

# Prediction of Energy Consumption by Ships at the port using Deep Learning

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## Abstract

The harbours using green ports have become a common mode of enabling the use of environment friendly energy consumption. In this paper, two major contributions are made: reduction of energy consumption in the ports by using ships; prediction of energy consumption with respect to a green port. The characteristics that will play a crucial role in energy consumption of ships are considered and a detailed analysis has been performed to predict the energy consumed by the ships. Deep learning methodologies such as, K-Nearest Regression (KNR), Linear Regression (LR), BP Network (BP), Random Forest Regression (RF) and Gradient Boosting Regression (GBR) are used to determine the different characteristics of the ships that are used while the external features of the ports are given as input. To determine the efficiency of the proposed work, k-fold cross validation is also incorporated. Based on feature importance, the crucial features of the algorithm are selected. The influence of different changing aspects on the ship's energy usage is identified, and reduction methods are implemented appropriately. According to the observed data, the most essential factors that may be utilised to estimate energy consumption of the ship are efficiency of facilities, actual weight, deadweight tonnage, and net tonnage. As the efficiency increases, there is also a significant reduction and the power consumption of the ship at the rate of 8% and 32% in port and berth respectively.

**Keywords:** Energy consumption strategies, machine learning, deep learning, green ports, regression

## 1. Introduction

Ports are one of the biggest energy consumers and ships are the primary objects in the ports that use maximum emission and energy consumption [1]. Generally, these ships are diesel powered. With the background of energy crisis and global warming as one of the largest energy consumer, these ports must build sustainable ways to decrease this conception. In recent years a number of ports [2] have taken drastic measures like adopting cold ironing or renewable energy and reducing voyage speed of ships' creased emissions and diesel consumption of the ships. In [3], it was identified that using cold ironing for ships at birth will significantly decrease the carbon dioxide emission by 39%. Similarly, reduction in emissions at port is also observed at 91% 78% 42% and 21% for NO<sub>x</sub>, CO, SO<sub>2</sub> and CO<sub>2</sub> respectively. Authors in [4] observed that it is possible to reduce the fuel consumption in ships by 5% on adjusting the voyage speed of the ships. This will also reduce carbon dioxide emission effectively [5]. Prediction of energy consumption will help evaluate the energy saving measures and its impact, determine the capacity of shore-side electricity system and allocate energy sources.

However there are a number of uncertain factors that have an influence over the ships' energy consumption like actual handling volume [6], duration of ships at berth and arrival time of ships [7]. This makes prediction of energy consumption at ports a more difficult task. Hence it is crucial to analyse the relationship between concern factors and ships energy consumption and to have an accurate mechanism to predict energy consumption of the ships [8]. In recent years almost all areas of energy consumption are working towards developing sustainable energy to attain green development and decrease energy consumption. In [9] the authors have used a methodology for sustainability education while authors in [10] analysed design indicators of sustainable buildings and explored the principle of sustainable architecture. In general ships are high energy consumers and a number of analysis and survey has been made on energy consumption prediction. On analysing historical data statistical methods can be utilised to determine the level of energy consumption by ships. However, this methodology [11] proved to be difficult in accurately identifying this prediction at a particular period of time.

Hence much work as required in terms of efficiency and accuracy because of Port operation complexity. Another methodology that was used to predict energy consumption was based on simulation technology [12] where a number of factors related to Port operation were also taken into consideration. In [13], the authors introduced two simulation models namely 'electric power consumption model' [14] and 'ship motion model' [15] to determine the amount of electricity consumed in an electric propulsion ship. The drawback with this methodology is a requirement of largest face due to huge workload resulting from unique simulation models required for different stages and correspondingly different ports [16].

A physical model was also used to determine the energy consumed by ships. The authors in [17] built a hydrodynamic model that is integrated with its learning parameter to determine the amount of energy consumed by the ships' propulsion system. Along with this wind direction, wind speed, draft, trim, ship power, engine speed and ship speed are also taken into consideration. LASSO regression algorithm, artificial neural networks (ANN) [18], polynomial regression, multiple linear regression, Monte Carlo simulations [19], statistical regression, nonlinear ANN, Gaussian process metamodel, support vector machine (SVM) [20] and LASSO regression algorithm are some of the methodologies used over the years for predicting energy consumption of ships at sea. Based on comparison with traditional simulation and statistical methodologies SVM and polynomial regression, it was identified by authors in [21] that artificial neural networks result in efficient and accurate in predicting energy consumption of ships. When in a voyage several parameters of the ship such as ship draft, cargo quality on board, power and speed of the ship change constantly and will have a direct impact on the ships energy consumption [22]. Hence the speed of the ships as well as a displacement was used to predict energy consumption of ships at sea.

