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Study on Vessel Schedule Recovery Based on Prospect Theory

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ABSTRACT

There is plenty of uncertainty in liner shipping, which has a great impact on the normal operation of liner shipping. Based on the prospect theory, together with the deviation between the disrupted situation and the original plan as a reference point, we design the value function and perturbation measurement function for users, i.e. liner shipping companies, and establish the model of vessel schedule recovery. In order to reduce the influence of disruption factors in the process of liner operation and seek the optimal solution of the optimization problem, we propose a genetic algorithm to solve the problem. The model and algorithm are validated by the actual example of Z Company. The results show that the model and algorithm are accurate and efficient, and can provide reference for the liner shipping companies in case of actual disruption.

Keywords: Prospect theory; Disruption management; Perturbation analysis; Liner shipping; Vessel schedule recovery

INTRODUCTION

As a major mode of transport in ocean transportation, liner shipping services are offered through ships which run on pre-announced schedules between fixed ranges of ports on regular basis in an established port order. With the continuous development of the world economy, liners are transporting goods all over the world. However, there is plenty of uncertainty in the actual operation of liners, such as bad weather, ship failure, port congestion, crew strikes, and regional political factors. These factors have an enormous impact on the operation of liner shipping. Currently, when disruption factors occur, we mainly rely on human experiences to recover the schedule, which makes it difficult to evaluate the effectiveness of vessel schedule recovery measures after each disruption. Theoretically speaking, while the extent of research in this field is still relatively limited, more and more people are delving into this field with increased attention to schedule disruption around the world.

Disruption management focuses on the design of the corresponding optimization model and method to generate the smallest perturbation recovery strategy to locally adjust an initial scheme according to the extent and nature of perturbation of a given problem[1] [2] [3]. Since the introduction of disruption management, it has been applied to air transport[4], rail transport[5], road transport[6], and supply chain [7]. In recent years, researchers have analogized the disruption theory in other fields to the shipping sector, and have made many achievements. Notteboom T E[8] analyzes the impact of disruption events and measures that liner shipping companies could take to reduce losses. Vernimmen B[9] analyzes the impact of unreliable scheduling on supply chain. Wang S[10] proposes a liner ship route schedule model to maintaining a required transit time service level when a delay occurs at the port or disruption events occur during navigation, and presents an exact cutting-plane based solution algorithm solve real-case problems. Brouer[11] analyzes the disruption factors and recovery strategies in liner shipping, and proposes a mixed integer programming model. Fischer A[12]presents different strategies for different liners during different disruption time. Xing J B[13] considers the problem of container flow recovery, and establishes a mixed integer nonlinear programming mathematical model for the vessel schedule recovery problem.

The above research provides a new way of thinking for disruption management in the shipping field, but human factors can not be ignored in liner shipping because people are rational, and decision preferences are different when the environment changes. If behavioral factors are neglected, the theoretical decision-making does not conform to the actual results. Current studies do not consider the influence of human behavior factors on the feasibility of the optimal solution. Therefore, we combine prospect theory, disruption theory and operation research to establish a vessel schedule recovery model and use genetic algorithm to solve the problem, so that the disrupted system can recover normal operation with minimum perturbation.

PERTURBATION MEASUREMENT BASED ON PROSPECT THEORY

The core of disruption management is to quickly and effectively generate the adjustment scheme to minimize the system perturbation after disruption. Therefore, before establishing disruption management model, we need to analyze the impact of perturbation so as to determine the objective function. As customers and liner shipping companies are major players in the transportation, we focus on their interests in this paper.

Analysis of vessel schedule perturbation

Customers hope to the vessel schedule remains unchanged no matter what happens. Even in case of disruption, schedule deviation is minimal. Schedule deviation refers to the sum of deviations between the actual arrival time of vessels and the scheduled arrival time at each port in case of disruption. When vessels are delayed due to disruption, it will have a ripple effect for customers and affect the subsequent delivery of goods. Therefore, whether containers can be discharged on time at ports without affecting the subsequent delivery of good is the primary objective for customers.

