New energy vessel routing and optimization for marine debris collection under uncertain environment

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Abstract. In this paper, the method of logistics network is adopted to optimize the route of marine debris collection by liquefied natural gas hybrid vessels. We regarded the weight of marine debris as a random variable, took capacity constraint as chance constraint, considered tank capacity, time window and carbon emission constraints, and established a model with the objective of minimizing the total cost. After transforming the random chance constraint into a deterministic constraint, a large-scale neighborhood search algorithm was used to solve it. The model was verified by taking the Yellow Sea as an example, and the results showed that the best collection time can save 21.74% of total cost and 22.47% of travel time. Compared with pure diesel vessels, liquefied natural gas vessels can save costs by 32.98% and reduce carbon emission by 28.65%. Vessel types with the best capacity can save costs by 22.07% and reduce carbon emission by 25.53%.

1. Introduction

With the rapid growth of population and economy, more and more wastes are produced by human production activities, which has led to the increasingly serious problem of marine debris[1]. The man-made or processed solid wastes that exist in marine and coastal environment for a long time are defined as marine debris[2]. Marine debris is of great variety and quantity. Common plastic products, textiles, wood products, metal, rubber, paper and other discharged into the ocean are considered as marine debris[3-4]. Marine debris not only threatens marine biota and ecosystems, but also affects human health, safety and economy. Cleaning up debris in the ocean is an effective measure to reduce pollution[5].

Due to the influence of ocean currents, sea breeze and other factors, the location of marine debris is constantly changing, which is very different from land-based garbage collection. Taking into account the characteristics of marine debris, Duan et al. first proposed a three-stage integrated framework to collect marine debris[6]. The first stage is to use remote sensing or satellite photography to locate the initial position of marine debris, the second stage is to use GNOME (General NOAA Operational Modeling Environment) and other software to predict the movement trajectory of marine debris, and the third stage establishes a vessel routing optimization model and solve it.

In the context of global sustainable development, carbon emission must also be considered when collecting marine debris. As the main source of greenhouse gases, the impact of carbon dioxide on the climate is well known. Issues such as global warming and sea level rise have caused widespread concern around the world[7]. Reducing the use of fossil fuels and encouraging the development of new energy vessels are effective measures to reduce carbon emission[8]. Compared with diesel, the use of liquefied natural gas (LNG) can reduce carbon dioxide emission by 10% to 20%, nitrogen oxide emission by 90%, and sulfide and particulate matter emission by 100%, which is a clean and low-carbon energy source[9-
Based on the framework proposed in literature [6], this paper uses the LNG hybrid vessel and utilizes the logistics network method to optimize the route for marine debris collection. Marine debris weight is regarded as a random variable because of the uncertainty of the weight of marine debris. A stochastic chance constrained programming model is established to minimize the total cost of debris collection. The total cost in the objective function includes fixed cost and variable cost. Fixed cost includes vessel rent, berthing cost, handling cost, and variable cost includes insurance cost, labor cost, and fuel cost. In addition to the vessel capacity and fuel tank capacity constraints considered in the traditional vessel routing problem, we also add carbon emission constraint to limit the carbon emission produced by vessels in debris collection. Considering the change of the location of marine debris, time window constraint of marine debris is introduced. Within the time window, the moving distance of marine debris is small, and the actual position of debris can be observed after the vessel arrives at the debris. Then the stochastic optimization problem is transformed into an equivalent deterministic optimization problem characterized by a probability density function, and the model is solved by a large-scale neighborhood search algorithm. Taking the Yellow Sea of China as a case study, the effects of collection time, vessel fuel ratio and vessel capacity on total cost are analyzed.

2. Problem description
We use logistics network to optimize the vessel collection route of marine debris. The optimization of marine debris collection route can be simply described as follows: a group of vessels sent by a harbor is responsible for garbage collection of multiple marine debris, each vessel sets off from the harbor, each debris must be collected and can only be collected by one vessel, and the vessel return to the harbor after debris collection. In this process, finding the route arrangement makes minimize the total cost.

