Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

Multi-objective Optimization of Heterogeneous Liner Fleet Deployment with Shipping Downturn Considerations

Shihao Gong, Zhangchi Sun, Jiabao Zhao*
College of Transportation Engineering, Dalian Maritime University, Dalian, Liaoning, China
*Corresponding Author.

Abstract:

This paper considers the optimization problem of fleet deployment during the shipping downturn for liner shipping companies. In the operation of the liner shipping companies, there is a rising trend to deploy a heterogenous fleet on certain route. Especially when the shipping market is depressed, the combination of ships with different carrying capacities (i.e., heterogeneous fleets) can reduce the waste of carrying capacity. The excessive transportation capacity will increase the capital cost and the maintenance cost. Consequently, the reduction of the capacity loss and the minimization of the operation cost of the liner ships are both vital for the liner shipping companies. The problem is formulated into a multi-objective optimization problem. And then an improved non-dominated sorting genetic algorithm-II (NSGA-II) is used to solve the problem. A case study is provided to illustrate the application of the model.

Keywords*: Multi-objective optimization, Heterogeneous fleet, Liner fleet deployment, NSGA-II, Shipping downturn.*

I. INTRODUCTION

International liner shipping is the keystone of the international trade and the major contributor to the global economy. The liner shipping transportation is known to be especially sensitive to the fluctuation of the global economy, which seriously influenced the demand, price of the liner transportation and the profitability of the liner shipping companies. [1] In this context, in order to cope with the constantly fluctuating transport demand, reduce the company's operational risks, and reduce the empty-loading ratio and loss of space caused by market fluctuations, the liner company have to deal with various problems at the strategic, tactical, and operational planning levels.

Fleet deployment decision is a crucial on the tactical planning level [2]. Liner shipping fleet deployment problem is a complex optimization problem, there is a large amount of literature on shipping route planning and a large amount models and algorithms to solve this problem. Yang Qiuping et al [3] used mixed integer programming model to simulate the fleet planning process for liner shipping and obtained the optimal solution to the multi-route, multi-ship, large-scale fleet planning through heuristic

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

algorithm. S.Gelarsh et al [4] established a nonlinear mixed integer for the fleet deployment problem within a short-term planning horizon. Considering the rising trend of the concept of green shipping, Christos A. Kontovas [1] reviews the literature on the green ship routing and scheduling problem, and summarized the major approaches to reduce emission and solve the green ship routing and scheduling problem. Wang Zhen-yu [5] et al. constructed a double-layer optimization model for ship allocation and cargo allocation under the influence of the COVID-19 and the low-carbon strategy, and optimized the main operating indicators of liner transport companies. Xu Huan [6] optimized the sailing speed of liner ships by introducing decision-making variables such as ship carbon emissions into the traditional liner shipping deployment model in order to balance the profit and the ecological pollution produced by the liner ship. In the heterogeneous shipping fleet planning, Junayed Pasha et al purposed an integrated optimization method for the heterogeneous ship fleet and environmental consideration.

Indeed, these literatures may have researched the liner shipping fleet deployment problems under different scenarios. However, few of these studies have considered the transportation demand fluctuations of the liner shipping market. Especially in the context of shipping market downturns, the empty-loading rate of container ships generally increases. On such conditions, except for the optimization of the liner shipping deployment of each route, liner companies are also dropping the sailing speed as an efficacious measure to absorb excessive transportation capacity. Whether the liner shipping companies can survive in the shipping market downturn is particularly relevant to the companies' fleet deployment decisions during that period. In addition, the majority of the researches assume that the liner companies deploy homogenous fleets of ships along many routes, which assumption has significant disadvantages in the real-world scenarios. Given the fact that many liners companies are now deploying heterogeneous fleets along many of their service routes and the advantages of the heterogeneous fleets compared with the homogeneous fleets, such as the lower port charges, higher flexibility and lower fuel consumption.

Consequently, to cope with the characteristics of the shipping market downturn, the present study constructs a multi-objective optimization strategy for the heterogeneous liner fleet deployment, which gives consideration to both the cost of the liner shipping companies and the loss of the transportation capacity caused by the transportation demand volatility, using the strategy to optimize the fleet and voyage allocation on each route. This strategy considers the effect of liner shipping deployment on the total operation costs while minimizing the transportation capacity loss of the liner company during the planning period.