Liner shipping companies aim to pursue the highest profits and long-term customers, that is, lowest cost and customer churn rates regardless of the circumstances. When vessels are delayed due to disruption, liner shipping companies have to face extra costs, port congestion, and reduced schedule reliability, and their reputation will be affected. Therefore, minimizing additional costs and customer churn rates are the primary objectives of liner shipping companies.

Therefore, this paper first analyses the impact of disruptions on the above two subjects and considers the interests of both sides according to their focuses so as to measure the degree of disruption of a system, and finally get the adjustment scheme to minimize the perturbation of the system.

2.2 Perturbation measurement function based on prospect theory

Prospect theory is a behavioral decision-making theory with a great impact on behavioral science. It is based on the limited rationality of human beings and literally describes human decision-making behavior under conditions of uncertainty[14]. Therefore, this section proposes the measurement method of system perturbation based on prospect theory.

Representation of value function

After perturbation occurs, given the objective of each subject is different, the value function of each objective is represented based on prospect theory. The value function $V_i(x)$ of objective i is denoted as[15]

$$V_i(x) = \begin{cases} x^{\alpha_i}, & x \geq 0 \\ -\lambda_i(-x)^{\beta_i}, & x < 0 \end{cases} \quad (1)$$

where α_i, β_i, and λ_i as parameters.

The shape of value function is shown as below.

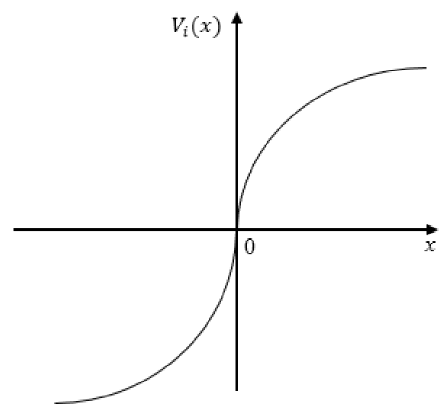


Fig. 1: Value function of objective i

Representation of perturbation measurement function

According to prospect theory, when disruptions occur, a decision maker needs to determine an appropriate point as a reference point, and gain and loss are relative around this reference point [16][17]. In this paper, we choose the deviation between actual disruption situation and original plan Δx =0 as a reference point of perturbation=0. When the disruption reaches a certain level, the perturbation will tend to reach a value. Therefore, the perturbation measurement function of the objective can be denoted as

$$u_i(\Delta x_i)=\begin{cases}1, & \Delta x_i \geq R_i\\ \lambda\Delta x_i^{\beta}, & 0<\Delta x_i<R_i\\ 0, & \Delta x_i \leq 0\end{cases} \quad (2)$$

The shape is denoted as

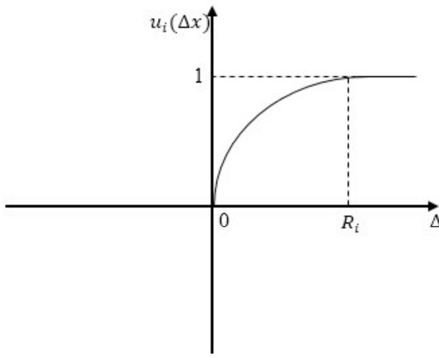
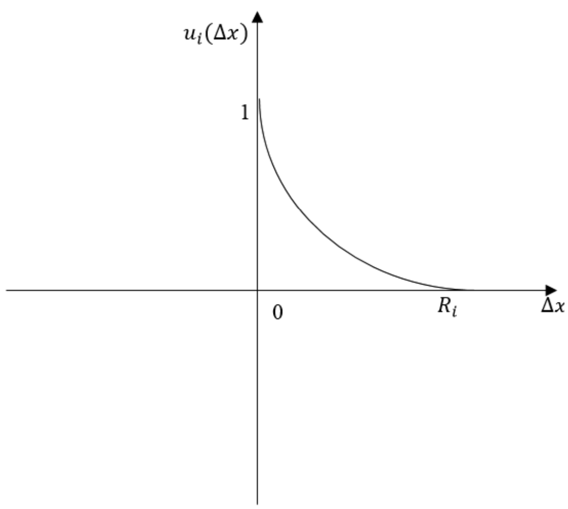