Different from the land garbage, the location of marine debris is constantly moving with ocean current and wind. In view of the characteristics of marine debris, we first determined the initial location of marine debris by remote sensing technology, then input the wind field, flow field and hydrological factor data in the GNOME software diagnostic mode to predict the moving trajectory of marine debris, and determined the location and time window of marine debris according to the moving trajectory. When the vessel arrives the predicted position within the time window, the actual position of the debris is close to the predicted position. We can observe the debris to be collected through telescopes and other equipment and collect it. Marine debris is subject to the effects of sunlight, wind erosion, diffusion, settlement, etc., and the weight of the marine debris may change. Therefore, the weight of marine debris is regarded as a random variable, and the chance constraint of vessel capacity is added. This paper uses a LNG hybrid vessel, which uses a certain proportion of diesel and LNG fuel. Compared to traditional diesel vessels, it consumes less diesel fuel, lower fuel costs, and lower carbon emission, which is conducive to environmental protection.

3. Model

3.1. Problem Assumptions
The basic assumptions of the model are as follows: (1) there is only one departure harbor, and the vessels dispatched must return to the departure harbor after collection; (2) homogeneous fleet, is vessels with the same parameters and fixed speed; (3) marine debris collected is visible floating garbage on the sea; (4) marine debris weight is regarded as a random variable, which obeys a certain distribution and is independent and identically distributed. The expected value is not greater than the maximum capacity of the vessel; (5) The moving distance of debris is relatively short in a given time window, and the actual location of debris can be observed when the vessel arrives at this position within the time window.

3.2. Proposed Model
An undirected graph $G(N, A)$ is defined for the vessel collection network, where $N$ is a set of nodes and $A$ is a set of arcs. The node set $N = N_0 \cup N_1 \cup N_2$ consists of an origin harbor $N_0$, set of $n$
debris areas in the predicted locations $N_1$, and a destination harbor $N_2$. The origin harbor $N_0$ and the destination harbor $N_2$ are the same harbor, which we have abstracted into two harbors for ease of representation. The arc set $A = A_0 \cup A_1 \cup A_2$, in which $A_0 = \{(n_i, n_j)|n_i \in N_0, n_j \in N_1\}$ denotes the set of arcs link the origin harbor $N_0$ with debris areas $N_1$, $A_1 = \{(n_i, n_j)|n_i \in N_1, n_j \in N_1, i \neq j\}$ denotes the set of arcs link debris areas $N_1$ with debris areas $N_1$, $A_2 = \{(n_i, n_j)|n_i \in N_1, n_j \in N_2\}$ denotes the set of arcs link debris areas $N_1$ with the destination harbors $N_2$. Let $P$ represent the set of vessels. Each debris area $i \in N_1$ has a collection time $r_i$ and weight $\xi_i$. Let $u^a_{n+1}$ and $u^l_{n+1}$ represent unloading cost and berth cost of the destination harbor, respectively. Each node $i \in N$ requires a time window $[t^e_i, t^l_i]$ where $t^e_i$ and $t^l_i$ denote the earliest start time and the latest start time for the collection work, respectively. Let $d_{ij}$ represent the length of the arc $(i, j)$. For each vessel $p \in P$, we have the following parameters: velocity $v$, maximum carrying capacity $C$, hourly fuel consumption per $h$, the mass percentage of LNG in the mixed fuel $\lambda$, diesel tank capacity $R^d$, LNG tank capacity $R^l$, hourly diesel cost $u^d$, hourly LNG cost $u^l$, rent cost $u^r$, hourly insurance cost $u^e$ and hourly labor cost $u^b$. The other parameters are carbon cap for all collection vessels in one collection $\text{cap}$, confidence level $\alpha$. Let $e^d$, $e^l$ be carbon emission factor per unit LNG and diesel, respectively.