The organization of this paper is as follows: section 2 gives assumptions and proposes a multi-objective model. Section 3 provides an improved NSGA-II algorithm [7] (I-NSGA-II) to solve the proposed model by a case. Finally, some conclusions and recommendations for further research are proposed.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

II. PROBLEM STATEMENTS AND MODEL BUILDING

2.1 Problem Statement

The liner shipping fleet deployment involves the ship deployment decisions of liner ships within the planning horizon, including the deployment of shipping fleets on specific liner service routes and determining the sailing speed of each ship on the shipping route, on the premise of satisfying the technical and operational requirements of each route [9]. In order to minimize the total cost of the liner transportation, liner shipping companies have to optimize their fleet deployment on specific routes. Also, in order to deal with the transportation demand decline caused by the shipping downturns, liner shipping companies also have to minimize the empty-loading ratio of the allocated liner ships required to cover the transportation demands in order to reduce waste of the transportation capacity [9].

Assume that there is one liner company that possesses m types of container ships in its fleet and n service routes. The liner shipping deployment optimization is designed to maximize the profit of the liner company and minimize the capacity loss of liner shipping companies.

2.2 Assumptions

In order to facilitate the research, the problem has some presumptions as follows:

1. The planning horizon of the liner shipping deployment decision is one year.

2. During the planning horizon, the transportation capacity of the liner shipping fleet remains the same. No investment in the new constructed vessels or demolition of the old ships is carried out. No ship is charted in or out.

3. The predicted transportation demand is distributed evenly throughout the planning horizon.

4. The transportation freight of each shipping route is the average freight rate of the planning horizon.

5. The sailing speed of the liner ship is predetermined in the liner shipping fleet deployment decisions, which will not be influenced by the loading conditions, route conditions.

2.3 Model Building

2.3.1 Parameters description

Suppose that a liner company has a set of ship types: $I = \{i \mid i = 1, 2, \ldots, m\}$ and a set of service shipping routes: $J = \{j \mid j = 1, 2, \ldots, n\}$. The sets, parameters and decision variables used in the model are defined as follows:

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

Sets

Notation	Denotation
I	set of ship types
J	set of routes
$D=\{d_1,d_2\}$	set of shipping courses(d_1 : forward course, d_2 : backward course)
H_{ij}	set of annual voyages for a ship of type $i \in I$ on route $j \in J$, $H_{ij}=[LF_{ij},UF_{ij}]$

Parameters

Notation	Denotation
$h_{ij} \in H_{ij}$	the number of annual voyages for a ship of type $i \in I$ on route $j \in J$
c_{ijh}	the voyage cost for a ship of type $i \in I$ on route $j \in J$ operating h_{ij}
r_{ij}	=1 if vessel type i can be deployed on route j; (=0 otherwise)
t	the planning horizon under consideration (in months)
l_j	the length of the round voyage of the route j (in nautical miles)
w_i	the capacity of a ship of type $i \in I$ (in TEU)
s_i	the number of ships of type $i \in I$
p_{jd_1}	the freight rate of forward course of route j (in USD/TEU)
p_{jd_2}	the freight rate of backward course of route j (in USD/TEU)
Q_{jd_1}	the estimated transportation demand of the forward course on route j within the planning horizon (in TEU)
Q_{jd_2}	the estimated transportation demand of the backward course on route j within the planning horizon (in TEU)
C_{ijh}	the single voyage cost of ship i to operate on the route j for h_{ij} round voyages within the planning horizon (in USD)
v_{ij}	the sailing speed of ship i to operate on the route j (in KNOTS)
$v_{i\min}$	the minimum sailing speed of ship i (in KNOTS)
$v_{i\max}$	the maximum sailing speed of ship i (in KNOTS)
LF_{ij}	the minimum annual voyage number of ship i operating on the route j , $LF_{ij}=\left\lfloor \frac{l_j}{v_{i\min}} \right\rfloor$
UF_{ij}	the maximum annual voyage number of ship i operating on the route

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

	j, $UF_{ij} = \left\lfloor \frac{l_j}{v_{i\max}} \right\rfloor$
E_i	the annual idle cost of the ship i during the planning horizon (in USD)
R_{jd_1}	The estimated average loading rate of the ship operating on the forward course of route j, $R_{j_{d1}} \in (0,1)$
R_{j2}	The estimated average loading rate of the ship operating on the backward course of route j, $R_{j_{d1}} \in (0,1)$

Decision variables

Notation	Denotation
x_{ijh}	the number of ships of type $i \in I$ to be deployed on route $j \in J$ completing h_{ij} voyages

2.3.2 Objective function

The objective function of the model is formulated as follows:

