The Evaluation Model of Ship Operating Efficiency and Verification in Massive Operation Data

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Abstract. Aiming at increasing the ship operating income, the ship operating efficiency is proposed and explained in detail. Based on the analysis of relevant factors affecting ship operation, the mathematical model of ship operating efficiency is constructed, in which the cargo transportation, cargo turnover, fuel oil consumption of the main engine and the general berthing time are employed to measure the annual operating efficiency of the ship which has a good rationality, and the calculation and verification are carried out using the mass operation data collected by a typical ship as an example. The results show that the ship’s operating efficiency model is effective, which can help shipping companies form a series of intelligent decision support in order to promote the level of ship operation management.

1. Introduction
Ship operating income involves many aspects of ship operation, and many shipping companies are very concerned about how to improve the level of ship operation to increase the operating income. This involves the operating efficiency of ships. At present, existing ships can evaluate the CO2 emissions of ships through the ship energy efficiency operation index\(^1\) to evaluate the energy consumption of ships, but energy consumption is part of the ship operating costs. It can only reflect the ship’s operating conditions partly, and in reality, ship operating efficiency involves many aspects\(^2\). At present, there is no uniform definition in academics. It is necessary to interpret ship operating efficiency, establish a mathematical model of operating efficiency, and reuse the data collected by the ship\(^3\) to verify.

The purpose of studying operating efficiency in this paper is to improve operating income. By studying operating efficiency to find out the key factors that affect ship operating income, shipping companies can improve ship management in a targeted manner and lay the foundation for intelligent ship management. This paper uses the operational data collected by a bulk carrier from January 1, 2016 to December 31, 2018. The total number of data is hundreds of millions, including the main and auxiliary engines. Almost all ship-related data such as operational parameters, cargo parameters, and sea trial data are used as the original data for the verification of the operating efficiency model to evaluate the operational level of the ship to help the shipping company form an intelligent series of decisions on ship operational management.

2. The interpretation of ship operating efficiency
The ship operating efficiency proposed in this paper refers to the quantitative value that can evaluate the continuous operation of ships. The basic principle is that the higher the ship operating efficiency, the better the operating income of ships.

In theory, the operating income of a ship is determined by subtracting operating costs from operating income. Generally, ship costs refer to the various expenses consumed in the process of shipping goods.
by the ship. Related literature generally divides ship operating costs into fixed costs and variable costs [4].

Fixed costs is the part of the cost that is relatively stable and unaffected despite changes in the volume of transportation within a certain period of time. When a shipping company is established, fixed costs are incurred and will not be affected by whether the volume of voyages is existent [4].

Variable costs is that the costs can change with changes in ship cargo volume, arrivals and departures, organizational methods and other factors. The division of ship voyage costs by Chinese enterprises is shown in Table 1 [4].

### Table 1. Voyage cost classification

| Fixed costs                      | Ship voyage costs                                      |
|---------------------------------|--------------------------------------------------------|
| Crew fee salary, bonus, overtime, food, travel and training fees | The costs of various lubricants and greases on board |
| Lubricant fee                   | Depreciation                                           |
| Depreciation                    | Spare parts of various mechanical equipment, rigging, cables, wood, paint, etc. |
| Spare parts and store cost      | Maintenance, dock repair, ship repair engineering, self-repair material, self-repair, ship inspection |
| Maintenance fees                | Insurance, freight insurance, crew insurance, etc.     |
| Management fee                  | Administrative expenses of management personnel and business activity fees and commissions for soliciting goods in the marketing process |
| others                          | Fresh water supply, sailing tool fees, nautical charts and nautical books fees, labor insurance supplies, etc. |

| Variable costs                  | Ship related: ship tonnage tax, berthing fee, pilotage, tugs, unberthing fee, quarantine, customs inspection, agency, etc. |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------|
| Marine fuel                     | Cargo related: tally fee, switch holds fee, waiting time fee, overtime fee, trimming fee, lashing fee and cargo handling fee |
| Port dues and disbursement      |                                                                                                                                 |

In summary, there are many factors that affect the evaluation of the operating income of ships, including fuel costs, freight, port dues and disbursement, and other factors. However, the costs of transportation and consumption costs is different due to ships type. Therefore, it is necessary to use a quantitative index to compare the operating conditions of a ship in different periods. This paper uses this quantitative index as the operating efficiency, then guide the company to improve ships operational management.

