Research Article

Container Shipping Scheduling Method Based on the Evidence Reasoning Approach in Fluctuating CCFI and BDI Cycle

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Received 30 March 2022; Accepted 27 June 2022; Published 18 July 2022

Abstract

Due to the COVID-19/Omicron pandemic and the trade war and tariffs between China and America, the supply chain between Asia and America, or Asia and Europe, faced unprecedented challenges. With the outbreak of the Russian-Ukrainian war, the global supply chain has become increasingly unbalanced. In particular, the shortage of container ships and the continuous fluctuation of the BDI and CCFI make shipping scheduling increasingly important for ocean carriers. To solve this problem, in this study, we propose an analytic approach considering the fluctuation of BDI and CCFI based on interval evidence reasoning and the Hungarian algorithm. The proposed approach uses two pairs of nonlinear optimisation models to construct a Nash equilibrium assignment model to compute the shipping company’s scheduling and maximum utility in the CCFI and BDI cycles. Compared to the simulation algorithm, the analytical algorithm can take advantage of stability and efficiency. Finally, a COSCO company’s container shipping scheduling problem was examined to demonstrate the efficiency and effectiveness of the proposed approach.

1. Introduction

One of the pervading headlines throughout 2020–2021 focused on the global supply chain disruption issues affecting businesses and consumers worldwide. However, these situations are likely to persist and are warnings that these critical problems may last in 2022 and potentially beyond. This would keep significant strains on, as they accept higher prices and costs of dealing with business in such a navigate continued uncertainty. According to the trade analysis unit of the S&P Global Market Intelligence survey, the CCFI (China Containerized Freight Index) and BDI (Baltic Dry Index) fluctuated 52% year on year, whereas the carriers had to deal with the capacity imbalance and shortage of container ships. Therefore, shipping scheduling becomes a critical task.

For decades, many scheduling methods have been developed, such as scheduling with Soft Time Window [1–3]; Maritime considering inventory, draft limits, and bunker cost [4–6]; routing problem with berthing time clash avoidance constraints [7–10]; green logistics, green ports [11, 12], and Big Data in Maritime Logistics [13, 14]. In these methods, scheduling problems are modelled using shipping matrices in which an attribute is assessed using a certain number of criteria. Under many decision situations, however, using a certain number to represent an evaluation proves to be difficult and unachievable. Evaluation would have been distorted or lost in the process of preaggregating differences, such as a probability distribution, a subjective judgment, or an incomplete part of the information, into a single number [15].

Note that using distributed assessment instead of certain numbers would enable various types of attribute values to be incorporated into an evaluation process without preaggregation [16] and in our study, belief decision matrix (BDM) concepts were adapted to evaluate the complex system. To take advantage of the distributed assessment structure contained in the BDM, the D-S theory was employed for information aggregation, which resulted in the ER approach [17–19].
In this study, container ship assessments were evaluated using a belief hierarchy, subsets of adjacent grades were set up and a ship assessment model was aggregated with the route data. An evidence-reasoning algorithm with a Nash equilibrium assignment model, ER-NAP, was developed to support ship evaluation and complex ship scheduling in fluctuating CCFI and BDI cycles. In most situations, the target of the assignment is to maximise the participant’s rationality instead of maximising the collective rationality. For example, in an emergency, the most important problem is whether each unit is equally considered [20, 21]. Another application is scheduling problems arising in satellite communications. While many of the base stations seek their most efficient satellites and assigning the satellites fairly is important for the third-party satellite administrators [22]. Contrary to the former, this is a cooperative assignment because a satellite can be assigned to more than one base station at a time. However, all assignment problems, including the noncooperative and cooperative assignment problems were modelled from the perspective of collective rationality and ignored the participants’ rationality. In addition, it is realized that taking the solution with collective rationality into practice may be difficult and sometimes unacceptable because the participants’ rationality would have been lost or distorted in the process of maximising collective rationality. Although such a choice is in a perfectly competitive market, no attempt has been made to test whether the optimal solution can be effectively conducted. However, if one adopts game theory, it may be argued that the existing model for finding the optimal solution experiences shortcomings in these competitive situations. Our study aims to rectify this critical shortcoming, and the optimal solution is extended for the first time.