The minimum operation cost of the liner shipping companies within the planning horizon:

$$\min Z_1 = \sum_{h \in H_{ij}} \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ijh} h_{ij} x_{ijh} + \sum_{i=1}^{m} E_i (S_i - \sum_{j=1}^{n} \sum_{h \in H_{ij}} x_{ijh}) \quad (1)$$

In the context of the shipping downturns, the liner shipping companies will try to minimize its operation cost of the liner shipping transportation to survive in the fierce competition. Objective function (1) considers the different transportation demands of forward and backward transportation on each route and the voyage cost of the transportation on each route and the idle cost of the ships (including the wages and maintenance fees of the custodian and other expenses of the laid-up ships).

The minimum loss of transportation capacity:

$$\min Z_2 = \frac{\sum_{h \in H_{ij}} \sum_{j=1}^{n} \sum_{i=1}^{m} w_i h_{ij} x_{ijh} - \sum_{j=1}^{n} (Q_{jd_1} + Q_{jd_2})}{\sum_{h \in H_{ij}} \sum_{j=1}^{n} \sum_{i=1}^{m} w_i h_{ij} x_{ijh}} \quad (2)$$

Besides the operation costs, the fleet itself also requires the regular maintenance and great financial investment, which will impose a heavy maintenance and capital cost for the liner shipping companies,

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

especially for the shipping downturn period. In order to cope with these costs, the liner shipping companies will have to minimize the loss of transportation capacity to reduce the costs except for the operation costs described in the objective function (1).

2.3.3 Constraints

$$0 < \frac{Q_{jd_1}}{\sum_{i=1}^{m}\sum_{h\in H_{ij}}(w_i h_{ij} x_{ijh})} \le R_{jd_1}, j = 1,2,\ldots,n \tag{3}$$

$$0 < \frac{Q_{jd_2}}{\sum_{i=1}^{m}\sum_{h\in H_{ij}}(w_i h_{ij} x_{ijh})} \le R_{jd_2}, j = 1,2,\ldots,n \tag{4}$$

$$0 \le \sum_{j=1}^{n}\sum_{h\in H_{ij}} x_{ijh} \le s_i, i = 1,2,\cdots,m \tag{5}$$

$$\sum_{h\in H_{ij}} x_{ijh} h_{ij} \le r_{ij} M \tag{6}$$

$$x_{ijh} \ge 0, x_{ijh} \in Z \tag{7}$$

Constraint (3)-(4) separately impose a maximum average loading ratio constraint on the liner ships which provide on the forward and the backward transportation. Given the fact that the loading ratio of the liner ships is generally low during the shipping downturns, these two constraints are introduced to simulate the capacity loss caused by the shipping downturn [9]. On the other hand, they also ensure the estimated transportation demands will be satisfied by the liner ships deployed on the route. Constraint (5) reflects ship deployed to the liner routes can't exceed the total quantity of this type of ships. Considering the fact that the liner shipping deployment decisions are also have to be technically feasible. Constraints such as port depth or loading and unloading equipment will make some ships unable to operate on certain routes. In constraint (6), M is a sufficient large value. If the ship i cannot be deployed on the route j, $r_{ij} = 0$, then the constraint (6) leads to $x_{ijh} = 0$. No ship i can be deployed on route j. Otherwise, constraint (6) becomes redundant. Constraint (7) guarantees the non-negativity of the ship's quantity.

III. SOLUTION METHOD

Considering the actual situation of liner fleet deployment, liner shipping companies need a set of equally good Pareto-optimal solutions, so that the decision-maker can choose the optimal solution based on the degree of demand volatility. The multi-objective genetic algorithm (MOGA) is a commonly used

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

heuristic algorithm to achieve this.

One significant concept in the MOGA is the non-dominated relationship between populations. For example, if there is k objective functions denoted as $f_i(x), i = 1, 2, 3, \cdots, k$. For any objective function, the solution x_1 is no worse than x_2, and at least one objective function solution is strictly better than solution x_2, which means that solution dominates solution. In each generation of population, all non-dominated solutions constitute the set of Pareto-optimal front solutions.

This paper uses the improved version of the non-dominated sorting genetic algorithm (I-NSGA-II) to solve the heterogeneous liner fleet deployment problem [10]. The NSGA-II combines the genetic algorithm with a fast non-dominated sorting approach and a crowding-distance assignment algorithm to create a various set of Pareto-optimal front solutions. But the elitism of the traditional NSGA-II algorithm will reduce the diversity of the gene pool. In order to solve this problem, this paper improves the traditional NSGA-II in terms of mutation strategy, and proposes a mutation probability adjustment strategy, which adjusts the mutation rate of its progeny chromosomes by calculating the correlation of crossed chromosomes, effectively alleviating the problem of insufficient population diversity and avoiding premature convergence of the algorithm to a local optimal solution [12].