Usually, when a ship runs, it should sail on its design speed and the design deadweight theoretically. However, the higher the design speed is, the higher the fuel consumption per nautical mile of the main engine is, which increases the cost of the voyage of the ship and reduces the operating income of the ship. Considering the sea margin and the main engine margin, the ship usually operates at a speed lower than the designed speed, and the speed needs to be reasonably optimized. In addition, a reasonable deployment of ships is also required. Therefore, in order to evaluate the operational effect of the ship within a specific period, it is necessary to model and quantify the operating efficiency of the ship reasonably. The quantitative value can evaluate the operational status of the ship covering many relevant aspects that affect the operating income.

### 3. Related literature and reasonable constraints

Since ship operating efficiency involves many factors, there are not many references to ship operating efficiency and related research literature. Literature [5] studies the energy efficiency index of inland watercraft, and mainly studies the effect of navigation environment on ship energy consumption. The literature [6] studies the efficiency of container ship agent deployment in a port operation, which will also have a certain impact on ship operations. The higher deployment efficiency is benefit to ship
operations; the literature [7] studies ship operating efficiency based on AIS data, but only on the port level. Literature [8] studies the impact of container ship’s stay time at the port on operating costs. The shorter the time, the more helpful it is to improve ship operating efficiency; Literature [9] shows ship speed is the key determinant of fuel cost by modeling research, and fuel cost is an important part of ship operating cost and one of the decision factors. These documents only study the relevant factors of ship operation in different aspects. In practice, ship operation involves many aspects. Shipping companies are very concerned about how much profit each ship can bring to the company. However, there are huge differences in initial investment, types and cargo conditions for ships. It is necessary to find a method to comprehensively evaluate the operating efficiency of ships, so that each ship has a specific numerical comparison of its annual contribution to the company's profits. Therefore, it is necessary to establish a model of the ship's operating efficiency and use the data collected by the ship for calculation verification.

Ship voyage costs involve fuel consumption, cargo volume, cargo turnover time, maintenance and management costs, etc. Ship freight has a great impact on the operating income of ships, and the freight price of some ships such as dry bulk ships is usually closely related to the Baltic Dry Bulk Freight Index (BDI). However, fuel prices do not affect the fluctuation of BDI[10]. All of these will affect the actual profit of the ship, and it is unrealistic to make the operating efficiency model considering all factors, the model will be complicated and difficult to establish. Therefore, in order to effectively study the operating efficiency of the ship, reasonable constraints need to be set according to the ship’s operating conditions. The established constraints are as follows:

(a) The operating efficiency ignores the changes in the fixed cost of the ship. For a ship, the fixed cost can be assumed to remain at the same level during each period evaluated the operating efficiency. As long as the ship runs, the fixed cost is the necessary loss of the ship, and the fixed cost can be ignored when evaluating its operating efficiency.

(b) Operating efficiency ignores changes in the types of goods transported by the ship and changes in freight prices per nautical mile deadweight. Under the premise of transporting the same cargo, the actual freight per nautical mile deadweight of a ship is actually related to the Baltic Sea Index [10], and the Baltic Sea Index keeps changing; the types of cargo carried by the ship may be different for each voyage. The corresponding freight rates are also different, which will have different effects on the ship's operating income. In order to facilitate modeling, it is assumed that the type of cargo of the ship and the freight price per nautical mile deadweight are constant during the period of evaluation of operational efficiency.

(c) The operating efficiency ignores the change in the unit price of fuel in the variable costs of the ship. The unit price of fuel oil bunkered on a ship is related to the place of production and market fluctuations. Assuming that the unit price of fuel oil is constant for a ship, only the total fuel consumption can be considered when evaluating operating efficiency, which can predigest the model.