By introducing the coefficients of CCFI and BDI, the ER-NAP algorithm provides a fusion modelling framework and an attribute aggregation process to deal with both ship and route information. A COSCO scheduling example was examined to demonstrate the implementation process of the ER algorithm and its applications.

In the following sections, the ER-NAP model is first explained, followed by the coefficient of CCFI and BDI introduction and a scheduling analytical structure fusion with ship route and CCFI and BDI information. In detail, the interval uncertainty of ship attributes, in both quantitative and qualitative terms, transforms into a standard form. Finally, all normalised data were input into the system, and the results were generated synchronously. Other details are demonstrated using a real example from the COSCO Company.

### 2. Evidence Reasoning-Nash Equilibrium Assignment Scheduling Structure

#### 2.1. Macrostructure of the Scheduling Process

First, suppose several ships need to be assessed and routes difference would be represented by the characteristic vector, as shown in Table 1.

(1) Assuming the number of ships is \( m \), the number of routes is \( n \).

#### 2.2. Interval Efficiency Matrix Calculation Method

The expected utility calculation model of ER nonlinear programming is a method for calculating the utility of a container ship using a nonlinear programming model. It has two equivalent algorithms: recursive and analytical. In contrast to the traditional evaluation method, the ER method uses basic credibility to evaluate the properties of attribute information in the efficiency matrix. This has the advantage of being able to model uncertainty information to describe the uncertainty of the subjective data. Existing evidence-based reasoning models require the evaluator to provide the basic credibility of the grade relative to the evaluation level. However, in practical applications, it is difficult for the evaluator to directly provide the basic credibility of a decision-making scheme relative to the evaluation level; however, it is possible to provide the range of the basic credibility of a decision-making scheme relative to the evaluation level.

For example, it is often difficult to accurately evaluate the basic credibility of the load factor of the ship relative to the evaluation level as \( S(e_i(\text{load factor})) = \{H_1, 0.3\}; \{H_2, 0.2\}; \{H_3, 0.5\} \); however, it can be determined that the range of the basic credibility of the load factor of the ship relative to the evaluation level is as follows: \( S(e_i(\text{load factor})) = \{[H_1, [0.3, 0.4]](H_2, [0.2, 0.3]); \{H_3, 0.4, 0.5]\} \), that is, the belief degree of attribute \( e_i \) of the decision-making scheme \( a_i \) relative to the evaluation level \( H_1 \) is a certain value in the

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Route</th>
<th>Ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w_{i1} )</td>
<td>( w_{i2} )</td>
<td>( w_{iL} )</td>
</tr>
<tr>
<td>( a_1 )</td>
<td>( a_2 )</td>
<td>( a_m )</td>
</tr>
</tbody>
</table>

(2) Each ship has \( L \) attributes, such as load efficiency, the number of standard TEU, speed, tonnage, fuel consumption, and age of the ship. The formation of attribute information includes qualitative data, quantity data, fuzzy data, and interval data.

(3) The characteristic of each route is represented by a weight sector. Every single weight correlate attribute of the ship. Different weight sectors suggest that the various ships competing for the most profitable route have disparate efficiency.

Based on the attribute metrics of the routes and ships in Table 1, we used the interval efficiency matrix calculation method (shown in Section 2.2) to generate the interval efficiency matrix of Route \( n \)’s characteristic vector with Ship \( m \)’s attributes in Table 2. The Nash equilibrium assignment model with CCFI and BDI eco-efficiency (shown in Section 2.3) was used to calculate the optimal matching of the ship and route.