Environmental features such as currents waves and winds also play a major factor in influencing the moments and external forces on the ship thereby affecting their power consumption. In [23] the authors used a novel prediction model which took into consideration the environmental factors at sea apart from the ships features. The experimental outcome [24]

proved that this is also more accurate when compared with the previously existing methodologies. However ships that come into the port consume energy at a level different from the ships at sea and are influenced by actual auxiliary power and arrival pattern of the ships [25]. Quay in scheduling, and berth allocation are some examples which indicate the power consumption increase due to duration of ships [26]. In this paper deep learning methodology is introduced to predict the amount of energy consumed by ships in the port. Further strategies to reduce the amount of energy consumed are also proposed.

## **2. Proposed Methodology**

### **2.1 Data pre-processing**

Based on the storage of the yard, handling equipment, berths [27], the occupancy of the anchorages and arrival time of ships the port equations the ships handling plan. Accordingly, the handling teams are issued Notice of Ship Loading and Unloading operation [28]. This notice will include requirements of efficiency of facilities, berth where ship moors, storage location of goods, weight of goods, type of goods [29] transported and the name of the ship. In general, due to the handling process advance or delay in arrival time, the ship that arrives at the port will not be able to moor at the berth immediately. Hence, the ship has to wait for idle berths and will eventually anchorage during the waiting process [30]. On identifying an idle berth, the ship will leave anchorage and using the channel in port, will moor at the berth. The process of handling begins after the ship moors at berth. Once this process is completed, the ship will leave. The following flow chart in Fig.1 indicates the ships entering the port and mooring at berth.

In this paper, we have calculated the amount of energy consumed by the ships using the equations (1)-(5). Using DWT of the various types of ships, it is possible to set the auxiliary and main power. Electricity is generated by the auxiliary machine when the ships are at berths and anchorage while two auxiliary and one main machine is used for ships sailing in the inner port channel.