The corresponding decision variables are described as follows. The single binary variables, $x_{ijp}$, is equal to 1 if collection vessel $p \in P$ traverses arc $(i, j) \in A$ and 0 otherwise. Continuous variables $t_{ijp}$, $Q_{ijp}$ are arrive time and cumulative weight at debris location $i \in N$ of collection vessel $p \in P$, respectively.

The chance constrained programming model with minimum total cost is proposed as follows:

$$
\min F = \sum_{i,j \in A} \sum_{p \in P} \lambda h u^L (t^a_{ij} - t^a_{ijp}) x_{ijp} + \sum_{i,j \in A} \sum_{p \in P} (1 - \lambda) h u^C (t^a_{ij} - t^a_{ijp}) x_{ijp} + \sum_{i \in N_1} \sum_{p \in P} (u^z + u^l_{n+1} + u^x) x_{i,n+1,p} + \sum_{i \in N_0} \sum_{j \in N_2} \sum_{p \in P} (u^B + u^R) (t^a_{ij} - t^a_{ijp})
$$

(1)

$$
\sum_{j \in N_1} x_{0jp} = 1 \quad p \in P
$$

(2)

$$
\sum_{i \in N_0 \cup N_1} x_{ijp} = \sum_{k \in N_1 \cup N_2} x_{ijkp} \quad j \in N_1, p \in P
$$

(3)

$$
\sum_{j \in N_1} x_{0jp} = \sum_{j \in N_2} x_{i,n+1,p} \quad p \in P
$$

(4)

$$
\sum_{i \in N_0 \cup N_1} x_{ijp} = 1 \quad j \in N_1
$$

(5)

$$
t^a_{ij} + r_i + \frac{d_{ij}}{v} \leq t^a_{ijp} + (1 - x_{ijp}) M_{ij} \quad (i,j) \in A, p \in P
$$

(6)

$$
t^e_i \leq t^a_{ij} \leq t^l_i \quad j \in N, p \in P
$$

(7)

$$
\Pr \left\{ \sum_{i \in N} \sum_{j \in N_1} x_{ijp} \xi_j \leq C \right\} \geq \alpha \quad p \in P
$$

(8)
\[
\sum_{(i,j) \in A} \lambda h \left( t_{pi}^a - t_{pi}^a \right) x_{ijp} \leq R^L \quad p \in P
\]  
(9)

\[
\sum_{(i,j) \in A} (1 - \lambda) h \left( t_{pi}^a - t_{pi}^a \right) x_{ijp} \leq R^C \quad p \in P
\]  
(10)

\[
\sum_{(i,j) \in A, p \in P} \lambda e^{L} h \left( t_{pi}^a - t_{pi}^a \right) x_{ijp} + \sum_{(i,j) \in A, p \in P} (1 - \lambda) e^{C} h \left( t_{pi}^a - t_{pi}^a \right) x_{ijp} \leq cap
\]  
(11)

\[Q_{p0} = 0 \quad p \in P\]  
(12)

\[x_{ijp} \in \{0,1\} \quad (i,j) \in A, p \in P\]  
(13)

\[Q_{pi}, t_{pi}^a \geq 0 \quad i \in N_1, p \in P\]  
(14)

The objective function (1) minimizes the total costs of debris collection, in which the first and second items represent LNG and diesel consumption cost, the third item represents rent cost, berthing cost and unloading cost, and the fourth item represents the vessel’s insurance cost and labor cost for every vessel.