Fig. 2: Perturbation measurement function of objective i



For customers, the deviation Δt_{1i} between the actual arrival time and scheduled arrival time of each port is chosen as the independent variable of the function. When=0, it is used as the reference point of perturbation = 0. Therefore, its perturbation measure function is denoted as:

$$u_{1i}(\Delta t_{1i})=\begin{cases}1, & \Delta t_{1i} \geq R_{1i}\\ \lambda_1\Delta t_{1i}^{\beta_1}, & 0<\Delta t_{1i}<R_{1i}\\ 0, & \Delta t_{1i} \leq 0\end{cases} \quad (3)$$

λ_1 and β_1 are perturbation coefficients, and different subjects have different perturbation coefficients. The boundary value R_{1i} is determined by perturbation coefficients, and the relationship is shown as below:

$$R_{1i}=(\frac{1}{\lambda_1})^{\frac{1}{\beta_1}} \quad (4)$$

Similarly, according to prospect theory, additional cost is selected as the independent variable of the liner shipping company's perturbation measurement function. When the additional cost $\Delta C=0$, it is used as the reference point of perturbation= 0. Therefore, for liner shipping companies, the perturbation measurement function can be denoted as:

$$u_2(\Delta C)=\begin{cases}1, & \Delta C \geq R_2\\ \lambda_2\Delta C^{\beta_2}, & 0<\Delta C<R_2\\ 0, & \Delta C \leq 0\end{cases} \quad (5)$$

λ_2 and β_2 are perturbation coefficients, and different subjects have different perturbation coefficients. The boundary value R_2 is determined by perturbation coefficients, and the relationship is shown as below:

$$R_2=(\frac{1}{\lambda_2})^{\frac{1}{\beta_2}} \quad (6)$$

VESSEL SCHEDULE RECOVERY MODEL

The vessel schedule disruption recovery problem is concerned with different possible actions to recover schedule and reduce the losses incurred by customers and liner shipping companies when disruptions occur. Ships are vulnerable to many disruptive factors such as uncertainty in needs before departure, harsh weather, mechanical failures, inability of the crew, uncertain waiting time for the canal, port congestion, tidal reasons, pilotage or tugboat, lower operation efficiency than the expectation, strikes, delay in delivery and political factors. In addition, this paper chooses four recovery strategies including increasing navigation speed, canceling port calling, rearranging port calling sequence and shortening in-port time.

3.1 Explanation of Symbols

N——Number of ports on the route

i, j——A collection of all ports on the route

d_{ij}——Distance between the sections (i, j) of the route

v_{ija}——Scheduled navigation speed of the ship sailing on the sections (i, j) of the route

t_{ija}——Scheduled navigation time of the ship sailing on the sections (i, j) of the route

v_{ijb}——Actual navigation speed of the ship sailing on the sections (i, j) of the route

t_{ijb}——Actual navigation time of the ship sailing on the sections (i, j) of the route

v_{min}——Minimum navigation speed of the ship sailing on this route

v_{max}——Maximum navigation speed of the ship sailing on this route

O_A——Daily oil consumption of auxiliary boilers during navigation

O_B——Daily oil consumption of auxiliary boilers during berthing

P_O——Fuel price

h——Fuel consumption constants of the ship

q_{li}——Scheduled container loading capacity of the ship at Port i

q_{ui}——Scheduled container unloading capacity of the ship at Port i

C^o_{ija}——Scheduled fuel costs of the ship sailing on the sections (i, j) of the route

C^o_{ijb}——Actual fuel costs of the ship sailing on the sections (i, j) of the route

C_{pia}——Scheduled unit time loading and unloading costs at Port i

C_{pib}——Unit time loading and unloading costs for shortening the in-port time at Port i

T_O——Time of unberthing of the ship from port of departure after disruption events occur

T_{ia1}——Scheduled berthing time of the ship at Port i

T_{ia2}——Scheduled unberthing time of the ship at Port i

T_{ib1}——Actual berthing time of the ship at Port

T_{ib2}——Actual unberthing time of the ship at Port i

t_{pia}——Scheduled stay time of the ship at Port i

t_{pib}——Actual stay time of the ship at Port i

Δt_{1i}——Delayed berthing time of the ship at Port i

$\Delta t_{pi\max}$——Maximum in-port time shortened of the ship at Port i

x_{ij}——Whether the ship is sailing on the sections (i, j) of the route, expressed by variable 0-1, where 1 means the ship is sailing on the section, and 0 means it is not

k_i——Whether the ship cancels calling ports of the route, expressed by variable 0-1, where 1 means the ship cancels calling ports, and 0 means it does not

u_i——Rollover punishment costs for calculating the additional costs caused by rollover