$$Ship_{EC} = E_{b-c} + E_b + E_{c-b} + E_a \quad (1)$$

$$E_{b-c} = P_{b-c} \times T_{b-c} \quad (2)$$

$$E_b = P_b \times T_b \quad (3)$$

$$E_{c-b} = P_{c-b} \times T_{c-b} \quad (4)$$

$$E_a = P_a \times T_a \quad (5)$$

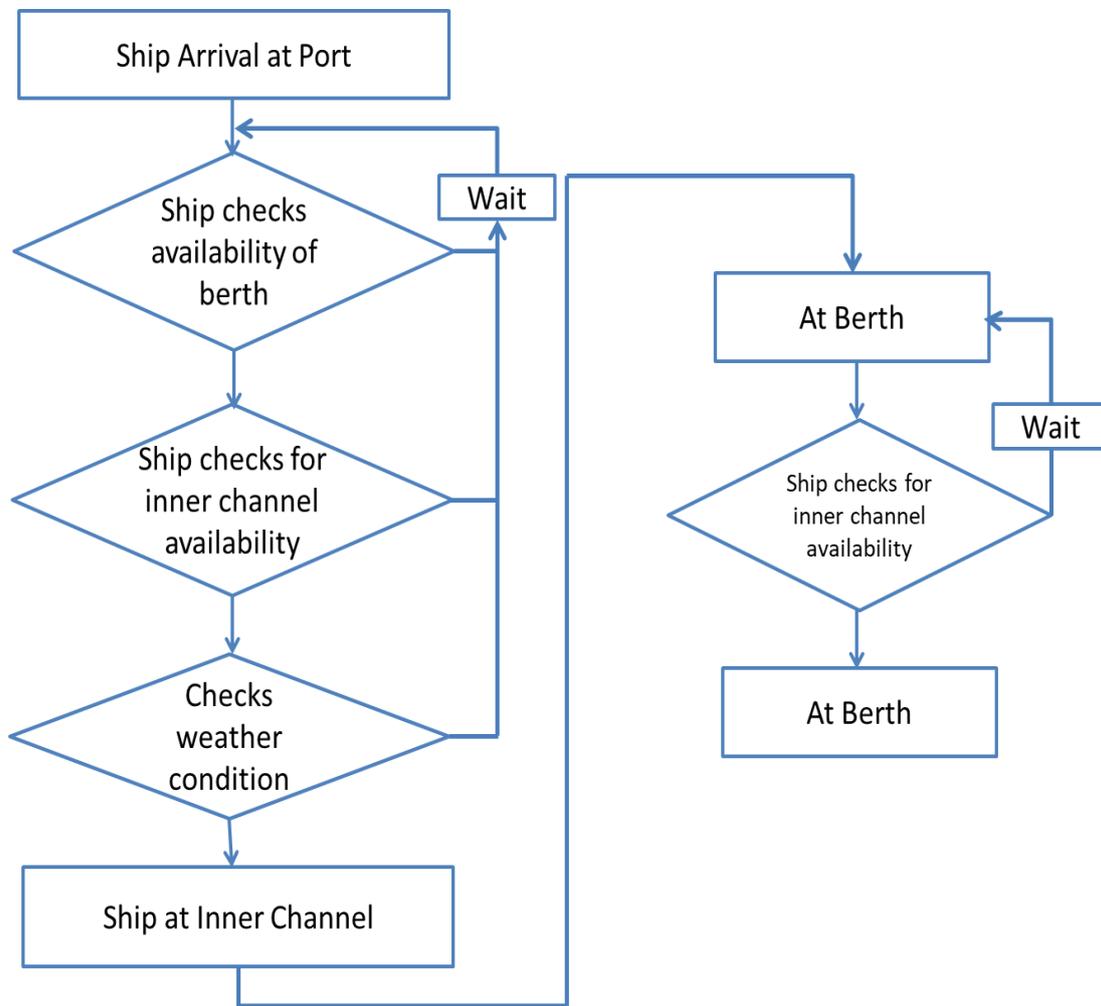
where ‘b-c’ represents ships leaving from berth along the channel, ‘b’ represents working at berth, ‘c-b’ represents sailing to the berth through channel and ‘a’ represents waiting at anchorage. Similarly,  $Ship_{EC}$  denotes ship’s energy consumption and E denotes energy consumption, P and T denotes power of ships and sailing time or dwelling time of ships respectively. Hence there are two factors involved in calculating the total energy consumption of the ships namely the time of ships (including the duration at berth, channel and at anchorage) and the power of ships ( including auxiliary and main power). Hence the input parameters are chosen based on these two factors.

A total of 15 characteristics are considered in this paper and are used to obtain a dataset from the ships data base for a period of one year. Type of trade, operation department, efficiency of facilities, goods, attribute of enterprise and actual handling volume are some of the characteristics under the chosen 15. The time of the ships at berth is influenced by Type of Trade, operation department, efficiency of facilities, goods, attribute of enterprise and actual handling volume and the duration of ships at berth, in channel and at anchorage depend on Month, Weekday, Import/ export, assigned berth and arrival time of ships. Apart from this, net tonnage, nation, length and deadweight tonnage is the inherent ship property that has great impact on time and power of the ship. Using the historical data, when the deep learning models are trained with respect to handling tie and volume of goods, it is possible to estimate the competence of the facilities on the basis of goods handled on an hourly basis. This is expressed as a ratio of volume of goods on the ship with respect to ships’ handling time. However, using

the trained model, it is possible to determine the ships' energy consumption based on the calculation of efficiency of facilities despite unknown handling data such as handling time and goods volume. The estimation is given by equation (6):

$$E_{a,b}^j = \frac{v_{a,b}^j}{t_{a,b}^j}, \quad a \in A, b \in B, j=1,2,3\dots J \quad (7)$$

$$E_{d,g} = \frac{1}{J} \sum_{j=1}^J E_{d,g}^j, \quad a \in A, b \in B, j=1,2,3\dots J \quad (8)$$