Constraint (2) forces that each vessel starts from the origin harbor, constraint (3) ensures inflow to be equal to outflow at each debris area, constraint (4) limits that the number of debris vessels dispatched from origin harbor equals the number of debris vessels return to destination harbor. Constraint (5) ensures that each debris location can only be collected once by one vessel, and constraint (6) calculates arrival time of vessel at destination harbor and debris areas, where \( M_{ij} = t_i^1 + r_i + d_{ij}/v \). Constraint (7) is the time window limit of each point. Constraint (8) is a capacity chance constraint, which guarantees the probability of each vessel’s accumulated debris weight does not exceed the vessel’s capacity \( C \) is not less than the preset confidence level \( \alpha \). Constraints (9) and (10) limit fuel tank capacity. Constraints (11) is carbon gap limit. Constraint (21) initializes the cumulative weight of vessel at origin harbor. Finally, constraints (13) and (14) are variables declaration.

The random chance constraint (8) in the model is transformed into an equivalent constraint (15) with a certain probability density[11], as follows:

\[
\sum_{i,j \in N} E[\xi_j] x_{ijp} \leq \bar{C}
\]  
(15)

The constant \( \bar{C} \) can be obtained by formula (16)[12]:

\[
\bar{C} = \left( 2C + \tau^2 - \sqrt{\tau^4 + 4C \tau^2} \right)/2, \tau = \Phi^{-1}(\alpha)
\]  
(16)

\( \Phi(\alpha) \) is the distribution function of debris weight \( \xi_i \), \( \xi_i \sim \Phi(\xi_i) \). \( \Phi^{-1}(\alpha) \) is the inverse function of \( \Phi(\alpha) \).

The deterministic model is as follows

Objective function: formula (1);
Constraints: constraints (2) - (7);
Constraints (9) - (15).

4. Solution Method
In this paper, a VRP Spreadsheet Solver is used to optimize the vessel routing problem of LNG hybrid vessel collect marine debris. The solver created by Günes, Erdoğan is an open source spreadsheet solver for the VRP and its many variants. It contains a worksheet named VRP Solver Console and 5 worksheets named Locations, Distances, Vehicles, Solution and Visualization. The user can get the result and visualize the route by inputting data to the solver. The solver has the potential to be used largely due to
its accessibility, strong adaptability, and ease of use[13].

Large-scale neighborhood search algorithm (LNS) was applied to create the VRP Spreadsheet Solver. LNS was first proposed by Shaw, which mainly includes three processes: destroy operation, repair operation and local search[14]. In the iterative process, the removal operator and the insertion operator are set to search the neighborhood of the solution space, and a better solution is gradually obtained. The algorithm designed a variety of removal operators and insertion operators, and used four local search methods: customer exchange, 1-opt, 2-opt and vehicle exchange to diversify the search. Through comparison, it is found that the algorithm has the advantages of strong adaptability and good solution performance[13].

5. Computational Study
In this section, the large-scale neighborhood search algorithm is used to solve the proposed mathematical model, and a real-life case study is analyzed. In this case, Qingdao harbor was selected as the starting harbor, and LNG hybrid vessels were used to collect debris on the Yellow Sea. The modeling results are verified visually, and the results are compared and analyzed. The following results are all performed on a PC with AMD Ryzen 5 3500U processor and 8.0 GB RAM. The running time is 60 seconds, and the average value is taken after ten times of running.

We take Qingdao harbor as the original harbor and destination harbor, which has the same type of LNG hybrid vessels. We obtain the initial location of 30 marine debris by remote sensing technology, and import the ocean current, wind data and hydrological elements of the next seven days in the diagnostic mode of GNOME software to predict the trajectories and locate the positions. Figure 1 shows the distribution of marine debris at 8:00 a.m. on the first, third, fifth, and seventh days. The circles in Figure 1 indicate the location of collection debris, and the red five-pointed star marks the Qingdao harbor.

This study considers the same type of LNG hybrid vessels to collect marine debris. The vessels use
more eco-friendly fuel and have lower carbon emission. The LNG hybrid fishing boat designed by Wu Hui is adopted here[15]. The vessel adopts Weichai 6170 series dual fuel engine, and the mass ratio of LNG and diesel consumed by the vessel is 7:3. Weight capacity $C = 20\text{t}$, velocity $v = 50\text{km/h}$, diesel tank capacity $R^C = 4\text{t}$, LNG tank capacity $R^L = 8\text{m}^3$, hourly fuel consumption $h = 64\text{kg/h}$.