### Table 1: Route weight vector and ship attribute.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Route</th>
<th>Ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w_{i1} )</td>
<td>( w_{i2} )</td>
<td>( w_{iL} )</td>
</tr>
<tr>
<td>( a_1 )</td>
<td>( a_2 )</td>
<td>( a_m )</td>
</tr>
</tbody>
</table>

For example, in an emergency, the most important problem was generated synchronously. Other details are demonstrated using a real example from the COSCO Company.
interval [0.3, 0.4]; the belief degree of the relative evaluation level $H_2$ is a certain value in the interval [0.2, 0.3]. Numerical value: The belief degree of the relative evaluation level $H_2$ is a certain value between [0.4, 0.5]. In an uncertain environment, the ER algorithm of the belief degree expressed in the form of intervals can help evaluators express their subjective wishes [27–28]. Therefore, this study used the ER parsing algorithm based on the belief degree of the interval form to construct the matching model.

### 2.2.2. ER Model Based on Interval Belief Degree

In the multi-attribute ship evaluation process, uncertainty data must be considered. Let $A = \{a_1, a_2, ..., a_m\}$ represent the set of $m$ ships; $a_i$ represents ship $i$; $E = \{e_1, e_2, ..., e_l\}$ represents each ship with $L$ attributes; $W = (w_1, w_2, ..., w_L)^T$ represents the weight vector of the attributes where $w_i$ represents the route’s characteristic correlate to the ship’s attribute $i$, and satisfies $0 \leq w_i \leq 1$ and $\sum_{i=1}^{L} w_i = 1$.

Suppose that each attribute is represented by $N$ complete and independent belief degree sets: $H_n = \{H_1, ..., H_N\}$, then the evaluation information of attribute $e_i$ based on the interval-belief degree can be expressed in the distribution form as $S(e_i(a_i)) = \{(H_n, [\beta_{n,i}^-(a_i), \beta_{n,i}^+(a_i)]), n = 1, ..., N\}$, where $\beta_{n,i}^-(a_i) \geq 0$, $\beta_{n,i}^+ \leq \beta_{n,i}^+ \leq \beta_{n,i}^+$, and where $\beta_{n,i}$ represents the attribute $e_i$ of ship $a_i$ is a single number between $\beta_{n,i}$ and $\beta_{n,i}$ in belief degree $H_i$. If $\beta_{n,i} = \beta_{n,i}^+$, $e_i$ is a single number instead of the interval in $H_i$.

For example, $H = \{H_1, H_2, H_3\}$, $S(e_i(a_i)) = \{(H_1, [0.3, 0.4]), (H_2, [0.2, 0.3]), (H_3, [0.4, 0.5])\}$,

$$\beta_{H,n}(a_i) = \max \left(0, 1 - \sum_{n=1}^{N} \beta_{n,i}^+(a_i) \right)$$

$$\beta_{H,n}(a_i) = \max \left(0, 1 - \sum_{n=1}^{N} \beta_{n,i}^-(a_i) \right) = \max \left(0, 1 - 0.4 - 0.3 - 0.5 \right) = 0,$$ (1)

$$\beta_{H,n}(a_i) = 1 - \sum_{n=1}^{N} \beta_{n,i}^-(a_i) = 1 - 0.3 - 0.2 - 0.4 = 0.1.$$

The ignorance $H$ is a single number between the interval [0, 0.1].

The efficiency metrics based on the interval belief degree were obtained until the evaluation of the $L$ basic attributes of $M$ ships:

$$D_g = \langle S(e_i(a_i)) \rangle_{L \times M}.$$ (2)

If the attribute evaluation is represented by the interval-based basic reliability, the evaluation information of decision plan $a_i$ after the attribute evaluation information is aggregated using the ER method is the interval-based basic reliability. Based on the evaluation information in the form of interval basic credibility, a pair of nonlinear programming models is used to aggregate the basic credibility of the attributes relative to the evaluation level as the basic credibility of the decision scheme relative to the evaluation level, which is used to calculate the interval-based evaluation. The basic credibility is located in the upper and lower bounds of the interval.