**Figure 1.** Flow Chart for Ships at the Port before Docking

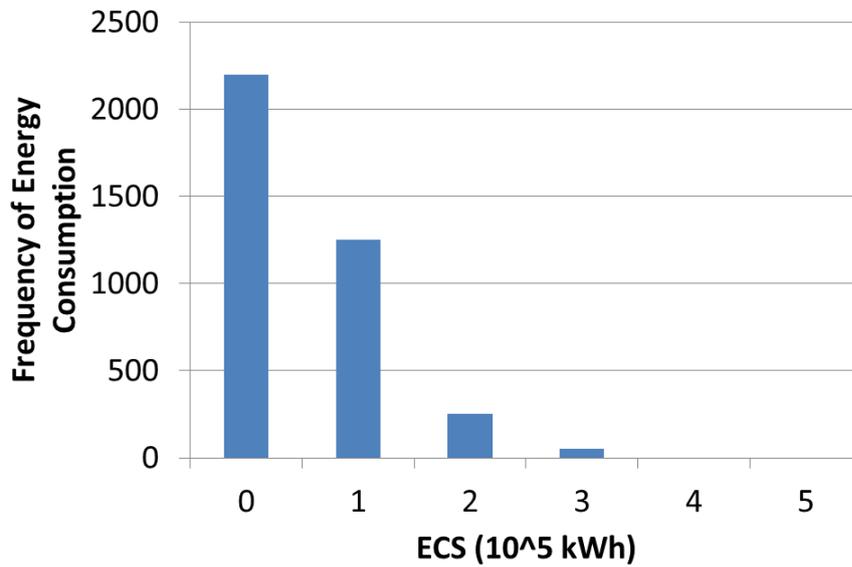
## ■ Statistical Analysis

Statistical analysis is carried out on the ships at berth where categorizing of the ships is done based on the energy consumption distribution and the types of carried goods. A total of 9250 ships mooring at various berths, like cement berth, ore berth, alkali berth, cargo berth, LNG berth, container berth and coal berths are chosen as the dataset. Excluding the data with inadequate information, a total of 6820 ships are chosen as data set. 202 ships, on an average, account for 3% of the total ships that are arriving. Based on observation, it has been identified that the ships arriving consists majorly of mining material ships, metal ore ships, iron ships, container ships and coal ships. The total amount of energy consumed by these ships lies in the range of 1000 KWh to 600000 kWh. On experimental verification, it has been determined than less than 100000 kWh energy is consumed by the ships. Hence a  $\log_{10}$  transformation is executed on ECSs (Energy Consumption of Ships) below 100000 kWh. Accordingly, a normal distribution is seen in  $\log_{10}(\text{ECS})$  with a standard deviation and median of 0.441 and 5.012 respectively. Moreover, it is also found that:

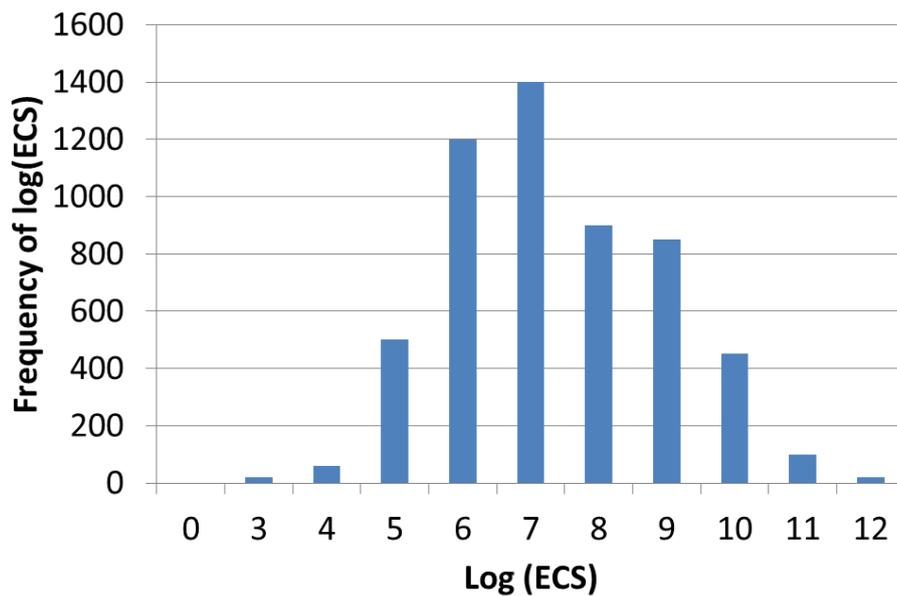
- 78.2% of  $\log_{10}(\text{ECS})$  are seen with distribution less than 6.01 indicating ECS of less than 78.2% distribution.
- 96.3% of  $\log_{10}(\text{ECS})$  are seen with distribution between 4.23 and 5.86 indicating ECS of less than 96.3% distribution.
- 48% of  $\log_{10}(\text{ECS})$  are seen with distribution between 4.72 and 5.02 indicating ECS of less than 48% distribution.