(d) Operating efficiency ignores the change in port dues and disbursement per unit time in the variable cost of the ship. Ships entering and leaving different ports have different port dues and disbursement. For a ship, assuming the port dues and disbursement per unit time is constant, it is only considered that the operating efficiency of the ship is related to the speed of cargo turnover.

It can be seen from the above four constraints that the research on operating efficiency in this paper is mainly aimed at evaluating the operational management level of the ship, that is, the ship is expected to be able to sail, load and unload cargo consecutively, and the relevant expenses are assumed to be constant, and the ship’s operating efficiency model is established before verification.

4. The operating efficiency model

The mathematical model of ship operating efficiency should be able to get the reasonable values. Essentially, the efficiency value should be a numerical indicator in the interval [0, 1]. The larger the value, the better the efficiency. It is considered perfect if it is equal to 1. Therefore, the value range of the model of ship operating efficiency constructed should be [0, 1]. Since the company usually needs to evaluate the annual operation of the ship, and the collected data is stored by voyages in the database. Therefore, in order to evaluate the annual operation of the ship, the model should be constructed by
voyages, then extend the cumulative number of voyages to years to get the annual ship operational
efficiency. For voyages that span multiple years, the evaluator can increase or decrease as needed, and
the corresponding calculation and evaluation results will be different.

The main factors that affect the operating income of the ship are the ship’s cargo capacity, ship speed,
main engine fuel consumption and general berthing time, etc. In order to compare annual operating
conditions of the ship, the model needs to be constructed with a reasonable reference value. Ideally, the
reference value should be the maximum value in the used field data, so that the value range after the
actual value is compared with the reference value is [0, 1], but due to the uncertainty of related
parameters, the maximum value in the field data may be changed with the update of data. Therefore, the
reference value is selected for verification of collected data, and its value is as close as possible to the
maximum value of the field. The annual operating conditions of the ship can be compared with the
reference value to evaluate the annual operating efficiency.

This paper constructs the following mathematical model to define the annual ship operating efficiency
\( \eta \):

Annual ship operation efficiency \( \eta = \text{annual cargo transportation utilization index} \times \text{annual cargo}
turnover index \times \text{annual navigation index} \times \text{annual deployment index} \)

Each parameter in the model is described below.

4.1. Annual cargo transportation utilization (ACTU) index
The cargo loaded of a ship has a relatively large impact on the operating income of the ship. Therefore,
the utilization rate of the cargo hold is a key factor. It can be modeled as an influencing factor of
operational efficiency, thereby introducing the annual cargo transportation utilization index.

The annual cargo transportation utilization index is defined as formula (1)

\[
\eta_{\text{load}} = \frac{\sum_{i=1}^{n} W_{Ri} \times L_{Ri}}{W_{D} \times \sum_{i=1}^{n} L_{Ri}}
\]

Where,

- \( \eta_{\text{load}} \) - Annual cargo transportation utilization (ATCU) index;
- \( i \) - the i voyage in the year, which one voyage is from port A to port B, regardless of whether the ship
  is carrying cargo;
- \( n \) - the total number of voyages per year;
- \( W_{Ri} \) - the actual cargo loaded of the i voyage. If the voyage is empty, the actual cargo loaded \( W_{Ri} \)
is calculated as 0, but the voyage still needs to be counted;
- \( L_{Ri} \) - the mileage of the i voyage;
- \( W_{D} \) - the designed cargo capacity of the ship, which is constant for the ship.

The reference value in this model is selected as the ship’s cargo capacity, and the calculation results
are shown in Table 2 based on a three-year data analysis of a bulk carrier. It can be seen from the
calculation results that the value is always less than 1, which shows that the reference value is reasonable,
and the model can be used as one influencing factor for evaluating operating efficiency.

| Years | ATCU index |
|-------|------------|
| 2016  | 0.459      |
| 2017  | 0.641      |
| 2018  | 0.561      |