In our problem, the decision variables are $\{x_{ijh}, i \in I, j \in J, h \in H_{ij}\}$. The chromosome (i.e., solution) is represented by an integer instead of traditional binary coding.

Fig. 1 shows the chromosome structure, and Fig.2 shows the I-NSGA II algorithm adopted in this paper, which consists of the following seven main steps.

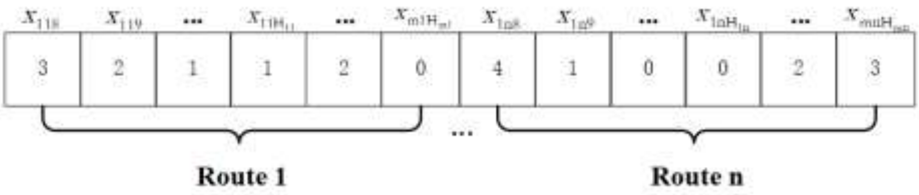


Fig 1: Chromosome structure

Step 1: Generate the initial solutions. According to the chromosome coding rules, generate the initial population P_t satisfying the constraints, and the population size is N. Each of them represents a route ship allocation plan;

Step 2: Non-dominating ranking. Consider a population with k objective functions and N in size, the initial population is categorized into subsets using the non-dominating ranking algorithm, and the specific steps are as follows:

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

(1) Assume $p=1$;

(2) For the all $q=1,2,\cdots,N$ and $q\neq p$, judge the dominance and non-dominance relationships between individual x^p and x^q based on the objective function;

(3) If there is no individual x^q is strictly better than x^p, then mark x^q as a non-dominant individual;

(4) Let $p=p+1$, go to step (1) until all non-dominated individuals are found. The non-dominated individuals obtained through the above steps are the first-level non-dominated layer of the population. Then ignores these marked non-dominated individuals. Steps (1)-(4) are performed in sequence until the entire population is stratified.

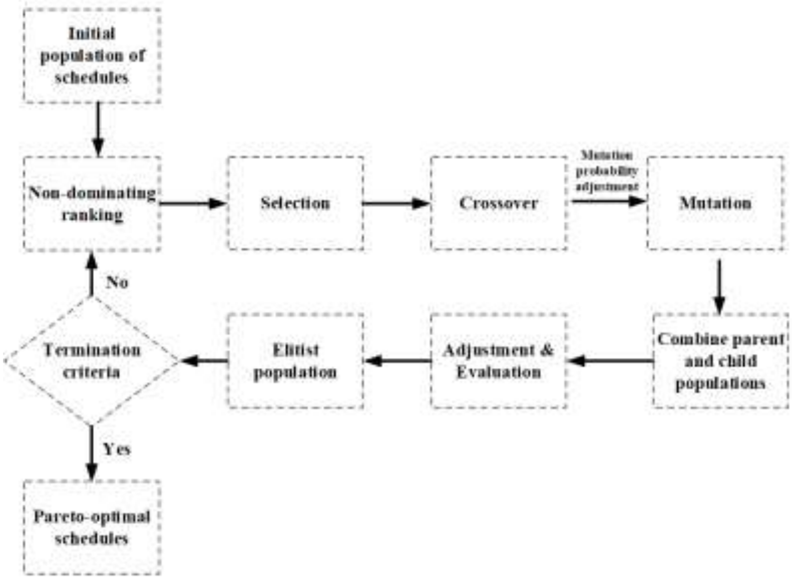


Fig 2: Process of I-NSGA II with mutation probability adjustment strategy

Step 3: Selection. The selection of parents' chromosome is carried out by the roulette algorithm, and each individual determines the probability of being selected according to its own crowding distance in this layer. Crowding distance refers to the density of individuals around a given individual in the population, which is measured by the length of the largest rectangle that only contains the individual itself around the individual. The higher the crowding degree, the greater the probability of being selected.