### 2.2.2. Calculation Process Based on Nonlinear Programming

First, according to formulas (1)–(5), the decision matrix is transformed into the form of belief degree, and the undistributed part of belief degree $m_{H,n}$ includes two parts: $\tilde{m}_{H,n}$ and $\tilde{m}_{H,n}$: $\tilde{m}_{H,n}$ is calculated by $e_i, e_j$ correlate weight, whereas $\tilde{m}_{H,n}$ represents the $e_i$’s evaluation information is incomplete.

$$m_{n,i} = m_i(H_n) \in \left[ m_{n,i}^-, m_{n,i}^+ \right] = \left[ w_i \beta_{n,i}^-(a_i), w_i \beta_{n,i}^+(a_i) \right], \quad n = 1, ..., L,$$ (3)

$$\tilde{m}_{H,n} = m_i(H) = 1 - w_i, \quad i = 1, ..., L,$$ (4)

$$\tilde{m}_{H,n} = m_i(H) \in \left[ \tilde{m}_{H,n}, \tilde{m}_{H,n}^+ \right] = \left[ w_i \beta_{H,n}^-(a_i), w_i \beta_{H,n}^+(a_i) \right], \quad i = 1, ..., L,$$ (5)

$$\sum_{n=1}^{N} m_{n,i} + \tilde{m}_{H,n} + \tilde{m}_{H,n} = 1, \quad i = 1, ..., L,$$ (6)

$$\sum_{i=1}^{L} w_i = 1.$$ (7)

Second, the evaluation information of the $L$ attributes of the ships is combined. Because the attribute evaluation information of the ships is expressed by the interval belief degree, the expected utility of the aggregated ship attributes may also be in the interval form. Therefore, it is necessary to use the objective-maximising nonlinear programming...
model (6) and objective-minimizing nonlinear programming model (7) to solve the upper and lower bounds of the expected utility of the ship, respectively.

\[
\text{Max } u_{\text{max}}(a_l) \sum_{l=1}^{N-1} u(H_n) \beta_n(a_l) + u(H_n) (\beta_N(a_l) + \beta_H(a_l)), \quad (8)
\]

\[
\beta_H = \frac{\bar{m}_H}{1 - \bar{m}_H},
\]

\[
m_n = k \left[ \prod_{i=1}^{L} \left( m_{n,i} + \bar{m}_{H,i} + \bar{m}_{H,i} \right) - \prod_{i=1}^{L} \left( \bar{m}_{H,i} + \bar{m}_{H,i} \right) \right],
\]

\[
\bar{m}_H = k \left[ \prod_{i=1}^{L} \bar{m}_{H,i} \right],
\]

\[
\bar{m}_H = k \left[ \prod_{i=1}^{L} \left( \bar{m}_{H,i} + \bar{m}_{H,i} \right) - \prod_{i=1}^{L} \bar{m}_{H,i} \right],
\]

\[
k = \left[ \sum_{n=1}^{N} \prod_{i=1}^{L} \left( m_{n,i} + \bar{m}_{H,i} + \bar{m}_{H,i} \right) - (N - 1) \prod_{i=1}^{L} \left( \bar{m}_{H,i} + \bar{m}_{H,i} \right) \right]^{-1}, \quad (9)
\]

\[
m_{n,i} - m_{n,i} \leq \bar{m}_{n,i} \quad n = 1, ..., N; \quad i = 1, ..., L,
\]

\[
\bar{m}_{H,i} = 1 - w_i,
\]

\[
\bar{m}_{H,i} \geq \bar{m}_{H,i} \quad i = 1, ..., L,
\]

\[
\sum_{n=1}^{N} m_{n,i} + \bar{m}_{H,i} + \bar{m}_{H,i} = 1, \quad i = 1, ..., L
\]

\[
\text{Min } u_{\text{min}}(a_l) = \sum_{n=1}^{N-1} u(H_n) \beta_n(a_l) + u(H_n) (\beta_N(a_l) + \beta_H(a_l)),
\]

Table 3: Two ships with four routes.