4.2. Annual cargo turnover (ACT) index
The turnover speed of goods is another factor which has a relatively large impact on the operating
income. The faster the turnover of goods, the greater the operating income. Therefore, the model extracts
the voyage mileage and voyage time fields in the database and introduces the annual cargo turnover
index. the model is defined as formula (2):

\[
\eta_{\text{cycle}} = \frac{\sum_{i=1}^{n} L_{Ri}}{V_{D} / \sum_{i=1}^{n} T_{Ri}}
\]
Where,

\[ \eta_{\text{cycle}} - \text{Annual cargo turnover (ACT) index;} \]

\[ i - \text{the } i_{\text{th}} \text{ voyage in the year, which one voyage is from port A to port B, regardless of whether the ship is carrying cargo;} \]

\[ n - \text{the total number of voyages per year;} \]

\[ L_{\text{RI}} - \text{the mileage of the } i_{\text{th}} \text{ voyage;} \]

\[ V_D - \text{the design speed of the ship, which is constant for the ship and can be extracted from the data collected;} \]

\[ T_{\text{RI}} - \text{the time of the ship on the } i_{\text{th}} \text{ voyage;} \]

In the model, the reference value is selected as the design speed of the ship. The actual operating speed of the ship is usually lower than the design speed of the ship. The larger the index, the higher the average annual speed of sailing, which shortens the cargo transportation cycle. Take the bulk carrier as an example, the design speed of the bulk carrier is 14.5 knots, and the calculation results are shown in Table 3. The statistics show the ACT index is always less than 1 in a year cycle, so the reference value in the model is reasonable, and the model can be used as an evaluation factor for operating efficiency.

Table 3. Statistics of the 3-year ACT index of the ship

| Years | ACT index |
|-------|-----------|
| 2016  | 0.555     |
| 2017  | 0.612     |
| 2018  | 0.677     |

4.3. Annual navigation (AN) index

In addition to cargo loading and turnover in ship operation, fuel consumption is also an important factor that cannot be ignored\(^\text{[11]}\). In theory, when a ship runs, the fuel consumption of equipment other than the main engine has little to do with the speed of the ship. It is only related to whether the ship is docked or repaired in the factory. As long as the ship is in operation, this part of the cost can always exist whether the ship is at port or at sail. According to the statistics, the fuel consumption of equipment other than the main engine is close to be constant every day, which means that, as long as the ship is put into operation for a year, this part of the consumption is unchanged. For the convenience of research, this paper ignores its impact on operating efficiency, and only considers the fuel consumption per nautical mile of the main engine. The model is used to measure the average annual fuel consumption of main engine fuel per nautical mile. The higher the fuel consumption per nautical mile of the main engine, the greater the variable cost of operating in the same sea mile \(^\text{[12]}\) (ignoring the fuel consumption of equipment other than the main engine), the lower the operating income, and the lower the operating efficiency

For ocean-going ships, most of the main engines with a fixed pitch propeller sail at the navigation speed. Assuming that the propeller efficiency and transmission efficiency remain unchanged. Since the fuel consumption rate per nautical mile of the main engine is related to the loading volume and the speed, when the ship is sailing at navigation speed, it can be assumed that the fuel consumption rate of the main engine remains unchanged. While the ship’s cargo loaded remains the same during the voyage, that is, the ship’s displacement remains the same (in fact, a slight decrease due to the loss of fuel and fresh water), and the theoretical relationship between the fuel consumption per nautical mile of the main engine and the ship’s speed is shown in the Figure.1\(^\text{[13]}\).

In fact, when the main engine’s fuel consumption per nautical mile \(g_n\) is the lowest, the ship speed is very low based on the analysis of collected data. This ship speed is defined as energy-saving speed \(V_{\text{b}}\)\(^\text{[13]}\). Usually, the ship’s operating speed is higher than this speed. The fuel consumption per nautical mile \(g_n\) should run on the curve where the ship speed is higher than \(V_{\text{b}}\). According to Fig.1, it is obviously showing that, on this part of the curve, the higher the ship speed is, the greater the fuel consumption per nautical mile of the main engine is. At the same time, the freight cycle will be shortened.
When the propeller efficiency and transmission efficiency are constant, the ship sails in a stable state, the actual annual fuel consumption per nautical mile $g_{fe}$ can be obtained by the formula (3):

$$ g_{fe} = \frac{\text{Annual total fuel consumption of main engine at navigation speed}}{\text{total annual mileage of navigation speed}} $$

