.75	268.5	4053	15.3	−1.2	69.8	747.7

Table 3.
The best optimal operational parameters.

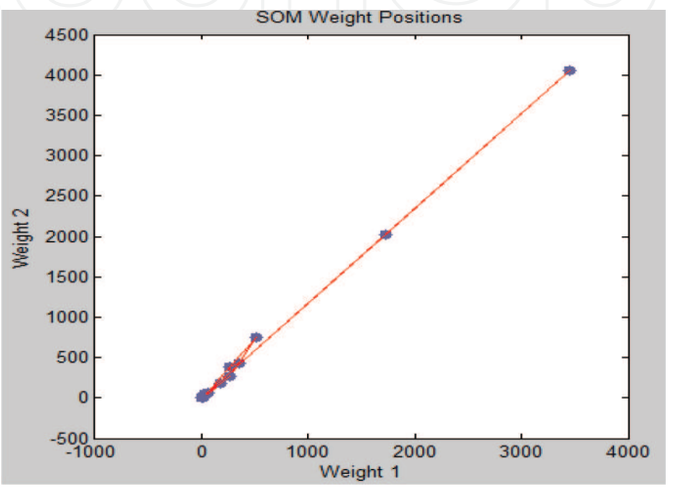

Figure 15.
SOM weight positions.

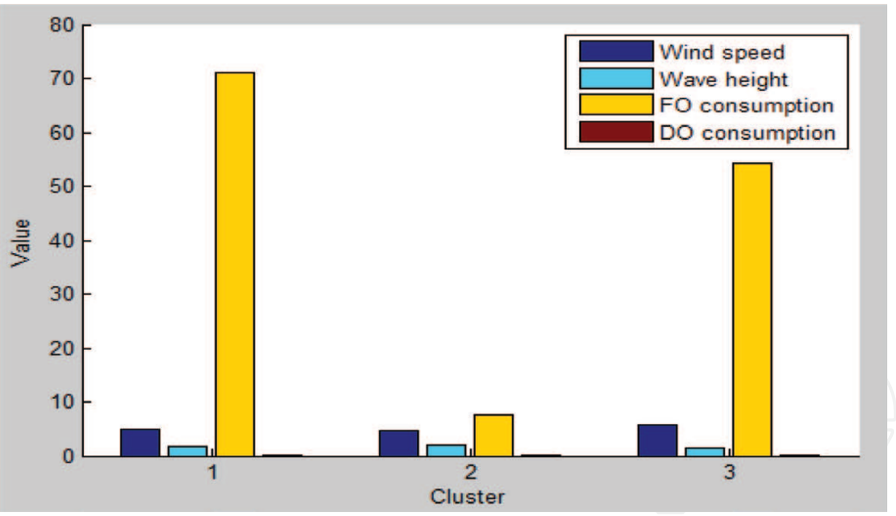

Figure 16.
Data clustering based on the fuzzy clustering method for M/V NSU JUSTICE 250,000 DWT [30].

5. Conclusions

The energy efficiency of ships has important properties in creating the green shipping nowadays. It is not only trending all ships following the International Maritime Organization (IMO)'s regulations, especially the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), Annex VI, Chapter 4 but also rising the economical effectivities for ship owners and ship operators. The operational parameters are important elements in order to decide the energy efficiency of ships. Hence, the selection of best optimal operational parameters plays an important role in the field by reducing the fuel consumption but ensuring the working ability of propulsion plants on ship, especially the main engine. Through the results of this research, the use of the clustering method in ANN has dealt with data analysis issue when ship operators are facing with the numerous operational data collected from voyages. Throughout the research results, the use of data clustering of the artificial neural network method can be selected by the optimal parameters in order to save the fuel oil consumption of main diesel engine for bulk carriers of VINIC shipping transportation company in Vietnam. These parameters will decide directly to fuel oil consumption of vessel. The navigation environment conditions, working hours, sailed distance, ship speed, and propeller speed split impact on fuel oil consumption of main diesel engine. The comparison between proposed method with other traditional methods then the data clustering method of artificial neural network has been presented more clearly through this research. This method has restricted some disadvantages of traditional data analysis methods. The data clustering quality clearly increases and determines the optimal voyage in the field by decreasing the fuel oil consumption of main diesel engine. Moreover, this research will bring effectively in saving the fuel consumption of main diesel engine and improving the ship's energy efficiency management in the shipping transportation industry.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this research chapter.

Author details

Tien Anh Tran
Faculty of Marine Engineering, Vietnam Maritime University, Haiphong, Vietnam

*Address all correspondence to: trantienanhvimaru@gmail.com

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