Step 4: Crossover. The crossover operation adopts the analog binary single-point crossover operator, and its calculation formula is as follows:

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

$$\bar{x}_{1j} = 0.5\left[(1+\delta_j)x_{1j}(t)+(1-\delta_j)x_{2j}(t)\right] \tag{8}$$

$$\bar{x}_{2j} = 0.5\left[(1-\delta_j)x_{1j}(t)+(1+\delta_j)x_{2j}(t)\right] \tag{9}$$

$$\delta_j = \begin{cases} (2u_j)^{\frac{1}{\eta+1}}, u_j \le 0.5 \\ \left(2(1-u_j)\right)^{\frac{1}{\eta+1}}, u_j > 0.5 \end{cases} \tag{10}$$

In the formula, x_{ij} and $\bar{x}_{i,j}$ (i=1,2)represent the gene of parent and child on the j position respectively; u_{ij} is a random number within $(0,1)$; η is distribution index, $\eta > 0$.

Step 5: Mutation. This paper optimizes the mutation process, designs a new mutation strategy, calculates the correlation of the two chromosomes that will be crossed, and calculates different mutation rates according to the progeny chromosomes of different blood relations to replace the traditional single mutation rate in the genetic algorithm, the algorithm diagram is as follows:

Algorithm 1. Mutation Probability Modification Strategy

Input: chromosome y_1, chromosome y_2, initial mutation probability p_m, the total number of genes in a chromosome n

Output: corrected mutation probability p'_m

```
1: t = 0  // t is the number of same genes in two chromosomes
2: for each i ∈ [1,n] do
3:     if y1(i) == y2(i) then
4:         t = t + 1
5:     end if
6: end for
7: s = t / n  // s is the correlation of two chromosomes
8: p'm = pm × s
9: return p'm
```

Fig 3: Mutation probability modification strategy

Further, a bidirectional random mutation operator is used to perform mutation operations on the individuals to be mutated. According to the bidirectional random optimization theory, the bidirectional random mutation operator performs random searches in both positive and negative directions for each gene, which further ensures the diversity of the population. The specific operations are as follows:

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

$$\bar{x}_j = \begin{cases} x_j(t) + \delta_j, u_j \le 0.5 \\ x_j(t) - \delta_j, u_j > 0.5 \end{cases} \tag{11}$$

Step 6: Merge the parent and child populations, use the elitism to build the merged population, retain the individuals with higher layers and large crowding distances until the limit of the population size N is met, and a new generation of population P_{t+1} is obtained;

Step 7: Stopping criterion. Determine whether the maximum number of iterations is reached, if so, stop the calculation and obtain the final Pareto solution set. The algorithm ends; otherwise, return to step;

IV. NUMERICAL CASE STUDY

4.1 Basic Data

In this section, the multi-objective optimization model is inspected through a numerical case study in order to examine the validity and the efficiency of the proposed model.

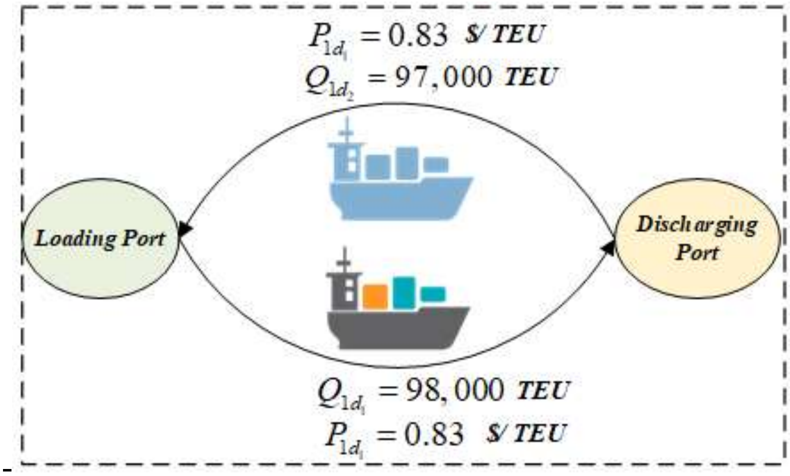


Fig 4: Heterogenous fleet (Route1)

The data used in the case study were served by Shao et al (2014)'s research. Some parameter values about the fleet operation conditions, shipping routes and voyage costs used in the case study were reasonably assumed and adjusted is presented in the TABLE I-III. Since the shipping speed limitation data were not reported by Shao et al, without loss of generality the following speed limitation have been assumed in this case study. The operation time of the liner fleet is 345 days during the planning horizon Considering the limitation of the route conditions, we assume that the ship type 4,5 can't operate on the route 4 and route 5 due the technical restrictions. In order to ensure the continuous service of the liner transportation, the actual operation speed of the liner ships must be within the limitations of the operation

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

speed.