$g_e$ - Specific fuel oil consumption of the main engine;
$g_n$ - Fuel consumption per nautical mile; $V_s$ - ship speed

![Graph showing the relationship between fuel consumption and speed.](image)

Figure 1. The relationship between fuel consumption and speed

The total fuel consumption of the main engine for a single voyage can be obtained from the data collected by the ship, including navigation fuel consumption and port fuel consumption. Since the fuel consumption per nautical mile of the main engine calculated by formula (4) based on that the ship is sailing stably, this model is only applicable to the ship sailing at navigation speed, while maneuvering is an unstable condition, and the model is not suitable. Therefore, this model only consider the average fuel consumption per nautical mile of the ship's sail at navigation speed in one year.

In order to compare the fuel consumption per nautical mile of the main engine in each year, the data of stable working conditions during the trial voyage was initially selected as the reference. This paper selects 85% of the main engine related data during the trial voyage as the reference, because it is often used as the actual operating power during normal navigation. (Engine margin and sea margin should be reserved). The main engine power, the main engine fuel consumption rate $g_e$ and ship speed can be obtained in the trial voyage. It should be noted that since no cargo was loaded during the trial voyage, but only ballast sailing was used. The fuel consumption per nautical mile of the main engine at this time was calculated by formula (4)\textsuperscript{[13]}:

$$ g_{fe} = \frac{P_{e0} \times g_e}{V_0} $$

Where,
$g_{fe}$ - fuel consumption per nautical mile of the main engine of 85% MCR under the sea trial condition;
$P_{e0}$ - power of the main engine corresponding to 85% MCR under the sea trial condition;
$g_e$ - the actual fuel consumption rate of the main engine (g/kw/h);
$V_0$ - the corresponding sea trial speed under the sea trial condition (85% MCR, knots);

Comparing the actual annual fuel consumption per nautical mile $g_{te}$ with the reference value $g_{fe0}$, formula (5) is obtained:

$$ \frac{g_{te}}{g_{fe0}} = \frac{\sum_{i=1}^{n} ME_{Ri} \times V_0}{P_{e0} \times g_e \times \sum_{i=1}^{n} (L_{Ri} + L_{Mi})} $$

Where,
$i$ - the $i$ voyage in the year, which one voyage is from port A to port B, regardless of whether the ship is carrying cargo;
$n$ - the total number of voyages per year;
$g_{te}$ - the actual annual fuel consumption per nautical mile;
$ME_{Ri}$ - the total fuel consumption of the main engine on the $i$ voyage at navigation speed;
$L_{Ri}$ - the mileage of the $i$ voyage;
$L_{Mi}$ - the maneuvering mileage of the ship on the $i$ voyage.
Since this ratio reflects the fuel consumption of the ship, if it is used as an influencing factor of the ship’s operating efficiency, its impact is opposite to the above two factors (ACTU index and ACT index), that is, the larger the value, the higher the annual fuel consumption per nautical mile of the ship, the higher the operating variable cost, and the less the operating income. Moreover, the ratio is slightly higher than 1 in individual cases through the analysis of collected data (if it is 0, the ship can be considered not consuming fuel and may use solar energy and other energy methods to propel), in order to make its impaction consistent with the previous two factors (ACTU index and ACT index), and limit it to the range of [0, 1]. Considering the ratio of cosine, the above ratio is equivalent to a radian value, and the value of cosine has the following advantages:

(a) Since the independent variable of the cosine function decreases monotonically in the range of [0, 1], even if the value of the independent variable is slightly higher than 1, as long as it is not higher than \( \pi/2 \), its value is still in the range of [0, 1];

(b) Since this factor is only a reference benchmark, the cosineization will not affect the evaluation of the fuel consumption per nautical mile of the ship;

(c) Since the independent variable of the cosine function itself decreases monotonically in [0, 1], the influence of the original value in the independent variable becomes the opposite: that is, the larger the original value, the smaller the cosine, the higher the annual fuel consumption per nautical mile of the ship’s main engine, the lower the operating income.