<table>
<thead>
<tr>
<th>Ship</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship 1</td>
<td>2</td>
<td>13</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Ship 2</td>
<td>10</td>
<td>4</td>
<td>14</td>
<td>5</td>
</tr>
</tbody>
</table>

Note. The elements represent the benefits.

Table 4: The equivalent game problem.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship 1</td>
<td>A</td>
<td>-</td>
<td>2, 4</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>13, 10</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>15, 10</td>
<td>15, 4</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>4, 10</td>
<td>4, 4</td>
</tr>
</tbody>
</table>

Note. "-" represents that ship 1 and ship 2 cannot take on the same route. The elements represent the benefits.
s.t. $\beta_n(a_i) = m_n / (1 - \overline{m}_H)$.  
\[
\beta_H = \frac{\overline{m}_H}{1 - \overline{m}_H} \\
m_n = k \left( \prod_{i=1}^{L} (m_{n,i} + \overline{m}_{H,i} + \overline{m}_{H,1}) - \prod_{i=1}^{L} (\overline{m}_{H,i} + \overline{m}_{H,1}) \right) \\
\overline{m}_H = k \left[ \prod_{i=1}^{L} (\overline{m}_{H,i} + \overline{m}_{H,1}) - \prod_{i=1}^{L} \overline{m}_{H,1} \right], \\
\overline{m}_H = k \left[ \prod_{i=1}^{L} \overline{m}_{H,1} \right], \\
k = \left[ \sum_{n=1}^{N} \prod_{i=1}^{L} (m_{n,i} + \overline{m}_{H,i} + \overline{m}_{H,1}) - (N - 1) \prod_{i=1}^{L} (\overline{m}_{H,i} + \overline{m}_{H,1}) \right]^{-1}. \\
m_{n,i} \leq m_{n,i}^+ \leq m_{n,i}^-, \quad n = 1, \ldots, N; \quad i = 1, \ldots, L, \\
\overline{m}_{H,i} = 1 - w_i, \\
\overline{m}_{H,i}^+ \leq \overline{m}_{H,i} \leq \overline{m}_{H,i}^-, \quad i = 1, \ldots, L, \\
\sum_{n=1}^{N} m_{n,i} + \overline{m}_{H,i} + \overline{m}_{H,1} = 1, \quad i = 1, \ldots, L.
\]

Models (6) and (7) constitute a complete ER-expected utility analysis algorithm. The $u_{M1}$ represents the floor of the object, whereas the $u_{M2}$ represents the ceiling of the object. Using this algorithm, the expected utility $[u_{M1}, u_{M1}^+], [u_{M2}, u_{M2}^+], \ldots, [u_{Mm}, u_{Mm}^+]$ of ship $a_i$ can be calculated using the route characteristic vector $w_{L1}^T = (w_1^T, w_2^T, \ldots, w_L^T)$.

2.3. Nash-Equilibrium Assignment Model. Nash equilibrium is a game approach in nature that provides a new way to study the rationality of ships in assignment problems. In this study, we briefly introduce the transformation method to pave the way for future discussion. Assuming that a ship’s payoff is directly proportional to its utility to the route, each ship pursues its most efficient route to maximise its payoff. To deal with conflicts, ships are viewed as players in a game and utility is viewed as their payoff.

To illustrate the Nash equilibrium of the ship assignment problem, a benefit-oriented example with two ships and four routes is presented in Table 3. Compared with the traditional objective, from an individual perspective, the question is what the best assignment is, while every ship pursues the most profitable route to itself.

In contrast to the classical solving process, the assignment problem was transformed into an equivalent game problem as shown in Table 4. If different ships cannot afford the same route, diagonal elements of the efficiency matrix do not exist.

Note that the assigned ship’s utility is transformed to its payoff equivalently, and then we can solve this problem using game theory. Table 5 shows the results solved by the Hungarian method and Nash equilibrium.

In contrast to the Hungarian method, the Nash equilibrium represents individual rationality. However, it is noted that the Nash equilibrium is not unique in this example, and may be equivalent to the Hungarian solution. In the next section, we will show a cost-oriented Nash equilibrium assignment problem example with three ships and four routes in which its maximal Nash equilibrium is also equivalent to the optimal solution, to lead to the question of...
In the assignment problem.