3.2 Model establishment and solution

Objective function

The model is a bi-objective function. The first objective is to minimize the customers' perturbation function, that is, to minimize the function for the deviation between the actual arrival time and the scheduled arrival time at each port. a_{1i} is the weight of each port's customers on the route. In this model, it is replaced by the percentage of cargo loaded and unloaded to the total cargo loaded and unloaded. The second objective is to minimize the perturbation function of liner shipping companies, that is, to minimize the function of the additional costs liner shipping companies have to pay.

$$|\min Y_1 = \sum_{i=1}^{N} \alpha_{1i} u_{1i}(\Delta t_{1i}) \tag{7}$$

$$\min Y_2 = u_2(\Delta C) \tag{8}$$

where $\Delta t_{1i} = \mathrm{T}_{ib1} - \mathrm{T}_{ia1}$, $i = 1, 2, \ldots, N$,

$$\Delta C = \left(\sum_{i=1}^{N}\sum_{j=1}^{N}\left(\frac{d_{ij}\bullet x_{ij}}{24v_{ijb}}\right) + \sum_{i=1}^{N}\frac{k_i t_{pib}}{24}\right)\bullet C_r + P_O\left[\sum_{i=1}^{N}\sum_{j=1}^{N}\frac{x_{ij}d_{ij}}{24v_{ijb}}(hv_{ijb}^3 + O_A) + \sum_{i=1}^{N} O_B\frac{k_i t_{pib}}{24}\right]$$
$$+\sum_{i=1}^{N} C_{pi}(t_{pia} - t_{pib}) + \sum_{i=1}^{N} k_i u_i(q_{li} + q_{ui}) + \omega\sum_{i=1}^{N} u_{1i}(\Delta t_{1i})\bullet C_{ly}$$
$$-\left(\sum_{i=1}^{N}\sum_{j=1}^{N}\left(\frac{d_{ij}\bullet x_{ij}}{24v_{ija}}\right) + \sum_{i=1}^{N}\frac{k_i t_{pia}}{24}\right)\bullet C_r - P_O\left[\sum_{i=1}^{N}\sum_{j=1}^{N}\frac{x_{ij}d_{ij}}{24v_{ija}}(hv_{ija}^3 + O_A) + \sum_{i=1}^{N} O_B\frac{k_i t_{pia}}{24}\right]$$

In order to facilitate calculation, this paper transforms the bi-objective function into a single objective function, assigns certain weights to each item and sets the sum value, establishes a balance formula of bi-objective, takes the minimum value of , and the objective function is:

$$\min Y = \omega Y_1 + (1-\omega) Y_2 \tag{9}$$

Constraints and Explanations

(1) Constraint on calling ports

This constraint is the most basic constraint of this model, that is, first of all, to ensure that the route is either linked to a port or not. Based on this, the vessel schedule can be recovered. This constraint is shown as below:

$$\sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{ij} + k_i = 1, \quad i = 1, 2, \ldots, N \tag{10}$$

(2) Constraint on cancellation of calling ports

In this paper, cancellation of calling ports is included in the disruption recovery strategy, but too much cancellation will increase the cost of container transportation, and affect the reputation of liner shipping companies as well. Therefore, this paper restricts the number of cancelled calling ports to be one at most. This constraint can be expressed as:

$$\sum_{i=1}^{N} k_i \le 1 \tag{11}$$

(3) Constraint on routes

The routes must be reasonable and turning back routes and circles should be avoided. This paper adopts the following method to ensure the rationality of the route.

$$\begin{cases} \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{ijb} = 1, & i = 1 \\ \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{jib} = 0, & i = 1 \\ \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{ijb} = 1, & i = N+1 \\ \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{jib} = 0, & i = N+1 \\ \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{ijb} - \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{jib} = 0, & i = 2, 3, \ldots, N \end{cases} \tag{12}$$