TABLE I. Shipping fleet data

Ship type	S_i	W_i **(in TEU)**	$v_{i\min}, v_{i\max}$ **(in knots)**	E_i **(in thousand USD)**	B_i	$r_{ij}, j \in J$
1	3	3 700	11.52, 17.28	2960	0.4487	1,1,1,1,1
2	4	5 400	12.08, 18.12	3690	0.5012	1,1,1,1,1
3	5	7 600	13.12, 19.68	4100	0.6389	1,1,1,1,1
4	5	10 000	13.44, 20.16	4860	0.7859	1,1,1,0,0
5	3	13 000	14.56, 21.84	5120	0.9288	1,1,1,0,0

TABLE II. Shipping Route data

Route	Q_{jd_1} **(in thousand TEU)**	Q_{jd_2} **(in thousand TEU)**	P_{jd_1} **(in thousand $/ TEU)**	P_{jd_2} **(in thousand $/ TEU)**	R_{jd_1}	R_{jd_2}	l_j **(in nautical miles)**
1	98	97	0.83	0.81	0.71	0.69	5706.08
2	86	85	0.86	0.85	0.78	0.76	6720.14
3	91	92	0.81	0.79	0.82	0.78	4583.34
4	79	81	0.73	0.72	0.76	0.73	7384.94
5	93	91	0.78	0.81	0.75	0.79	8372.03

TABLE III. Voyage cost P_{ij} **(in thousand $/ TEU)**

Ship type	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**
1	572	473	411	328	406
2	709	586	509	407	613
3	1218	1007	876	701	597
4	1314	1098	955	-	-
5	1688	1389	1207	-	-

To start with, the upper bound and the lower bound of the number of the annual voyages of each ship type on each shipping route is acquired through the route distance and the limitations of the shipping speed.

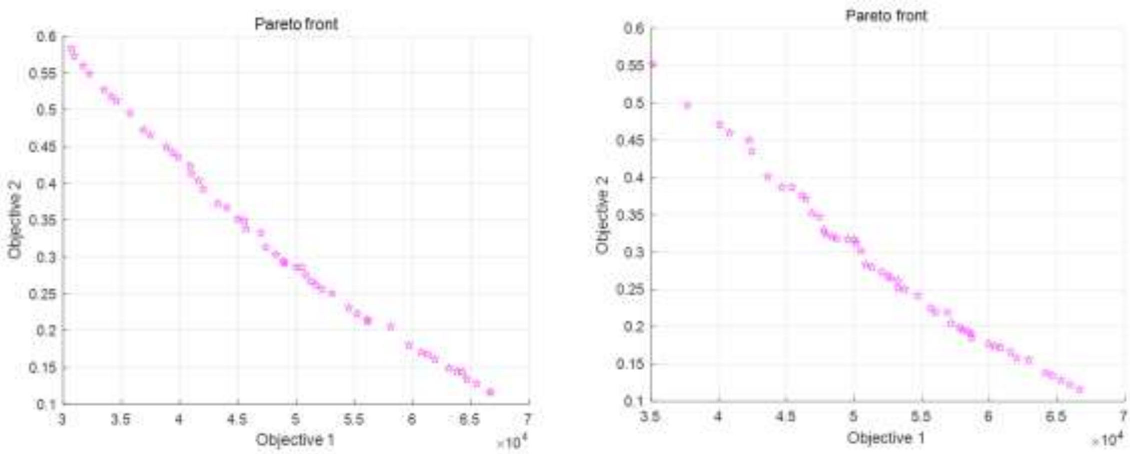
TABLE IV. Limitations of annual voyage numbers (UF_{ij}, LF_{ij})

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

Ship type	Route1	Route2	Route3	Route4	Route5
1	12,8	10,7	15,10	9,6	8,5
2	13,8	11,7	16,10	10,6	8,5
3	14,9	12,8	17,11	11,7	9,6
4	14,9	12,8	18,12	11,7	9,6
5	15,10	13,8	19,13	12,8	10,7

4.2 Computational Results

In this paper, we use MATLAB as the platform to implement the multi-objective heterogeneous fleet deployment model. The parameters are as follows: population size $N = 200$, the crossover probability $P_c = 0.8$, the initial mutation probability $P_m = 0.1$, the maximum number of number of iterations $G = 2000$. We simultaneously find the optimal value convergence of NSGA-II and I-NSGA-II, which is shown in Fig.5. For the Pareto-optimal front solutions obtained by I-NSGA-II, 10 ship allocation solutions that meet the requirements are obtained after screening, which is shown in TABLE V.