Theorem 2. The optimal solution is a Nash equilibrium point in the assignment problem.

Table 6: Three ships with four routes.

<table>
<thead>
<tr>
<th>Ship</th>
<th>Route</th>
<th>Route</th>
<th>Route</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>Ship 1</td>
<td>10</td>
<td>14</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Ship 2</td>
<td>9</td>
<td>14</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Ship 3</td>
<td>7</td>
<td>8</td>
<td>11</td>
<td>9</td>
</tr>
</tbody>
</table>

Note. The elements represent the benefits.

Table 7: Results solved by the Hungarian method and game method.

<table>
<thead>
<tr>
<th>Hungarian method</th>
<th>Nash equilibrium 1</th>
<th>Nash equilibrium 2</th>
<th>Nash equilibrium 3</th>
<th>Nash equilibrium 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship 1</td>
<td>Route B (4)</td>
<td>Route A (10)</td>
<td>Route C (14)</td>
<td></td>
</tr>
<tr>
<td>Ship 2</td>
<td>Route A (9)</td>
<td>Route D (13)</td>
<td>Route D (13)</td>
<td></td>
</tr>
<tr>
<td>Ship 3</td>
<td>Route D (9)</td>
<td>Route B (8)</td>
<td>Route A (7)</td>
<td>Route B (8)</td>
</tr>
<tr>
<td>Total utility</td>
<td>22</td>
<td>31</td>
<td>24</td>
<td>31</td>
</tr>
</tbody>
</table>

Proof by contradiction:

Assume that a limited assignment problem has \( m \) Ships and \( n \) Routes, which can be equivalently transformed into a game. This game can be expressed as \( G = \{ S_1, \ldots, S_m; U_1, \ldots, U_m \} \). The optimal solution strategy is \( s^* = (S_1^*, \ldots, S_m^*) \), if existing \( i \), \( U_i(S_i^*, S_j^*) \leq U_i(S_i, S_j^*) \), when the others’ choice is \( S_i = (S_1^*, \ldots, S_{i-1}^*, S_{i+1}^*, \ldots, S_m^*) \). The total efficiency of strategy \( s^* = (S_1^*, \ldots, S_m^*) \) can be increased by \( U_i(S_i, S_j^*) - U_i(S_i^*, S_j^*) \). However, this contradicts the assumption that the strategy is the optimal solution.

Therefore, for strategy \( s^* = (S_1, \ldots, S_j, \ldots, S_m) \), the optimal solution is a Nash equilibrium point.

Based on Theorem 2, we can conclude that the optimal solution is a subset of game solutions. The solution to the assignment problem is extended for the first time. The proposed approach uses two pairs of nonlinear optimisation models to construct an assignment model to compute the matching order and maximum utility of the shipping company, and proposes a method to choose between different assignment sequences. Compared to the simulation algorithm, the analytical algorithm can take advantage of stability and efficiency. Finally, a cargo ship routing problem was examined to demonstrate the implementation process of the proposed approach.

In cases where there was competition among the participants, it should be reappraised that the credibility of an assignment is exempted from market power. To address this issue, each participant was viewed as a player who sought to maximise their efficiency, and the assignment problem was solved using game theory for the first time. Specifically, it is proven that the optimal solution is the Nash equilibrium point of the assignment problem. Finally, relevant issues are discussed.

2.4. Calculation Process with CCFI and BDI Coefficient.

Owing to the fluctuation of the CCFI and BDI, the scheduling operator faces increasingly complex price data. To pursue profit maximisation, they must periodically adjust the scheduling plan with the indexes. From the perspective of the operator of scheduling, the route’s characteristic
vector \( \mathbf{w}_L \) includes two opposite parts: benefit variables' weights and cost variables' weights. For example, the benefit variables include load factors, deadweight, and a number of standard TEUs, whereas the cost variables include annual M&R and manning costs, sea fuel consumption, and off-hire days. If the route price increases rapidly, the benefit variables should be assigned higher weights. Otherwise, if the route price plummets, the cost variables should be assigned higher weights. Fortunately, all these price changes can be reflected by the CCFI indices as shown in Table 8.