### 3. Results and Discussion

Figure 4 depicts a consideration for lowering the energy consumption rate by ships with improved facility efficiency. In this work, we have used a cubic polynomial function. Ships' energy consumption in the range of 1000 kWh and 600000 kWh is observed and the distribution of the same is represented in Fig.2.

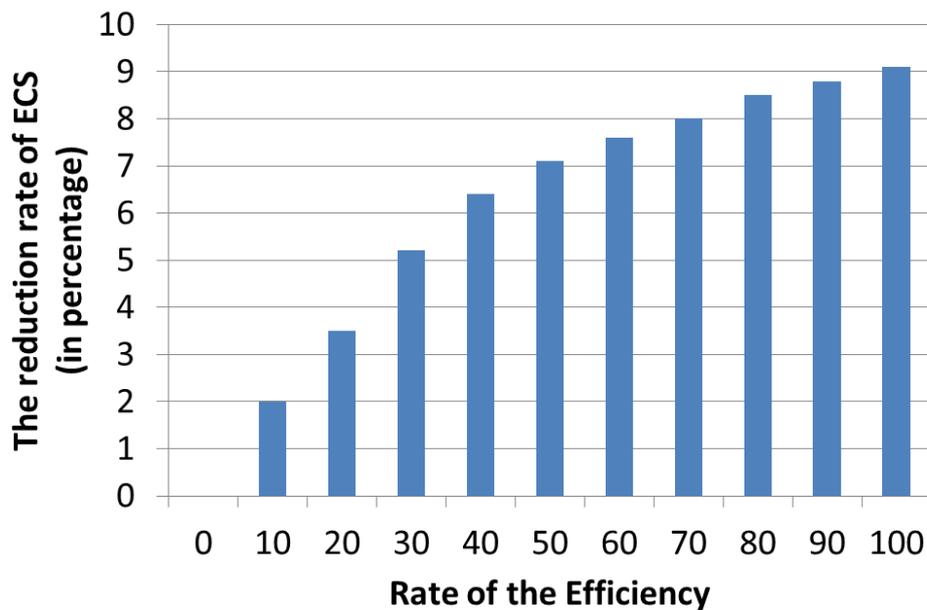


**Figure 2.** Distribution of Energy Consumption



**Figure 3.** Log(ECS) Distribution

Fig.3 represents a log(ECS) transformation that carries out normal distribution with a standard deviation of 0.442 and median of 4.623.



**Figure 4.** Reduction of Rate of ECS

#### 4. Conclusion

In this paper, the issue of energy consumption of ships prediction in ports is tackled to arrive more accurately. Similarly, prospective methodologies to reduce this energy consumption using green ports are also analysed. A deep learning approach is followed by considering over 6000 ships with respect to 15 features by including the external port and inherent ship features. To process and understand the energy consumption of ships, five models namely K-Nearest Neighbour Regression feature, Linear Regression, BP Network, Random Forest and Gradient Boosting Regression are used. Based on the analysis, the importance of features is calculated and the most crucial features are selected. An energy saving strategy based on the changeable features of the ship's energy consumption is obtained. The historical data of ship details such as their arrival time, porting, efficiency, handling volume, deadweight tonnage and net tonnage are collected and used to predict the energy consumption of the ships.

As part of the future scope, machine language and convolutional neural network (CNN) is incorporated to predict the energy consumption of the ships that are entering the inner canner.

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