(4) Time variable relational expression

In this paper, we give many time variables, and their relationships are shown as below:

$$\begin{cases} t_{pia} = \mathrm{T}_{ia2} - \mathrm{T}_{ia1}, & i = 1, 2, \ldots, N \\ t_{pib} = \mathrm{T}_{ib2} - \mathrm{T}_{ib1}, & i = 1, 2, \ldots, N \end{cases} \tag{13}$$

(5) Constraint on ship speed

In this paper, increased navigation speed is included in the disruption recovery strategy, but ship speed is usually limited. Therefore, the following constraint is used to restrict the speed:

$$v_{\min} \le v_{ijb} \le v_{\max}, \quad i, j = 1, 2, \ldots, N \tag{14}$$

(6) Constraint on shortened in-port time

In this paper, shortened the in-port time is included in the disruption recovery strategy, but loading and unloading capacity of each port is prioritized, the following constraint is used to limit the shortened in-port time:

$$0 \le t_{pia} - t_{pib} \le \Delta t_{pi\max}, \quad i = 1, 2, \ldots, N \tag{15}$$

MODEL INTEGRATION

According to the introduction of above parameters and establishment of the model, the vessel schedule recovery model in this paper is shown as below:

$$\min Y = \omega Y_1 + (1-\omega) Y_2 \tag{16}$$

The constraints are:

$$\begin{cases} \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{ij} + k_i = 1, & i = 1, 2, \ldots, N \\ \sum_{i=1}^{N} k_i \le 1 \\ \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{ijb} = 1, & i = 1 \\ \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{jib} = 0, & i = 1 \\ \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{ijb} = 1, & i = N+1 \\ \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{jib} = 0, & i = N+1 \\ \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{ijb} - \sum_{\substack{j=1 \\ j \neq i}}^{N+1} x_{jib} = 0, & i = 2, 3, \ldots, N \\ t_{pia} = \mathrm{T}_{ia2} - \mathrm{T}_{ia1}, & i = 1, 2, \ldots, N \\ t_{pib} = \mathrm{T}_{ib2} - \mathrm{T}_{ib1}, & i = 1, 2, \ldots, N \\ \Delta t_{1i} = \mathrm{T}_{ib1} - \mathrm{T}_{ia1}, & i = 1, 2, \ldots, N \\ v_{\min} \le v_{ijb} \le v_{\max}, & i, j = 1, 2, \ldots, N \\ 0 \le t_{pia} - t_{pib} \le \Delta t_{pi\max}, & i = 1, 2, \ldots, N \end{cases} \tag{17}$$

From the above description, we can see that the model belongs to a NP problem. For NP problem, if the scale of the problem, that is, the number of ports involved in the route is too large, the solution time will be longer. Therefore, this paper uses genetic algorithm to solve this kind of problem in order to improve the efficiency of solution.

EXAMPLE ANALYSIS

We take Z Company as an example in this paper. The route is N-PNW, and the main ports of this route are Shanghai, Busan, Seattle, Portland, Vancouver, Guangyang, Hong Kong and Shenzhen. During a liner trip, the ship encountered bad weather and port congestion at the starting port, Shanghai Port. Finally, with the joint efforts of the ship, port and maritime authorities, the delay occurred as the ship departed 48 hours later than schedule. It is necessary to reschedule and take reasonable measures to recover the schedule.

4.1 Basic data

Ship

We obtained the detailed particulars of the ship through investigation. The related data are shown as below:

Table 5-1 Ship particulars

Ship parameters	Parameter values
Length overall	279m
Breadth	40m
Moulded depth	25.6m
Deadweight	68324t
Loading quantity	5816TEU
Minimum ship speed	15kn
Maximum ship speed	25.6kn
Fuel consumption constant	0.0123
Auxiliary boiler consumption per navigation day	8t
Auxiliary boiler consumption per berthing day	9.5t

Source: Z Company website and www.clarksons.com

The ship speed is between 15 and 25.6 knots, therefore, $v_{i\min}=15$, and $v_{i\max}=25.6$. In this paper, the average fuel price in 2017 is 460 USD per ton.