(a) I-NSGA-II (b) NSGA-II

Fig 5: Optimal value convergence

In TABLE V, the total cost of the liner companies in the pareto solution $5^{\#}$ is 46.27 million US dollars, and the waste of capacity is 31.12%. Compared with the solution $10^{\#}$, although the total cost has increased by 30.64%, the rate of waste of capacity has been reduced by 43.83%. The difference of these two parameters is the largest among all Pareto solutions, reaching 13.19%, which means that the solution $5^{\#}$ can be used as a more rational choice for decision-makers. The specific fleet deployment decision of the scheme is shown in TABLE VI. The numbers in parentheses represent the annual operating voyages, and the numbers before the parentheses represent the number of ships of this type that operate on the route

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

with the voyages in parentheses. For example, "1(9), 1(8)" means that on route 5 ships of No. 3 should be allocated, one of which operates 9 voyages per year, and the other operates 8 voyages per year. The last column in the table shows the number of laid-up ships of each type.

TABLE V. The parameter corresponding to the Pareto solution set

Pareto solutions	Operation cost (thousand $)	Loss of capacity	Compared to solution $10^{\#}$		
			Percentage of cost increase	Percentage of reduction in capacity loss	Difference
1	66673.06	11.21	82.60	79.77	-2.83
2	65193.85	12.69	78.84	77.09	-1.75
3	47757.21	29.48	34.42	46.79	12.37
4	58178.51	19.30	60.97	65.16	4.19
5	**46271.59**	**31.12**	**30.64**	**43.83**	**13.19**
6	44075.11	35.47	25.05	35.97	10.92
7	48471.71	28.66	36.24	48.27	12.03
8	49270.22	27.65	38.28	50.09	11.81
9	39262.55	46.21	12.79	16.59	3.80
10	34241.52	55.40	-	-	-

TABLE VI. Ship deployment plan

Ship type	Route 1	Route 2	Route 3	Route 4	Route 5	sealed
1	0	1(10)	1(12)	0	0	1
2	1(11)	0	0	1(15)	1(10)	1
3	0	0	1(10)	1(11),1(7)	1(9),1(8)	0
4	1(11),1(10)	1(12)	1(9)	-	-	1
5	1(12)	1(13)	1(19)	-	-	0

Of course, in the above Pareto solution, decision makers can flexibly choose the ship deployment plan according to their own preferences and the strategic goals of the company[13]: if the company predict the downturn period of the shipping market will be alleviated soon, the liner company can give priority to the minimum total cost, that is, choose $10^{\#}$ scheme; Otherwise, $1^{\#}$ scheme will be a better choice.

Using NSGA-II to solve the calculation example, the ideal result in Pareto-optimal front solutions is that the total cost is 48.82 million US dollars, and the loss of capacity is 31.87%, which proves that the mutation strategy designed in this paper can improve the population. diversity, resulting in better individuals.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

V. CONCLUSION

This study considers the heterogenous fleet deployment of the liner shipping deployment strategies of the liner shipping companies and presented a multi-objective optimization model for the liner shipping deployment problems of the heterogeneous liner fleets in order to minimize the operation costs of the liner shipping companies and the transportation capacity loss of the fleet deployment. The optimization objective of this model is to minimize the operation costs of the liner ships and reduce the capacity loss of the liner shipping companies. The model considered the costs of the liner shipping operations, including the idle cost of the ships. Also, it incorporated several restraints (i.e., the technical compatibility between ship types and the route, the employ-loading ratio caused by the demand decline) and allowed the model to have more managerial meaning to guide the real-world liner shipping fleet deployment decisions, especially for the shipping downturns.

Considering the computational complexity of the multi-objective optimization model for the liner shipping deployment problems of the heterogeneous liner fleets, an improved non-dominated sorting genetic algorithm (I-NSGA-II) was used to solve the heterogeneous liner fleet deployment problem. Given the fact that the elitism of the traditional NSGA-II algorithm will reduce the diversity of the gene pool, to cope with the problem, the proposed I-NSGA-II algorithm adopted a mutation possibility modification strategy based on the relevance of the correlation of crossed chromosomes to adjust the mutation rate of its progeny chromosomes, and effectively alleviating the problem of insufficient population diversity.