There are some parameters set with reference to the market price in 2020. The price of diesel is set at 5 yuan/liter and that of natural gas is set at 3000 yuan/ton. Vessel rent cost $u^Z = 1800\text{yuan/day}$, insurance cost $u^B = 10\text{yuan/hour}$, labor cost $u^R = 80\text{yuan/hour}$, unloading cost $u^u_{n+1} = 100\text{yuan/day}$, berth cost $u^t_{n+1} = 50\text{yuan/berth/day}$. Carbon capacity $cap = 30\text{ton}$, carbon emission factor of diesel $e^C = 3\text{kg/L}$, carbon emission factor of LNG $e^L = 1.19\text{kg/L}$[16].

Suppose debris weight $\xi_i$ is obeyed normal distribution function, expectation $\mu = 2$, variance $\sigma^2 = 1.3^2$, confidence level $\alpha = 0.9$, debris collection time $\tau_i = 2\text{h}$. The earliest departure time of the vessel is 8:00 and working time limit is 16 hours. According to the trajectory of debris movement predicted by GNOME, we take debris location at 8:00 a.m. as the initial position. According to the daily movement of garbage points, we record the time when debris location moves more than 5 nautical miles and set it as the latest service time $t^f$, set 8:00 as the earliest service time $t^e$.

5.1. Best collection time
Under the influence of ocean currents and wind, marine debris location is constantly changing. The changes of debris location will have a certain impact on the vessel collection route. Considering the total cost of debris collection, we prefer to choose the time when debris are closest to the harbor and the overall distribution is more concentrated. In this way, fewer vessels will be dispatched and the working hours of vessels and workers will be shorter, which will help us save cost and resource. So it is crucial to choose the right time to collect.

We calculated the distance between debris and the harbor, and counted the shortest distance, longest distance and average distance, as shown in Figure 2. It can be concluded from the figure that the shortest distance, the longest distance and the minimum average distance all appear in the fifth day. We can preliminarily judge that the best time to collect debris is the fifth day.

![Figure 2. Distance from debris to harbor.](image-url)

After a simple analysis of the distance between debris and the harbor, we initially think that the fifth day is the best collection time. In order to calculate total cost and travel time, the large-scale neighborhood search algorithm is used to optimize collection route of seven days, as shown in Figure 3.
It can be seen that the total cost and travel time of debris collection show a downward trend from the first day to the fifth day, and it shows an upward trend after the fifth day. It reached the lowest value on the fifth day. Among the seven days, the total cost of debris collection on the first day is the highest, which is 71,892.85 yuan, and the travel time is 153.15 hours. The lowest total cost was 56,262.40 yuan on the fifth day, and the travel time was 118.73 hours. Compared with the first day, collecting debris on the fifth day can reduce costs by 15,630.45 yuan, a reduction of 21.74%; travel time is reduced by 34.42 hours, a reduction of 22.47%.

Based on the above analysis, we recommend sending vessels to collect debris on the fifth day, so as to minimize the total time and cost. Next, we will only analyze the debris distribution state on the fifth day.

5.2. Sensitivity analysis of vessel fuel ratio

For hybrid vessels, the fuel ratio is an important factor affecting the total cost and carbon emission. In this case, a hybrid vessel with a mass ratio of 7:3 LNG to diesel fuel was initially utilized. Next, we explore the impact of fuel mass ratio on total cost and carbon emission. Table 1 shows the rent cost of vessels with different fuel mass ratios, of which vessel A4 is used above.