(d) Since the independent variable of the cosine function itself decreases monotonically in [0, 1], the influence of the original parameter in the independent variable becomes the opposite: that is, the larger the original parameter, the smaller the cosine, that is, the equivalent. The higher the annual fuel consumption per nautical mile of the ship’s main engine, the lower the operating income. This is the factor of operating efficiency, which is consistent with the effect of ACTU index and ACT index on operating income, and also in line with the evaluation operation. Therefore, the cosine value is defined as the ship’s annual navigation index \( \eta_{navigate} \), which is formula (6).

This can be the factor of operating efficiency, which is consistent with the effect of formula (1) and formula (2) on operating income, and also in line with the evaluation operation. The trend of efficiency. Therefore, the cosine value is defined as the ship’s annual navigation index \( \eta_{navigate} \), i.e. the formula (6):

\[
\eta_{navigate} = \cos \left( \frac{\sum_{i=1}^{n} M.E_{BLi} \times V_{D}}{P_{BO} \times \theta_{c} \times \sum_{i=1}^{n} (L_{Bi} - L_{Mi})} \right)
\]  

(6)

Where,

\( \eta_{navigate} \) - Annual navigation (AN) index,

the meaning of other parameters is the same as formula (5).

It should be noted that the AN index ignores the fuel consumption of the ship's maneuvering navigation, which is a good evaluation for ocean-going ships. However, ships with more maneuvering sailing need to be handled carefully when evaluating their operational efficiency. The larger the AN index, the smaller the fuel consumption per nautical mile of the main engine. After cosineization, the model was verified with the data collected from the bulk carrier, and the results are shown in Table 4.

### Table 4. Statistics of the 3-year AN index of the ship

| Years | AN index |
|-------|----------|
| 2016  | 0.664    |
| 2017  | 0.618    |
| 2018  | 0.617    |

The value is less than 1 in a one-year cycle, so the AN index model is reasonable, and the model can be used as an evaluation factor for operating efficiency.

#### 4.4. Annual deployment (AD) index

In addition to sailing, the normal operating efficiency of ships also involves the company’s reasonable deployment of ships, including cargo deployment, arrival and departure in time, and rapid
communication with ship inspectors and other related capabilities\textsuperscript{[6]}, from which modeling introduces the annual deployment (AD) index of ships.

If the company deploys a ship perfectly, the ship usually has a general berthing time of 0, that is, only the loading and unloading time at the port and sailing time, which means that the ship is constantly loading, unloading, and sailing. This is an ideal state, and the index can be defined as 1. If the deployment is not good, the schedule may be extended. Therefore, the general berthing time of ships can reflect the deployment of ships. Generally, the longer the berthing time, the poor deployment of ships. If the ship has been berthed for some reason such as ship repair or inspection, the deployment index should be smaller and closer to zero. In order to reflect the deployment efficiency in the interval [0,1], this paper adopts the exponential function and makes the following definition:

\[ \eta_{\text{deploy}} = e^{-x} \]  

(7)

Where,

- \( \eta_{\text{deploy}} \) - Annual deployment (AD) index;
- \( e \) - natural logarithm;
- \( x \) - the annual total general berthing time, which can be calculated from the general berthing time of each voyage in the year collected by the ship, and the unit is year.

According to the AD index model, when \( x \) is 0, that is, there is no general berthing time throughout the year, only loading and unloading and sailing time, \( \eta_{\text{deploy}} \) is 1, indicating the highest deployment efficiency. When \( x \) is 1, it means the ship is berthing throughout the year, \( \eta_{\text{deploy}} = e^{-1} = 0.368 \), which can be considered as a benchmark. The model uses the data collected by the bulk carrier to analyze and calculate as shown in Table 5. The AD indexes are less than 1 in a year cycle, the model can be used as an evaluation factor for operating efficiency.