Route

According to the actual schedule and through investigation, we obtained the actual situation of each port of call as shown below:

Table 5-2 Schedule and container data

	Loading quantity	Unloading quantity	Berthing time	Unberthing time	In-port time	Maximum in-port time shortened
Shanghai Port	3360	0	0	56	56	13
Busan Port	1120	200	81	120	39	10
Seattle Port	750	1495	376	426	50	13
Portland Port	520	1070	446	488	42	11
Vancouver Port	300	1265	508	543	35	9
Guangyang Port	100	220	803	820	17	4
Hong Kong Port	0	800	880	900	20	5
Shenzhen Port	0	1060	902	927	25	6

Distance between two ports

The distance between ports is calculated by BLM_SHIPPING shipping practice software

Distance /nm	Shanghai Port	Busan Port	Seattle Port	Portland Port	Vancouver Port	Guangyang Port	Hong Kong Port	Shenzhen Port
Shanghai Port	0	451.07	5054.37	5093.94	5060.22	411.9	794.88	839.87
Busan Port	451.07	0	4610.98	4650.56	4616.83	81.56	1134.46	1179.45
Seattle Port	5054.37	4610.98	0	352.33	117.4	4688.46	5735.86	5780.84
Portland Port	5093.94	4650.56	352.33	0	350.18	4728.04	5775.44	5820.42
Vancouver Port	5060.22	4616.83	117.4	350.18	0	4694.31	5741.71	5786.7
Guangyang Port	411.9	81.56	4688.46	4728.04	4694.31	0	1089.92	1134.91
Hong Kong Port	794.88	1134.46	5735.86	5775.44	5741.71	1089.92	0	29.39
Shenzhen Port	839.87	1179.45	5780.84	5820.42	5786.7	1134.91	29.39	0

Source: Calculated by BLM_SHIPPING shipping practice software.

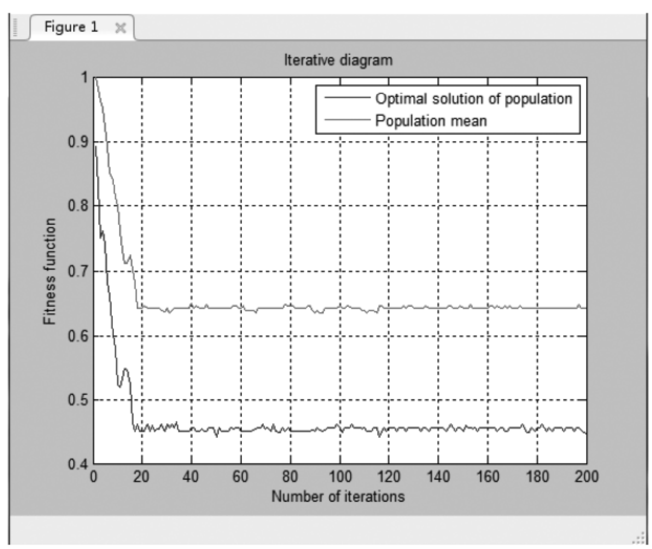
Calculation results

In order to validate the rationality of this model based on customer expectation, this paper compares and analyses the different decision-making schemes with different weights ω from 0-1, and ω=0 and ω=1 represents considering the expectation function of liner shipping companies and the expectation function of customers respectively.

Firstly, the parameters of genetic algorithm are set. The initial population size is 500, the maximum number of iterations is 200, the crossover probability is 0.7, and the mutation probability is 0.1.

According to the investigation, when making a decision about schedule recovery, the liner shipping company puts the customer satisfaction first, and pursues the lowest recovery cost while meeting the customers' requirements. Therefore, this paper gives the situation of schedule recovery when =0.8. By using the Matlab genetic algorithm to solve the problem, the optimal solution and the change of population mean under each iteration are shown as below:

Fig. 5-2 Genetic algorithm iterative diagram



The recovered schedule is shown as belowÿ

Table 5-4 The recovered schedule when ω =0.8

Calling sequence	Calling	Section speed (kn)	In-port time shortened (h)	Actual berthing time (h)	Schedule deviation (h)
Shanghai Port	Yes	16.06	0	0	0
Busan Port	Yes	20.21	8.6	125	44
Seattle Port	Yes	15.28	6.7	382	6.5
Portland Port	Yes	16.33	6.9	449	2.8
Vancouver Port	Yes	17.31	7.1	505	-2.6
Guangyan Port	Yes	18.07	0.5	80	1.5
Hong Kong Port	Yes	20.16	1	881	1.3
Shenzhen Port	Yes		1.2	901	-0.2