Numerical experiments were conducted on the basis of the 5 real-world shipping routes served by the liner shipping companies. The proposed I-NSGA-II algorithm produced a set of good-quality Pareto solutions to the liner shipping fleet deployment problem which reduces the capacity loss and the operation capacity simultaneously compared with the exacting single-objective optimization method. In order to illustrate the efficiency of the I-NSGA-II algorithm, the performance of the I-NSGA-II algorithm is compared with the results produced by the NSGA-II algorithm. The results shows that the average operation cost of this model was 5.22% lower and the loss of the transportation is 37.53% lower, which means the improvement of the algorithm could improve the efficiency of the solution of the problem.

Based on the results of the research, generally the capacity loss ratio will increase with the reduction of operation costs of the liner shipping fleets. In order to cope with the pressure of the shipping downturn, the liner shipping companies have to make the rational decision based on the operating situation of the liner shipping company itself. If the company predict the downturn period of the shipping market will be alleviated soon, it can increase the transportation capacity operating on the shipping routes to save operation costs and try to take advantage of the future market recovery. However, if the shipping downturn will persist for the relatively long period, the maintenance and the capital cost of the excessive transportation capacity will be a heavy burden for the liner shipping companies. Consequently, the liner shipping companies should modify the sailing speed of the liner ships to absorb the excessive transportation capacity and reduce the empty-loading ratio of liner ships to reduce the maintenance and capital costs during the downturn period.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 426-440
Article History: Received: 05 April 2022, Revised: 27 April 2022, Accepted: 03 May 2022, Publication: 14 May 2022

REFERENCES

[1] KONTOVAS, Christos A. The green ship routing and scheduling problem (GSRSP): a conceptual approach. Transportation Research Part D: Transport and Environment, 2014, 31: 61-69

[2] PASHA, Junayed, et al. An integrated optimization method for tactical-level planning in liner shipping with heterogeneous ship fleet and environmental considerations. Advanced Engineering Informatics, 2021, 48: 101299

[3] Yang Qiuping, Xie Xinlian, Pei Guangshi. Modeling and Simulation of Fleet Planning for Liner Shipping. Journal of Southwest Jiaotong University,2011,46(06):1046-1054

[4] GELAREH, Shahin; MENG, Qiang. A novel modeling approach for the fleet deployment problem within a short-term planning horizon. Transportation Research Part E: Logistics and Transportation Review, 2010, 46.1: 76-89

[5] Wang Zhenyu, Xie Xinlian, Xu Xiaowei. Multi-objective optimization of liner transportation under COVID-19 and dual carbon strategy background. Journal of Dalian Maritime University, 2022, 48(01): 31-41. DOI: 10.16411/j.cnki. issn1006-7736.2022.01.004

[6] Xu Huan, Liu Wei, Shang Yuting. Fleet Deployment Model for Liners under Low-carbon Economy and Its Algorithms Implementation. Transportation System Engineering and Information, 2013, 13(04): 176-181+192. DOI: 10.16097/j.cnki.1009-6744.2013.04.010

[7] DEB, Kalyanmoy, et al. A fast and elitist multiobjective genetic algorithm: NSGA-II. IEEE transactions on evolutionary computation, 2002, 6.2: 182-197

[8] Shao Jungang, Xue Yingxia. Optimization for fleet allocation and voyage planning in downturn shipping phase. Journal of Shanghai Maritime University,2014,35(02):38-42. DOI:10.13340/j.jsmu.2014.02.008

[9] SONG, Yajie; YUE, Yixiang. Optimization model of fleet deployment plan of liners. Procedia engineering, 2016, 137: 391-398

[10] Pan Jingjing. Fleet Deployment for Liner Ship Based on Bi-objective Programming. Journal of Chongqing Jiaotong University(Natural Science Edition), 2016,35(06):136-140+167

[11] Wu Nuan, Wang Nuo, Huang Qi. A Multi-objective Optimization for Liner Fleet Deployment Based on Improved NSGA- II. Industrial Engineering and Management, 2018, 23(01): 79-85. DOI: 10.19495/ j.cnki.1007-5429.2018.01.012.

[12] KUMAR, Mithilesh; GURIA, Chandan. The elitist non-dominated sorting genetic algorithm with inheritance (i-NSGA-II) and its jumping gene adaptations for multi-objective optimization. Information sciences, 2017, 382: 15-37

[13] Bao Tiantian, Du Hong, Xie Xinlian. A bi-objective model with economy and environmental protection for fleet deployment of liner routes. Journal of Shanghai Maritime University, 2016, 37(01): 1-6. DOI: 10.13340/j.jsmu. 2016.01.001