### Table 5. Statistics of the 3-year AD index of the ship

| Years | AD index |
|-------|----------|
| 2016  | 0.807    |
| 2017  | 0.839    |
| 2018  | 0.887    |

4.5. Ship’s annual operating efficiency model

Multiply each of the above factors together to construct the annual operating efficiency model for a ship. That is, the annual operating efficiency \( \eta_A \) of a ship is as follows:

\[ \eta_A = \eta_{\text{load}} \times \eta_{\text{cycle}} \times \eta_{\text{navigate}} \times \eta_{\text{deploy}} = \frac{\sum_{i=1}^{n} W_i \times L_i}{W_D \times \sum_{i=1}^{n} L_i} \times \frac{\sum_{i=1}^{n} L_i}{V_D \times \sum_{i=1}^{n} T_i} \times \cos \left[ \frac{\sum_{i=1}^{n} ME_i \times V_0}{P_R \times \theta \times \sum_{i=1}^{n} (L_i - L_M)} \right] \times e^{-x} \]  

(8)

Where the meaning of each factor is the same as that described above.

Based on the calculation results in the above model, the three-year annual operating efficiency calculation results of the bulk carrier are shown in Table 6. Generally speaking, the larger the value, the higher the annual operating efficiency. When the ship’s loading rate remains unchanged and the ship’s speed increases, the ATC index \( \eta_{\text{cycle}} \) increases, but the fuel consumption per nautical mile of the main engine will increase at this time, making the AN index \( \eta_{\text{navigate}} \) decrease. Which one has a greater impact on operational efficiency and require comprehensive evaluation and more data for follow-up research.

In the actual evaluation of the operating efficiency of a ship, the values and total values of the four indexes in the formula can be compared at the same time on an annual basis, so that the annual operating efficiency of the ship can be evaluated.

### Table 6. Statistics of the 3-year annual operating efficiency of the ship

| Years | Annual operating efficiency |
|-------|-----------------------------|
| 2016  | 0.137                       |
| 2017  | 0.204                       |
| 2018  | 0.208                       |
5. Diversified evaluation of operational efficiency

Based on the mathematical models established in this paper, the calculation results of each model are used to obtain a line chart of the annual operating efficiency of the bulk carrier as shown in Figure 2. Comprehensive analysis and comparison of the ship’s operating efficiency and various indexes can make the following evaluations of the bulk carrier’s operation:

1. From the chart, the annual operating efficiency of the ship was the largest in 2018, that is, the overall operating income of the ship in 2018 was better than the previous two years;
2. The ACTU index in 2017 was the highest, indicating that the cargo utilization rate of the ship in 2017 was the best.
3. The ACTU index in 2018 is in the middle. Although the cargo hold is not fully utilized, the ACT index is the highest, indicating that the average speed of the ship in 2018 is higher, which makes the main engine's fuel consumption per nautical mile the highest, that is, the AN index is the smallest.
4. The AD index of the ship in 2016 was the smallest, indicating that the general berthing time in 2016 was the longest; the AD index in 2018 was the largest, indicating that the general berthing time was the shortest in 2018, and the ship deployment in 2018 was the best.

The results of the analysis were communicated with the company and confirmed by the company. It can be seen from the above that using the model established in this paper, through the typical calculation of the bulk carrier data, it can effectively give an evaluation of the annual operating efficiency of a ship. Since each index in the model is less than 1, the number obtained after multiplication is slightly smaller, but because this value is only used as an evaluation, it does not affect the actual result, and has good rationality.

![Figure 2. A line chart of the 3-year annual operating efficiency of the bulk carrier](image)

6. Conclusion

This paper conducts a modeling study on ship operating efficiency, and uses the massive data collected by the ship to verify the model. Through the model, the annual ship operating efficiency value of a single ship is quantified, and calculation and analysis are performed for a bulk carrier. The calculation results have pointed out the direction for the company to improve the operational effects of ships. At present, the model has been applied to a variety of ships and has been validated meaningfully and has been confirmed by the company. As more data becomes available, other factors affecting ship operations, such as changes in fuel prices, can be added to further optimize and modify the model, laying a research foundation for the intelligentization of ships.
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