In Table 8, the CCFI index is calculated by all routes' price indexes with the weighted average methods, and we can use equation (8) to generate a vector of weights for a vector of routes.

\[
W_{\text{Route}} = \frac{C_i}{\mathbf{C}} \tag{11}
\]
First, all the route’s characteristic vectors $w_{L}^{T} = (w_{1}^{(1)}, w_{2}^{(1)}, ..., w_{l}^{(1)})$ can be divided into two parts: benefit variable weights and cost variables’ weights. The weights of the benefit variables’ weights are multiplied by $W_{Route}$, whereas the cost variables’ weights are divided by $W_{Route}$. Secondly, normalizing the new benefit variables and cost variables constructs the route’s characteristic vector. Finally, we use the route’s characteristic vector, which considers the CCFI indices to match the routes and ships with the methods described above. In addition, if we use the BDI indexes instead of the CCFI indexes, all steps are the same.

### 3. Application of the ER-Nash Equilibrium Assignment Approach to a COSCO Container Ship Scheduling Problem

In this section, the ship scheduling problem of COSCO Company is examined to demonstrate the application of the evidence reasoning-Nash equilibrium assignment approach with interval belief degrees. One of the important reasons for choosing COSCO as the research object is that it assumes the first place in container carrier areas worldwide. The corporation has invested in 58 terminals, including 51 container terminals, and the annual throughput of its container

**Table 11: Original assessment data for COSCO’s sixteen cargo ships.**

<table>
<thead>
<tr>
<th>Attribute/ship name</th>
<th>COSCO SANTOS</th>
<th>COSCO WELLINGTON</th>
<th>XIN NAN TONG</th>
<th>SONG YUN HE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMO</td>
<td>9484376</td>
<td>9484417</td>
<td>9262132</td>
<td>9160700</td>
</tr>
<tr>
<td>Load factors</td>
<td>(A, [0.4, 0.5]), (G, [0.55, 0.65])</td>
<td>(A, [0.4, 0.5]), (G, [0.55, 0.65])</td>
<td>(P, [0.5, 0.65]), (A, [0.4, 0.5])</td>
<td>(P, [0.5, 0.65]), (A, [0.4, 0.5])</td>
</tr>
<tr>
<td>Number of standard TEU</td>
<td>4253</td>
<td>4253</td>
<td>4051</td>
<td>1432</td>
</tr>
<tr>
<td>Deadweight (tonnage)</td>
<td>49959</td>
<td>49959</td>
<td>50151</td>
<td>24237</td>
</tr>
<tr>
<td>Speed (knots)</td>
<td>9.2</td>
<td>16.2</td>
<td>15.6</td>
<td>13.5</td>
</tr>
<tr>
<td>Maximum draft (meter)</td>
<td>11</td>
<td>11</td>
<td>12.8</td>
<td>10</td>
</tr>
<tr>
<td>Date of built (year/month)</td>
<td>201303</td>
<td>201306</td>
<td>200311</td>
<td>199809</td>
</tr>
<tr>
<td>Annual M&amp;R and manning costs (million dollars/year)</td>
<td>1.49</td>
<td>1.33</td>
<td>1.59</td>
<td>1.81</td>
</tr>
<tr>
<td>Sea fuel consumption (tons per day)</td>
<td>[68, 87]</td>
<td>[69, 91]</td>
<td>[69, 87]</td>
<td>[22, 31]</td>
</tr>
<tr>
<td>Off-hire (days per year)</td>
<td>[13, 15]</td>
<td>[12, 15]</td>
<td>[16, 19]</td>
<td>[16, 18]</td>
</tr>
</tbody>
</table>