From the above calculation results, we can see that the results obtained by genetic algorithm are not the optimal solution, but sub-optimal solution. This is mainly due to randomness of the size and selection of initial population, and the selection from the parent to the offspring has a certain probability. The results of each iteration are different. Because the distance between Shanghai Port and Pusan Port is short, the number of containers unloaded is small, and the ship delayed 48 hours later than schedule at Shanghai Port. In case of increasing the navigation speed to catch up with the schedule, the ship can not arrival at Pusan Port on time. Therefore, the ship did not increase the speed to a high level after considering the fuel costs and customers' requirements. While the distance between Pusan Port and Seattle Port is long, the ship has enough time to adjust its schedule, and therefore, the speed increase is larger. Meanwhile, this paper gives a better strategy by weighing the additional fuel costs caused by the speed increase and additional costs of shortening the in-port time. From the port of departure to the port of destination, we can see that the ship is sailing in accordance with the schedule, basically eliminating delays before departure. In addition, this calculation has a larger weight of customers, and each port has a large amount of loading and unloading, and therefore there are calling ports and calling sequence remains unchanged.

We take 11 values from ω =0-1 and analyze their decisions respectively. We calculate the objective functions of the model with different values, as shown in the table below.

Table 5-5 Integration of schedule recovery strategies when ω has different values

ω	Route	Customer expectation function	Liner shipping company expectation function	Global objective function
0	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.6033	0.5064	0.5064
0.1	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.5579	0.5729	0.5714
0.2	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.5216	0.5933	0.57896
0.3	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.4715	0.6136	0.57097
0.4	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.4133	0.6517	0.55634
0.5	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.4523	0.6375	0.5449
0.6	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.3828	0.6723	0.4986
0.7	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.3455	0.7536	0.46793
0.8	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.3116	0.7327	0.39582
0.9	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.3097	0.8123	0.36896
1	Shanghai Port - Busan Port - Seattle Port - Portland Port - Vancouver Port - Guangyang Port - Hong Kong Port - Shenzhen Port	0.2958	0.8854	0.2958

In all the solutions, there is no case of canceling calling ports or changing the port sequence. This is mainly due to the short distance between Shanghai Port and Busan Port after the delay occurred at the departure port, and even the ship is sailing at the maximum speed can not catch up with the schedule. From Busan Port to Seattle Port, the ship has enough time to increase navigation speed or shorten the in-port time to adjust the schedule. After arriving at Seattle port, the ship will sail according to the schedule without changing the calling sequence.

From the results of different weights mentioned above, how the decision-makers look at the weights of two objectives is particularly important. When the decision-makers think that the customer expectations should be given higher weight, the vessel recovery strategy focuses on the customer expectations, i.e., the minimum deviation of schedule. As the additional costs for schedule recovery is not valued, the liner shipping companies have to spend a lot of money to catch up with the schedule. When the decision- makers think the liner shipping companies' expectation should be given higher weight, the vessel schedule recovery strategy focuses on the liner shipping companies' expectation, i.e., the minimum additional costs. As whether the schedule deviates from the original plan is not valued, ships will be sailing at the optimal speed on route while the scheduled arrival time and loading and unloading time are ignored.

CONCLUSION

(1) In this paper, we propose a perturbation measurement method based on prospect theory, provide a new way of thinking for perturbation measurement involving human behavior perception in liner shipping schedule and enrich the disruption management theory.

(2) We extend the schedule recovery model established in this paper to vessel schedule recovery strategy, and apply four vessel recovery strategies to the mathematical model, including increasing navigation speed, canceling port calling, rearranging port calling sequence and shortening in-port time, which makes the model closer to reality and the optimization scheme more valuable.

(3) Aiming at the NP model established in this paper, we use the genetic algorithm to solve the problem, and compare and analyze the results accordingly. We provide a new idea for solving the disruption management model, and make a useful exploration on the multi-objective optimization problem.

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