**Table 1. Parameters of vessel with different fuel ratios.**

| Vessel Types | Fuel Ratio (LNG: Diesel) | Rent Cost (yuan/day) |
|--------------|--------------------------|---------------------|
| A1           | 10:0                     | 2100                |
| A2           | 9:1                      | 2000                |
| A3           | 8:2                      | 1900                |
| A4           | 7:3                      | 1800                |
| A5           | 6:4                      | 1700                |
| A6           | 5:5                      | 1600                |
| A7           | 4:6                      | 1500                |
| A8           | 3:7                      | 1400                |
| A9           | 2:8                      | 1300                |
| A10          | 1:9                      | 1200                |
| A11          | 0:10                     | 1000                |
Figures 4 and 5 show the total cost, carbon emission and their change rate of debris collection by vessels with different fuel ratios, respectively. It can be seen with the increase of diesel proportion, the total cost and carbon emission show an upward trend. The higher proportion of LNG in the hybrid fuel, the more vessel rent cost. However, due to the economy and environmental conservation of LNG, the higher the proportion of LNG, the lower hourly fuel cost consumed by vessels, and the lower carbon emission.

As can be seen from the figure, for every 10% increase in the proportion of LNG, the total cost can be reduced by 1669.58 yuan or 3.26%; the carbon emission can be reduced by 611.70 kg or 2.86%. Vessel A1 is a LNG vessel, and the total cost and carbon emission of choosing vessel A1 to collect debris are the lowest, with a total cost of 51253.65 yuan and a carbon emission of 21352.40 kg; vessel A11 is a diesel vessel, and the total cost and carbon emission of choosing vessel A11 to collect debris are the highest, with a total cost of 68159.49 yuan and a carbon emission of 27469.37 kg. Compared with vessel A11, using LNG vessel A1 to collect debris can save cost 16905.84 yuan, reduce 32.98%, and save carbon emission 6116.97 kg, reduce 28.65%. Compared with vessel A4 with the mass ratio of LNG to diesel 7:3, the total cost can be reduced by 5008.75 yuan, down 9.77%; the carbon emission can be reduced by 1835.09 kg, down 8.59%. This fully reflects the advantages of new energy vessels, which can not only save costs, but also reduce carbon emission. Therefore, encouraging the use of new energy vessels is conducive to environmental protection and sustainable development.

Compared with vessel A2, the proportion of LNG fueled by vessel A1 is increased by 10%, the rent
cost is increased by 100 yuan, and the hourly fuel consumption cost is reduced by 20.80 yuan. Through
calculation, it is found that if the travel time of a vessel is more than 4.81 hours, choosing vessel A2 will
have lower total cost and carbon emission; otherwise, choosing vessel A2 is conducive to cost saving,
but the higher proportion of LNG, the less carbon emission.

It is found that when the travel time is more than 4.81 hours, the total cost and carbon emission of
the vessel with a higher proportion of LNG are always lower. Otherwise, the vessel with a lower
proportion of LNG has a lower cost, but the carbon emission of the vessel with a higher proportion of
LNG will be lower.

5.3. Analysis of Total Cost and Carbon Emission by Changes in Vessel Capacity
Vessels with different capacity have a certain influence on the marine debris collection. In this section,
we will discuss the impact of changes in vessel capacity on total cost and carbon emission. Table 2
shows the specific parameters of vessels with different capacities, in which vessel III is the basic vessel
type A4 used above.

Table 2. Vessel parameters of different capacities.

| Vessel Type | Vessel Capacity(t) | Fuel Consumption(kg/h) | Rent Cost(yuan/day) |
|-------------|--------------------|------------------------|-------------------|
| I           | 10                 | 48                     | 1000              |
| II          | 15                 | 56                     | 1400              |
| III         | 20                 | 64                     | 1800              |
| IV          | 25                 | 72                     | 2200              |
| V           | 30                 | 80                     | 2600              |