**Table 12: Route’s characteristics with route’s weights.**

<table>
<thead>
<tr>
<th>Attribute/Weights (Route)</th>
<th>Trans-Pacific line</th>
<th>Europe line</th>
<th>Europe (Mediterranean Sea) and Atlantic line</th>
<th>Asia-Pacific line</th>
<th>Latin America and Africa line</th>
<th>Central America line</th>
<th>Southeast Asia and South Asia line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load factors</td>
<td>0.12</td>
<td>0.18</td>
<td>0.1</td>
<td>0.1</td>
<td>0.14</td>
<td>0.1</td>
<td>0.12</td>
</tr>
<tr>
<td>Number of standard TEU</td>
<td>0.15</td>
<td>0.14</td>
<td>0.12</td>
<td>0.12</td>
<td>0.17</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Deadweight (tonnage)</td>
<td>0.1</td>
<td>0.08</td>
<td>0.15</td>
<td>0.08</td>
<td>0.12</td>
<td>0.09</td>
<td>0.14</td>
</tr>
<tr>
<td>Speed (knots)</td>
<td>0.1</td>
<td>0.08</td>
<td>0.1</td>
<td>0.2</td>
<td>0.12</td>
<td>0.09</td>
<td>0.1</td>
</tr>
<tr>
<td>Maximum draft (meter)</td>
<td>0.12</td>
<td>0.18</td>
<td>0.1</td>
<td>0.1</td>
<td>0.14</td>
<td>0.1</td>
<td>0.06</td>
</tr>
<tr>
<td>Date of built (year/month)</td>
<td>0.15</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.1</td>
<td>0.17</td>
<td>0.09</td>
</tr>
<tr>
<td>Annual M&amp;R and manning costs (million dollars/year)</td>
<td>0.1</td>
<td>0.08</td>
<td>0.1</td>
<td>0.12</td>
<td>0.1</td>
<td>0.12</td>
<td>0.17</td>
</tr>
<tr>
<td>Sea fuel consumption (tons per day)</td>
<td>0.1</td>
<td>0.08</td>
<td>0.15</td>
<td>0.1</td>
<td>0.08</td>
<td>0.12</td>
<td>0.17</td>
</tr>
<tr>
<td>Off-hire (days per year)</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.08</td>
<td>0.07</td>
<td>0.06</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Data resource: https://lines.coscoshipping.com/home/Services/route/11 (COSCO’s official website)
terminals amounts to 115.1 million TEU (data source: COSCO official website).

In this paper, we choose sixteen representative cargo ships to show the application of the method. OKhe assessment grades are shown in Table 9; the original assessment data of ships is shown in Tables 10 and 11; the route’s characteristic is shown in Table 12; and the index of CCFI is shown in Table 13. In the reality, the maximum draft of Panama Canal is 13.41 meters, whereas the maximum draft of Suez Canal is 18.9 meters. And each route has one ship at least, each ship pursues its profit maximisation. Finally, the result showed in Table 14.

4. Conclusions

In this study, we propose a ship scheduling method for fluctuating price routes based on evidence reasoning and the Nash equilibrium assignment model in fluctuating CCFI and BDI cycles. Compared to the current simulation algorithm, this method is an analytical algorithm and has better stability, accuracy, and computational efficiency. In particular, it is suitable for the ship scheduling problem of correlated route information, including quantitative, qualitative, and interval data. With the strong fluctuation of the BDI or CCFI indexes, dynamic scheduling can be implemented by programming this method to solve the large number of problems. An example of the COSCO company scheduling problem shows that the method can achieve overall optimal matching according to the fuzzy data. In addition, according to the nature of the assignment problem, the method can be extended to a matching problem, where the number of routes is not equal to the number of ships. When the route price increases, the virtual route is set up in the Nash equilibrium assignment problem, whereas the virtual route cuts down with its plummet.

Data Availability

Most data used to support the findings of this study are available from the corresponding authors upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Acknowledgments

This article was funded by “The National Social Science Foundation of China,” No. 20CGL001.

References