Figure 6 shows the travel time and total cost of debris collection by vessels with different capacities.
As can be seen from the figure, when the vessel capacity increases from 10 tons to 15 tons, the total cost
decreases; when the vessel capacity is more than 15 tons, the total cost increases. The travel time shows
a downward trend when the capacity increases from 10 tons to 20 tons and remains unchanged when
capacity is more than 20 tons. When capacity is equal to 30 tons, the total cost is the highest, which is
70198.27 yuan. When capacity is equal to 15 tons, the total cost is the lowest, which is 54706.41 yuan.
Compared with 30 tons, the total cost is reduced by 15,491.86 yuan, or 22.07%. When capacity is equal
to 10 tons, the travel time is 151.32 hours; the minimum travel time is 118.73 hours when the capacity
is equal to 20, 25 and 30 tons, which can save 32.59 hours or 21.54%.

Through the comparison of solutions, it is found that when the vessel capacity is 10 tons and 15 tons,
15 vessels and 10 vessels need to be dispatched respectively. With the increase of vessel capacity, the
total fixed cost and collection time decrease, and the time-related variable cost and total cost decrease.
When the vessel capacity is 20 tons, 8 vessels are dispatched. Compared with 10 vessels with a capacity
of 15 tons, the total fixed cost increases. Although the total time is reduced by 7.5 hours, the total variable
cost increases due to the increase of hourly fuel consumption, resulting in the increase of total cost. When the vessel capacity is 20 tons, 25 tons and 30 tons, 8 vessels are dispatched. The total fixed cost and fuel consumption cost increase with the increase of vessel capacity, while the travel time remains unchanged, the variable cost increases, and the total cost shows an upward trend. The collection routes of each kind vessels are the same, although the capacity is increased, they can not collect more debris due to the time window, which lead to the waste of vessel capacity.

![Figure 7. CO2 emission and change rates of debris collection by vessels of different capacities.](image)

Figure 7 shows the change in carbon emission of debris collection by vessels with different capacities. As can be seen from the figure, vessels with a capacity of 30 tons produced the most carbon emission, which is 28,964.84 kg; vessels with a capacity of 15 tons produced the lowest carbon emission of 21,570.69 kg. Compared with 30-ton vessels, it can save 7394.15 kg of carbon emission, reducing 25.53%.

6. Conclusion

With the increasing attention to marine debris pollution, how to collect marine debris efficiently has become a hot topic. From the perspective of logistics network optimization and considering the uncertain factors of debris weight, this paper adopted LNG hybrid vessels to collect marine debris, established a stochastic chance constrained programming model, and used LNS algorithm to solve and analyze the problem, get the following conclusion.

(1) The distribution of debris affects the total cost and travel time. The more concentrated the distribution of debris is, the closer it is to the port, the less the total cost will be. Compared with the worst case, the total cost and travel time of the best collection time can be saved by 21.74% and 22.47% respectively.

(2) The total cost and carbon emission decrease with the increasing proportion of LNG in vessel fuel. Every 10% increase in the proportion of LNG will reduce the total cost by 3.26% and the carbon emission by 2.86%. Compared with diesel vessels, LNG vessels can save cost by 32.98% and reduce carbon emission by 28.65%. When the travel time of a vessel collecting debris is more than 4.81 hours, the total cost and carbon emission of the vessel with larger proportion of LNG will be less. Otherwise, the total cost of the vessel with smaller proportion of LNG will be less. The greater the proportion of LNG, the less the carbon emission will always be.

(3) In order to make full use of the vessel capacity, the weight and time window of the debris should be taken into account when selecting the vessel capacity. In this case, the vessel with a capacity of 15 tons has the lowest total cost and carbon emission, which can reduce the cost by 22.07% and carbon emission by 25.53%.

This paper only considered the uncertainty of marine debris weight. Due to the complexity of the marine environment, the locations of marine debris are changing constantly, so it is difficult to determine its location accurately, which brings great difficulties to the problem of marine debris collection route,
which is also an aspect worth studying and discussing in the future.

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